Province of British Columbia Standards, Specifications and Guidelines for Resource Surveys Using Global Positioning System (GPS) Technology

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LIST OF ACRONYMS

1D, 1-D	One-dimensional
2D, 2-D	Two-dimensional (e.g. horizontal North / East)
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
BCACS	British Columbia Active Control System
BCGS	British Columbia Grid System
BCGSR	British Columbia Geo-Spatial Reference
B.C.L.S.	British Columbia Land Surveyor
CRGB	Crown Registry and Geographic Base (part of ILMB)
C/A	Coarse/Acquisition GPS signal (civilian)
CACS	Canadian Active Control System
CADD	Computer Aided Drafting & Design
CCG	Canadian Coast Guard
CEP	Circular Error Probable (50% confidence)
CSRS	Canadian Spatial Reference System
CVD28	Canadian Vertical Datum 1928 (orthometric elevations)
CDGPS	Canada-wide Differential GPS
CGG2000	Geodetic Survey Division year 2000 Geoid model for NAD83 ellipsoid to orthometric height conversion (also see HT2_0)
DGPS	Differential GPS
DOP	Dilution Of Precision
DRMS	Distance Root Mean Square (see 2DRMS)
DXF	Drawing eXchange Format (CAD drawing exchange format)
ECEF	Earth-Centered, Earth-Fixed
EDOP	East DOP
GALILEO	Proposed European GNSS (similar to GPS)
GCM	Geodetic Control Monument
GDOP	Geometric DOP (3D plus Time)
GIS	Geographic Information System
GLONASS	Russian GNSS (similar to GPS)
GNSS	Global Navigation Satellite System (GPS, GALILEO, GLONASS, etc)
GPS	Global Positioning System (also called NAVSTAR by military users)
GRS	Geodetic Reference System
GSD	Geodetic Survey Division, Natural Resources Canada (NRCan)
GSR	Geo-Spatial Reference
HDOP	Horizontal DOP (2D)
HT2_0	Height transformation based on the CGG2000 Geoid model with corrections (used to transform GPS ellipsoidal heights to CVD28 orthometric elevations)
Hz	Hertz (1/second)
IERS	International Earth Rotation Service
ILMB	Integrated Land Management Bureau (Ministry of Agriculture and Lands)

IGDS	Interactive Graphic Design System
INCOSADA	Integrated Corporate Spatial and Attribute Database (MoF)
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
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
MoFR	Ministry of Forests and Range
MSL	Mean Sea Level
NAD27	North American Datum 1927
NAD83	North American Datum 1983
NAD83 CSRS)	NAD 1983 (Canadian Spatial Reference System)
NANU	Notice Advisory to NAVSTAR (GPS) Users
NAVD88	North American Vertical Datum 1988 (USA)
NAVSTAR	Navigation Satellite Timing And Ranging (US military acronym for GPS)
NDOP	Northing DOP
NRCan	Natural Resources Canada (Federal Government)
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 code (unique code for each satellite)
PSGUC	Public Sector GPS Users Committee
QA	Quality Assurance
QC	Quality Control
RIB	Resources Inventory Branch, Ministry of Forests
RISC	Resources Information Standards 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 (civilian degradation, removed 2nd May, 2000)
SAIF	Spatial Archive and Interchange Format
SEP	Spherical Error Probable (50% confidence)
SNR	Signal to Noise Ratio
SPS	Standard Positioning Service (civilian)

TDOP	Time DOP
TRIM	Terrain Resource Integrated Mapping
UTC	Universal Time Coordinated
UTM	Universal Transverse Mercator
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)

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SECTION A - INTRODUCTION

SECTION A - INTRODUCTION

The Global Positioning System (GPS) has become an effective tool for positioning and navigation and is widely used by both the private and public sector. As a developing technology, there are risks involved with using GPS. These risks are best understood and minimized by ensuring appropriate levels of education, training and experience by everyone involved with these projects. This includes government staff overseeing GPS contracts. Previously, no publications have been directed specifically at this audience, resulting in staff having varying levels of GPS knowledge, and contractor submissions being accepted without an assurance of appropriate quality. Lack of a published specification will result in an uncontrolled degradation of the spatial databases which are used for planning and management of British Columbia's (BC's) resources.

The Public Sector GPS Users Committee (PSGUC) recognized the need for establishing appropriate GPS specifications for government works and within the framework of the Resources Inventory Committee (RIC). Various draft specification documents evolved during 1994-1995, however, it became clear that a single document could not apply to all types of GPS contracts required by different Agencies. A decision was made to separate this task of setting specifications into three main sections, known as the ***British Columbia Standards, Specifications and Guidelines for Resource Surveys Using Global Positioning System (GPS) Technology*** (hereafter called the *RIC Standards*). These RIC Standards were initially published in October 1995 as Release 1.01, with an update Release 2.0 in March 1997, followed by Release 2.1 in March 1998, with a clarification addendum issued in July 1999. Release 3.0 in 2001 addressed changes following the removal of Selective Availability (SA), including the addition of a new section (*Section E)* for those considering autonomous (uncorrected) GPS positioning. This Release 4.0 in 2008 refreshes the materials to bring them up to date following developments in GNSS (including GPS modernization), plus update Agency names, acronyms, etc. Readers familiar with Release 3.0 will recognize that some names and acronyms have changed including:

- RIC (Resource Inventory Committee) became RISC (Resources Information Standards Committee)
- GDBC (Geographic Data BC) became CRGB (Crown Registry and Geographic Base)

This document particularly targets GPS surveys where the required project accuracies are in the 1m to 10m accuracy class (95%). For higher accuracy requirements (millimetres to few decimetres), please refer to the document ***British Columbia Standards, Specifications and Guidelines for Control Surveys using Global Positioning System (GPS) Technology*** as available from Crown Registry and Geographic Base (CRGB), Ministry of Agriculture and Lands. Publications by other Provincial and Federal agencies also describe procedures for using GPS for high accuracy surveys (see *Appendix B - References).*

Section B covers *Standards*. The *Standards* define accuracy standards for any positioning in the province (i.e. conventional and/or GPS) with further development of the standards for GPS surveys for the resource sector in the province. This includes positioning accuracy values, interpretive accuracy values and GPS Base Station categories.

Section C outlines *Specifications*. The *Specifications* are meant to be a "pull out section" of this document, that would be completed by a Contracting Agency based on the requirements for each specific GPS project using the information and instructions provided in the *DGPS Guidelines* (*Section D*). Sections in the *Specifications* that require the contract administrator to complete entries for specific survey projects (e.g. *Section C-6 - Fieldwork*) are referenced in the *DGPS Guidelines.* This referencing has been done to allow the administrator to easily locate the relevant areas of the *DGPS Guidelines* for the information necessary to complete the contract documents. The completed *Specifications* can then be attached to GPS survey contracts as the Technical Requirements section of the contract. *Appendix C* shows a completed *Specifications* document for a typical resource surveys.

It should be noted that though reference is made to contracts and the contracting process, the intent thereby is to simply separate out the different *functions* required when managing and conducting a GPS project. Thus, a "Contractor" may simply be interpreted as assigned in-house staff, which may be separate from the in-house "Contract Administrator".

Section D outlines *DGPS Guidelines* for contract administrators. The *DGPS Guidelines* provide basic educational information to assist the contract administrators to complete the *Specifications* section for contracts (and in numerous cases suggested values are provided). The *DGPS Guidelines* are intended to provide information in the following specific areas:

- overview and history of GPS including measurement techniques and terminology
- detailed information required to set and administer GPS contracts
- quality assurance techniques for evaluating contract deliveries. An index is provided at the end of the *DGPS Guidelines* to assist contract administrators in completing the *Specifications* with information appropriate to their specific GPS survey projects.

Section E outlines *Autonomous (uncorrected) GPS Guidelines*. This section was added with Release 3.0 of this document, and is intended to provide guidelines for those considering autonomous (uncorrected) GPS for positioning of non-critical features.

CRGB recommends that these ***British Columbia Standards, Specifications and Guidelines for Resource Surveys Using Global Positioning System (GPS) Technology*** be used by all government agencies commissioning GPS projects. This will help to establish a uniform standard for in-house contracted works. *These documents should be considered as a minimum information level for GPS contract administrators, with supplementary training recommended (*see the DGPS *Guidelines Section D-4.1.)*

It should also be noted that these *Standards, Specifications* and *Guidelines* are equally applicable to non-government users. As such, it is recommended that private users also adhere to the *Standards* and *Specifications*, thereby providing uniform standards across the province. In doing so, data exchange and data sharing between private and government agencies will be greatly enhanced.

Feedback and queries on any aspects of the *Standards, Specifications* and *Guidelines* is welcomed. Please direct your comments to CRGB, Ministry of Agriculture and Lands (see *Preface* or *Appendix B* for contact numbers).

SECTION B - STANDARDS

SECTION B - ACCURACY STANDARDS

1. INTRODUCTION

In order to help classify different surveys according to the geometrical resolution and accuracy of the data capture, the following classification tables have been constructed. The Accuracy Standards presented in this document are derived from the Accuracy Standards developed for all positioning methodologies by the Federal Geodetic Survey Division (Natural Resources Canada). The Standards presented here have been enhanced to deal specifically with GPS-related surveys for resource mapping in order to clarify and distinguish them for the non-traditional surveying and mapping specialist.

By using the tables in the following sections users may define their requirements in a standardized manner, thereby enabling proper tagging and subsequent use of captured data. Typically, one or more class levels will be specified from each of the tables.

2. GENERAL CONCEPTS and DEFINITIONS

These Standards refer to the Geo-Spatial Reference (GSR). The GSR is a particular form of spatial reference that relates to universal latitudes, longitudes and elevations. Geo-referencing is the process of referencing, or tying into, the GSR.

Positioning Standards specify the absolute and/or relative accuracy of positions. Standards are independent of the measurement equipment and the methodology. Standards should have a long life; that is, they should not be rewritten merely because new technology becomes available. Rather, Standards should be derived from the objectives of the Geo-Spatial Reference in terms of fulfilling the needs of professionals and the society. Thus, Standards may require revision as the uses of geodetic networks, which form a realization of the Geo-Spatial Reference on the ground, change.

Specifications, on the other hand, contain the rules as to how the Standards can be met - that is, Specifications are the recipe. As new technology becomes available, the Specifications may require modifications, additions or revisions.

Accuracy is defined as the degree of closeness of an estimated quantity, such as a horizontal coordinate or an orthometric height, to the true (but usually unknown) value. Because the true value is not usually known, but only estimated through the measurement process, by definition the accuracy of the estimated quantity is also unknown. We can therefore only estimate the accuracy of coordinate information. Rigorous procedures are used in the establishment of the highest levels of the Canadian Spatial Reference System (CSRS) and BC Geo-Spatial Reference (BCGSR) in order to ensure the reliability of the associated accuracy estimates.

Accuracy relates to the quality of a result, and is distinguished from precision, which relates to the quality of the operation by which the result is obtained.

Precision in statistics is a measure of the tendency of a set of numbers to cluster about a number determined by the set itself (i.e. repeatability). Precision relates to the quality of the method by which measurements were made. Various measures of precision are commonly used in positioning applications, including standard deviation, error ellipse, confidence region and others. Each provides an indication of the spread or dispersion of the set of estimates about their mean or expected value, reflecting the random error in the repeated measurements.

Precision measures are relatively simple to compute and are often used to estimate accuracy. They provide useful estimates of accuracy ***only*** if the data is unaffected by biases due to blunders or uncorrected systematic effects. Without some assurances that such errors do not exist, a precision measure provides information that is of limited use. A graphical explanation of accuracy and precision is provided in *Figure B-1 Network vs. Local Accuracy Analogy*.

A simple example is measuring the length of a table with a measuring tape. Accuracy relates to how well the measuring tape is calibrated, i.e. how close it is to the truth (metric standards). On the other hand, irrespective of how well the measuring tape is calibrated to the truth; one may measure the table length very precisely, i.e. with careful measurement procedure and readings of the tape. Consider another example of a horizontal position that has been determined using the most precise GPS measurements and processing techniques. If the positioned point is misidentified as one that is actually ten metres away, the precise position for the wrong point is of little use. While the precision measures may indicate that a precision of ten centimetres has been achieved, the bias introduced by misidentifying the point limits its accuracy to ten metres.

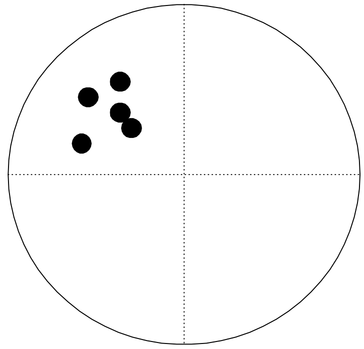
In summary, precision plus reliability, or precision without bias, results in true accuracy. In constructing the accuracy tables below, it is assumed that such true accuracy is being referred.

These standards are based on two types of accuracy that can be estimated for the geodetic coordinates of latitude, longitude (horizontal coordinates) and height: ***Network Accuracy*** and ***Local Accuracy***.

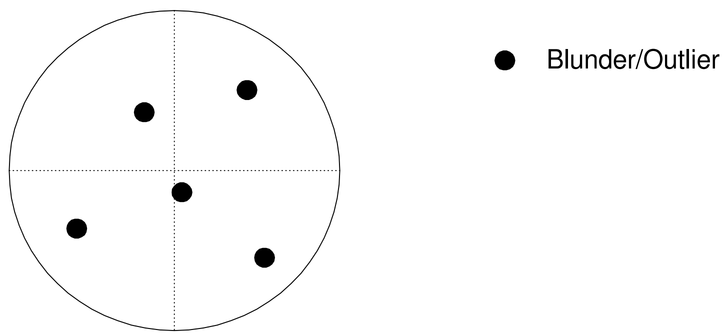
1. ***Network Accuracy*** is the absolute accuracy of the coordinates for a point at the 95% confidence level, with respect to the defined Geo-Spatial Reference system. Network Accuracy can be computed for any positioning project that is connected to the BCGSR.

2. ***Local Accuracy*** is an average measure (e.g. mean, median, etc.) of the relative accuracies of the coordinates for a point with respect to other adjacent points at the 95% confidence level. For horizontal coordinate accuracy, the Local Accuracy is computed using an average of the semi-major axes of the 95% relative confidence ellipses between the point in question and other adjacent points. For orthometric height accuracy, the Local Accuracy is computed using an average of the 95% relative confidence intervals between the point in question and other adjacent points.

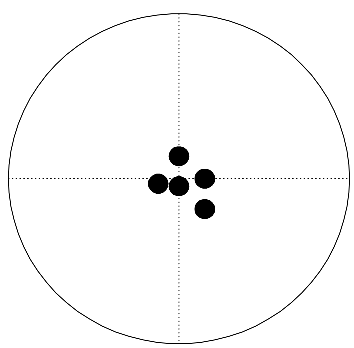
Figure B-1 Network Accuracy vs. Local Accuracy Analogy



*Precise But Not Accurate ... or ...
High Local Accuracy and Low Network Accuracy*

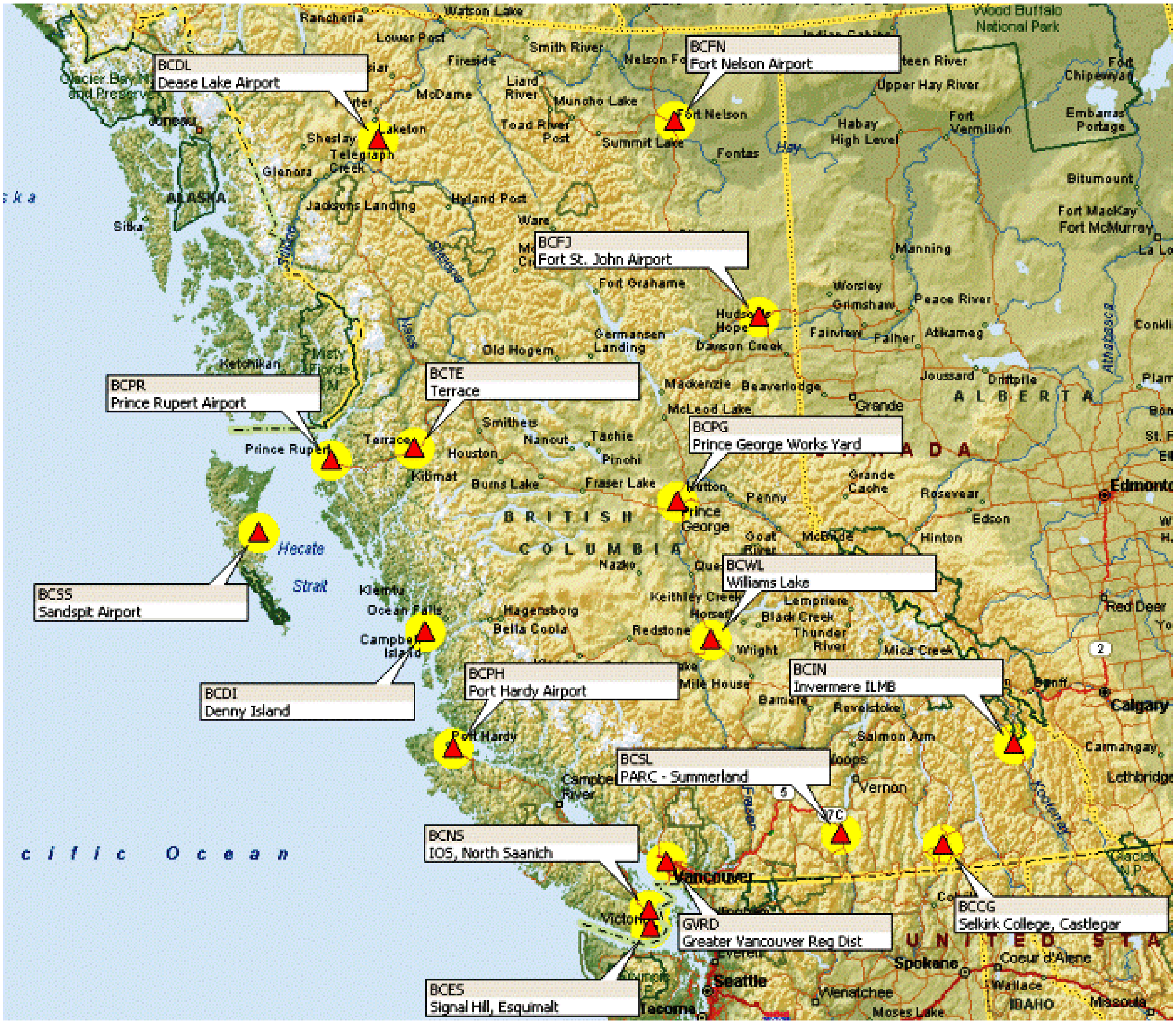


*Accurate But Not Precise ... or ...
High Network Accuracy and Low Local Accuracy*



*Accurate and Precise ... or ...
High Network Accuracy and High Local Accuracy*

Figure B-2 The British Columbia Geo-Spatial Reference



3. RESOURCE GPS ACCURACY STANDARDS

The classification standards presented here are recommended for use during both the survey design and evaluation phases of a positioning project. When planning a particular survey, pre-analysis for achieving a specific accuracy level should be consistent with the standards against which the survey results will be evaluated. Following the completed GPS project, an evaluation of the results will be done and classified accordingly.

The classification process provides an opportunity to assess the reliability of the results of a positioning project and assign accuracy classes accordingly. For resource survey applications of spatial referencing, precision measures may not be an appropriate means of estimating accuracy. For instance, the root-mean-square or RMS value generated from a Autonomous (uncorrected) GPS positioning receiver, using a short observing period, may be overly optimistic if the position estimates have all been affected by the same troposphere effects and other sources of systematic error.

A more realistic estimate of the accuracy attainable by the positioning system may be determined through the use of a validation procedure where test results are compared against known control coordinates. The validation process is particularly useful for evaluating GPS positioning systems. Statistical testing of validation results is recommended to assess their compatibility with known coordinate values. Knowledge of the capabilities of a positioning system is essential in assigning realistic accuracy classes to the results of any positioning project.

For points included in the provincial network of the BCGSR, Network and Local Accuracies are computed by CRGB using the standard accuracy representations presented in the Standards document (see *Figure B-2 The British Columbia Geo-Spatial Reference*). In addition, the Network and Local Accuracy may be classified by comparing the 95% confidence ellipse for horizontal coordinate accuracy, and the 95% confidence interval for ellipsoidal height accuracy, against a set of standards. This set of accuracy classification standards appears in *Table B-1 Accuracy Classification Standards* that lists the accuracy classes and their associated range. Class boundaries increase by doubling, or approximately doubling, the upper boundary value of the previous class.

Table B-1 below provides the basic Accuracy Classifications for Positioning within the Province of British Columbia – the Network Accuracy Classifications relevant to this document (i.e., 1m to 10m) are highlighted. The following Sections of this document take the Accuracy Classification one step further by categorizing the Interpretive Accuracy of features being mapped as well as categorizing GPS Base Stations. The final section looks at the practical application of the Standards to resource surveys.

ACCURACY CLASSIFICATION STANDARDS

ACCURACY CLASS	CLASS RANGE
1 millimetre	≤0.001m
2 millimetre	>0.001m to 0.002m
5 millimetre	>0.002m to 0.005m
1 centimetre	>0.005m to 0.01m
2 centimetre	>0.01m to 0.02m
5 centimetre	>0.02m to 0.05m
1 decimetre	>0.05m to 0.1m
2 decimetre	>0.1m to 0.2m
5 decimetre	>0.2m to 0.5m
1 metre	>0.5m to 1m
2 metre	>1m to 2m
5 metre	>2m to 5m
10 metre	>5m to 10m
20 metre	>10m to 20m
50 metre	>20m to 50m
100 metre	>50m to 100m
200 metre	>100m to 200m
500 metre	>200m to 500m

Table B-1 Accuracy Classification Standards

3.1. Network Accuracy for Resource GPS Surveys

Network Accuracy, also known as *datum-related accuracy*, or *absolute accuracy*, is the absolute accuracy of the coordinates for a point at the ***95% Confidence Level***, with respect to the defined Geo-Spatial Reference (GSR). In British Columbia this is the BC Geo-Spatial Reference (BCGSR). Network Accuracy can be computed for any positioning project that is connected to the BCGSR (*see Figure B-3 Network Accuracy and Resource GPS Surveys*).

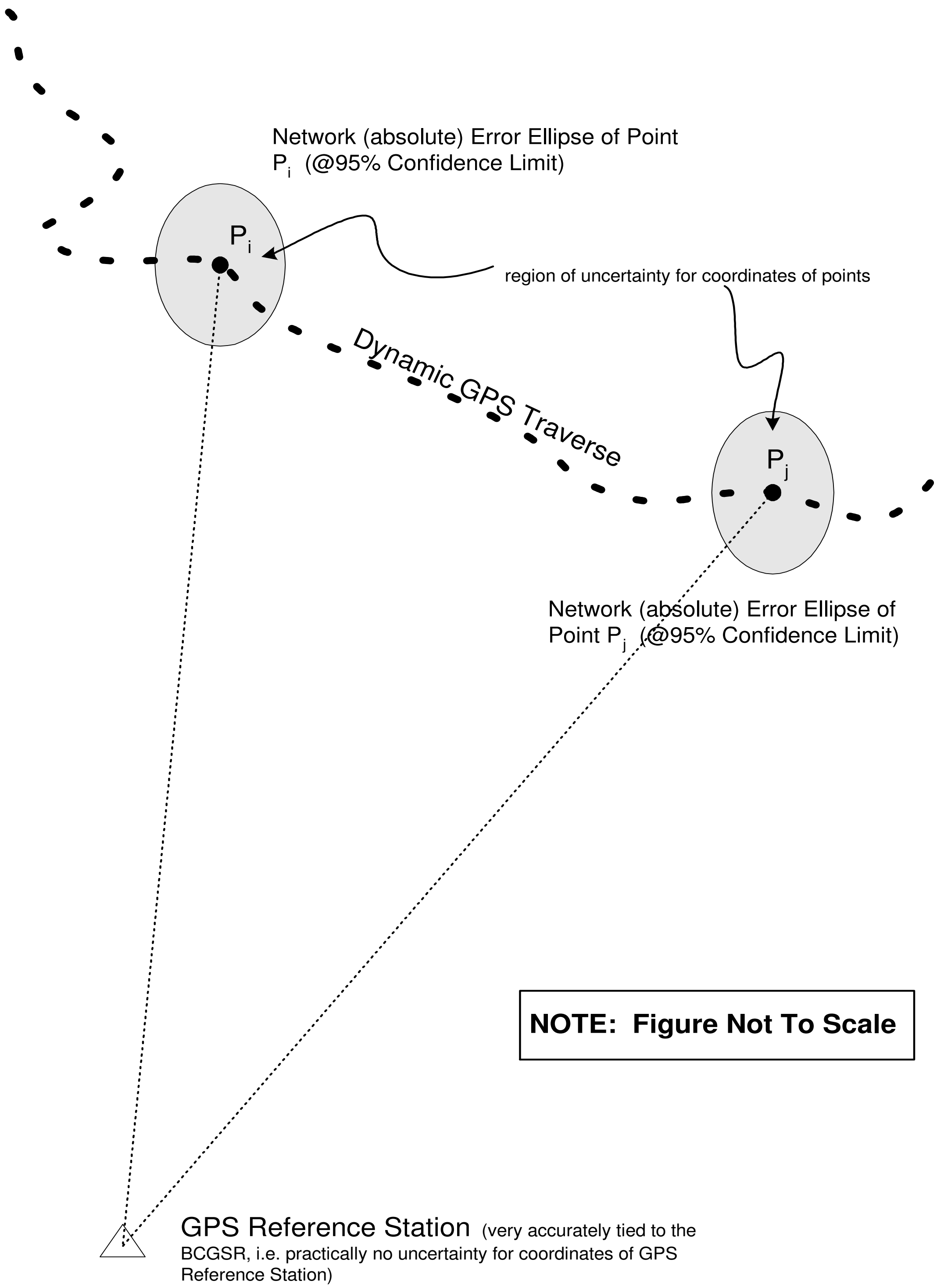
The BCGSR horizontal datum is physically marked on the ground by a system of approximately 50,000 accurately positioned geodetic control monuments placed throughout the province, and also through the GPS data products derived from the British Columbia Active Control System (BCACS). The BCACS is defined by a network of continuously operating GPS Base Stations, known as Active Control Points (ACPs), distributed throughout British Columbia. These positions define the North American Datum of 1983 (NAD83 (CSRS)) in the province. Accuracies of these coordinates range from 0.001m to ~1m (95%) with respect to the fundamental datum points at Whitehorse, Yellowknife, Penticton and Seattle (*see Figure B-2 The British Columbia Geo-Spatial Reference).*

To use the Horizontal Network Accuracy classification, statistically add the horizontal geodetic control monument error (or BCACS ACP error) to the horizontal survey error and classify the result according to the different classes. For example, assume that the survey point is tied to a geodetic control monument with a published horizontal error of 0.32m (at 95% confidence level). Further assume that the horizontal survey error relative to the geodetic control monument is 0.8m (95% confidence level). The Horizontal Network Accuracy for the newly established point is thus $\sqrt{(0.32^2 + 0.8^2)}$, or 0.86m. The point may therefore be classed as Horizontal Network Accuracy = 1m, since it is better than 1m but ***not*** better than the next higher class of 0.5m. This principle applies to all methods of geo-referencing, such as those based on the BCACS (i.e. surveys tied to a GPS Base Station that is rigorously integrated into the NAD83 (CSRS) datum) or various base mapping (i.e. surveys tied to features clearly defined on the NAD83 (CSRS) based mapping).

For general spatial referencing applications, the points in the British Columbia Active Control System (BCACS) may be considered to approach an error-free realization of the defined reference system. Accuracy with respect to these monumented points in the provincial network can be interpreted as an expression of Network Accuracy.

Absolute vertical accuracy with respect to the provincial Geo-Spatial Reference (GSR) is calculated in the same way. The GSR vertical datum is demarcated on the ground by a system of accurately leveled benchmarks (and geodetic control points) dispersed throughout the province. These elevations define the current Canadian Vertical Datum of 1928 (CVD28). While rigorous accuracies are not available on this old vertical datum, elevations refer to Mean Sea Level and generally range in accuracy between 0.01m to 2m for spirit leveled points and 1m to 3 m for elevations derived from other methods (trigonometric heighting, etc.). As with horizontal classification, statistically add the benchmark elevation error estimate to the vertical survey error and classify the result according to the different accuracy classes.

Figure B-3 Network Accuracy and Resource GPS Surveys



3.2. Local Accuracy for Resource GPS Surveys

Local Accuracy, also known as r*elative accuracy*, is an average measure (e.g. mean, median, etc.) of the relative accuracies of the coordinates for a point with respect to other adjacent points at the ***95% Confidence Level***. For horizontal coordinate accuracy, the Local Accuracy is computed using an average of the semi-major axes of the 95% *relative* confidence ellipses between the point in question and other adjacent points. For orthometric height accuracy, the Local Accuracy is computed using an average of the 95% *relative* confidence intervals between the point in question and other adjacent points (*see Figure B-4 Local Accuracy and Resource GPS Surveys*).

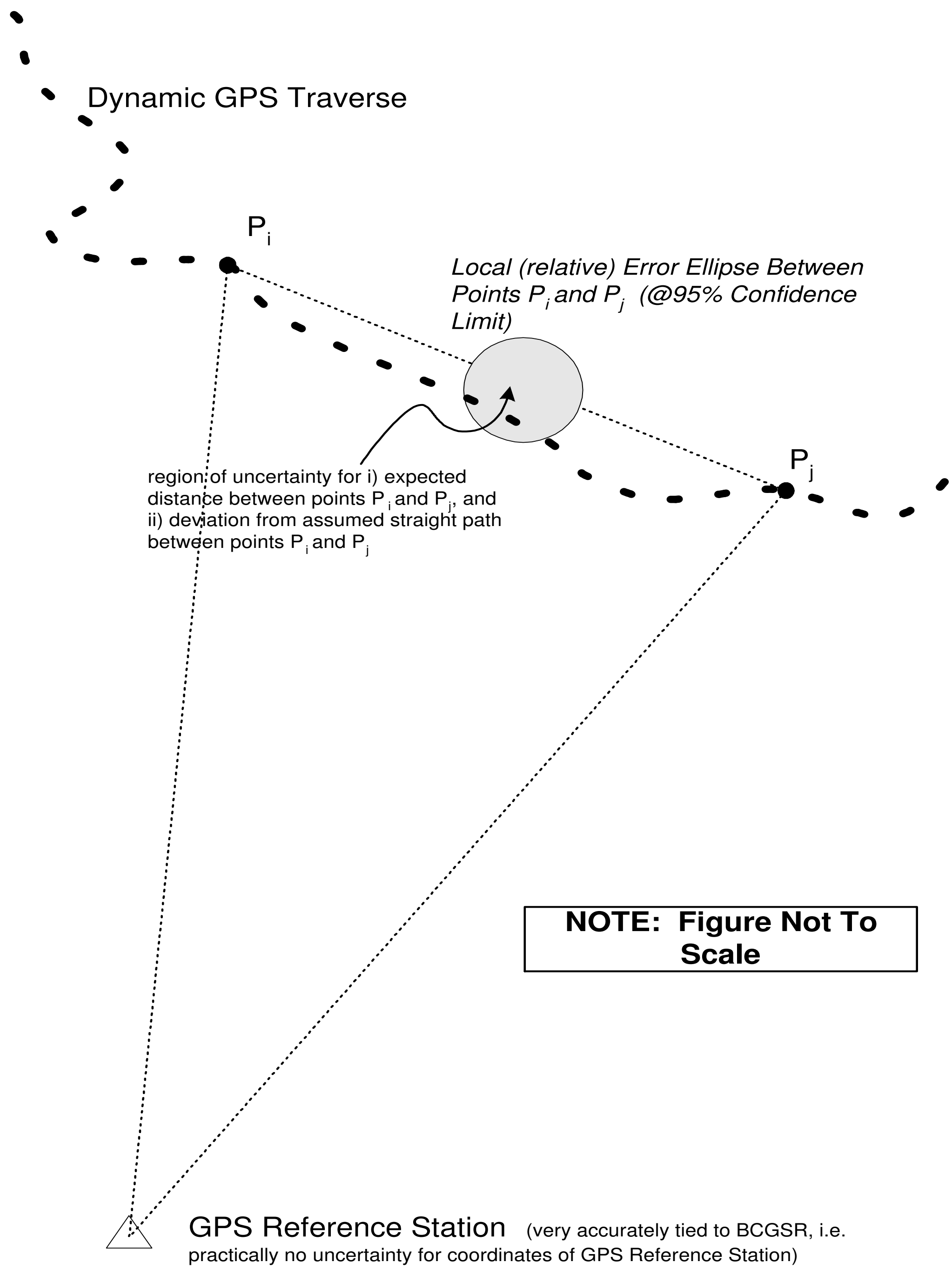
The Network and Local Accuracy values at a point provide two very different pictures of positioning accuracy. Network Accuracy indicates how accurately a point is positioned with respect to the reference system, and is therefore dependent upon the connection to the BCGSR. For a positioning project connected to the reference system through the use of a monumented control point of known coordinates, network accuracies for the new points in the project will depend upon the Network Accuracy at the known point and the relative accuracies within the new work.

Local Accuracy indicates how accurately a point is positioned with respect to other adjacent points in the survey. Based upon computed relative accuracies, Local Accuracy provides practical information for users conducting local surveys between control monuments of known position. Local Accuracy is dependent upon the positioning method used to establish a point. If very precise instruments and techniques are used, the relative or Local Accuracy related to the point will be very good.

While a point may have good Local Accuracy it may not necessarily have good Network Accuracy, and vice versa. Different positioning applications will have varying objectives that emphasize either network or Local Accuracy, or have specific requirements for both types of accuracy.

The following situation is provided as an example: A number of points in a GPS traverse are surveyed and after processing the data and adjusting the data the average horizontal 95% relative confidence ellipse measure between these stations is 0.43m. The points may therefore be classed as Horizontal Local Accuracy = 0.5m, since the average error ellipse measure is better than 0.5m, but ***not*** better than the next higher class of 0.2m.

Figure B-4 Local Accuracy and Resource GPS Surveys



3.3. Resource GPS Interpretive Accuracy

If the Interpretive Accuracy is expected to vary widely across the surveyed features of a project, and the magnitude of this error is significant when compared to other error sources, then it is best to require that an Interpretive Accuracy attribute be logged at every surveyed feature. For example, a stream bank may be clearly defined (resolution of a few decimetres) in fast-running areas, but can become fuzzy (resolvable only to several metres) in slow-running marshy areas. In other cases it may be possible to ignore Interpretive Accuracies (all features sharply defined), or to assign a single Interpretive Accuracy to all features. The Field Operators must use their best judgment in assigning these values. See *Section D-5.1* for more information on feature interpretation.

The following tables provide some examples of features that may be mapped and the applicable Network Accuracy Classification (derived from *Table B-1 - Accuracy Classification Standards*) that would be attached to the feature. These tables are expected to help provide a level of consistency in applying Horizontal and Vertical Interpretive Accuracy.

Horizontal Interpretive Accuracy Class	Accuracy Range	Examples
1 millimetre	≤0.001m	fixed-centering monument (i.e. pillar)
2 millimetre	>0.001m to 0.002m	survey control marker – center punched
5 millimetre	>0.002m to 0.005m	iron pin - no center punch
1 centimetre	>0.005m to 0.01m	well defined urban facilities (e.g. hydrant)
2 centimetre	>0.01m to 0.02m	edge of pavement – sidewalk
5 centimetre	>0.02m to 0.05m	edge of pavement - no sidewalk
1 decimetre	>0.05m to 0.1m	center of utility pole, centerline of RR tracks
2 decimetre	>0.1m to 0.2m	edge of lake or gravel road
5 decimetre	>0.2m to 0.5m	center of gravel road, overhead power line crossing
1 metre	>0.5m to 1m	intersection of seismic lines
2 metre	>1m to 2m	edge of clearing (cut)
5 metre	>2m to 5m	edge of marsh
10 metre	>5m to 10m	edge of clearing (natural)
20 metre	>10m to 20m	center of buffer strip
50 metre	>20m to 50m	river channel in marsh/delta
100 metre	>50m to 100m	center of small lake/swamp

Table B-2 Horizontal Interpretive Accuracy Classification

Vertical Interpretive Accuracy Class	Accuracy Range	Examples
1 millimetre	≤0.001m	fixed-center monument (i.e. pillar)
2 millimetre	>0.001m to 0.002m	survey control marker or BM
5 millimetre	>0.002m to 0.005m	supplemental control
1 centimetre	>0.005m to 0.01m	well defined “street furniture” (e.g. hydrant)
2 centimetre	>0.01m to 0.02m	water level - calm lake
5 centimetre	>0.02m to 0.05m	water level - calm seas & crown of road
1 decimetre	>0.05m to 0.1m	water level - rough lake
2 decimetre	>0.1m to 0.2m	Ordinary High Water Mark (OHWM)
5 decimetre	>0.2m to 0.5m	water level - rough seas
1 metre	>0.5m to 1m	top of bank
2 metre	>1m to 2m	summit of hill
5 metre	>2m to 5m	
10 metre	>5m to 10m	
20 metre	>10m to 20m	
50 metre	>20m to 50m	
100 metre	>50m to 100m	

Table B-3 Vertical Interpretive Accuracy Classification

The examples provided in the above tables are intended as a guide only. Different Interpretive Accuracy classifications may be used depending on the unique feature and project.

3.4. GPS Base Station Accuracy

In most cases, resource GPS surveys utilize GPS Base Stations (such as the BCACS network) as part of their survey methodology. The level of positional accuracies in such surveys is directly affected by the absolute positional accuracies of the GPS Base Station. It is a good survey practice to ensure that the datum related positional accuracy of the Base Station is an order of magnitude (~10 times) better than the highest equivalent accuracies sought in any particular project. This ensures the affect of any GPS Base Station positional errors on the project survey can be considered negligible.

While there are other very important factors affecting proper location and functioning of GPS Base Stations, (see *Section D-4.3* of the *DGPS Guidelines* document), it is nonetheless appropriate and important to establish accuracy standards for GPS Base Stations.

The following table outlines GPS Base Station Network Accuracy requirements for three general categories of user project Network Accuracy requirements - all at the 95% Confidence Level.

GPS Base Station Category	Proposed Project Horizontal Network Accuracies	Base Station Horizontal Network Accuracy	Proposed Project Vertical Network Accuracies	Base Station Vertical Network Accuracy
I	<2m	<0.05m	<2m	<0.05m
II	2m to 10m	<0.5m	2m to 10m	<0.5m
III	>10 m	<2m	>10m	<2m

Table B-4 GPS Base Station Network Accuracy Categories

Note that the vertical accuracies referred to in the above table are Orthometric Heights (i.e. Mean Sea Level) and *not* Ellipsoid Heights. Orthometric heights are referred to the Canadian Vertical Datum of 1928 (CVD28). Also note that the Vertical Base Station Categories are more difficult to meet than their Horizontal counterpart due to the following:

a) the Geoid uncertainty that influences the derivation of Orthometric Heights from GPS-based Ellipsoidal Heights; and
b) the generally less accurate vertical component of GPS (e.g. approximately half as accurate as horizontal component)

A GPS Base Station, classified as above, may support all lower categories but not higher categories. For example, if a GPS Base Station is classified as a "Horizontal Category II", and then it may serve projects under that category as well as those under Horizontal Category III (but not Horizontal Category I).

The process for establishing GPS Base Stations is outlined in *Section D-4.3* of the *DGPS Guidelines*.

3.5. Summary and Application of the Standards for Resource Surveys

To review, the Network Accuracy and Local Accuracy values at a point provide two very different pictures of positioning accuracy. Network Accuracy indicates how accurately a point is positioned with respect to the Geo-Spatial Reference (GSR) system and is therefore dependent upon the connection to the BC Geo-Spatial Reference (BCGSR). For a positioning project connected to the BCGSR by using a monumented control point of known coordinates, Network Accuracies for the new points in the project will depend upon the Network Accuracy at the known point and the relative accuracies within the new survey work.

Local Accuracy indicates how accurately a point is positioned with respect to adjacent points in the network. Based upon computed relative accuracies, Local Accuracy provides practical information for users conducting local surveys between control monuments of known position. Local Accuracy is dependent upon the positioning method used to establish a point. If very precise instruments and techniques are used, the relative or, Local Accuracies related to the point will be very good.

While a point may have good Local Accuracy it may not necessarily have good Network Accuracy…and vice versa. Different positioning applications will have varying objectives that emphasize either Network or Local Accuracy, or have specific requirements for both types of accuracy.

The Network and Local Accuracies for points in the provincial BCGSR network are separated into their horizontal and vertical components. Although the horizontal coordinates and ellipsoidal heights for points in these networks may have been determined using the same three-dimensional GPS (and conventional) observations, the consistently weaker vertical component of the GPS results tends to dominate three-dimensional accuracy statements. Because many applications of GPS positioning principally require only horizontal coordinates, a clear statement of horizontal accuracies is of practical importance.

For general geo-spatial referencing applications, the points in the Canadian Active Control System (CACS); the Canadian Base Network (CBN); and the BC Active Control System (BCACS) may be considered to approach an error-free realization of the defined Geo-Spatial Reference system. Accuracy with respect to these monumented points in the federal Canadian Spatial Reference System (CSRS) and provincial BCGSR networks may then be interpreted as an expression of Network Accuracy.

For points included in the provincial network of the BCGSR, Network and Local Accuracies are computed by CRGB using the standard accuracy representations presented in the *Standards* section (see *Figure B-2 - The British Columbia Geo-Spatial Reference*). In addition, the Network and Local Accuracies may be classified by comparing the 95% confidence ellipse for horizontal coordinate accuracy, and the 95% confidence interval for ellipsoidal height accuracy, against a set of standards. This set of accuracy classification standards appears in *Table B-1* that lists the accuracy classes and their associated range. Class boundaries increase by doubling, or approximately doubling, the upper boundary value of the previous class.

Thus, in the most complete case, a station position will be classified in both Local and Network Accuracy for horizontal position, ellipsoidal height and orthometric height (six separate measures). Because the classification of the horizontal and vertical accuracy is separate, the proposed scheme is especially meaningful when the horizontal accuracy is much better than the vertical, or in the future, when the accuracy of the ellipsoidal height is better than that of the orthometric height, or vice versa.

A complete description of a position's accuracy (say for the centreline of a gravel road) might be as follows:

Local Horizontal Accuracy	1.0m
Network Horizontal Accuracy	2.0m
Interpretive Horizontal Accuracy	0.5m
Local Ellipsoid Height Accuracy	2.0m
Network Ellipsoid Height Accuracy	5.0m
Interpretive Vertical Accuracy	0.5m
Local Orthometric Height Accuracy	3.0m
Network Orthometric Height Accuracy	6.0m

For the purpose of these standards, the generalized Local Accuracy at a point is based on an average of the individual Local Accuracies (or relative accuracies) between the point in question and other adjacent points. In practice, the relative accuracy between two points must be available if they are to be considered adjacent for purposes of computing Local Accuracy. Therefore, the availability of complete covariance information between the points must be assured.

Any chosen combination of criteria, to determine adjacency, should always encompass at least some pairs of points that are ***directly connected*** via survey observations in the data. In general, relative accuracy is more reliably known between directly connected points than between points which have only indirect connections through the survey network. An average Local Accuracy should therefore be at least partially based upon these better-known relative accuracies.

Thus, the Local Accuracy statistic in the majority of resource surveys can not be derived via the GPS post-processing as there is usually no direct measurement between any of the local, or adjacent points (as with baselines in a geodetic survey). Therefore, in the majority of the cases, the Contractor will not be required to present the Local Accuracy statistic for resource surveys done by the GPS methods when a distant GPS Base Station is used.

In summary, for a typical resource GPS survey only the ***Network Horizontal Accuracy***, the ***Interpretive Horizontal Accuracy***, the ***Network Orthometric Height Accuracy*** and the ***Interpretive Vertical Accuracy*** will be specified and defined. In the above example of a gravel road survey, we thus have:

Network Horizontal Accuracy	2.0m	(i.e. Class = 2 metres)
Interpretive Horizontal Accuracy	0.5m	(i.e. Class = 0.5 metres)
Network Orthometric Height Accuracy	6.0m	(i.e. Class = 10 metres)
Interpretive Vertical Accuracy	0.5m	(i.e. Class = 0.5 metres)

This confirms that, for this example:

- the road centerline is horizontally integrated within the BCGSR (i.e., NAD83(CSRS)) at the 2m accuracy level,
- the road centerline was definable and surveyed at the 0.5m level (i.e. the road edges were defined well enough to determine and occupy the centerline accurately),
- the road centerline is vertically defined (Mean Sea Level CVD28) at the 6.0m accuracy level (which falls into the 10m accuracy class), and
- the road centerline crown is vertically discernible at the 0.5m level

SECTION C - SPECIFICATIONS

SECTION C - SPECIFICATIONS

1. APPLICATION

These *Specifications* have been developed in response to a need for standardized Global Positioning System (GPS) data collection procedures for all GPS resource surveys in the province. In particular, the *Specifications* will facilitate standardization and quality control for land related information collected for government databases using GPS technologies. The *Specifications* are supported by two other sections in this document: the *Standards* and the *DGPS Guidelines*.

The *Standards* section outlines geo-spatial referencing categories in a standardized and uniform manner. Using the *Specifications* section, the project target accuracies can be specified based on the standardized categories established within the *Standards* section. As well, the *Standards* section establishes standards for GPS Base Station accuracies within the provincial geo-spatial reference framework.

The second supporting section is the *DGPS Guidelines*. The *DGPS Guidelines* section provides relevant background information in order to complete those areas of the *Specifications* that vary project by project. This *Specification* document, when completed using the *DGPS Guidelines*, will form the technical section of a GPS survey contract. Refer to *Section D-3.2* for a cross-reference table to assist the Contract Administrator in completing these *Specifications*. Also, see *Appendix C* for a sample *Specifications* document completed for a typical resource survey requiring 10m horizontal Network Accuracy.

This schedule is intended for use as an adjunct to all contracts for surveys undertaken in the Province of British Columbia using differential GPS techniques (DGPS), with accuracy requirements focused on the 1m to 10m horizontal accuracy classes (at 95% confidence) and the 5m to 20m vertical accuracy classes (at 95% confidence). These specifications can also be applied for the 20m and 50m horizontal classes and up to the 100m vertical accuracy class (at 95% confidence). The actual accuracies required for the project or application are to be entered under *Specification C-5.7.*

For higher accuracy requirements (millimetres to a few decimetres), refer to the document ***British Columbia Standards, Specifications and Guidelines for Control Surveys using Global Positioning System Technology*** as available from CRGB of the Ministry of Agriculture and Lands. Publications by other provincial and Federal agencies also describe procedures for using GPS for high accuracy surveys.

2. INTERPRETATION

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

Note that the term GPS can be exchanged with the generic term GNSS where appropriate. This is to allow use of systems that are more than just GPS (e.g. combined GPS / GLONASS / GALILEO systems). The period from 2008 onwards will see significant developments both within GPS, and with other GNSS, and these advancements can be applied during resource surveys where appropriate (of course following careful confirmation of new equipment / techniques / methods).

In this schedule, the following definitions and abbreviations are used:

Agency	Ministry, Department or other entity administering the Contract.
BCGS	British Columbia Grid System defining the map graticules within the province at various scales.
CRGB	Crown Registry and Geographic Base, Integrated Land Management Bureau, Ministry of Agriculture and Lands, Province of British Columbia.
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.
CVD28	Canadian Vertical Datum of 1928.
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 CRGB for the current provincial standard Geoid model.
GNSS	Global Navigation Satellite System (e.g. GPS, GLONASS, GALILEO, etc)
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 Base 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 GPS Base Station.
NAD27	North American Datum of 1927 based on the Clarke 1866 ellipsoid.
NAD83 (CSRS)	North American Datum of 1983 (Canadian Spatial Reference System), based on the Geodetic Reference System 1980 (GRS80) ellipsoid and as defined by the GRS in British Columbia.
RISC	Resources Information Standards Committee
Static-mode	Mult-epoch collection of GPS data at a point while remaining stationary.
Supplemental Traverse	Supplemental Traverses are conventional traverses (e.g. compass and tape) that are integrated with GPS surveys.
UTM	Universal Transverse Mercator projection (map projection system).

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

Highly recommended	Used to describe tasks that are deemed *highly* desirable and are good practice. Exceptions are possible, but only after careful consideration.
Should	Used to describe tasks that are deemed desirable and good practice, but are left to the discretion of the Contracting Agency.

3. GOALS

3.1. 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.

3.2. To provide capability for integration of requirements across government agencies and to standardize those requirements where common standards are applicable.

4. PRE-QUALIFICATION AND VALIDATION

4.1. Total System - It is ***highly recommended*** that any Contractor proposing 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 Base Station receivers; and reporting techniques. All parts of the System are to be capable of meeting these contractual specifications.

4.2. Field Operator Training – It is ***highly recommended*** that Field Operator(s) be qualified through the RISC course: "Field Operator GPS Training for Resource Mapping".

4.3. Data Processor / Project Manager Training – It is ***highly recommended*** 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. It is ***highly recommended that*** they be qualified through the RISC course: "Comprehensive GPS Training for Resource Mapping”.

4.4. It is ***highly recommended that*** all GPS Base Stations be validated according to the procedures outlined in *Section D-4.3* of the *DGPS Guidelines* document. This includes public, private, permanent, or semi-permanent GPS Base Stations.

5. PRE-FIELDWORK PROCEDURES

5.1. The Contract Administrator ***should*** conduct a pre-fieldwork conference for all potential contractors. The Contract Administrator ***should*** 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, a specimen layout for interpretive purposes ***should*** be provided. The Contract Administrator ***should*** also provide a clear definition of the deliverables, services, work quality, payment schedule, and other relevant contract issues. There should be no doubt as to the nature and quantity of work expected.

5.2. The Contract Administrator ***should*** 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).

5.3. The Contract Administrator ***should*** 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. Adjacent information outside the contract area or station marking should be defined and negotiated prior to contract award.

5.4. If physical reference markers are required to be established, it is ***highly recommended that*** the interval and type of markers be stated in the contract, and be established according to existing Agency guidelines or requirements.

5.5. All projects ***should*** include sufficient map ties such as creek junctions, road intersections or other features to enable accurate geo-positioning and to provide reliability checks. The Agency representative ***should*** specify the number of tie points required, and ***should***, if possible, specify where and what these tie points should be.

5.6. ***Cadastral survey boundaries in British Columbia may only be definitively and legally located on the ground by a British Columbia Land Surveyor (B.C.L.S.) or, in specific cases, a Canada Lands Surveyor (C.L.S.). Non-qualified persons may misinterpret boundary marks when occupying legal survey monuments. This could result in legal action being taken against the Contractor or the Agency if damages occur on adjacent lands*** (see *DGPS Guidelines Section D-5.4).*

5.7. The required survey accuracies (i.e. target accuracies at 95%) for the project are:

Network Horizontal Accuracy =	_______ m	(Class = ____________)
Interpretive Horizontal Accuracy =	_______ m	(Class = ____________)
Network Orthometric Height Accuracy =	_______ m	(Class = ____________)
Interpretive 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. If statistical methods are used to reject outliers, 2 sigma ***should*** be used.

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

6. FIELDWORK

6.1. 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 (this mode is sometimes referred to as "3D" positioning mode).

6.2. It is ***highly recommended*** that the *minimum* satellite elevation angle/mask for the field GPS receiver is set to 15 degrees above the horizon.

6.3. It is ***highly recommended*** that the DOP not exceed the following values:

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

Not all DOP values are required to be completed (e.g. VDOP applies only when accurate elevations are required)

6.4. It is ***highly recommended*** that during Static (point-mode) surveys, occupations will adhere to the minimum values shown below:

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

6.5. It is ***highly recommended*** that positions for linear features mapped statically (i.e. static or point-to-point traverses) be no more than _______metres apart, with the traverse points defined as Standard Significance Points and established to the *Specification C-6.4* above.

6.6. It is ***highly recommended*** that position fixes for linear features mapped dynamically (i.e. dynamic traverse) be no more than ______ metres apart.

6.7. It is ***highly recommended*** 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)).

6.8. 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.

6.9. Times of GPS Events (i.e., interpolated points captured while moving) on dynamic traverses ***should*** be accurate to at least ______ seconds. It is ***highly recommended*** that the Contractor do representative testing to prove that the GPS Event methodology produces results that meet the accuracy specifications.

6.10. It is ***highly recommended*** that for point offsets, the following specifications be observed:

a) 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.
b) Magnetic Declination is to be applied to all compass observations before computing offset coordinates.
c) The *maximum* distance for point offsets is ______ metres or ______ metres if offset observations are measured forward and backwards.
d) Bearings are to be accurate to at least ______ degrees, and distances to at least ______ metres.

6.11. It is ***highly recommended*** that for linear offsets, the following specifications be observed:

a) The Field Operator is to record the following information: horizontal distance and the direction (left or right) perpendicular to the direction of travel.
b) The *maximum* linear offset (i.e. horizontal distance) allowable is ______ metres.
c) Linear offset distances are to be checked and adjusted periodically.

6.12. It is ***highly recommended*** that supplementary traverses meet these following rules:
a) The supplementary traverse is to begin and end on physically marked High-Significance GPS static points (PoC and PoT).
b) The distance traversed is to be less than _______ metres.
c) The supplementary traverse is to close between the GPS PoC and PoT by ________________ of the linear distance traversed.
d) The supplementary traverse is to be balanced between the GPS PoC and PoT by an acceptable method (i.e., compass rule adjustment or similar method).

6.13. Physical reference markers are to be established every ______ metres along linear features *(enter N/A if not applicable)*. These markers must adhere to Contracting Agency standards, or be accepted before the work commences.

6.14. It is ***highly recommended*** that static point features be collected at all physical reference markers. These static point features are to be collected as HIGH / STANDARD *(circle one)* Significance points.

6.15. It is ***highly recommended*** that the field GPS receiver's default Signal to Noise Ratio (SNR) mask for high accuracy be used. This CAN / CANNOT *(circle one)* be relaxed during traversing of linear features. See *Section D-7.2.5* of the *DGPS Guidelines* for more information on SNR masks and their effect on positional accuracy.

7. GPS BASE STATIONS

7.1. All GPS Base Stations established by the contractor are to be monumented (physically marked) to allow the Contracting Agency or other Contractors to re-occupy the same location. Reference marks are to be semi-permanent and the station referenced using adjacent features (i.e. road intersections, bearing trees, etc.) to assist during relocation, and in determining that it is undisturbed. Suitable markers include iron bars driven into the soil, spikes in asphalt or concrete, or other markers which the Contractor and Agency determine will remain stable during and, for a reasonable time, after project completion.

7.2. It is ***highly recommended*** that the separation distance between the GPS Base Station and field GPS receivers be less than ______ kilometres.

7.3. The *minimum* elevation angle/mask of the GPS Base Station ***should*** be 10 degrees.

7.4. If real-time differential corrections are used, it is ***highly recommended*** that they be from a GPS Base Station validated according to CRGB procedures.

7.5. If real-time corrections are used, it is ***highly recommended*** that the Total *Correction Age* of the field GPS receiver not exceed ______ seconds. See *Section D-8.5.2* of the *DGPS Guidelines*.

8. PROCESSING AND QUALITY CONTROL

8.1. All GPS positions are to be corrected by standard differential GPS methods (pseudorange or position-shift corrections). If position-shift corrections are used, the same set of GPS satellites are to be used at the GPS Base Station as at the field Rover receiver for all corrected position epochs.

8.2. If the GPS receiver and/or post-mission software provide the option for dynamic filtering, the filters are to be set to reflect the speed of the Rover receiver, and the software versions and filter settings are to be noted in the project returns. If filtering/smoothing is applied to GPS Base Station data, this is also to be noted.

8.3. The Contractor ***should*** outline and 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).

8.4. The Contractor ***should*** be prepared to entirely re-survey those areas that do not meet the compliance standard at their own cost.

9. PROJECT DELIVERABLES

9.1. The Contractor ***should*** 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, and a project name (if available).
- A brief description of the project work (i.e. purpose, target accuracies, 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.).
- A list of all hardware and software used on the project; including but not limited to:
  - GPS hardware (i.e. receiver model, antenna, datalogger, 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.)
- Details regarding the GPS Base Station(s) 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.

9.2. The Contractor ***should*** submit the following digital deliverables in the indicated format and datum (see *Sections 9 & 10* of the *DGPS Guideline* for details).

Deliverables	Format	Notes
GPS Base Station Data	Proprietary or RINEX	Merged if possible
Raw Field GPS Data	Proprietary or RINEX	Originally downloaded
Original Corrected GPS Data		Unedited
Final Interpreted GPS Data		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.*

9.3. The final Interpreted 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; Contracting Agency name; Contractor name; and date of survey.*
- *Plan datum (e.g. NAD83(CSRS)) and the Map Projection (e.g. UTM).*
- *Plan scale (e.g. 1:20,000) with BCGS map identifier.*
- *Plan orientation, (e.g. north arrows showing True North, Magnetic North and Grid North as appropriate).*
- *Geographic (e.g. latitude/longitude) and/or Mapping Projection (e.g. UTM) graticule as requested.*
- *Source of any non-project information (i.e. TRIM backdrop, Forest Cover data, etc.).*

9.4. Final data is to be reduced and presented referenced to the NAD83(CSRS) datum. If the Contract Agency requires data to be provided on the NAD27 datum, then the National Transformation algorithm (latest version) is to be used to create a ***copy*** of the data. If the Agency requires any other local datum, the methods used to transform the data is to be explicitly described in the project report and approved by the Agency.

9.5. If orthometric elevations are required for submission, vertical data is to be referenced to the CVD28 using the standard Geoid model for British Columbia - with local Geoid modelling if required (i.e. for high vertical accuracy projects).

9.6. 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 ***should*** be made available to the Contract Administrator or designate. The Agency ***should*** be responsible for storage or destruction of the data files in accordance with government standards.

9.7. The data provided ***should*** 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.
- Type, model and version number of hardware used to collect and store data.
- GPS Base 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.

9.8. Digital returns are to be submitted on the storage media and format as required by the Agency.

10. TECHNOLOGICAL/PERSONNEL CHANGE

10.1. If there are 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. The Contract Administrator may require confirmation that the new system will continue to meet the contract specifications.

10.2. The Contractor and the Contract Administrator ***should*** ensure that the most current versions of the RISC Standards are used.

SECTION D – DGPS Guidelines

SECTION D - DGPS GUIDELINES

1. INTRODUCTION

This section of the document is a reference of Global Positioning System (GPS) related information intended for Contract Administrators (i.e. administering mapping, or inventory, contracts utilizing GPS technology). Apart from a general overview of the GPS system (i.e. history, observables, measurement techniques, etc.) this section provides information corresponding to each phase of a typical GPS project/contract. This information is provided roughly in the chronological order in which the phases would occur in a GPS project; namely:

- i) GPS Overview
- ii) Contract Management
- iii) Validation Concepts
- iv) Feature Interpretation and Mapping Details.
- v) GPS Project Management and Planning.
- vi) GPS Field Data Collection Considerations.
- vii) GPS Data Processing and Quality Control
- viii) Digital Mapping and GIS Integration
- ix) Deliverables and Data Management Issues.
- x) Quality Assurance and Audit Procedures.

This section D is also designed to assist Contract Administrators to complete the *Specifications* section of the document (see *Section D-3.6*). That is, relevant information is presented here in order to help fill in the blanks left in the *Specifications* section.

Be aware that section E contains a guideline for those considering the use of autonomous (uncorrected) GPS positioning for *non-critical* features.

CRGB recommends that the ***British Columbia Standards, Specifications and Guidelines for Resource Surveys Using Global Positioning System (GPS) Technology*** be used by all government agencies commissioning GPS projects. This will help to establish a uniform standard for contracted works. These documents should be considered as a minimum information level for GPS Contract Administrators. It is recommended that supplemental training be used to compliment this document.

Note that the term GPS can be exchanged with the generic term GNSS where appropriate. This is to allow use of systems that are more than just “pure” GPS (e.g. combined GPS / GLONASS / GALILEO systems). The period from 2008 onwards will see significant developments both within GPS, and with other GNSS, and these advancements can be applied during resource surveys where appropriate (of course following careful confirmation of the accuracy performance of the new equipment / techniques / methods).

2. GPS BACKGROUND

2.1 What is GPS?

The Global Positioning System (GPS) is a US military satellite system that provides continuous three-dimensional positioning (latitude, longitude, and height) anywhere on or above the earth. GPS is best described by understanding the 3 major segments that make up the system: the *space* segment, the *control* segment and the *user* segment.

The *space* segment is made up of nominally 24 satellites (currently 30 as of early 2008) that orbit the earth with a period of 12 hours. The satellites (also called Space Vehicles or SVs) are arranged to optimize coverage so that at least 4 satellites are visible at all times from anywhere on earth. Each satellite contains atomic frequency standards (clocks) that are extremely precise allowing them to remain synchronized with other GPS satellites and also with the ground control system. All satellites broadcast at the same frequencies, but each has a unique PRN code (Pseudo Random Noise) that identifies a particular satellite and allows the user's receiver to make time-based distance measurements to each satellite. Each satellite also broadcasts the data elements necessary to compute the position of that satellite within its orbit at the exact time when the corresponding distance measurement was made. These data elements are called the ephemeris message.

The *control* segment consists of monitoring stations continuously tracking GPS at various locations around the earth, plus a master control station at an air force base in the USA. The control stations monitor individual satellite performance, determine their orbits, model their atomic clock behaviour, and inject (upload) each satellite with their broadcast data (including the ephemeris message).

The *user* segment includes any user equipped with a GPS receiver. In the basic mode of GPS operation (called pseudoranging), the user's receiver shifts a replica of each PRN code into alignment with the incoming signal from the satellites, and by scaling this time shift by the speed of light determines a distance (range) to each satellite. However, because the user's receiver is not precisely time synchronized with the GPS system, this time-based one-way range is corrupted by an unknown amount referred to as the range bias or user clock offset (this is why the mode of positioning is called ***pseudo****ranging* rather than simply ranging). With four pseudorange measurements, combined with the satellite positions from the ephemeris messages, the range bias can be computed along with the 3 dimensional coordinates for the user's receiver. In most cases it is the position that is important to the user and the computed range bias is ignored. If more than 4 satellites are visible, the user's position can be improved by using all measured pseudoranges in an over-determined solution. This basic mode of positioning is called *autonomous* or *uncorrected* as it is based on a single GPS receiver operating independently.

2.2 GPS History

GPS developed from earlier satellite navigation systems of the 1960s and 1970s. The first GPS satellites were launched in 1978 and gave limited coverage during the initial development years that followed. Commercial receivers became available in the early 1980s and the civilian use of GPS began modestly, gathered momentum as new measurement techniques were invented and refined, and then exploded to the level where civilian users now far outnumber military users. The space shuttle Challenger disaster of 1986 setback the GPS launch programs, and it was not until 1993 that the system was declared IOC (Initial Operational Capability). The system was declared FOC (Full Operational Capability) as of December 12, 1995. Other GPS milestones include May 2, 2000 when the deliberate civilian accuracy degradation was removed, and the fall of 2005 when the 1st modernized GPS satellites became available (new L2C civilian signal).

2.3 GPS Positioning Techniques

The mode of positioning described above (autonomous pseudoranging) is available at two service levels.

Military users have access to the PPS (Precise Positioning Service) via tracking of the P or Y (Precise) codes transmitted on 2 frequencies (called L1 & L2) which can produce instantaneous autonomous horizontal accuracies typically <3m (95%) using a single receiver. Civilian users currently have access to the SPS (Standard Positioning Service) via tracking of the C/A (Coarse Acquisition) code transmitted on just 1 frequency (L1). Before May 1st, 2000 SPS was deliberately corrupted to limit civilian horizontal accuracies to 100m (95%). The process of corruption was called Selective Availability (SA), and was based on a deliberate "dithering" of each satellite's atomic clock and/or the broadcast ephemeris. This affected *all* civilian receivers operating in autonomous mode (i.e. the cheapest to the most expensive receivers). On May 2nd, 2000 SA was removed, and instantly the SPS accuracy levels improved by an order of magnitude. Depending on the GPS receiver type used, horizontal accuracies of approximately 5m – 10m (95%) are now available autonomously under clear tracking conditions (under forest canopy these accuracies typically degrade by a factor of 2 – 5 because of the worse tracking conditions). Note that autonomous (uncorrected) GPS has low positional integrity (see *section E* of this document for an explanation of positional integrity). It should also be noted that vertical accuracies are typically 1.5 – 2.5 times worse than horizontal accuracies. Planned GPS modernization will enhance SPS (civilian) positioning with a new code on the L2 frequency (1st modernized satellite became available fall 2005), and another new code on a new frequency (called L5) is expected to become available after 2008.

Most surveying and mapping tasks can not accept the accuracy levels of autonomous GPS, nor can the low positional integrity be accepted. These two issues of accuracy and integrity drove the development of Differential GPS techniques.

Differential GPS (DGPS) is a technique based on a receiver operating at a previously surveyed location to allow measurement of instantaneous GPS errors, and then make these available as differential corrections to other GPS receivers. DGPS can produce reliable position accuracies in the range of <1m to 10m (95%) depending on a number of factors, for example:

- GPS satellite configuration (geometry)
- GPS data collection environment (i.e. obstructions, multipath, etc.)
- GPS field (Rover) receiver type
- GPS Base Station receiver type
- GPS Base Station and field receiver separation distance

DGPS surveys can be processed post-mission by merging the raw GPS data recorded at both the Base Station receiver and at the field (i.e., Rover) receivers. DGPS can also be applied in real-time with the addition of a communication link between the Base Station and Rover (i.e. radio, satellite, cellular phone, etc.). Prior to May 2000, SA was the largest single error source, and it was also the fastest changing. This meant that when SA was active, real-time corrections needed to be updated quickly with minimal delay between when they were calculated at the Base and when they were applied at the Rover. This requirement has been "relaxed" since the removal of the deliberate corruption of SA as the remaining errors are smaller in magnitude and change more slowly.

The original differential methodology developed in the early 1980s was based on a simple position-shift correction calculated at the Base Station (corrections to latitude, longitude and height), which were then applied to the Rover's computed position at the same epoch. This method provides reasonable accuracies *only* when the Base Station and Rover are tracking the *identical* set of satellites.

By the mid-late 1980s a more rigorous DGPS technique was developed by calculating the individual corrections to each pseudorange at the Base Station, and applying these corrections to the Rover's measured pseudoranges before computing the position. This marginally increased the accuracy and also relaxed the operating restrictions as it was no longer required for the Base Station and the Rover receivers to track the identical set of satellites. Note that some manufacturers still use a modified form of position-shift DGPS in their current post-processing software, however, all receivers using real-time DGPS corrections are based on individual pseudorange corrections (differential correction format name: RTCM).

In the never-ending quest for improved accuracies, some early researchers recognized the possibility of using the GPS signal in a different way. In this technique, the GPS phase angles of the carrier waves are tracked and recorded at a number of sites, and are then processed together post-mission using software to form interferometric differences. This results in very precise relative "baselines", or vectors (3 dimensional coordinate differences) between each GPS antenna pair. The amount of GPS data needed for a strong solution is dependent on factors that include satellite geometry and the length of baseline, with time periods of 15 - 60 minutes of static observations being typical. The precision of the baselines range from a few millimetres to a few decimetres. To obtain the most precise results, the integer number of carrier wavelengths between each receiver and satellite pair must be resolvable. Finding the correct integer numbers is called the ambiguity resolution problem, and if it is incorrect, the resulting position may be in error by more than 1m, and the internal statistics may not immediately identify this problem. GPS receivers that can track and record accurate carrier-phase observations are usually classified as *geodetic* or *survey-grade* receivers.

Dual frequency receivers can take advantage of the "wide lane" technique (a numerical combination of phase measurements on 2 frequencies) to make precise static baseline measurements in 5-15 minutes within a localized area. This technique is called Rapid Static or Fast Static. Dual frequency receivers also have an accuracy advantage for long baseline measurements (>25km) as the ionospheric signal delays can be directly measured and applied. This is not possible with single-frequency receivers. Both single and dual frequency baseline measurements can be adversely affected by wildly fluctuating ionospheric conditions during geo-magnetic storms. These storms are somewhat predictable, and various prediction and monitoring services are available via the internet.

Static phase techniques soon developed into kinematic phase solutions with centimetre-level precision possible nearly instantaneously. Kinematic solutions require the receiver to maintain uninterrupted phase lock on at least 4 or 5 satellites at all times. The original method for kinematic surveys was post-mission, but in the early 1990s this evolved into Real-Time Kinematic (RTK) with the addition of a data telemetry link between the RTK Base and Rover receivers. RTK can be an extremely productive and precise methodology in the right project environment. Kinematic solutions are best suited for project areas that are substantially free of obstructions. Carrier-phase techniques do not apply to under-canopy tracking, and are not used on most resource projects.

2.4 GPS Hardware and Software

This section is intended to give guidelines for evaluating GPS receivers and software. It provides some questions and trade-offs to be considered when evaluating equipment. However, specific or even generic recommendations are beyond the scope of this section since project requirements vary so widely.

GPS receivers and software can be used to obtain positions with accuracies ranging from tens of metres to sub-millimetre. This discussion will concentrate on GPS receivers capable of achieving 1m to 10m (95%) accuracy using standard L1, C/A-code differential techniques. For further information on basic GPS concepts, the reader should consult the references listed in *Appendix B*.

There are thousands of GPS receiver models available from many different manufacturers around the world. The market has matured from the time when a first-generation commercial receiver was used for all applications, to the present where specific GPS products are being developed and marketed for niche applications. Competition has improved the products and reduced prices, but has also added to confusion for the buyer. The following table is offered as a generic guideline to available GPS products (2008). By 2010 expect to see more receivers capable of tracking modernized GPS signals, as well as other satellite positioning systems (e.g. GALILEO, GLONASS, etc)

Use	Size	Best case accuracy (95%)	DGPS capable	Carrier Phase	Raw Data Recording	Price Range
Recreational / casual - Hiking, hunting, etc	small hand-held, watch, PDA, cell	5-10+ m	Some	-	-	$100 - $500
General Navigation - Marine, aircraft, land vehicles etc.	Compact, internal / external antenna	5-10+ m	Most	-	-	$250 - $1000
Low-End Mapping - standard-correlation code	Compact, internal / external antenna	2-5m	Yes	Some	Yes	$1000 - $5,000
High-end Mapping - narrow-correlation code	Backpack, external antenna or large-format handheld	<1-2m	Yes	Most	Yes	$7500 - $15,000
Geodetic Surveying - single frequency	Backpack, external antenna	sub cm	Yes	Yes	Yes	$5000 - $15,000
Geodetic Surveying - dual frequency	Backpack, external antenna	sub cm	Yes	Yes	Yes	$10,000 - $30,000

Table D-1 General GPS Equipment Guideline

GPS receivers appropriate for use in resource surveys can be broadly divided into two classes; for this document they will be referred to as "Low-End" and "High-End" differential GPS receivers. Geodetic quality GPS receivers can easily achieve resource accuracy specifications in the open, but are not considered here because of their poor tracking performance under forest canopy (i.e. tracking not optimized for forest conditions). The following table lists some features of each of the mapping classes.

Specifics	Low-End DGPS receivers	High-end DGPS receivers
Price Range ($):	$1,000 - $5,000	$7,500 - $15,000
Accuracy (95%, best case):	2m - 5m	<1m - 2m
Channels:	5 – 12	Usually "all in view" (12+)
Tracking:	Parallel (older: multiplexing)	Parallel
Carrier-Phase Smoothing:	Some	Most
Other attributes:	Standard-correlation tracking	Narrow-correlation with better multipath detection & rejection
Examples:	Magellan MobileMapper Pro CMT MC-GPS Trimble GeoExplorer III	Sokkia GIR (NovAtel engine) Trimble ProXR, Geo-XT Leica GS20

Table D-2 Typical GPS Equipment Guideline for Resource Surveys

Various receivers will have specific features and performance characteristics that may or may not be appropriate for the type of surveys being done. The following are some of the issues that should be considered when choosing receivers for resource GPS work.

The Number and Type of Channels. Receivers with 10 or more parallel channels will usually out-perform others. These receivers can dedicate a hardware channel to each satellite in view. Measurements are made simultaneously and if a signal is interrupted (for example by tree foliage/stems), it can be used immediately upon re-acquisition. Some Low-End GPS receivers use four parallel channels dedicated to track four satellites, and one or more channels multiplexing, or rapidly sequencing between the other available satellites. This older technique is an acceptable tracking scheme for open conditions, but performance will not be as good under more difficult tracking conditions.

Support for modernized GPS, GNSS and Augmentations. Some receivers support modernized GPS signals (L2C, L5), and/or other GNSS signals (GLONASS available now, and likely GALILEO in the future). These changes will become significant in the period 2008 – 2012+, and most will require hardware changes in order to benefit from these changes. Almost all receivers manufactured now support WAAS augmentation (a wide-area RT-DGPS solution intended for aviation), but this is of limited use for most resource projects. Some receivers directly integrate CDGPS which can be a useful RT-DGPS method for resource projects. Another RT-DGPS source is Coast Guard corrections, and some GPS systems directly integrate a beacon receiver to allow RT corrections when within range of a transmitter. See Section 2.5 for more information.

The Signal Tracking Characteristics. Even in the open, GPS signals are extremely weak upon arriving at the antenna. All electronic signal tracking will add some noise to the signal due to antennas, cables, signal processing, etc. Better designed receiver-antenna combinations will be able to track signals with very little added noise and therefore are able to more accurately measure the pseudoranges, even when those signals are relatively weak due to signal propagation and interference effects. The High-End narrow-correlation GPS receivers have sophisticated tracking algorithms to reduce the effects of multipath and signal attenuation. These receivers give better productivity and accuracy than standard-correlation receivers.

Range Measurement Accuracy. A GPS receiver measures the range (distance) from the antenna to the satellite. The range measurement accuracy multiplied by the DOP value (see the *Section D-7.2.3)* gives an estimate of the positioning accuracy of the receiver. Narrow-correlation receivers can resolve ranges to about 1/1000 of the signal wavelength, or about 0.3m for the C/A code. Low-End receivers can resolve ranges to only 1m or worse. Carrier phase smoothing is a technique used by some High-End receivers to smooth the ranges and thus produce "quieter" positioning (better fix-to-fix stability, but not necessarily more accurate).

Signal Re-acquisition and Time-To-First-Fix. "Time to first fix" (TTFF) is a measure of how long it takes for a receiver to get a position fix after being switched on. Manufacturers commonly use this to indicate a receiver's performance. A more appropriate test for receivers to be used in difficult tracking conditions would be the signal re-acquisition performance. When satellite tracking is lost (usually due to canopy blockage), and then becomes available again, how soon can the receiver use that signal for measurement? Receivers that perform well under canopy will have very good (almost instantaneous) signal re-acquisition times. Walking with a receiver into moderate forest cover and watching the satellite tracking is a good test of this.

Antenna. GPS antennas have a significant effect on the overall receiver's performance. The antenna must be capable of accepting weak signals without adding much noise. Some antennas use a powerful signal pre-amplifier to track very weak signals, but this may introduce so much additional noise that the ranges and the resulting positions have low accuracy. Other antennas are designed for static, level applications and may have a large ground plane or choke ring, which are devices attached to the antenna to reduce multipath (reflected signals). These are preferable for GPS Base Stations, but are not suitable for field surveys. Many Low-End GPS receivers have an antenna integrated within the receiver housing. This is usually a compromise of the antenna's performance in order to make the packaging smaller (and the observer's head and body often block signal reception). Some handheld receivers can accept an input from an external antenna, and often this produces better tracking performance than the built-in antenna.

Robustness and Reliability. Resource surveying (specifically Forestry) is perhaps the ultimate "torture test" for a GPS receiver (short of guided missile navigation). The unit must be able to withstand severe weather, soakings, knocks, dust, etc. Cables and connectors are usually the most vulnerable to failure. Thread chain and branches will cut through the outer insulation of many cables. Carrying spare cables is a good policy. Data logger robustness and reliability can be another weak point. Some poorly designed receivers are prone to static electricity charges that can cause random errors and failures. The entire system must be able to withstand real-world treatment day after day.

Memory and Battery Capacity. It is important that the data collector be able to log all the data which can be recorded in a day – with some to spare as well. Less expensive systems may have a fixed amount of memory, and perhaps are suited for only intermittent use rather than continuous GPS data collection. Battery capacity, charging systems, and battery replacement costs should be considered as well. Some systems use consumer grade batteries that give limited life and necessitate carrying many spares in order to complete a day's work. Some systems require two (or more) batteries, one for the data collector and one for the GPS receiver; thus creating twice the potential for problems.

Data Logger Software Functionality and Ease of Use. The data logger software must have a well designed interface to support feature and attribute recording, while at the same time communicating essential GPS fundamental information (# satellites tracked, DOPs, RT status, battery levels, etc). Operator feedback should be clear and unmistakable. Audio beeps are a good way to communicate changes in receiver "states", as well as to confirm data logging. User control of the receiver configuration settings must be well organised and intuitive. Some systems allow "locking-out" certain key control parameter settings to prevent accidental (or deliberate) miss-use by field crews. Basic navigation functionality should be available. Graphical map displays are becoming more wide-spread, and there can be operational benefits if this is available.

Post-Processing Software Functionality and Ease of Use. The post-processing software must perform either pseudorange or the modified position-shift method of differential corrections (see *Section D-8.1*). The software must be capable of importing Base Station files in RINEX format if planning to utilize different manufacturer's Base Station data. Functions for averaging point features and generating basic statistics is recommended; otherwise this will have to be performed manually (e.g. in a spreadsheet). The software should allow graphical viewing of the GPS data, although it does not need full CAD or GIS functionality. The differential correction software must be easy to use and intuitive. Processing should follow a natural progression that will help ensure that no steps are missed. Since GPS projects can generate enormous amounts of raw, temporary, corrected, and final files for each project, some reasonable way of managing and organising the project and data files is essential.

Control Over Processing Parameters and Poor GPS Data. Better software programs will allow the operator some control over processing parameters such as the ability to filter out data with high DOPs or to process only sections of a file. The ability to remove bad satellite data from a solution or to flag position fixes which may be of questionable accuracy can be very useful. Although these functions are not essential, and may not be used by most people, an experienced GPS Data Processor can make very good use of these features. Be aware that some software is very limited (i.e. problematic, data specific, lacking statistics/quality control, etc.). The software is an important part of the full "system" and should be thoroughly checked before a purchase decision.

Quality Control and Reporting. It is vital that the processor be able to perform some Quality Control (QC) functions (see *Section D-8.6*). One of the basic QC functions is a visual check with a scale reference. This can be done within the software's graphical view, or else by exporting the data to a CAD or GIS program. More sophisticated software packages provide other QC information such as satellite observation residuals, standard deviations of point features, etc. As above, an experienced GPS processor can use these features to improve the accuracy and reliability of the GPS positions. It is convenient for the software to create processing reports indicating file names used, processing parameter settings, outcome statistics, etc. Better software packages will create these report files with all the appropriate information from a processing session (these can be included with the project returns).

CAD/GIS Interface. Most GPS survey projects will be integrated within a CAD or GIS system. The software should be capable of exporting data in a format that can be easily integrated into the required CAD or GIS program(s). Most processing software will export to DXF format (Drawing eXchange Format), and although this has become a *de-facto* standard, it has structural limitations. DXF files may require a lot of manipulation before the data is useable in standard mapping and GIS programs. It is more convenient and productive to have the GPS processing software export directly to the appropriate format(s).

Service and Support. An important consideration before purchasing any GPS system is the on-going support available from the manufacturer and/or distributors. Some issues to keep in mind are: local technical support (locally available replacement parts, technicians, etc), manufacturer direct support; available maintenance agreements for on-going support of hardware / software / firmware; company history (track record with previous products / models); warranty; support format (i.e. toll-free phone and email support, web help and FAQs, etc.); and available training.

Most of the systems marketed for use in resource GPS have the basic features above, but some are lacking in important areas. Most of the Low-End software packages, and at least one of the most common of the High-End software packages, allow the operator very little control over processing parameters, and have only the most basic quality control and reporting capacity.

It should be noted that GPS marketing materials can be misleading. Manufacturer's specifications and accuracy claims should be reviewed carefully, as they usually represent "best case" conditions, and the reported accuracies may have low statistical confidence. Receivers and software should be assessed for their suitability in performing surveying tasks under real-world conditions.

2.5 GPS Modernization, other GNSS, and Augmentations

GPS is an evolving system, and modernization plans are worth understanding, especially if considering equipment purchases. Originally, civilians had direct access to only the C/A code on 1 frequency (L1). Beginning in 2005 with the block IIR-M transitional satellites, a new civilian code on the L2 frequency was added (called L2C). This is important as it enables direct tracking on 2 frequencies, and this allows a determination of the instantaneous ionospheric errors to each satellite. The follow-on generation of satellites (block IIF) will add a third civilian code on a new frequency called L5, and this should further enhance positioning beyond 2009. Looking even further down the road, watch for Block III GPS satellites which will add a new more robust civilian code to the L1 frequency. This GPS modernization is phased-in over time, and the advantages will be realized only after a significant number of the new satellites are available. For example, in early 2008 there are 30 satellites in the GPS constellation, but only 5 are IIR-M allowing L2C tracking. The original signals and codes will remain, and therefore legacy equipment will still function, but over time the anticipated advantages of modernized GPS (increased signal availability, reliability, integrity, accuracy, and resistance to radio interference) will mean that user equipment will need to change.

GPS users should also be aware of other Global Navigation Satellite Systems (GNSS) which may be useful for resource survey/mapping. GLONASS is a Russian system that is similar in design to GPS. Some existing receivers can track both GPS and GLONASS and this improves the available satellite coverage. This may require operating a dedicated Base Station with the same type of receiver in order to process differential GPS/GLONASS. The full GLONASS constellation of 24 satellites was completed in 1996, but this degraded to less than 10 operational satellites by 2000. Official Russian statements indicate that GLONASS will be re-built to a full constellation before 2010. Note that the GLONASS constellation does not repeat daily, therefore the augmentation impact to GPS is variable.

The European Union is planning to build a GNSS called GALILEO. It is likely that this system will be structurally compatible with GPS, and dual system receivers will be possible (and technically simpler to build than GPS/GLONASS receivers). There have been delays in the planned GALILEO schedule, and the funding structure hit a major stumbling block in 2007. It seems likely that GALILEO will proceed, but availability will be delayed to sometime after 2012.

In 2007 China announced plans to expand its regional satellite positioning system into a full global system to be called BEIDU-2 or COMPASS. There is currently not much information available on the technical details or schedule of this proposed system.

There are also a number of regional systems that augment GPS for specific purposes. Civil aviation has a need for precise navigation with extremely high integrity (safety-of-life). The US Wide Area Augmentation Service (WAAS) is based on geo-stationary communication satellites broadcasting differential correction and integrity messages to end-users. This system utilizes many Base Stations across North America to compute a rigorous wide-area solution. The European, Japanese, and Indian aviation authorities have similar augmentation systems for their regions (called EGNOS, MSAS, and GAGAN respectively…or generically called SBAS for Satellite Based Augmentation System). Most current GPS receivers have WAAS capabilities built-in (including the cheapest recreational handheld receivers). The WAAS correction signals are relatively weak, and do not reliably penetrate canopy, therefore there has been limited use on resource projects. Note there is also an issue with the WAAS survey datum being different than the official Canadian survey datum.

Another wide-area system is CDGPS (Canada-wide Differential GPS) which is based on a network of North American GPS tracking stations. The Federal government GSD (Geodetic Survey Division) compiles this information, and creates correction and integrity messages that are then transmitted via geo-stationary satellites. Some integrated receivers can directly apply these messages, while others that can not use a separate dedicated CDGPS radio to transfer a standard-format correction (RTCM format). The CDGPS signal has been designed to better penetrate canopy (higher output power, repeated messages, and forward error correction), and the survey datum is consistent with the official Canadian datum (NAD83(CSRS)), therefore it is technically a better choice than WAAS for resource surveys.

Another GPS augmentation is Coast Guard differential corrections intended for mariners, but also useable by others within range of the specific transmitter beacons. This reliable correction service has good achievable accuracy and signal propagation, and a number of manufacturers have created integrated GPS/Coast Guard beacon systems that are well-suited to resource survey/mapping. The BC coastal area is covered with 4 Canadian Coast Guard beacons (Richmond, Ucluelet, Alert Bay and Sandspit), plus there is coverage from US Coast Guard beacons in Washington and Alaska. Only the Canadian Coast Guard beacons have been validated for resource surveys in BC.

3. GPS OPERATIONS and CONTRACT MANAGEMENT

The organization performing GPS surveys will be termed a GPS Operation for the purposes of this discussion. The term includes any organization performing GPS surveys within the scope outlined above. A single GPS Operation would be a self-contained unit that collects, processes, and produces final data (coordinates or maps) using GPS, perhaps in conjunction with other surveying technologies. A GPS Operation could be a GPS contractor's office, a Forest Licensee's field operation, a consortium of smaller firms, or an MoF district office.

3.1 GPS Project Personnel

Within a GPS Operation there may be one or more personnel dedicated to each, or many, of the following tasks (note this is a generic description of GPS tasks, some operations may be different):

- Field Operator
- Field Party Manager
- Data Processor
- Mapping Technician
- Project Manager

A **Field Operator** is the person on the ground collecting data with GPS. Typically, they must be familiar with: operation and troubleshooting of the GPS receiver, basic GPS concepts, methods of data capture to be used, and have sufficient knowledge to properly interpret features to be surveyed in the field. The Field Operator should have instruction and guidance provided by the 2-day RISC Field Operator training course, or by equivalency (i.e., direct supervision and training within the GPS organization).

The **Field Party Manager** is responsible for equipment care and maintenance, downloading and archiving of field data, and support for the Field Operators. In many cases, Field Operators will assume these responsibilities for their own equipment, especially on remote projects (e.g. based in a camp). The Field Party Manager should have the qualifications of a Field Operator, as well as training in the care and maintenance of GPS equipment, PCs, downloading and backup procedures.

The **Data Processor** is responsible for the processing of GPS data to meet the project accuracy specifications. The Data Processor must have a good knowledge of GPS concepts, data collection methodologies, differential GPS processing, QC/QA procedures, as well as basic geodetic concepts including datums and coordinate systems. It is highly recommended that the Data Processor take the RISC Comprehensive GPS Training course and have gained sufficient experience under supervision of senior personnel.

The **Mapping Technician** is responsible for using the corrected GPS data to create the final map or GIS products. In many cases, the Mapping Technician will also be the GPS Data Processor. The Mapping Technician must be familiar with GPS data and mapping concepts, including: integrating GPS data with other data sources (e.g., conventional traverses, digital orthophotos, etc), interpreting GPS data and field information to develop the final map or coordinate products, file translations between GPS and mapping software, attribute data models, map and geodetic datum and coordinate systems, and the mapping and/or GIS software used. The Mapping Technician should have GPS-specific training or else work closely with the Project Manager and Data Processor.

The **Project Manager** is ultimately responsible for the quality and reliability of all parts of a GPS survey. The Project Manager is responsible for ensuring that all personnel have adequate training and supervision, and that GPS data are correctly processed, QC edited, interpreted, presented, and archived. As well, they are usually responsible for project planning, implementation, and completion. The GPS Project Manager should have taken the RISC Comprehensive GPS Training course, as well as have suitable prior experience with GPS surveying and mapping projects. In summary, they should be very familiar with all tasks outlined above.

3.2 GPS Contract Administration

Proper management of GPS contracts is important to all Agencies, especially considering the QA of delivered GPS data. Contract administration involves a number of phases including defining the project goals, setting specific target accuracies and feature definitions, filling in a *Specifications* form as the technical section of a contract, selection of contractors, award of the contract, monitoring contract progress, QA of delivered GPS data, and the management and archiving of the contract returns. The selection of contractors is described briefly below. The award and monitoring of contracts should follow standard Agency procedures. The management and archiving of returns is also covered in *Section D-10* and the QA and audit process is outlined in *Section D-11*.

Private Contractors perform most GPS resource surveys in BC. In these instances, personnel with the contracting Agencies (e.g. the MoFR or Licensees) will be required to manage the contracts. In some instances, only portions of the survey will be done by outside contractors. With these situations two more levels of personnel are defined:

- Technical Contractors
- Contract Administrator

A **Technical Contractor** will perform some aspects of GPS operations, under the supervision of Agency Project Managers. The Contractor will not provide the full service from project planning to project returns, but instead will provide technical support to the Agency for larger survey projects. An example would be a GPS consultant providing project planning and GPS data processing, with Agency personnel performing the field data capture, mapping, and overall project management functions. The Technical Contractor would require the skills, experience, and qualification to perform their tasks as outlined in *Section D-3.1* above.

A **Contract Administrator** would manage the competition, award, quality assurance, and management of the contract performed by a GPS Contractor (i.e. the GPS operation). Typically Contract Administrators would be senior personnel within the Agency (e.g. in the case of GPS forestry contracts, the Licensee's organization). Contract Administrators must be familiar with managing contracts within the structure of the organization. As well, they must also be familiar with GPS concepts as they apply to resource surveys, and be able to perform (or supervise) the QA and contract management tasks outlined later in this document. It is not essential that Contract Administrators have extensive GPS field experience, as long as they can properly and consistently administer the appropriate guidelines in this document.

3.3 GPS Project Structure

GPS projects will vary in the personnel and facilities available, but most can be divided into one of two categories: local or remote. In either case, GPS data should be processed and checked as soon as possible after data collection. This will help ensure that data collected in the field is complete and acceptable, and gives an opportunity to correct any deficiencies before leaving the area.

Local GPS projects are within a reasonable travel distance of the GPS Operation's offices allowing field crews to return to the office each evening. In this case, it may be that the Field Operators will do no more than collect data in the field. The GPS Data Processor would be responsible for downloading, charging batteries and maintaining the equipment, processing the data, and perhaps also the mapping / GIS phase.

Remote GPS projects are more distant, and field crews stay at a remote location such as a field camp or motels out of town. In this case it is usually necessary for the Field Operators to download and maintain their own receivers. Some remote projects may operate with an on-site dedicated Data Processor, and others may transmit the raw GPS data to the operation's office for off-site processing. Some of the mapping / GIS may be done at the remote location, but it is likely that the final map production will be done at the main office where plotters and other specialised facilities are available.

3.4 Selection of Contractors

Contractors should be pre-qualified as outlined in *Section D-4.1* of the *DGPS Guidelines*. Contractors will be chosen based on the existing guidelines and according to the requirements of a particular project. The skills and experience of GPS contractors and consultants vary greatly, and therefore the guidelines presented with respect to training, experience and validation have been presented with this in mind. Contractor pre-qualification is intended to ensure that contractors are competent to perform basic resource GPS surveys. Specific experience, expertise, equipment, system validations, past performance, cost and other factors (e.g. location, availability, emergency conditions, etc.) should be considered in evaluating potential contractors.

A list of individuals with RISC Certification (Comprehensive or Field Operator) is maintained by CRGB and is available at: **http://ilmbwww.gov.bc.ca/CRGB/gsr/gps_val.htm**. *It is recommended that this list be consulted as part of the RFP/ITQ review to confirm RISC Certification of Contractor's staff.*

3.5 Pre-Fieldwork Procedures

After issuing a Request for Proposal (RFP), or Invitation to Quote (ITQ) the Agency representative will usually conduct a pre-work conference for all potential and qualified contractors. It is at this meeting that the Agency representative must define the following items/issues:

- Features to be surveyed.
- Boundaries of the features.
- Guidelines for interpretation of special features (High-Significance, etc).
- Requirements for marking any field features (e.g., monuments to be used, distribution of monuments, methods of demarcating features, information to be supplied on the physical markers, etc.).
- Deliverables, schedules, services and work quality (i.e. define project accuracies).
- Payment schedule.
- Other relevant contract issues.

There must be no doubt or confusion as to the nature, quantity, and quality of work expected. For further information and discussion on the above issues refer to *Section D-5.*

3.6 Contract Specifications

This particular section is provided to assist the Contract Administrator in locating the appropriate section of the *DGPS Guidelines* document when completing the *Specifications* document as a contract schedule (note: this cross-reference table is repeated in Appendix E). It is recommended that if a portion of the *Specifications* document is not relevant to a particular subject project then that portion will be crossed out and initialled by both contracting parties.

Specification Section	Particulars	DGPS Guidelines Section
C-4.1	Total System concept	D-4, D-7.2.1
C-4.2	Field Operator training	D-3.1, D-4.1
C-4.3	Data Processor/Project Manager training	D-3.1, D-4.1
C-4.4	GPS Base Station validation requirement	D-4, D-4.3, D-7.3
C-5.1	Pre-Fieldwork meeting to clarify interpretation issues	D-3.5, D-5.1
C-5.2	Audit process notification	D-3.5, D-11, D-11.3
C-5.3	Field Inspection to clarify issues	D-3.5, D-5.1
C-5.4	Clarifying reference marker type, markings, etc.	D-3.5
C-5.5	Map and photo tie requirements	D-5.3
C-5.6	Cadastral Ties and boundary tenures	D-5.4
C-5.7	Defining project accuracy target specification	B-3, D-7, D-8.6.2, D-11.2
C-6.1	GPS receiver positioning-mode	D-2.3, D-2.4, D-7.1, D-7.2.2
C-6.2	GPS receiver elevation mask settings	D-2.4, D-7.2.4
C-6.3	GPS receiver DOP settings	D-2.4, D-7.2.3
C-6.4	Static feature mapping specification	D-7.1.1
C-6.5	Linear features - point-to-point data collection	D-7.1.3, D-7.1.4
C-6.6	Linear features - dynamic data collection	D-7.1.2, D-7.1.4
C-6.7	Dynamic traverses to start/end on static survey points	D-7.1.2
C-6.8	Significant deflections must be mapped	D-5.2, D-7.1.2, D-7.1.3
C-6.9	GPS Events and the importance of GPS receiver timing	D-7.1.5
C-6.10	Point offset specifications	D-7.1.6
C-6.11	Linear offset specifications	D-7.1.6
C-6.12	Supplementary traverse specifications	D-7.1.7
C-6.13	Physical marker locations specifications	D-5.5
C-6.14	Physical marker survey methodology specification	D-5.5, D-7.1.1
C-6.15	GPS receiver SNR settings	D-7.2.5
C-7.1	Physical marking of GPS Base Station	D-0, D-5.5
C-7.2	Base Station Rover separation distance	D-7.3, D-8.5
C-7.3	GPS Base Station elevation mask setting	D-7.2.4, D-7.3
C-7.4	The use of real-time correction services	D-4.3.4, D-7.3, D-8.5.2
C-7.5	Total Correction Age	D-8.5.2

C-8.1	Differential GPS correction specification	D-2.3, D-8.1, D-8.2
C-8.2	Dynamic filter setting specification	D-8.3
C-8.3	Contractors Quality Control (QC) procedures	D-8.6
C-8.4	Re-survey of non-compliant surveys	D-8.6.2, D-11.3.1
C-9.1	Contractor survey report content	D-10, D-10.1
C-9.2	GPS digital submissions (i.e. data format, datums, etc.)	D-9.1, D-10.3
C-9.3	Final plan submission specifications	D-8.4, D-9.3, D-10.2
C-9.4	GPS data on NAD83 (CSRS) horizontal datum	D-9.1
C-9.5	Vertical data on CVD28 vertical datum	D-9.2
C-9.6	Data ownership and storage	D-10.4, D-10.5
C-9.7	Data cataloguing	D-10.5, D-10.6
C-9.8	Digital data delivery medium	D-10.6
C-10.1	Change in Contractor's GPS System	D-4, D-11.1
C-10.2	The use of the current document versions	D-1, D-3

4. PRE-QUALIFICATION & VALIDATION CONCEPTS

CRGB and other agencies involved with the development of this document have approached the issue of Quality Assurance (QA) for GPS resource surveys with a balanced effort to ensure quality with a minimum of additional administrative bureaucracy. With this in mind, two general approaches deemed appropriate are by means of Training and by GPS System Validation.

Two standardized GPS Training courses have been developed in support of these RISC Standards. ***It is highly recommended that Contractor personnel doing GPS-based resource mapping surveys in the Province have completed the formal, standardized RISC courses relevant to their duties.***

Ideally, a series of formal GPS Validation Ranges would be established around the Province to allow contractors to evaluate and confirm their GPS system performance. These formal GPS Validation Ranges would be set-up in typical forest canopy environments for a particular ecological region, and they would attempt to replicate most of the typical GPS surveying tasks encountered by Contractors. The point and linear features in the Validation Range would be accurately surveyed horizontally and vertically, and this would be a benchmark for GPS system comparisons (e.g. confirmation of network accuracy). However, at this time there is only one formal GPS Validation Range that is available to the public (Maple Ridge area). This works well for Contractors applying GPS in coastal environments, but it is not representative of other tracking environments encountered in other areas of the Province. Therefore, the Contractor GPS System Validation procedures detailed below provides an alternate solution.

Also detailed below are the procedures for categorizing a GPS Base Station and acquiring validation accreditation by CRGB so that the GPS Base Station data may be used for Provincial contracts.

4.1 Personnel Qualification and Training

GPS surveys are routinely performed for many resource mapping and inventory operations (e.g. MoFR field operations such as cruise, block layout, silviculture, engineering, etc.), however, it is not reasonable to expect all government Contract Administrators to know the GPS contracting community well. It is preferable to have a form of operator pre-qualification and a "roster" or a list of qualified GPS Contractors available to all government personnel (and private agencies as well).

Contractor pre-qualification is a standard practice in many areas of the government (e.g. MoFR creates a contractor pre-qualification list at the start of each Fiscal Year for many operational tasks). Many aspects of pre-qualification such as past performance, volume of work, number of employees, etc. are standard for each Agency and will not be dealt with in this document. This section discusses some of the aspects of pre-qualification specific to GPS surveys. Training, equipment, GPS System Validation, and GPS Base Stations will be discussed.

It is highly recommended that GPS personnel be qualified to perform the tasks outlined in the GPS operations personnel section above. This qualification can be achieved by completing a training course designed for that position. However, completion of a training course should be considered only the minimum qualification for personnel. Experience in performing GPS surveys is essential for all levels of personnel. This experience should be gained while working under direct supervision of senior personnel with substantial experience.

It is highly recommended that each GPS Contractor should have pre-qualified to the Agency's satisfaction for the current field season before awarding any contracts. Pre-qualification consists of appropriate training for all personnel, and may also include a Contractor GPS System Validation as outlined in Section D-4.2 below.

4.1.1 Training Requirements For GPS Contractors

For purposes of pre-qualification, GPS Contractors should submit a list of all GPS personnel in their organization, their responsibilities, and their training/experience. It is expected that at least the GPS Data Processor and Project Manager will have completed an approved GPS training course as outlined below.

Appropriate levels of training and experience for other staff are the responsibility of the GPS Project Manager. Since the qualified Project Manager is ultimately responsible for the quality of all GPS and mapping information produced by the operation, using unqualified and inexperienced personnel in any aspect of the operation is not in their best interest.

Experience is essential for performing any technical task and GPS surveys are no different (contrary to the claims of some GPS vendors). It is difficult to objectively assess experience levels without informed interviews, which are impractical in a centralized pre-qualification process. GPS contractors who have acquired GPS equipment and attended a course, but have no experience in the organization, are potential liabilities to the Agencies and themselves. They also reflect poorly on the GPS contracting community. A *Contractor GPS System Validation* (described below) may help in identifying potentially incompetent contractors - both to themselves and to contracting agencies.

It should be noted that in the past there was little formal requirements of people providing GPS training. Training courses were approved simply by submitting a simple syllabus to an Agency representative (who may have only minimal GPS knowledge or experience). There was no test that that material was appropriate, or that it would be presented competently or even correctly. It has been observed over the years that misinformation was spread through these type of non-standard courses. In response to this, CRGB in co-operation with other agencies developed 2 standardized GPS Training courses for the resource sector in support of these RISC Standards. Instructors must be approved in advance, and there are course evaluations of both the materials and the instructor following every course delivery. These course evaluations provide the critical feedback necessary to improve both the course materials and the instructor's delivery. More information on the 2 RISC GPS training course can be obtained from:

Crown Registry and Geographic Base (CRGB),
Integrated Land Management Bureau (ILMB),
Ministry of Agriculture and Lands
PO Box 9355 STN PROV GOVT
Victoria, BC, V8W 9M2
Phone: 250-356-0969 Fax: 250-356-7831
http://ilmbwww.gov.bc.ca/CRGB/gsr/courses.htm

4.1.2 Training Requirements for Agency Personnel

It is ***highly recommended*** that all government agencies that regularly use GPS technology, or administer GPS contracts, adhere to the standardized RISC Training courses for all levels of GPS operations personnel. Corresponding to the GPS Contractor personnel listed above, the following table lists appropriate ***minimum*** training times for each level of personnel.

Field Operators	2 days
Field Party Managers	2 days
Data Processors	5 days
Mapping Technicians (GPS-specific)	2 or 5 days
Contract Administrators	2 or 5 days
Project Managers	5 days

Much of the training would overlap between levels, and courses could be developed to efficiently handle different levels. GPS Field Operators and Field Party Managers will likely come from different operational divisions in the Agencies, since the tool should be in the hands of the professional and technical staff if at all possible. It may be that some operational divisions (e.g. MoFR Regional and District offices) will be able to allocate a dedicated group of trained personnel to these positions. The required training could then be based on the RISC Training Courses and delivered on-site by local personnel who have completed higher levels of training and who have extensive GPS experience. An essential component of training should be GPS fieldwork and processing on actual real-world projects.

The training for Data Processors and Project Managers would follow the general guidelines currently in place (5 day Comprehensive course). Mapping Technicians would require GPS training beyond their GIS/mapping training in order to integrate GPS data and to help troubleshoot and Quality Assure (QA) incoming data for the Contract Administrator. Contract Administrators should have training in QA procedures for GPS contracts, and in evaluating GPS contractors. Preferably, both the Agency Mapping Technicians and Contract Administrators would have the 5 day Comprehensive training; however, the 2 day Field Operator training may be sufficient. Some Agencies have designated 1 or 2 key personnel in each office to have the Comprehensive training, and the remaining personnel have the Field Operator training.

Each Agency could provide training to every branch, region, and district involved with GPS surveys in the province. Qualified training consultants could do much of the training outlined above utilizing the RISC training standards. It is recommended that selected Agency personnel (with previous GPS experience) assist in this training - these people could then become GPS resource people within the particular Agency.

4.1.3 RISC Standardized Training Courses

This section of the *DGPS Guidelines* provides a brief overview of the three RISC training courses. Thirteen core modules have been developed that provide the basis for these two courses (CRGB has developed another course in 2007 for recreational GPS navigation users, but this is not applicable for resource-level surveys).

Module Number	Module Title	Module Type
1	GPS Basic Concepts	Class
2	GPS Data Capture Concepts	Class
3	GPS Data Capture I	Practical Field
4	GPS Data Capture II	Practical Field
5	Navigation with GPS	Class & Field
6	Basic Geodesy	Class
7	GPS Positioning Techniques	Class
8	GPS Data Processing	Practical Class
9	RISC GPS Standards	Class
10	GPS Project and Contract Management	Class
11	Quality Control and Quality Assurance	Class
12	GPS Equipment and Software	Class
13	General Information	Class
Appendices	Acronyms/Glossary/Units of Measure	

4.1.3.1 Comprehensive GPS Training for Resource Mapping

The 5 day Comprehensive GPS training for Resource Mapping covers all 13 modules listed above and consists of classroom theory discussions, practical field exercises, GPS data processing and interpretation exercises, and competency evaluations (passing grade is 75% in all evaluations). Individual RISC certificates will be issued by CRGB upon meeting all requirements.

The audience for this course is typically industry personnel, consultants and government employees responsible for the design, implementation, processing and supervision of GPS mapping and surveying operations. This course applies to the operational positions of Project Manager, Data Processor, and possibly the Mapping Technician. This GPS certification is recommended for professional and technical staff overseeing provincial government resource mapping contracts. This specifically includes personnel responsible for GPS project management QC and QA.

Information specific to the Comprehensive GPS course can be found at the following link:

http://ilmbwww.gov.bc.ca/CRGB/gsr/comprehensive_course.htm

4.1.3.2 GPS Training for Field Operators

The 2 day GPS Field Operator course introduces the concepts and methods relevant to resource surveys in order to ensure reliable and consistent GPS field data collection. The course focuses on the first 7 modules listed above and consists of classroom theory discussions, practical field exercises, software demonstrations, and a practical field evaluation. Some of the modules taught in this course are a partial subset of the full module taught in the Comprehensive course. Individual RISC certificates are issued by CRGB upon meeting the course requirements.

The audience for this course is typically industry personnel, consultants and government employees responsible for GPS field data collection. This course applies to the operational positions of Field Operator, Field Party Managers, and possibly the Mapping Technician.

More information specific to the Field Operator course can be found at the following link:

http://ilmbwww.gov.bc.ca/CRGB/gsr/fieldoperator_course.htm

4.1.3.3 Recreational GPS Navigation Course

In addition to the 5-day Comprehensive GPS course and the 2-day Field Operator training course, CRGB has designed and made available training materials for users utilizing recreational-grade (consumer grade) GPS receivers - such as Garmin or Magellan models.

The materials are designed for field personnel who are utilizing recreational/consumer grade GPS receivers for general navigation and data location. These users do not require full knowledge about GPS, Geodesy, GPS data processing, etc. This 1-day course is, however, developed for those people requiring some basic knowledge and field experience in order to make informed decisions in the field while collecting GPS-referenced data. The course provides information on two basic subjects:

1. Guidance as to when to use and not to use a recreational-grade GPS receivers and;
2. If a recreational-grade GPS receiver is being used; the course provides general guidelines for capturing the best possible solution using this grade of receiver (3-10 m level).

The instructional materials and more information for this course is provided online free of charge and can be utilized for personal use or in an internal classroom/training setting at the following link:

http://ilmbwww.gov.bc.ca/CRGB/gsr/RecreationalGPS.htm

4.2 GPS System Validation

Errors in GPS surveys may not be as obvious as errors in conventional surveys (e.g. compass and chain surveys). With GPS there is no "magic" closure formula or balancing procedures which can detect blunders and distribute random errors throughout a survey. A thorough knowledge of basic GPS concepts, and a sound base of experience are required in order to reliably correct, assess, interpret, and present GPS data.

To comprehensively evaluate a GPS system (hardware, software, processing, etc), a validation survey can be very useful to allow comparing results against a known benchmark. The ideal benchmark is a formal GPS Validation Range made up of point and linear features that have accurately known coordinates, and with tracking conditions similar to the actual projects. There is currently only 1 formal GPS Validation Range available to the public (this is in Maple Ridge area, contact CRGB for details). This range is suited for users in SW BC working under coastal forest canopy. If this formal GPS Validation Range in Maple Ridge is not applicable, an informal GPS Validation Range can be created by a Contractor made-up of point and linear features under typical tracking conditions for their area. Even if the absolute coordinates for all of the features are not known, this would still be valuable in comparing relative performance of different systems (e.g. new hardware, software, different settings, etc), as well as to serve as an excellent training area for new staff. It is desirable that at least some of the point features in the informal Validation Range have accurately known coordinates for confirmation of network accuracy. If this was not possible/practical, an additional GPS point feature survey could be performed on existing survey monuments, but this is really only representative if the tracking conditions are similar to the project (and this is often *not* the case for existing survey monuments which are usually in open areas with good visibility).

An Agency may choose to require contractors do a GPS System Validation before they would be accepted on a pre-qualification list. It is up to the Agency to set guidelines for the validation, but they should be consistent with the Specifications that will apply to future production surveys. Remember that this is a *System* validation which includes Rover hardware, software, settings, differential corrections from a Base Station, and field and office staff. The GPS System and key conditions that should be consistent between the Validation and future production surveys include:

- key personnel (Project Manager, Data Processor)
- type of Rover hardware (e.g. receiver, antenna, data collector)
- critical Rover observational settings (e.g. DOP, SNR, and elevation masks)
- field observation methodology (e.g. number of fixes recorded during static point features)
- differential correction methodology (e.g. RT or post-processed)
- type of GPS Base Station receiver (e.g., narrow-correlation)
- separation distance between Base Station and Rover
- processing software (e.g. type and version number, plus significant settings)

All Validations should include at least some point features that allow reliable confirmation of the achievable network accuracy. This can be done at an existing survey monument with known coordinates and elevation. See the MASCOT database to find suitable survey control monuments:

http://ilmbwww.gov.bc.ca/CRGB/gsr/index.htm *(then follow the links to MASCOT).*

4.2.1 GPS Contractor Equipment

The Contractor's GPS equipment (i.e. hardware and software) affects how accurately and productively work can be performed. As mentioned in *Section D-2.4*, different receivers and software may be appropriate for different tasks. It is not possible to recommend or censure specific equipment in a document of this scope.

Certain equipment, such as recreational hand-held, GPS cell phones, or PDA based receivers intended for general navigation are not appropriate for resource GPS surveys. These are precluded by the requirement in the data capture specification that position fixes be determined from at least four simultaneous pseudoranges, with limits on elevation angles, DOPs etc.

It is left to the Contractor to choose GPS equipment that will meet the accuracy requirements of the survey, while satisfying all of the Specifications. The quality assurance process outlined in *Section D-11*, and / or a *GPS System Validation Survey* as discussed above, will ensure that the GPS system meets the project requirements.

One indicator if GPS equipment will meet the requirements is if it has a history of successful use on similar projects. Currently, most resource GPS surveys in the Province are done with a few types of “High-End” GPS receivers that perform well under forest canopy. Although this does not mean other manufacturer’s receivers are not appropriate, it does give an indication for Agency personnel evaluating a new Contractor’s equipment.

Many government resource Agencies are acquiring GPS receivers and building-up in-house expertise to perform specific and / or sensitive projects which are best done directly by government (this could include QA (Quality Assurance) on work submitted by Contractors). The guidelines in *Section D-2.4* give some qualities to look for when evaluating equipment. It is preferable that each Agency centrally evaluates appropriate receivers and publishes (for internal use) recommendations for specific equipment, along with training and implementation guidelines.

4.3 GPS Base Station Validation

GPS Rover data must be differentially corrected relative to high quality GPS Base Stations. The Base Station should use appropriate GPS equipment, have an accurately surveyed location, and be substantially free from obstructions, multipath, and radio interference. Issues related to GPS Base Stations are discussed in the following sections. CRGB performs validation of GPS Basee Stations in the Province.

An extensive network of suitable permanent Base Stations exists in British Columbia, most of which provide public access. The preferred source of GPS Base Station data for Contractors working on government projects is the BCACS (BC Active Control System). Use of the BCACS ensures an accurate referencing to the NAD83(CSRS) datum, and a source of “clean” data from high quality geodetic-grade GPS equipment. These BCACS Base Stations are located at sites selected for their good tracking environment, and availability of stable infrastructure (i.e. power, communication, support, etc.).

Some Contractors maintain their own permanent GPS Base Stations. When properly established, this is an acceptable method of generating differential corrections. These GPS Base Stations may result in improved Rover accuracies if the distance from the project site is less to a Contractor’s Base Station than it is to other Base Stations. The three primary concerns for Contractor Base Stations are:

i) Establishing accurate coordinates for the GPS Base Station antenna.
ii) Ensuring that the site does not experience significant multipath or interference effects.
iii) Utilization of a good quality GPS receiver / antenna, and knowing the limitations of the system for the users.

Any error in the GPS Base Station coordinates (latitude, longitude or ellipsoidal height) will be directly transferred to the differentially corrected Rover’s position. Establishing these coordinates should be done using a survey method that is an order of magnitude more accurate than the DGPS methods that will be used from this Base Station.

The first consideration when choosing a Base Station is usually the separation distance to the project area, but there are other considerations as well. One factor is the atmospheric conditions at the project area and at the Base Station. If these conditions are similar, then the computed differential corrections from the Base Station will give optimum accuracies at the Rover because both sets of pseudoranges will have experienced similar atmospheric delays. Conversely, if one is on the warm humid coast, and the other is on the cold and dry interior plateau, then the differential corrections will not be optimum. In this case, better Rover accuracies may result from choosing a different Base Station in the same general climate zone…even if it is somewhat father away than the original Base Station. Another consideration factor is the elevations of the project area and the Base Station (it is best to try to keep the 2 elevations similar).

4.3.1 Permanent Validated GPS Base Stations

As of 2008, the validated GPS Base Stations in BC include 20 BCACS (7 in municipal networks in Victoria / Vancouver, and the remaining 13 around the province), 4 Canadian Coast Guard (real-time transmission only), and >10 private GPS Base Stations. From a data quality standpoint, these GPS Base Stations can be considered equivalent for resource GPS surveys. The status of validated Base Stations can be checked at:

http://ilmbwww.gov.bc.ca/CRGB/gsr/specs/#validations

Also, Federal government owns and maintains validated GPS Base Stations throughout Canada. There are 46 of these reference stations and they provide raw data for Phase differential baseline post processing. Data is available to download in RINEX format in 24 hr datasets, collected at every 30 seconds. Detailed information is provided at the following link:

http://www.geod.nrcan.gc.ca/products-produits/gps_e.php

4.3.2 Temporary GPS Base Stations

On some projects it may be desirable to establish a temporary GPS Base Station. Example reasons for this are described below:

- The highest DGPS accuracies are achieved with relatively small separations between Base Station and Rover (~100 km). Surveys with a high accuracy requirement may benefit from a local GPS Base Station operated within the project area.
- Real-time surveys can be very productive for layout and to provide real-time quality control and mapping information. Generating and transmitting corrections from a temporary local GPS Base Station may be the most effective way of implementing real-time DGPS.
- On remote projects a local GPS Base Station may be the only way of obtaining timely correction data due to unavailable, unreliable, or expensive data communication.

The procedures for validating permanent or temporary GPS Base Stations are described in the next subsection (4.3.3).

In some cases, such as real-time layout surveys, or where no outside communication is possible, a temporary position may be adopted for the GPS Base Station position. If the adopted position is from an averaged autonomous GPS solution, this should normally result in horizontal accuracies <10m (95%) and vertical accuracies of <15m (95%)...but it may be much worse (remember the low positional integrity of autonomous GPS!). Any Rover positions differentially corrected with these initial adopted Base Station coordinates will have good *Local Accuracy*, but will have poor *Network Accuracy,* and these positions can not be considered properly referenced to NAD83(CSRS). This may be fine for some projects, but if at a later date the Rover data is to be integrated with other properly geo-referenced information, a better solution for the temporary GPS Base Station position must be made. This could involve establishing an accurate NAD83(CSRS) position for the Base Station and then re-processing all the Rover data. Alternatively, the coordinate shifts (3D) between the initial adopted coordinates and the later accurately surveyed coordinates could be simply applied to all Rover positions. In either case, it is especially important to observe a sufficient number of map ties in the field, to document all steps well, and to carefully manage the resulting data so that only the final properly geo-referenced coordinates are used.

4.3.3 GPS Base Station Validation Procedures

GPS Base Stations are validated according to a list of categories that represent typical GPS applications. The accuracy requirement for a particular project determines the category of GPS Base Station that must be used. These categories are shown in the following table (all accuracies @ 95%):

GPS Base Station Category	Proposed Project Horizontal Network Accuracies	Base Station Horizontal Network Accuracy	Proposed Project Vertical Network Accuracies	Base Station Vertical Network Accuracy
I	<2m	0.05m	<2m	0.05m
II	2m – 10m	0.5m	2m – 10m	0.5m
III	>10 m	2m	>10m	2m

Table D-3 GPS Base Station Categories

Note that the vertical accuracies in the above table refer to Orthometric heights (i.e. height above Mean Sea Level (MSL)), and not to the height above ellipsoid (HAE). Orthometric heights are referred to the Canadian Vertical Datum of 1928 (CVD28). Vertical Base Station Categories are more difficult to meet than their Horizontal counterpart due to:

a) the Geoid uncertainty that influences the derivation of Orthometric heights from GPS-based ellipsoidal heights; and
b) the generally less accurate vertical component of GPS (e.g. approximately half as accurate as horizontal

components).

A GPS Base Station, classified as above, may support all lower categories but not higher categories. For example, if a GPS Base Station is classified as a Horizontal Category II, then it may serve projects under that category as well as those under Horizontal Category III (but not Horizontal Category I).

The GPS Base Station Validation process also includes an evaluation of a long GPS data set (minimum 24 hours) processed against data from one or more BCACS stations. These data are to be collected using the same GPS system that will be permanently installed at that GPS Base Station (i.e. antennae, receiver, and recording software). The evaluation will include scrutiny for short-term deviations that may indicate multipath affecting the pseudorange measurements. Multipath effects generally repeat day to day (with a 4-minute constellation advance). An acceptable GPS Base Station site will not show gross multipath deviations. Placing radio frequency (RF) absorbent materials over surrounding reflective surfaces and utilizing antennas that incorporate a choke-ring ground plane can diminish multipath effects.

GPS Base Station Category	Base Station Horizontal Network Accuracy	GPS RX Accuracy	Antenna	Control Point Monument
I	0.05m	Geodetic Dual Freq.	Geodetic, L1/L2 compatible	Geodetic Pillar
II	0.5m	Survey, L1	L1	Mount on Stable Platform
III	2m	L1	other	Mount on Building

Table D-4 GPS Base Station Characteristics

The following subsections provide some typical procedures, issues, survey methodologies, and survey returns for the validation of all categories and types of GPS Base Stations (i.e. private, semi-private, permanent semi-permanent and temporary). ***These are not the only methodologies acceptable and have been provided to clarify any issues and "streamline" the validation procedure and timelines – CRGB will entertain alternative proposals as well.*** This document also provides a sample GPS Base Station Validation report, which has been included in *Appendix D.*

The *GPS Base Station Validation* procedure is composed of two distinct phases (each with essentially the same procedures within each phase):

A) Validation of the survey equipment to be used during the survey of the GPS Base Station (i.e. conventional or GPS); and
B) Validation of the actual control survey of the GPS Base Station.

The submission of a GPS Base Station Validation should clearly define which GPS Base Station Category (e.g., Horizontal I, II, or III) is being applied for. The different GPS Base Station categories influence choices regarding:

i) the accuracy of the Geodetic Control Monuments (GCMs) to be used;
ii) the survey methodologies to be used in the control survey process; and
iii) the GPS receiver/antenna to be utilized for the GPS Base Station (see discussion of GPS Base Stations in *Section D-7.3*)

That is, the survey equipment validation is done on GCMs of varying accuracy (i.e. GPS Basenet or local GCMs); the GPS Base Station control survey will be integrated into the provincial Geo-Spatial Reference system by tying into GCMs of varying accuracy (i.e. standard deviation of geodetic control monuments); the survey equipment and methodology used to survey in the GPS Reference System may vary (i.e. from conventional traverses to geodetic GPS receivers); and lastly the quality of the GPS equipment (i.e. receiver, antenna, firmware, etc.) used for GPS Base Stations varies.

Each of these two phases should be considered as a separate project; whereby a proposed survey plan is submitted and accepted by CRGB; the survey is done (e.g. EDM validation); the data is processed and submitted to CRGB for analysis along with a survey report. The following pages detail these two phases, identifying the most important features of each.

A. Survey Equipment Validation Phase

A.1 Survey Design

i) If conventional equipment is to be used (i.e. total station) to survey the GPS Base Station, then an EDM Validation must be performed on one of the provincial EDM Baselines and all baseline combinations should be observed (if possible).

- *EDM Validations have no real "Survey Design" per se, because there is a fixed infrastructure to use and a well-defined procedure to follow.*
- *EDM Validation forms are available from CRGB - these forms define what is to be observed and how they are to be observed.*
- *EDM Validation returns (i.e. a fully completed EDM Validation form) is submitted to CRGB, who will then process the data through specialized software.*

ii) If GPS equipment is to be used to survey the GPS Base Station then; depending on which GPS Base Station category is being applied for; a GPS Validation must be performed either on a GPS Basenet, or on accurate/precise local geodetic control monuments (GCMs).

- *A GPS Validation survey plan is to be submitted to CRGB indicating how the validation survey will be done (i.e. which stations occupied, sessions, baseline lengths, etc.).*
- *CRGB will examine the design, and it will either be accepted as submitted, or suggestions will be provided.*

A.2 Control Survey

i) An EDM Validation survey is performed following the guidelines specified on the EDM Validation Form.

ii) A GPS Validation survey generally replicates the project survey for which the GPS Validation is being done. For example, if the Base Station is going to be surveyed to Category I Standards using static GPS methodologies from local geodetic control monuments within 30km of the proposed Base Station - then the GPS Validation survey should attempt to replicate this survey on the GPS Basenet

- *Depending on which GPS Base Station category is being applied for; the Equipment Validation survey will take place on either one of the GPS Basenets in BC, or on local geodetic control monuments (GCMs).*
- *An important aspect of both the Equipment Validation survey and the Base Station survey is reliability…specifically in the form of double occupations of all pillars/control monuments in order to detect blunders (i.e. incorrect antenna heights, etc.).*

A.3 Survey Returns

i) EDM Validation returns are in the form of reduced distances (mark-to-mark) provided on the CRGB supplied form.

ii) GPS Validation returns consist of the following items (these items vary depending on which category GPS Base Station is being applied for):

- *A survey report detailing: the Survey Equipment Validation survey (i.e. observation scheme); equipment used; software used; hardware used; personnel used; processing details; problems, etc.*
- *All intermediate GPS processing results (i.e. baseline/session results; etc.) and adjustment results (i.e. adjustment input/output files) and coordinate comparisons.*
- *A digital GPS Validation-format file including: final derived coordinates, associated statistics (i.e. standard deviations and/or associated covariance matrix, and comparison of surveyed Vs. published coordinates).*

B. GPS Base Station Control Survey Validation Phase

B.1 Survey Design

i) Provide a proposed survey plan to CRGB indicating how the GPS Base Station survey will be done (i.e. which GCMs to be occupied, ties to existing Base Stations, survey methodology, etc.).

ii) CRGB will examine the proposed survey design, and it will either be accepted as submitted, or suggestions will be provided

B.2 Control Survey

i) A control survey is performed to define the coordinates of the GPS Base Station.

ii) It will be evident from the survey procedures and the final adjustment results if the GPS Base Station Validation is acceptable for the category of GPS Base Station being applied for.

iii) An important aspect of both the Survey Equipment Validation survey and the GPS Base Station survey is reliability…specifically in the form of double occupations of all stations in order to detect blunders (i.e. incorrect antenna heights, etc.).

B.3 Control Survey Returns

i) Conventional Survey returns consist of the following items:

- *Survey report detailing: the Base Station survey (i.e. observation scheme); equipment used; software used; hardware used; personnel used; problems; etc.*
- *Intermediate data processing (i.e. loop closures) and adjustment results (i.e. adjustment input/output files).*
- *Final observation data in digital MASCOT- or GHOST-format.*

ii) GPS Survey returns consist of the following items:

- *Survey report detailing: the Base Station survey including the observation scheme; personnel; equipment; software; processing details; problems, etc.*
- *Intermediate GPS processing results (i.e. baseline, session adjustments, etc.) and adjustment results (i.e. adjustment input/output files).*
- *Digital GHOST-format files (i.e. GPS baseline/session observations and covariance/correlation information).*

iii) *GPS Base Station details, will include (but not be limited to):*

- *A final survey report (see Appendix D).*
- *Multipath analysis sample data set (minimum 24 hours).*
- *GPS Base Station location details (i.e. pictures, diagrams, proximity to obstructions, access information, etc.).*

A sample *GPS Base Station Validation Report* has been supplied in *Appendix D* of this document. This report and the information provide within, will assist those GPS Base Station operators in providing a *GPS Base Station Validation* and will reduce the time between submissions of the validation survey to the time of acceptance. This report is an outline of the minimum required, and operators are encouraged to provide more information for analysis.

The following table will assist in identifying some of the similarities and differences between the procedures for each of the GPS Base Station categories:

Phase	Category I	Category II	Category III

A. EQUIPMENT VALIDATION	• GPS (phase)	• GPS (phase) or Conventional	• GPS (code or phase) or Conventional
a.1 Survey Design	• GPS Basenet	• GPS Basenet, or GCMs Sd <0.1m • EDM baseline	• GPS Basenet, or GCMs Sd <0.2m • EDM baseline
a.2 Survey	• GPS Static	• GPS occupation to replicate control survey (i.e. same settings and methodology) • EDM Validation Guidelines	• GPS occupation to replicate control survey (i.e. same settings and methodology) • EDM Validation guidelines
a.3 Deliverables	• Report • GPS Validation Format • see Control Specifications	• Report • GPS Validation Format • see Control Specifications	• Report • GPS Validation Format • See Control Specifications
B. CONTROL SURVEY VALIDATION	• GPS (phase)	• GPS (phase) or Conventional	• GPS (code or phase), or Conventional
b.1 Survey Design	• Submitted to CRGB before survey for approval	• Submitted to CRGB before survey for approval	• Survey design not required, but suggested
b.2 Control Survey	• Static GPS (phase) methods • Ties to at least 3 surrounding GCMs Sd <0.02m	• Static GPS (phase), or Conventional Survey • Ties to at least 3 surrounding GCMs Sd <0.1m, or • Ties to at least two BCACS stations and one local GCM	• GPS (code or phase), or Conventional • Ties to at least 3 surrounding GCMs Sd <0.2m,or • Ties to at least two BCACS stations and one local GCM
b.3 Deliverables	• Report • Network adjustment • 24hour data set • see Control Specifications	• Report • Network adjustment • 24 hour data set	• Report • Network adjustment • 24 hour data set

Table D-5 General Procedures for Various GPS Base Station Categories

4.3.4 Other Base Station Issues

The evolving world of GPS modernization and other developing GNSS and augmentations has an impact on Base Stations. In some cases, it may be necessary to operate dedicated Base Stations in order to take advantage of new signals not available from the existing Base Stations. As systems and technologies become mature and stable, it is expected that the hardware on existing Base Stations will be upgraded to include the newer signals. Equipment modernization of the BCACS is currently underway (2008). More information can be found in *Section D-2.5* and at the internet references listed in Appendix B.

5. FEATURE MAPPING and FIELD INTERPRETATION

There are two sources of mapping error in GPS resource surveys:

i) errors inherent in the GPS positions, and
ii) errors due to interpretation and definition of the features.

Errors inherent in the GPS positions are discussed and dealt with elsewhere in this document. The accuracy specification should be met if the standards are followed and proper field and office procedures are followed for all stages of the project. However, the coordinates from the GPS survey only describe the location of the GPS antenna, and they do not necessarily describe the actual location of the features intended to be mapped.

In some cases, the largest error in a GPS mapping project may be how well the feature can be interpreted. That is, how well can the operator define features such as streams, edges of marshy areas, cut block boundaries, forest polygon (timber stand) edges, etc.?

GPS surveys are performed for many operational reasons, and it is not possible to define all operational requirements in this document. It is left up to Agency personnel in the branches, regions, or districts to define how features are interpreted and mapped. This section is intended to provide guidelines on how operational requirements can be met using GPS surveying techniques.

5.1 Interpretation of Features

Natural and man-made features such as cut-block boundaries, grazing ranges or beetle attack areas are often difficult to define on the ground accurately. It is essential that the GPS Contractor know exactly how the feature is to be interpreted to minimize errors. This should be accomplished through a pre-contract conference (see *Section D-3.5*). There must not be any doubt or confusion as to the nature and quantity of work expected in the contract.

For example, consider the boundary of a post-harvest cut block. The boundary could be considered as any of the following definitions: inside of a fireguard, outside of a fireguard, drip line, stump line, the centre of live stems, etc. There could be 10m or more difference between these interpretive boundaries and this can have a significant impact on the derived areas. Another issue is the accuracy in which the Field Operator follows a linear feature. As the GPS Field Operator walks in the forest, there are inevitable detours caused by deadfall, creek crossings, overhanging branches, etc., and if the operator is careless, the antenna may not be guided exactly over the linear feature. If the survey is being done from a helicopter other issues should be taken into account such as snags, wind, and other hazards that may dictate the pilot err on the side of safety, however, this may compromise the proper survey of the feature. Given that the boundary of a cut block is one of the natural features and one of the easiest to follow it is easy to see where errors can be introduced into the survey.

Realistically, an interpretive uncertainty surrounding most natural features should be expected (*Section B - 3.3* of the *Standards* gives some examples of interpretive accuracies). The feature's position data should be considered no more accurate than this interpretive accuracy, regardless of the GPS accuracy (unless special procedures are followed). Man-made features such as plot centres, survey transects, and road edges/centrelines, can be defined more accurately. In the case of a marked permanent plot location, there is no significant interpretive uncertainty, and the feature can be mapped to the accuracy limitations of the GPS receiver (which depends, of course, on equipment, methods, tracking environment, etc.).

It is very important that all parties involved agree in advance on how natural and man-made features are to be interpreted and mapped. If possible, the Agency Contract Administrator should be explicit about what line (e.g. drip line, top of stream bank, 1m inside of painted trees, etc.) is to be followed, and perhaps review the lines in the field with the GPS Field Operator or Agency Field Operators. Included with the returns should be an estimate for the Interpretive Accuracy of the mapped features (e.g. 2m, 5m, etc.), along with any comments the Field Operator has noted. If the Agency can implement appropriate metadata in their GIS operations, this information should be saved with the points, lines, and/or area features.

5.2 Delineation of Features

Although *Section D-7.1.2* discusses the maximum separation between GPS fixes, the Contractor must ensure that all significant deflections of linear features are appropriately captured. Often natural features are very irregular and care should be taken to pick up any deflections which will show up at the intended mapping scale, or which are significant to the accurate estimation of linear distance or area calculations. In most cases, the actual GPS fix spacing will be considerably less than the maximum values specified in the contract.

5.3 Map and Photo Ties

Many GPS surveys identify new or modified features with the purpose of adding this information to an existing map. In this case, it is important to observe map / photo ties during the GPS survey to ensure correct alignment. Differentially corrected GPS positions are inherently on the NAD83(CSRS) datum (assuming a validated GPS Base Station was used). These positions can be transformed to other survey datums such as NAD27 using specific transformation software. Unfortunately, some existing maps in BC are not based on an accurate mathematical datum, and in these cases discrepancies will arise between the GPS-derived positions and the mapped location of features. For example, a GPS block layout traverse may appear to encroach over a creek when superimposed on an existing map, when in reality the field layout leaves a 15m buffer.

Map ties are features that are identifiable on the map or other base (e.g. Orthophotos) and which also have surveyed GPS positions. Map ties are used to resolve discrepancies with the map base (which may be due to inaccurate or out-of-date mapping), and may also be to provide permanent ground-based evidence for tenure purposes. Some examples of map ties are creek junctions, road intersections, bridges, buildings, etc.

In cases where datum discrepancies arise, it may be necessary to either move the GPS data to fit the existing maps, or move the existing map to fit GPS. If sufficient map ties exist, or if the map sheet has a known relationship to NAD83(CSRS), this can be done without much ambiguity. In other cases the reason for the discrepancies may not be clearly known. Performing map ties can also indicate any problems with the GPS Base Station coordinates used during differential processing.

Sufficient map ties must be established and surveyed for each GPS operation. In some hinterland areas there may not be enough well defined, identifiable features to tie. The Agency Contract Administrator must specify the number of tie points required and should, if possible, specify the location and type of these tie points. Factors to consider in identifying tie points are the reliability and compatibility (with GPS) of the local map base, the cost of establishing the ties, and other requirements (e.g. permanency).

If ties to geodetic or cadastral monuments are required, the Agency Contract Administrator must ensure that there is no confusion as to their location, and if possible they should be found, marked and shown to the Contractor during the pre-fieldwork conference.

5.4 Tenure Boundaries

Legal Boundaries

For the purpose of this document, legal boundaries can be defined as cadastral boundaries or tenure boundaries.

(a) Cadastral Boundary

Cadastral boundaries include the boundaries of parcels of land, the boundaries of interests in land such as rights of way, easements and covenants, and the boundaries of administrative areas.

Parcels of land include District Lots, Sections, Blocks, Parcels and Lots. A right of way is a defined corridor or parcel of land over which a party other than the owner has specified rights. Administrative areas include parks, ecological reserves and lands, such as Indian Reserves, over which the administration and control has been transferred to a government agency.

Cadastral boundaries are established by one of two methods. They can be established by ground survey where the corners and boundaries are physically marked on the ground, or they can be established by a description (such as a metes and bounds description, or an Explanatory Plan).

(b) Tenure Boundary

Examples of tenure boundaries are Forest Tenure boundaries. These include the boundaries of Tree Farm Licences, Woodlot Licences, Timber Sale Licences, and all Cutting Permits and Road Permits.

Determining Cadastral Boundaries

Only a British Columbia Land Surveyor (B.C.L.S.) may:

- Establish the location of a cadastral boundary on the ground.
- Demarcate on the ground cadastral boundaries established by metes and bounds descriptions
- Re-establish missing or damaged parcel corners that were originally established by ground survey.
- Provide an opinion on the location of a cadastral boundary.

The true location of a cadastral boundary must be determined on the ground, where the limit of a forest tenure cutting boundary lies within 150m of the cadastral boundary as depicted by Cadastral Data Base Management System (CDMS) reference maps.

Where the true limits of a previously surveyed cadastral boundary must be determined and all original posts **are found** in place for each boundary line facing or being adjacent to the forest tenure boundary, the licensee may cut within 20m of the true cadastral boundary where the boundary is located and marked by a survey technician. The licensee may cut to the boundary where the cadastral boundary is certified by a B.C.L.S.

Where the true limits of a previously surveyed cadastral boundary must be determined and all original posts **are not found** in place for each cadastral boundary facing or adjacent to the forest tenure boundary, the licensee may cut within 30m of the true cadastral boundary where the boundary is located and marked by a survey technician. The licensee may cut to the boundary where the cadastral boundary is defined by a B.C.L.S.

The B.C.L.S. must submit a sketch plan showing the certified cadastral boundaries, primary evidence found, ancillary evidence found, posts replaced and horizontal distances along the boundary including distances to semi-permanent markers. The B.C.L.S. must submit a posting plan or post renewal form to the Office of the Surveyor General when cadastral monuments are upgraded or re-established.

A survey technician may find and use survey evidence so long as that evidence is in its original location and so long as the survey technician is properly qualified and experienced. A survey technician may use such survey evidence to mark boundaries lying between monuments found and to determine the location of features relative to those boundaries.

The contractor and the Ministry representative must consult a B.C.L.S. if part of a project is defined by cadastral boundaries, and if the condition of the survey evidence or the method in which the cadastral boundaries were defined, is in doubt. The B.C.L.S. will advise if establishment or reestablishment of certain boundaries is recommended or required. Misinterpretation of cadastral boundaries may result in (and has resulted in) legal action being taken against the contractor and/or the Ministry where damage occurs on adjacent parcels.

Questions regarding requirements for surveys of cadastral boundaries should be directed toward the Surveyor General Division of the Land Title and Survey Authority (see *Appendix B* for contact details).

Watershed Boundaries
Forest tenure boundaries established by a metes-and-bounds description that refers to watershed boundaries, which are not contiguous to a cadastral boundary, may be determined by a qualified technician.

If the forest tenure watershed boundary is indeterminate (lacking definition, i.e. marshy or hummocky ground), the contractor and ministry representative should consult a B.C.L.S. regarding the establishment of that boundary.

Where Forest Tenure boundaries follow watershed boundaries, which are not contiguous with cadastral boundaries, but are contiguous to adjacent forest tenure, they may be established by a qualified technician along a series of tangents that are mutually agreed upon by all stakeholders.

As a last warning, it must be noted that misinterpretation of cadastral boundaries has resulted in legal action being taken against the Ministry and its consultants where damage has occurred on adjacent parcels.

5.5 Reference Markers

Many linear traverses require that the Field Operator establish physical reference markers periodically along the traverse. These may be metal tags affixed to trees, wood hubs, survey disks, or pin flags, etc. Usually these physical reference markers will have an identification code and other information such as date, etc. These markers may be required to reference subsequent work (e.g. a waste and residue survey can tie reference trees from the original block layout survey which also ties cruise plots), and the markers may also be used for audit purposes to verify the accuracy of the GPS survey. Some agencies have defined classes of physical markers depending on their purpose (e.g. permanent, semi-permanent, temporary, etc.).

All reference markers should be captured as static point features (see *Section D-7.1.1*), and offsets should be applied if necessary. High-significance point features such as map tie points, field sample plot centers, PoC and PoT should also be physically marked on the ground.

The location, type, and identifier of these markers must be included in the digital files and any hard copy maps that are submitted by the Contractor.

As with many other contract requirements, it must be remembered that there is an incremental cost to requiring reference markers. Most resource GPS surveys are done dynamically (i.e. linear traverse) where the boundary is walked and mapped with the GPS receiver continuously logging the position of the antenna. For each reference tree, for example, the GPS Operator must stop, write on an aluminium tag, place it on the tree, flag the tree, and remain still for the amount of time required to capture a GPS static point feature. The time required to do all this can be significant, especially in marginal observing conditions (e.g. heavy canopy and terrain obstructions). By halving the spacing of required reference markers, the cost of the survey may increase by 50% or more. If an Agency budgets for GPS services based on last year's spacing of, for example, 200 metres and the spacing is decreased to 100 metres, that will mean that Contractors will be submitting larger bids and the budget figures will not be sufficient for the work to be performed. If spacing (or any other) requirements are changed after a bid is accepted, of course, an amendment must of course be made to the contract.

6. GPS PROJECT MANAGEMENT and PLANNING

As with most complex projects, careful management and planning of GPS projects is essential. Most of the requirements of GPS project management are discussed in various sections of this document. The responsibilities and qualifications for GPS Project Managers are discussed in *Sections D-3.1 and D-4.1*. Much project management, logistics, and planning for GPS projects is general to any field project, and experienced Party and Project Managers will be familiar with the tasks. Contract management is discussed in *Section D-11*. This section will only deal with GPS planning of satellite availability for field scheduling.

6.1 Satellite Availability Planning

GPS positioning is sufficiently accurate for resource surveys only when certain conditions are met. Two critical conditions are a minimum of five satellites, and an upper limit on the Dilution of Precision (DOP) values.

With the current (2007) GPS constellation of 30 satellites, detailed satellite predictions is not as crucial anymore. Predictions may generally be assumed that there will be at least five satellites available above 15 degrees elevation with reasonable geometry; however, this does not mean that the GPS coverage is balanced throughout the day. Typically there will be time periods that are more productive than others, and satellite prediction planning will help identify those periods. In difficult project areas such as under heavy forest cover or mountainous areas with many terrain obstructions, it is important to plan field work during optimum satellite coverage. Often there are times of the day when GPS surveying is not productive on certain slopes and aspects, or in certain canopy conditions. With careful planning, field crews can avoid these situations and still achieve productive and accurate surveys.

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 (see examples in *Section D-7.2.3)*. Satellite prediction programs are included with most commercial receiver/software packages. 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 orbits of each GPS satellite, and from which their positions can be predicted. 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 uninterrupted minutes to ensure that the current broadcast almanac message is complete, and some receivers may have to be manually instructed to discard the old almanac and collect a new almanac. It is also possible to obtain almanac files from other sources including manufacturer's 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 GPS messages known as NANUs (Notice Advisories to NAVSTAR Users), which alert users in advance of planned satellite outages (e.g. down time for maintenance), as well as send notices of unplanned satellite outages (e.g. satellite problems/failures). NANU bulletins occur fairly often (sometimes more than 1 a day), and it is recommended that the NAVCEN email listserver 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 can be helpful to give the field crews satellite planning plots for specific times and they can adjust their schedules in the field accordingly. Some GPS receiver systems can do limited satellite predictions on the field Rover unit.

7. GPS FIELD DATA COLLECTION

The largest factor in the accuracy and efficiency of GPS surveys lies in how data is collected in the field. The data capture specifications and parameters affect the resulting positional accuracy. Efficient surveying, processing, and mapping require that data capture methods be well designed and rigorously followed, and the attribute data structured carefully. Interpretation of features (e.g. the edge of a clearing or the centreline of a road) also has an impact on the final accuracy of the survey.

This section provides most of the information and instructions necessary to complete *Section C - Specifications* for specific GPS projects. In preparation for using these *Specifications* as a contract schedule for a particular project/contract, the following project details need to be defined beforehand:

- The target/required project accuracy (as defined in *Section B - Standards).*
- The horizontal and/or vertical survey datum.

- A clear definition of the features to be surveyed, and the spacing of survey measurements along these features.

In the following subsections, guidelines are provided for identifying possible features that will be mapped/positioned with GPS. The methodology of defining features in the field is detailed and how the GPS receiver is to be configured to capture these features for various accuracies (i.e. completing details of *Section C - Specifications*).

If there are difficulties or uncertainties in defining the operation-specific details, consult with Agency staff familiar with surveying, drafting or GIS. Agency issues such as these are beyond the scope of this document.

7.1 GPS Data Collection Methods

There are three general feature types in mapping and Geographic Information Systems (GIS): points, lines (arcs), and polygons (areas). Most GPS receivers and software will structure their data capture options to correspond to these three feature types.

A GPS receiver measures pseudoranges (distances) to satellites at an instant in time referred to as the measurement epoch. From four or more simultaneous pseudoranges the Rover’s position fix is computed. GIS-capable GPS receivers will also store feature and attribute details along with the position fix, and this forms the core information used to create structured maps and GIS databases.

GPS data can be collected while stationary over a point (e.g. at a road junction), or dynamically along a linear feature (e.g. a road centerline or cut block edge). These data collection methods are called static or dynamic modes. In either case the receiver must be able to record data individually for each measurement epoch (position fix). This section will define these data collection methods in detail and will suggested field methods and GPS receiver settings to achieve target accuracies.

7.1.1 Static Point Features

Static point features are normally surveyed by grouping a number of individual position fixes to produces an averaged single position. Examples of static point features are: a plot centre, a tie to a cruise strip on a block layout traverse, or a traverse Point of Commencement (PoC). The GPS antenna is stationary during data collection at the point feature. 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 between the start and end times to compute a single position for the feature (as well as some simple statistics such as the internal standard deviation of the position fixes), and attach any attributes for export to a GIS or mapping system.

The largest errors in 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 metres 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 Data Processor 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.

During point feature surveys it is possible to improve positional accuracy by averaging a number of fixes while remaining stationary over the point. Random measurement noise and multipath effects are both improved with static averaging. One manufacturer suggests static averaging of 5 fixes when using narrow-correlation receivers, and 180 fixes when using standard-correlation receivers (these suggestions are for open tracking, longer averaging periods are suggested for under-canopy surveying). In theory, accuracy continues to improve as more data is averaged; however there is a diminishment of returns after a number of minutes of recording. After approximately 15 to 20 minutes of continuous data averaging (900 to 1200 fixes at a recording rate of 1 fix per second), little accuracy is gained from the additional data. ***It is recommended that at least 15 fixes be averaged for every static point observed, regardless of the project's accuracy***. This will allow an inspection of the individual fixes after post-processing in case a problem arises. The number of static fixes averaged during a contractor's Validation should serve as the minimum to be used during subsequent production surveys (but this should be at least 15 fixes).

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.

The table below shows guideline values which are based on theoretical and empirical studies (assuming a "High-End" narrow-correlation receiver, appropriate DOPs, and reasonable under-canopy tracking conditions)

Desired Network Accuracy	Suggested Data Collection Duration	Suggested Number of Fixes
1.0 m	10 minutes (600 sec)	150
2.0 m	5 minutes (300 sec)	75
5.0 m	2.5 minutes (150 sec)	50
10.0 m	0.75 minutes (45 sec)	15

Table D-6 Static Data Collection – Suggested duration and number of fixes

This document defines two levels of significance for static point features***: Standard Significance*** and ***High Significance*** points. The Agency representative must clearly define which point features are to be considered High Significance based on operational requirements (and additional time and costs should be considered). Some typical examples of *High Significance* point features are; inventory sample plots, cadastral survey monuments, map / photo tie points, PoC / PoT points, and permanent reference points for tenure purposes. Contract management personnel must decide which point features should be considered *High Significance*. The longer occupation times will help ensure that multipath biases do not go undetected. On some projects the survey crew will be doing other work in the vicinity of the point feature for a relatively long time anyway (e.g. making sample plot measurements). In these instances it is recommended that long GPS datasets be recorded at the point feature while the other work is being done.

As a suggestion, a point deemed as a *High Significance* point should be surveyed to one Accuracy Standard level better than the general accuracy level specified for the survey. For example, if the specified level of accuracy for a GPS road survey is a Horizontal Network Accuracy class of 10m; then the High Significance PoC / PoT point features should be surveyed to a Horizontal Network Accuracy class of 5m.

7.1.2 Linear Features - Dynamic Mode

Line features consist of many individual GPS position fixes that are connected to form a line. Examples could be a road centreline, stream centreline, or the perimeter of a cut block. Similar to point features, line features have a start and end time, and can have attributes associated with them. There are two modes of collecting linear features; dynamic traverses and point-to-point traverses.

Dynamic Traverses are analogous to stream-mode digitizing of a line. The Field Operator guides the GPS antenna along the linear feature to be mapped while collecting 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 travelling 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.

Many resource surveys are done on foot by a Field Operator wearing a GPS backpack. Other methods include aerial (helicopter and fixed-wing), and 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 correctly. These surveys must also conform to the fix spacing limits set by the Agency (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 is a practical upper limit.

During dynamic linear positioning the data recording rate should be set according to the fix spacing desired which is related to the vehicle speed. For example, if a road is to be surveyed at 10m fix spacing and the vehicle speed is 36 km/hr (10m/s), then the system must be capable of recording one fix per second.

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

Example Modes of Transportation	Speed Metres/second, (kilometres/hour), *knots*	Data Collection Rate (sec) And corresponding Point Separation (m)
Walking	1.4m/s (5km/h)	@1.0 sec separation = 1.4m

		@5.0 sec separation = 6.9m
Bike	4.2m/s (15km/h)	@1.0 sec separation = 4.2m @5.0 sec separation = 21m
Vehicle – slow, or Helicopter – working	8.3m/s (30km/h) *(16 knots)*	@1.0 sec separation = 8.3m @5.0 sec separation = 42m
Vehicle – fast	17m/s (60km/h) *(32 knots)*	@1.0 sec separation = 17m @5.0 sec separation = 83m
Helicopter – ferrying	28m/s (100km/h) *(54 knots)*	@1.0 sec separation = 28m @5.0 sec separation = 139m
Aircraft - fast (fixed-wing)	83m/s (300km/h) *(162 knots)*	@1.0 sec separation = 83m @5.0 sec separation = 417m

Table D-7 Dynamic Traversing - Speed & Data Rate Vs. Point Separation

7.1.3 Linear Features - Point-to-Point Mode

Point-to-Point Traverses are analogous to point-mode digitizing where the Field Operator stops for static traverse point observation, then moves to another spot along the linear feature for another static traverse point. GPS data is not logged while the operator is moving, so the path between successive traverse points is not mapped. The averaged static traverse points are then connected to form a linear feature in CAD / GIS software. Generalizing the line is usually not required. It should be noted that a point-to-point traverse is not necessarily more accurate than a dynamic traverse under forest canopy as multipath and signal attenuation can cause significant biases to the individual traverse points. Also, care must be taken to ensure that all deflections are surveyed (i.e. the feature is defined sufficiently). Point-to-point traverses may be a practical and likely more accurate survey method for defining post-harvest cut block boundaries. In this example the Field Operator can move into the opening (away from the standing timber) and get much better GPS accuracies (e.g. set a higher SNR mask). Offsets can then be measured to a sequence of points defining the boundary (see *Section 7.1.6* below for a description of point offsets).

7.1.4 Linear Features – Hybrid-mode

A hybrid mode of linear feature surveying can be used in which case the data collector records dynamic traverse data along the feature as well as static traverse points. The extra data can provide valuable QC and troubleshooting information. Both the dynamic and static data can be used in creating the final interpreted line. This hybrid method may be a preferable for under canopy surveys as the mostly random nature of dynamic errors may help identify biases in static points.

Polygon (area) features consist of individual position fixes connected together; with the first fix connected to the last fix to form a closed polygon. Examples are a cut block polygon, site treatment zone, or a parcel of land. Most organizations prefer to form polygon features from data collected in the field as linear features (instead of using the system's "area feature" data capture option). Creation of polygon features from linear features is easily accomplished within CAD / GIS.

7.1.5 GPS Events

Another method of capturing a point feature is a GPS Event. This is also referred as an *Interpolated Point* or as a Quickmark. A GPS Event is a position corresponding to a recorded time, and is interpolated from surrounding fixes recorded in the data collector. Events are used when the antenna cannot be stationary over a point feature. An example would be a fixed-wing aerial survey to position the confluence points of tributaries entering a river's mainstem. In this example it is clearly not possible to stop and survey these locations as static (averaged) point features. Instead, the Field Operator presses a key on the data collector when the tributary is directly below the antenna. The data collector records the precise time when the key is pressed, as well as recording the GPS position fixes available immediately before and after this time (GPS fixes are often available on only integer seconds in most systems). The position for the Event is computed later by interpolating between these surrounding position fixes. GPS Events are appropriate only in certain types of surveys, and only if the antenna is not obstructed. It should be understood that interpolated GPS Events are not a substitute for static GPS point features as described above and should not, for example, be used to derive positions for reference markers on a block layout survey. One manufacturer supported GPS Events in earlier models, but discontinued this later.

An important requirement for a GPS Event is that the recorded times must be accurate enough to allow for proper interpolation of the Event's coordinates. This is especially important in aerial or land vehicle surveys when the antenna is moving at high speeds. Some GPS systems do not properly provide for this type of survey, and merely record the next available integer GPS fix. Before being allowed as a data capture method, the GPS system must be proved under controlled and verifiable conditions using the same vehicle dynamics as during the production survey. This can be done by creating a test area alongside a road with a number of previously surveyed point features, and compare positions generated by the GPS Event method at different speeds and in different directions.

7.1.6 Point and Line Offsets

Often it is desirable to use offsets from the GPS antenna to the feature for reasons including accuracy, safety, and efficiency. For example, an offset can be made to a reference marker on a tree trunk while the GPS antenna is in the open; or the edge of a road can be surveyed on an active logging road and offsets applied to generate the road centre line. Offsets that are appropriately measured have the potential to improve the accuracy of feature positions; in some cases the improvement can be substantial. However, be aware that offsets can be confusing and may introduce errors if they are not properly managed.

Many resource GPS systems can directly accept offset information entered by the Field Operator (or directly connected from a digital offset measuring device). These offsets are associated with each feature, and can be viewed and modified if necessary at later stages of processing. If the GPS system does not directly accept offsets, manually recorded offsets may be applied later using CAD / GIS.

Be aware that there is room for blunders and confusion with offset features. The Field Operator must be careful to measure and record offsets correctly in the field. This includes a proper understanding of magnetic and true azimuths (magnetic *declination* is the difference between these 2 azimuths), inclination angles, and slope and horizontal distances. If the GPS system does not directly support offsetting, any features surveyed with offsets should be labelled clearly to ensure that these are applied later.

Point Offsets
The following are suggestions for point offsets:

- Azimuth measurements should be consistent – either all magnetic or all true. Magnetic declination used for the project area should be recorded in the field notes.
- Azimuth measurements should be made ***from*** the GPS antenna ***to*** the point feature.
- Point offsets should not be over 50m if measuring the azimuth "one-way", and should not be over 100m if measuring the azimuth "forward and back". These are suggested maximums; some projects may set smaller values. See table D-7 below.
- Distance measurements should have an accuracy of at least 1m, and must be reduced from slope to horizontal (this is calculated internally with GPS systems that directly accept offsets when the inclination angle is measured and recorded).

Magnetic declination uncertainty can contribute to an accuracy loss during offset measurements. The accuracy of the predicted magnetic declination is somewhat variable, but is expected to be <0.5 degrees in most of southern Canada, and ~1 degree farther North (source: Geological Survey of Canada - GSC). The magnetic declination adopted for the survey should be noted in the project report, as well as the methods used to measure distance, direction and inclination. Magnetic declination must be applied to all compass observations before computing offset coordinates. This can be done by setting the declination on the field compass to allow direct reading of true azimuths, or the declination can be applied to magnetic azimuths afterwards. The official source of magnetic declination in Canada is GSC, and values can be computed using their on-line Magnetic Declination Calculator (note that declination changes over time…1 degree every 3 to 6 years in BC):

http://www.geolab.nrcan.gc.ca/geomag/apps/mdcal_e.php

Magnetic *deviation* is the distortion in the magnetic field caused by local attractions. These attractions can be natural such as local ore bodies, or they can be man-made attractions such as vehicles, watches, electrical devices, etc. The proximity of the compass to the attraction affects how much deviation is induced (e.g. a knife placed close to a compass may cause it to swing wildly). The Field Operator should be aware of local attractions and use good observing techniques to minimize their impact.

Magnetic *variation*s are time-varying changes caused by short-term differences in the earth's magnetic field…usually as a result of solar flares. During violent solar events the earth's field can be distorted causing compasses to be in error. This effect is most pronounced near the magnetic North pole.

The following table is provided to assist the Contract Administrator in defining the maximum allowable offset for various instrumentation. Note that declination and deviation affect all types of compasses (analogue and digital). The table is based on the assumption that the combined uncertainty of magnetic declination, deviation, and variation is 1°.

Compass Instrumentation	Compass Precision	Declination, Deviation & Variation Uncertainty	Offset Distance	Offset Point Uncertainty (approximate)
Standard Compass	2.0°	1.0°	25m	1.0m
e.g. Silva Ranger (15T)			50m	2.0m

			100m	3.9m
Precise Compass e.g. Suunto KB-14D	1.0°	1.0°	25m	0.6m
			50m	1.2m
			100m	2.5m
Digital Compass e.g. MapStar, Laser Atlanta	0.3° - 0.5°	1.0°	25m	0.5m
			50m	1.0m
			100m	2.0m

Table D-8 Offset Accuracy vs. Instrumentation Precision & Offset Distance

Linear Offsets

For some linear feature surveys, it may be preferable to offset the line. An example is a project requiring the centreline of an active road be surveyed. In this case it would be safer to survey this feature in a vehicle driving in the right-hand lane, with an offset of left 3m applied to derive the centreline. Linear offsets are based on being able to maintain a constant offset from the feature (left or right of the direction of travel).

Suggested guidelines for linear offsets:

- Linear offset distances should be limited to 5m (since it is difficult to maintain a constant parallel offset for distances much longer than this).
- The offset distance should be checked regularly. It is a good idea to draw a sketch of the feature and the antenna direction of travel, and show the offset direction. This will allow later confirmation that the offset was applied in the correct way.
-

7.1.7 Supplementary Traverses

A supplementary traverse is a conventional traverse (connected bearings and distances) integrated within a GPS survey. As GPS techniques are applied in more difficult tracking environments (such as coastal forests), it is often a combination of GPS and conventional survey methods that can provide the most productive and accurate results. For example, the portion of a boundary traverse that crosses a steep, heavily wooded gully on a North aspect may best be surveyed with conventional methods. It is likely that the GPS observing conditions in the gully would be marginal because of terrain blockage and foliage effects.

The Field Operator is to establish the Point-of-Commencement (PoC) and Point-of-Termination (PoT) for the supplementary traverse as High-Significance static point features (see *Section D-7.1.1*). Both the PoC and PoT are to be physically established with reference markers. The points should be given an identifying attribute that specifically describes their purpose (such as S1 PoC) for *Supplementary Traverse 1 Point of Commencement*.

Any method can be used for supplementary traverses as long as it can meet the specifications. In some cases, thread chains, clinometers (for slopes more than 5 degrees) and hand compasses may be adequate. In other cases better measurement tools will be needed. Some traversing instruments such as laser range finders (with slope corrections) can be very accurate and productive, and these instruments may integrate directly with the GPS data collector software and allow the supplementary traverse lines to be automatically computed. However, supplementary traverses should be specifically noted as such, and the survey returns should indicate sections that were surveyed by supplementary traverses.

Conventional traverse observations may be kept on paper field notes or electronically, and must be submitted with the returns. The traversed portion should, if possible, be a different colour or line style on the map or digital file.

Methods and equipment used for the supplementary traverse must meet existing Agency standards and accuracy specifications. The closure requirements can be stated as a ratio of the distance plus an allowance for the GPS errors at the PoC and PoT. Statistically, this GPS allowance is computed as the square root of the sum of squares of the errors at both ends. Assuming that these points were surveyed as High Significance point features, they should be approximately one-half the Network Accuracy target of the GPS survey. The following table provides some guidance on providing this specification (showing both 1:100 and 1:500 traverse closure ratios). Any misclosure in the traverse must be balanced according to the contracting Agencies procedures.

Target Accuracy (Horizontal Network Accuracy)	Specification (ratio + GPS error allowance)	Distance Traversed	Expected Closure	Specification Achieved
2.0m	1:100 + 1.4m	250m	2.5m + 1.4m = 3.9m	-
		500m	5.0m + 1.4m = 6.4m	-
		1000m	10.0m + 1.4m = 11.4m	-
	1:500 + 1.4m	250m	0.5m + 1.4m = 1.9m	Yes
		500m	1.0m + 1.4m = 2.4m	-
		1000m	2.0m + 1.4m = 3.4m	-
5.0m	1:100 + 3.5m	250m	2.5m + 3.5m = 6.0m	-
		500m	5.0m + 3.5m = 8.5m	-
		1000m	10.0m + 3.5m = 13.5m	-
	1:500 + 3.5m	250m	0.5m + 3.5m = 4.0m	Yes
		500m	1.0m + 3.5m = 4.5m	Yes
		1000m	2.0m + 3.5m = 5.5m	-
10.0m	1:100 + 7.1m	250m	2.5m + 7.1m = 9.6m	Yes
		500m	5.0m + 7.1m = 12.1m	-
		1000m	10.0m + 7.1m = 17.1m	-
	1:500 + 7.1m	250m	0.5m + 7.1m = 7.6m	Yes
		500m	1.0m + 7.1m = 8.1m	Yes
		1000m	2.0m + 7.1m = 9.1m	Yes

Table D-9 Supplemental Traverse Closure Requirements

7.2 GPS Equipment, Settings and Techniques

This document focuses on only SPS (civilian) differential pseudorange GPS receivers (applicable for resource surveys). For information on geodetic carrier phase GPS equipment please refer to the document ***British Columbia Standards, Specifications and Guidelines for Control Surveys Using Global Positioning System Technology***, available from CRGB.

There are many differences between available GPS receivers. The highly competitive and dynamic nature of this market ensures that new hardware developments will be ongoing. However, be aware that the GPS industry, like other high-technology industries, has been known to over-sell products and features. Some claims are exaggerated, or may be valid only during specific conditions that are not typical operating environments. This is one of the reasons why Contractor GPS System Validation is important. Refer to *Section D-4.2* for more information on GPS System Validation.

7.2.1 Receiver Design

The number of satellites that a particular receiver can observe is dependent on the number and type of tracking channels. A parallel channel tracks one satellite at a time while a serial channel sequences quickly (i.e. multiplexes) between more than one satellite. Parallel channels outperform serial channels in high dynamic situations, and under conditions of low signal strength (e.g. under tree canopy). Early receivers could track only 4 satellites; while today 8 - 10 is considered a minimum (many receivers now have 12 or more parallel channels). The current GPS constellation of 30 satellites (2007) provides coverage in BC with between 5 and 12 satellites visible above 15 degrees elevation. Any receiver with 12 or more channels can therefore be considered “all-in-view”, whereas receivers with less than 12 channels must select a sub-set of the available satellites to track. Under conditions with intermittent satellite obstructions, a receiver with many channels will outperform one with fewer channels.

Satellite tracking under tree canopy (or other local obstructions) is a problem for all GPS receivers. Manufacturers continue to work on optimizing receiver-tracking sensitivity. It appears that there is no easy solution to the basic physical problem of tracking a weak signal from a distant satellite. Some tracking improvement can be expected with the modernized civilian signals that will become available in the next few years.

Signals affected by multipath are longer than the direct distance from the satellite to the antenna; therefore they corrupt the solved position. Multipath can add over 50m to a measured range, and can affect either the Base Station and / or the Rover receiver’s data. In either case the Rover’s solved DGPS position can be significantly corrupted, often on the order of tens of metres. At least one manufacturer offers a receiver with a signal-tracking threshold that is adjustable by the Field Operator. This can be useful, but it can also be a dangerous control that may lead to accepting less accurate pseudoranges (and therefore less accurate positions). It is recommended that receiver tracking controls be left at default values during all GPS operations, unless changes have been confirmed to be acceptable with rigorous, scientific studies that support target accuracy levels for point and linear features. In an effort to increase receiver sensitivity to weak signals, some users have replaced the originally supplied antenna with a third-party unit. This may also increase the risk of accepting multipathed signals. Contractors choosing to use a non-standard antenna should be required to prove that their modified system is not susceptible to increased multipath under conditions with local obstructions. This may be demonstrated during validation along a route under tree canopy that has also been surveyed by conventional methods.

A significant development in receiver technology occurred in the early 1990s involving the over-sampling of the C/A code signal to improve ranging accuracy. This measurement technique is referred to as *narrow-correlation* and allows range accuracies of a few decimetres - this has previously been defined in this document as a “High-End” receiver. This compares to *standard-correlation* receivers that can produce range accuracies of a few metres - previously referred to as “Low-End” receiver. Narrow-correlation over-sampling has a side-benefit in that it also significantly improves multipath rejection. A GPS Base Station equipped with a High-End receiver will improve the accuracy of differential corrections for all Rovers (including standard-correlation Rover receivers). The highest DGPS accuracies of ~1m (95%) are possible under good tracking conditions using a High-End receiver for both the GPS Base Station and the Rover.

Sections C-6 of the *Specifications* list requirements for GPS equipment and data collection. These are further explained in the following paragraphs.

7.2.2 Minimum Number of Satellites

Observations to a minimum of four satellites are required to solve for the 3D antenna position (latitude, longitude, and height) as well as the receiver clock offset (range bias). If the antenna's ellipsoidal height is already known accurately, it is possible to fix this value and compute a 2D position (latitude, longitude, and range bias) from just 3 GPS satellites, however, the antenna height must be known to at least three times the horizontal accuracy target (e.g., the antenna height must be accurate to <3m for a 10m horizontal accuracy target). This is unlikely to achieve under most conditions, especially considering that only orthometric (e.g. mean sea level) heights are available in most places in Canada. This orthometric height must be transformed to the ellipsoid using a Geoid model, and this step also contributes to the vertical errors. Be aware that some GPS systems can operate in an automatic positioning mode in which 3D positions will be solved when four or more satellites are tracked, but it will revert to 2D positions if only three satellites are tracked (or the geometry of the 4 satellite fix becomes too weak). This mode should not be used; instead the GPS Rover should always be set to generate only 3D positions from 4 or more satellites during all surveying / mapping.

In summary, GPS positions calculated using 2D (fixed height) is **not** acceptable for any RISC surveying or mapping tasks.

7.2.3 Dilution of Precision (DOP)

Probably the most important concept to understand, and the most important quality indicators that are available to GPS Contractors and Contract Administrators are the Dilution of Precision (DOP) values. The DOP numbers indicate the geometric strength of a particular group of satellites.

The DOP parameter/values are used during all phases of a GPS resource survey. They are used in the planning stages of a GPS survey to pre-analyze the suitability of available satellites throughout the workday. DOP values are monitored during field data collection as an indicator if the current solution can meet the project accuracy requirements. DOPs are also monitored during the Quality Control (QC) phase of a project by the Contractor to ensure acceptable position fix geometry was achieved. Data not meeting the DOP specifications can be selectively excluded during post-processing and export. Lastly, DOPs can be used as a Quality Assurance (QA) check by the Contract Administrator to ensure the Contractor has not submitted sub-standard work.

7.2.3.1 DOP Basics

The DOP (Dilution of Precision) is a measure of how the satellite geometry will affect the accuracy of the computed position. Errors in the range measurements can be multiplied by the DOP value to give an estimated accuracy of the final position. For example, if the corrected pseudoranges are accurate to 0.5m (narrow-correlation, good tracking conditions), and the tracked constellation has an HDOP of 2.0, then the horizontal accuracy would be expected to be: (0.5m*2.0) = 1.0m (note this example is for clear tracking conditions…not under canopy).

There are a number of different DOPs that may be considered depending on the dimensions that are important for the final position. The commonly used DOPs and their geometrical meaning are summarized in the table below. The relationships between the different DOPs are also provided below.

DOP		North (or Lat)	East (or Long)	Height	Range Bias	Geometrical Meaning and Comment
Geometric DOP	GDOP	X	X	X	X	• four dimensions • latitude, longitude, height and time
Position DOP	PDOP	X	X	X		• three dimensions • latitude, longitude & height • commonly used in 3D-positioning
Horizontal DOP	HDOP	X	X			• two dimensions-horizontal • latitude & longitude
Vertical DOP	VDOP			X		• one dimension-vertical • height
Time DOP	TDOP				X	• one dimension - time • rarely used (only for time transfer)
North DOP	NDOP	X				• one dimension - North • latitude “strength”
East DOP	EDOP		X			• one dimension - East • longitude “strength”

Table D-10 DOP Components

Precise time is not generally of direct interest to Land Surveyors; therefore the TDOP and GDOP are less applicable than the other DOP values that reflect only positional components. The PDOP is often used both in pre-analysis of the available satellite coverage, and during monitoring of field operations, however, this is rigorously correct only when the 3-dimensional solution (horizontal & vertical) is required for a specific project. Unfortunately, some GPS receivers (and also some pre-analysis software) compute only the PDOP. The NDOP and EDOP are used rarely, with the HDOP being a more common method to indicate the combined horizontal strength. For projects that require only horizontal positioning (e.g. the height solutions will not be used), the HDOP is the best indicator of the GPS constellation strength.

In cases where DOP values must be converted, the following relationships can be used:

$$GDOP^2 = PDOP2 + TDOP^2$$
$$PDOP^2 = HDOP2 + VDOP^2$$
$$HDOP^2 = NDOP2 + EDOP^2$$

In general, the HDOP is normally lower than the VDOP (resulting in better horizontal positioning than vertical positioning), however, this can be reversed. There is no formula that can convert between HDOP or VDOP alone and PDOP or GDOP (or vice-versa).

7.2.3.2 Project Planning Using DOPs

DOPs are a measure of how the satellite geometry will affect the accuracy of the computed position. DOPs are unit-less scalars that can be multiplied by the pseudorange measurement accuracy of a particular GPS receiver to give an estimate of the resulting positional accuracy. Under normal conditions, lower DOP values result in more accurate positioning. An example of this concept is provided below.

*Example - **High-End Receiver***
Narrow-correlation, phase-smoothing Receiver
Pseudorange accuracy = 0.5m (i.e. narrow-correlation receiver with differential corrections from a Base Station within 100km, clear tracking resulting in good SNR values)

PDOP:	*3.6*
HDOP:	*2.0*
VDOP:	*3.0*

Under these good conditions, the following accuracies would be estimated:

Positional (horizontal & vertical):	*(0.5 x 3.6) m = 1.8m*
Horizontal:	*(0.5 x 2.0) m = 1.0m*
Vertical:	*(0.5 x 3.0) m = 1.5m*

*Example - **Low-End Receiver***
Standard-correlation code Receiver
Pseudorange accuracy = 1.5m (i.e. standard-correlation receivers with differential corrections from a Base Station within 100km, clear tracking resulting in good SNR values)

PDOP:	*3.6*
HDOP:	*2.0*
VDOP:	*3.0*

Under these good conditions, the following accuracies would be estimated:

Positional (horizontal & vertical):	*(1.5 x 3.6) m = 5.4m*
Horizontal:	*(1.5 x 2.0) m = 3.0m*
Vertical:	*(1.5 x 3.0) m = 4.5m*

These examples are intended to show how DOPs work as scalars. The computation of estimated accuracies is of a more theoretical than practical use because the actual pseudorange accuracy is not precisely known for each measurement. This is because short-term ionospheric, tropospheric, multipath and other effects affect the ranges. Also, the DGPS processing software and other factors may also affect accuracies.

If GPS planning software is available, various DOP plots for a time period should be compared. However, relationships from this analysis will only be valid if all satellites used in the planning are available in the field. The loss of satellites at lower elevation angles (usually the case in forestry surveys) generally causes a greater loss in horizontal accuracy (HDOP) than in vertical accuracy (VDOP).

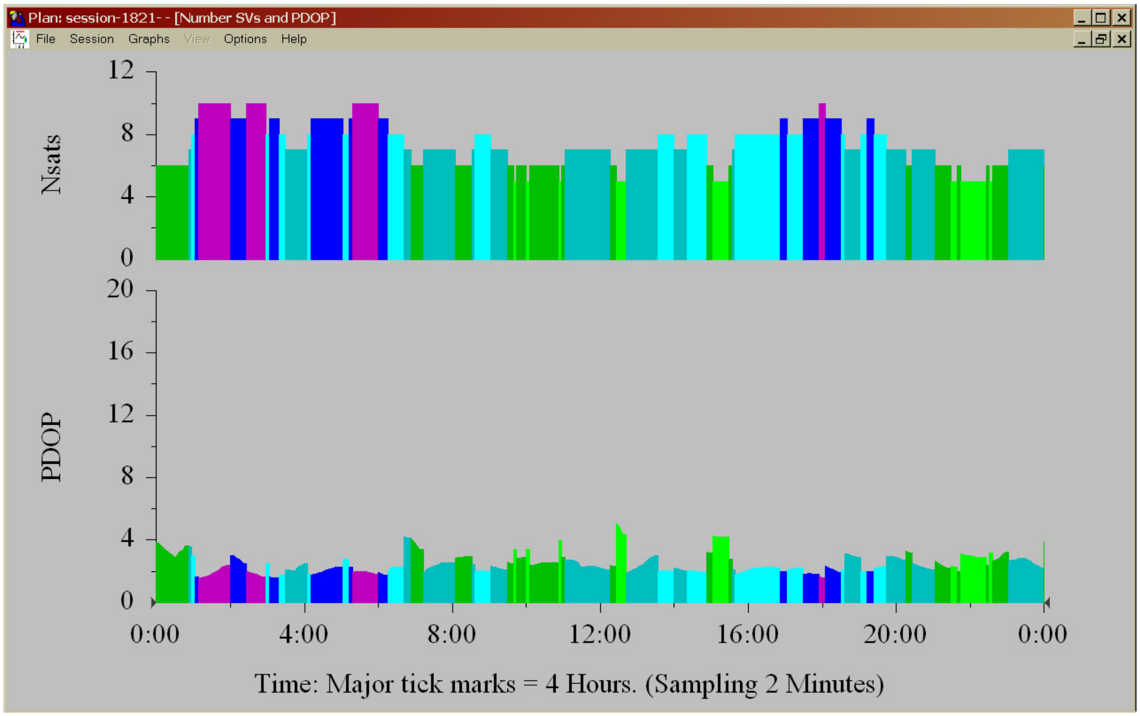
The 6 screen captures in *Figure D-1* shows the predicted satellite coverage for a 24-hour period at Prince George, BC for July 1st, 2007. The individual screen captures show in order: the number of satellites & PDOP, the skyplot showing satellite trajectories as seen at the user's location, GDOP, PDOP, HDOP, and the VDOP plots.

For this location and date, GPS coverage using an elevation cut-off of 15 degrees shows between 5 and 10 satellites visible, with a PDOP range: 1.6 - 5.0, an HDOP range: 1.0 – 3.0, and a VDOP range: 1.2 – 4.0. The 2 periods with the most available satellites and lowest DOPs are early morning (~1am to 6am), and late afternoon (~4pm to 8pm). Remember that the entire constellation advances ~4 minutes per day (~2hrs per month), therefore the afternoon strong session will more useable during working hours by August 1st, 2007.

This coverage looks strong, and it appears that there would be no problem using GPS at any time of the day in Prince George…but recall that this was computed using an elevation mask of 15 degrees. When under tree canopy it is often not possible to track low elevation satellites, and a better representation may be obtained using a higher mask angle. If 25 degrees is used instead, it shows that it would be impossible to work (<4 satellites) for ~1hr in the evening, and there are 3 PDOP spikes >20 totaling over 2 hours duration (including a spike between 12:00 and 13:00…this would be lunch time!).

Remember that the actual number of GPS satellites observed in the field is usually less than the pre-computed theoretical number due to local obstructions. This is why it is important that Field Operators understand DOPs and monitor / control them carefully during data collection.

Figure D-1 Sample GPS predictions for central British Columbia



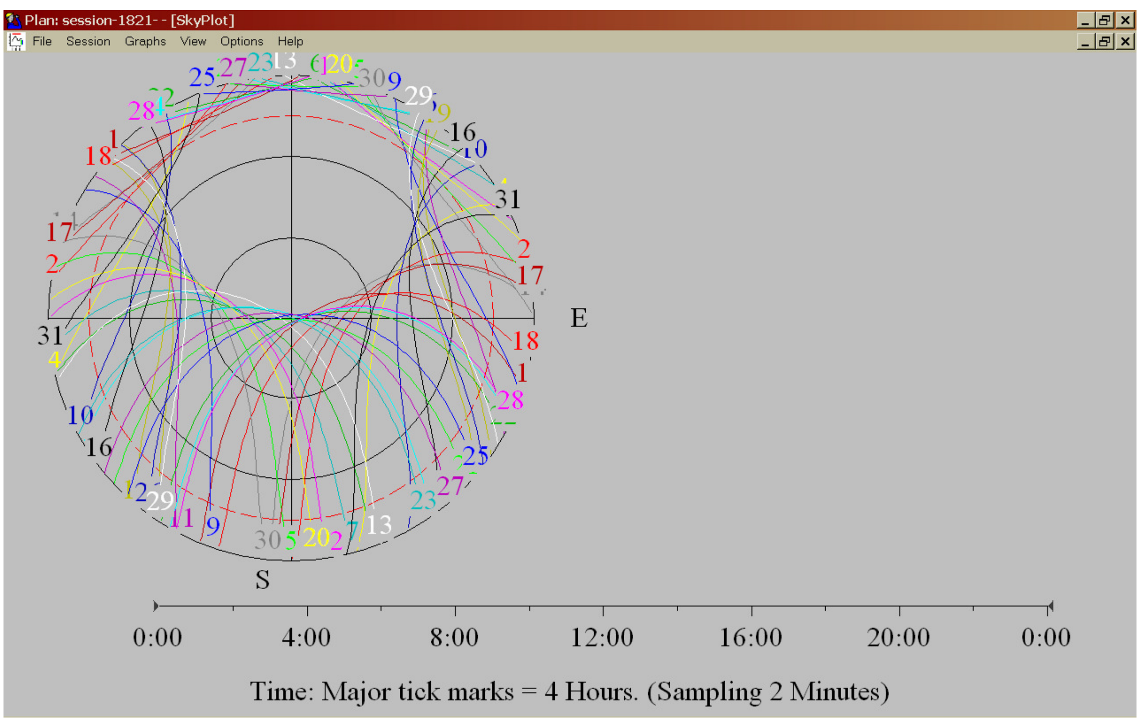
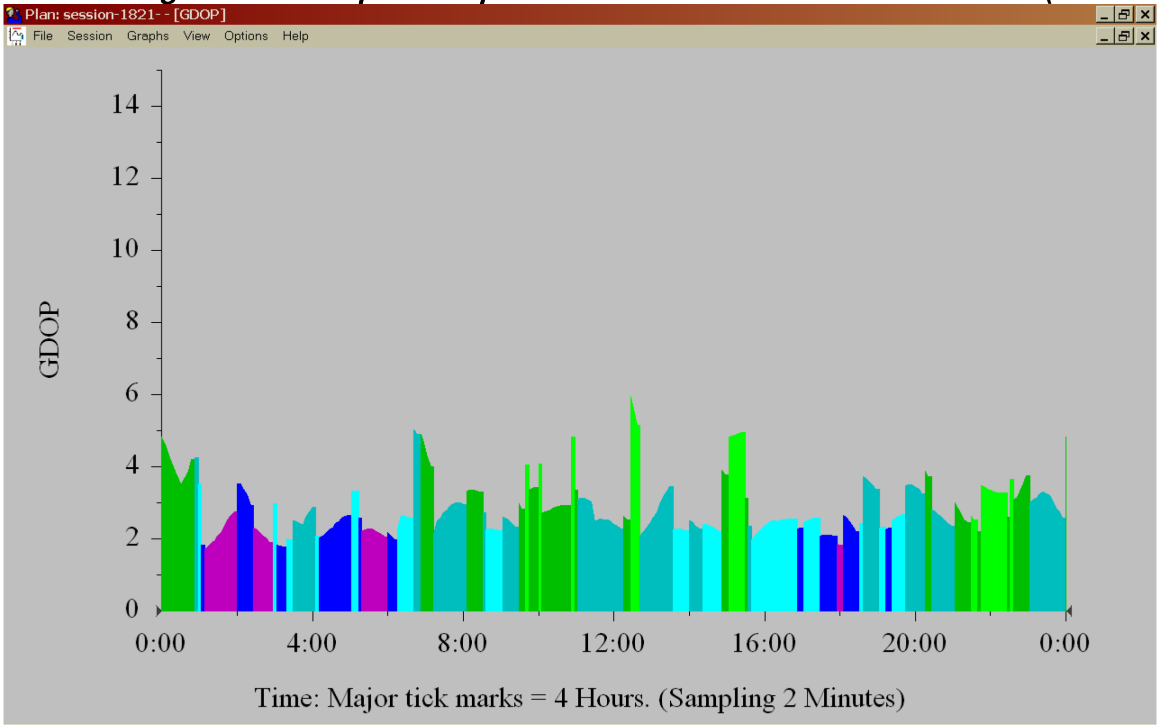


Figure D-1 Sample GPS predictions for central British Columbia (continued)



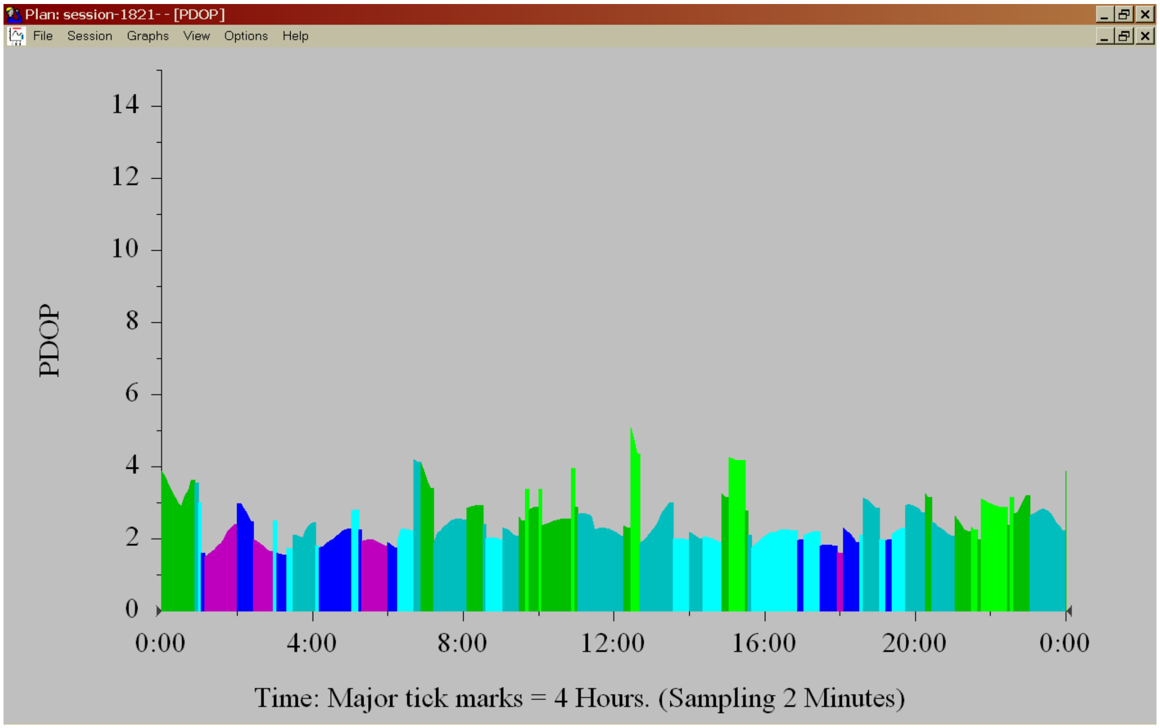
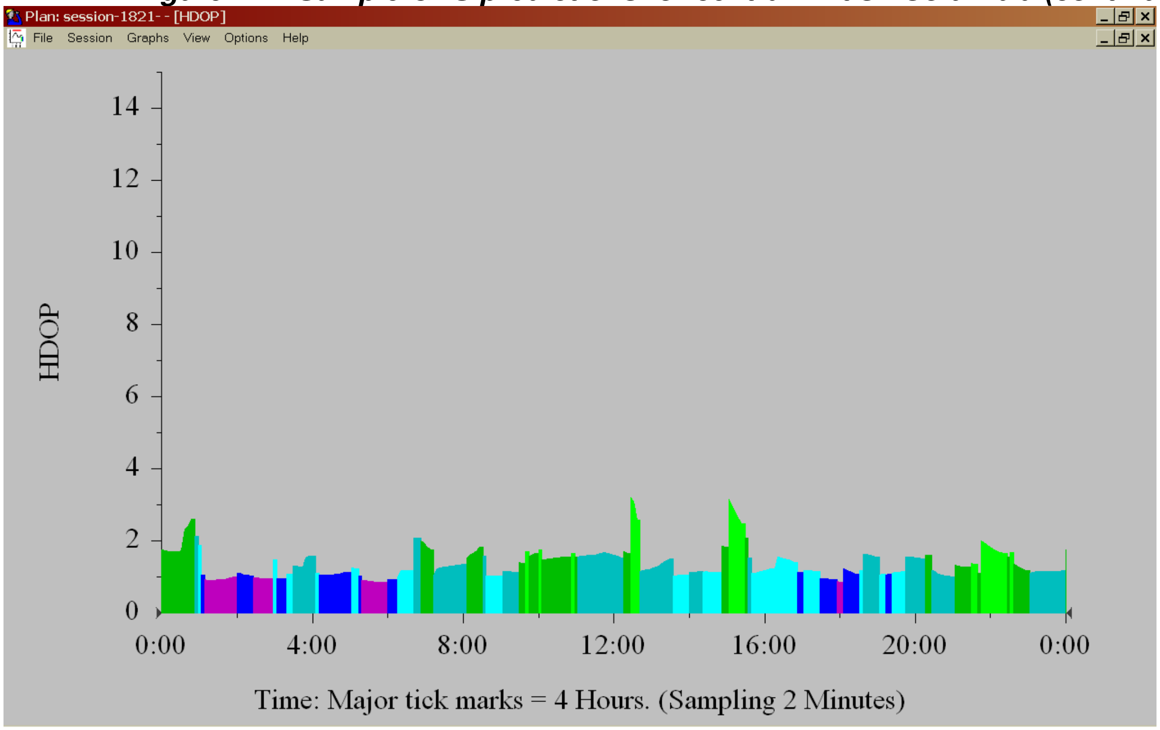
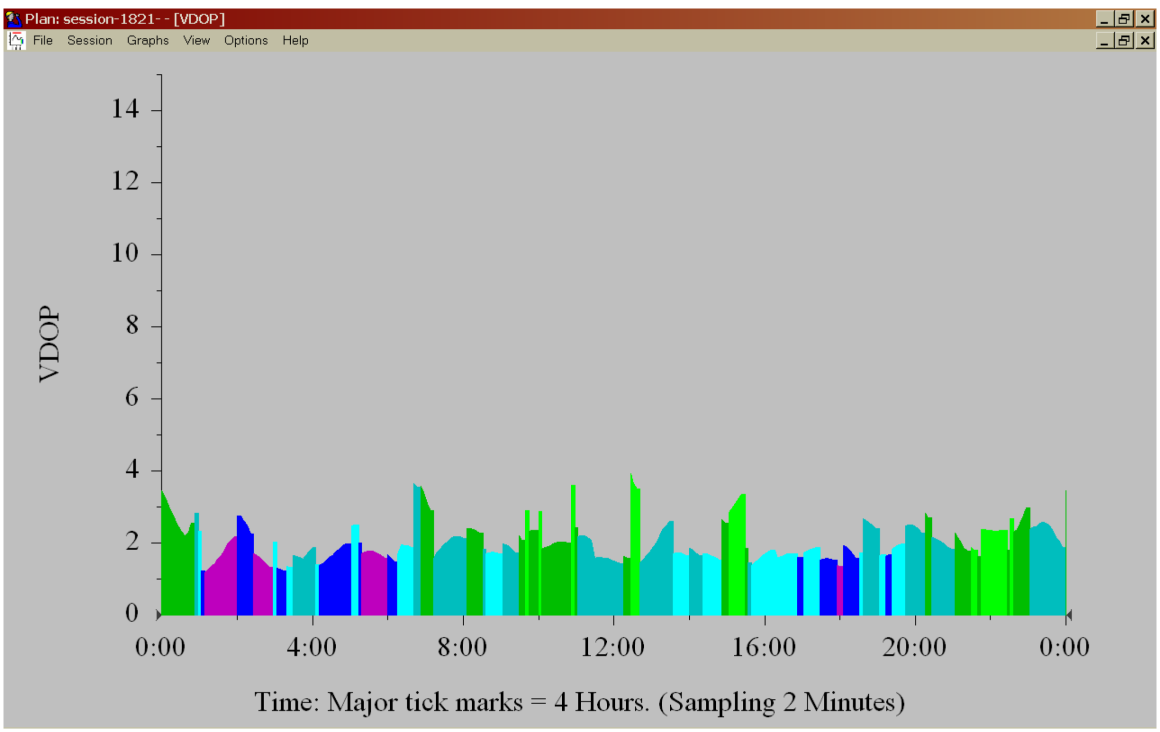


Figure D-1 Sample GPS predictions for central British Columbia (continued)





7.2.3.3 DOPs Used in Data Collection

It is very important that DOP values are kept as low as practicable, and never exceed the maximum for the survey. Whenever possible, field data should be collected with the lowest possible DOP thresholds. This will lead to better data, and less editing later in the office. As discussed in the section Quality Control (QC) and Quality Assurance (QA), Rover DOP values should always be recorded.

Good (low) DOP values result from having satellites well distributed in the sky. Because of the way the GPS satellite orbits are inclined, most of the useable satellites are to the east, west, and south of an observer in BC. *Figure D-1* shows the sky plot of all GPS satellites for 24 hours in central BC. In many resource surveys, terrain blockage limits the visible satellites and tree cover blocks even more. For these reasons it is important to carefully monitor DOP values during field data collection. Careful project planning can help to make field surveys more productive by showing ideal observation times.

Most receivers will allow the user to set a DOP threshold value, also known as a DOP mask, which will alert the Field Operator when this value is exceeded; some GPS systems will suspend data collection as well. For best results the threshold should be set as low as the terrain and tree cover allow, but never more than the maximum allowable. Any position fixes collected with more than the maximum allowable DOP must be rejected.

Most resource GPS surveys are concerned with horizontal coordinates only. For these cases, it is preferable to monitor the HDOP (Horizontal Dilution Of Precision). For surveys concerned with elevation (e.g. a road profile), it is desirable to monitor the VDOP value. Some GPS systems allow setting of only a PDOP threshold, but do display HDOP and VDOP values. If using these systems for horizontal or vertical surveying, it is recommended to set a reasonable PDOP threshold, but ensure that the Field Operator is monitoring the HDOP or VDOP values throughout data collection. The Project Manager should instruct the Field Operator as to appropriate HDOP or VDOP maximums for data collection. In this case it may be required that the PDOP threshold be changed throughout the day as the constellation changes.

Vertical surveying (for MSL elevations) with GPS is also affected by uncertainties in the Geoid-ellipsoid separation. The 2m level of vertical accuracy is possible only within a small localized area (i.e. 20 kilometres between the GPS Base Station and Rover receiver) and with VDOPs below a suggested maximum of 2.5 using narrow-correlation receivers. The 5m level of vertical accuracy is achievable over a wider area and under less stringent DOP conditions; however, VDOPs should be kept below 4.0 for all GPS elevation surveys. CRGB should be consulted regarding use of an appropriate Geoidal undulation model (i.e. CGG2000 or HT2_0), and connections to local vertical benchmarks.

DOPs are an important quality indicator that must be appropriately specified for a particular project. Some typical resource-mapping target Network Accuracies are listed below with suggested maximum DOP values. GDOP and PDOP values are shown as only an approximate guideline for GPS systems that do not directly compute the HDOP or VDOP.

Target Network Accuracy (95%)	**Narrow-Correlation Suggested Maximum DOPs**	**Standard-Correlation Suggested Maximum DOPs**	**Comments**
1m	GDOP = 4 PDOP = 3 HDOP = 2 VDOP = 2	Not applicable	Narrow-correlation receivers only (with clear tracking conditions)
2m	GDOP = 5 PDOP = 4 HDOP = 3 VDOP = 3	Not applicable	Narrow-correlation receivers only (with mostly clear tracking conditions)
5m	GDOP = 8 PDOP = 6 HDOP = 4 VDOP = 4	GDOP = 5 PDOP = 4 HDOP = 3 VDOP = 3	Both narrow and standard correlation receivers can meet the 5 & 10m accuracy targets …*but with different DOP limits*.
10m	GDOP = 10 PDOP = 8 HDOP = 5 VDOP = 5	GDOP = 8 PDOP = 6 HDOP = 4 VDOP = 4	Typical projects with 10m accuracy targets are done under difficult tracking conditions (e.g. under tree canopy)

Table D-11 Suggested Maximum DOP Values

7.2.3.4 Use of DOPs in Quality Control(QC)

The Dilution of Precision (DOP) indicates the achievable accuracy of GPS positions. It is a unit-less number that can be multiplied by the receiver measurement accuracy to give the position accuracy. There are different ways of stating the DOP value, depending on what dimensions are required. It is highly desirable that DOP values be kept to a minimum in all cases. No positions with DOP values greater than those specified in the contract will be accepted. The receiver should be set to log DOP values for audit and troubleshooting purposes.

The contractor must be able to demonstrate competent understanding of DOPs. It is recommended that the contractor be required to submit both raw GPS data as well as processed positions. This will allow an independent assessment of observations in the event that positioning conflicts appear (i.e. the DOPs can be re-computed from the raw observation data).

7.2.4 Elevation Cut-off / Mask

A significant source of error in GPS pseudorange measurements is disturbances while the signal propagates through the atmosphere (i.e. how the signal is disturbed as it travels through the upper ionosphere and lower troposphere). This error increases significantly and becomes unstable at low satellite elevation angles, and for this reason 15 degrees elevation is considered a minimum for Rovers during most surveying purposes. Elevation angles below 15 degrees can be accepted at the Base Station to ensure overlapping data with Rovers. Satellites for which both the Base Station and Rover data are not available will not be used in the corrected position, so the elevation mask at the Rover will determine which Base Station satellites are used during processing.

The field GPS receiver **must** be capable of setting an elevation mask or threshold. The elevation mask for the GPS field receiver should not be set lower than 15 degrees.

The GPS Base Station is typically set to record satellites at lower elevations to ensure a data overlap with any Rover receivers. Up to 1 degree of elevation angle difference will result for every 100km of separation between GPS Base Station and field receiver. The elevation mask for GPS Base Station should not be set lower than 10 degrees.

7.2.5 Signal To Noise Ratio (SNR) Mask

Some GPS receivers allow a mask to be set for the minimum signal strength, or signal-to-noise ratio (SNR). If the signal from a particular satellite is received with SNR strength below this mask value, the receiver will not use this measurement in the position computation. This is a filter to reject weak pseudoranges that are more likely to be distorted or grossly corrupted by multipath. Weak signals are harder to track consistently and pseudorange measurements tend to be less accurate.

Receivers from other manufacturers may display an SNR value, but do not allow a user-configurable SNR mask. It is not correct to assume that these receivers have no SNR threshold; rather, they have internal hard-wired minimum thresholds for signal strength. Different manufacturers compute and display SNR values in different ways. This makes it difficult to compare SNR performance between manufacturers, or even between models from the same manufacturer.

The GPS models that allow user-configurable SNR masks are widely used for resource surveys in BC. The following test and discussion is based on Trimble's original SNR scale (0-10), however this has changed with data collector firmware released ~2005. The new SNR scale of 30-45 is approximately equivalent to the original SNR scale of 0-10. The following paragraphs refer to the original SNR scale.

Trimble suggests a default SNR mask setting of 6, and warns of reduced accuracy if lower strength signals are accepted. Users soon discovered that productivity increases as the SNR mask is lowered. This is because more satellites pass the SNR test, and positioning is then possible in conditions where otherwise it may not be. Reduced SNR mask values of 4, 3, and even 0 were used, but without a clear understanding of the impact on positional accuracy. A detailed study was done in coastal BC during the fall of 2000 to isolate and understand the relationship between SNR and positional accuracy. This isolation of the test variable was possible because one antenna was used to feed two receivers via an antenna splitter. Testing was done at the FERIC Test Range near Maple Ridge. The full study is available from CRGB. The study showed that under coastal canopy, there is a significant reduction in both the horizontal and vertical accuracy when the SNR mask is dropped from the default of 6 to 3 or 0. This occurs **despite** the fact that lower SNR masks allow more satellites to be used and the constellation geometry therefore improves. During these tests the reduced SNR PDOP was 31% better than the PDOP when the SNR mask was left at 6. *Note that this contradicts the general rule that lower DOPs produce better positional accuracy.* The reason for this contradiction is that the better geometry is caused by additional satellite measurements; however, these additional measurements made from weak SNR signals have larger errors. Table D-12 shows the overall accuracies for point features seen in this test. Note the tracking conditions for this test are classified as difficult with dense 2nd growth and mature coastal forest. This environment is possibly the most difficult for GPS to work under.

SNR Mask	Horizontal accuracy (95%)	Vertical accuracy (95%)
6 (default)	5.3m	8.3m
3 or 0	9.5m	15.9m

Table D-12 SNR Mask vs. Accuracy (Trimble Pro-Xx, Coastal Forest)

Note that the accuracies above indicate only the GPS error components of feature mapping. Interpretive errors in the field will also contribute to the combined total errors in feature mapping. This suggests that point feature positioning under coastal canopy will *not* meet the 10m accuracy class if the SNR mask is reduced to 3 or 0. Data capture was clearly more productive with lower SNR settings (in this test the lower SNR settings resulted in approximately 25% more fixes than the SNR 6 setting). However, productivity is a secondary concern, whereas accuracy must be considered a primary concern.

The linear routes through the Test Range were graphically compared against the ground-truth routes established by accurate conventional surveys. This comparison was done based on the linear interpretation of the GPS data that an experienced Data Processor would be expected to produce. This is necessarily subjective, and does not lead to the definitive and quantitative statistical comparisons that are possible with point features. However, it does reflect the way that linear features are mapped with GPS.

The test loops through dense 2nd growth conifers produced linear interpretations with errors generally at or below 5m for all SNR settings. The most accurate linear results were from the Control receiver SNR 6, however, the reduced SNR results did not show much degradation. The reduced SNR receiver collected approximately twice as many fixes as the SNR 6 receiver. This is an indication of the better productivity that results from reduced SNR settings.

The test loops through the mixed mature forest produces linear interpretations with errors generally between 5m and 10m for all SNR settings. The reduced SNR receiver collected approximately twice as many fixes as the SNR 6 receiver. During 2 of the tests through the mixed mature forest, the SNR 6 receiver could not effectively survey the route (too few satellites or PDOP > 8), while the reduced SNR receiver continued to collect GPS data. The linear interpretations resulting from these 2 reduced SNR tests showed the worst accuracies seen in the study; however, they still substantially met the 10m accuracy class. Similar to the results seen in the static point feature comparisons, this indicates that the SNR setting does indeed work as an accuracy filter.

Most test loops showed sections of GPS data that could be wrongly interpreted leading to linear errors over 10m. This reinforces the importance of having well trained and experienced Data Processors and Mapping Technicians interpreting the GPS data.

To summarize the SNR findings, static point features suffer more degradation than dynamic linear features, although both feature types were less accurate with lower SNR masks. Field data collection productivity is clearly higher with reduced SNR masks. Some projects may benefit from this increased productivity while still meeting linear accuracy targets (e.g. pre-harvest cut block surveys with an accuracy target of 10m (95%)). Static point feature accuracy targets may not be met with reduced SNR masks. This may require that the Field Operator change the SNR mask when switching between static point and dynamic linear feature data collection. Switching the SNR mask can be done quickly in the field (few keystrokes). Section 6.15 of the *Specifications* establishes whether reduced SNR masks are acceptable for a contracted project. This coastal testing suggests that reduced SNR masks be allowed only for projects with an accuracy target of 10m (95%), and only for dynamic linear features.

Note that the results from this study are specific to Trimble Pro-Xx receivers, and the SNR / accuracy behaviour can not be directly related to other receivers. However, the principle that low signal strength measurement is less accurate than measurement from stronger signals would be expected to apply to all GPS receivers. Note that some manufacturers group a number of receiver control parameter settings together (SNR, DOP, elevation angles, etc), with generalized labels such as maximum accuracy or maximum productivity. This does not allow direct control over the receiver's performance, and the user should determine the specific parameter values corresponding to each generalized label. Production surveys and the contractor's GPS System Validation should be done with the same receiver parameter settings.

7.3 GPS Base Station Settings

All GPS surveys requiring high positional integrity and with accuracy requirements of 1m to 10m (95%) must use some form of differential GPS corrections. Differential GPS techniques require a GPS Base Station, which is a GPS receiver observing over a known point in the same region and at the same time as the field survey is being done. An extensive network of suitable permanent Base Stations exists in British Columbia, most of which provide public access. Using a single GPS Base Station to correct Rover data is called Local Area DGPS (LADGPS). Another form of DGPS is a Wide Area (WADGPS) solution that computes corrections based on information from multiple Base Stations.

Due to the nature of the operation of the GPS Base Station it is not necessary to specify as many issues and parameters as with field GPS receivers. Also, the *GPS Base Station Validation* procedure will highlight any deficiencies with the GPS Base Station. However, the following brief discussion will note some of the more important issues.

It is recommended that GPS Base Stations have a GPS receiver that incorporates advanced signal processing technologies to ensure the best possible base data quality. This includes narrow-correlation (e.g. some trade-names are: Maxwell-chip; Narrow-correlator; Pulsed Aperture; Strobe-Correlator; Super-C/A code, etc.); carrier-aided pseudorange smoothing; RFI rejection; and multipath rejection. The GPS antenna should be optimized for static Base Station operation with a ground plane or choke-ring to minimize multipath reflections.

It is recommended that GPS Base Stations have at least 12 parallel tracking channels. These systems must be capable of storing at least L1 code pseudorange and carrier phase or doppler data at integer-second intervals (synchronized within 1 millisecond of GPS time). This will allow correction of GPS field data with accurate, carrier-smoothed pseudoranges from the GPS Base Station. Elevation masks at the GPS Base Station should be set to 10 degrees to ensure overlapping satellite coverage with GPS field Rover receivers.

The GPS Base Station logging interval is an issue requiring further discussion. Some processing software will interpolate between reference epochs. For example, if the GPS Base Station is logging data at a 5-second interval and the field receiver logs data at a 1-second interval; the post-mission software will interpolate the GPS Base Station data to match the field receiver's data. This method is valid as long as a reasonable interpolation time limit is used. For typical resource mapping, it is recommended that permanent GPS Base Stations log at no less than 0.2 Hz (that is, once every 5 seconds). This represents a good compromise between GPS accuracy and file size. If the processing interpolation algorithm is not accurate enough, this should be apparent from the results of the GPS System Validation.

It may be that accurate interpolation over longer intervals (e.g. 30 seconds or more) is possible using sophisticated algorithms. The US National Geodetic Survey has made available a version of software to interpolate pseudoranges on their 30 second CORS data. The Geodetic Survey of Canada has an alternative correction methodology (PPP a web-based correction service), which uses post-computed precise clock and orbit corrections and an ionospheric grid model to correct field data to the metre-level. This works only with RINEX file format, therefore it does not apply to most field GPS projects (PPP can not handled feature and attribute information…only raw GPS observations in RINEX format).

The US aviation WAAS augmentation is a wide-area solution based on many GPS Base Stations (mostly in USA, but with a few in Mexico, Canada, and Greenland). Most current GPS receivers can track and utilize WAAS, however, it is not a practical option for resource surveys because the signal can not be reliably tracked under forest canopy, and there is also a difference in the defining survey datum (WAAS is based on WGS84, not NAD83(CSRS) which is the official survey datum in BC). WAAS is not recommended as a correction method for RISC projects (even if it is applied using an appropriate mapping-grade Rover GPS receiver).

Another wide-area solution more applicable in Canada is CDGPS. This is based on the Federal Government CACS network of GPS tracking stations, plus some additional trackers outside of Canada. The corrections are sent via a communication satellite, and the CDGPS message structure is more robust than WAAS when used under marginal tracking conditions. The survey datum for CDGPS is NAD83(CSRS) which allows it to be used directly in BC. CDGPS is an option worth considering for resource surveys needing real-time corrections.

8. DATA PROCESSING and QUALITY CONTROL

To meet the specifications and target accuracy of this document, all GPS surveys must use some form of differential GPS corrections. Differential GPS utilizes data from a GPS Base Station at a known point to correct data collected at a roving field receiver. An extensive network of suitable permanent Base Stations exists in British Columbia, most of which provide public access.

Crown Registry and Geographic Base (CRGB), Ministry of Agriculture and Lands is tasked with validating GPS Base Stations and other GPS correction services in the Province. Information on approved services and methods can be obtained from CRGB (see *Appendix B References* for contact numbers).

8.1 Differential GPS Correction Methods

The original differential GPS methodology developed in the early 1980s was based on a simple 3D position-shift correction calculated at the Base Station (corrections to latitude, longitude and height at a particular time) which were then applied to the Rover unit's solved position at the corresponding time. This methodology is also called position-shift DGPS, and it produces acceptable results *only* when the Base Station and Rover positions are computed using identical satellites. By the mid 1980s a more rigorous DGPS technique was developed based on using the Base Station's measurements to calculate corrections to each individual satellite's pseudorange, and then applying these corrections to the Rover's corresponding measured pseudoranges before solving for its position. This increased the positioning accuracy somewhat, and reduced the operating restrictions (i.e. it was no longer required for the GPS Base Station and the Rover receivers to track the identical set of satellites).

One manufacturer's software (applied widely in resource surveys) makes use of both DGPS methodologies. When post-processing data from older version data collectors the software applies the position-shift methodology, but when used with newer version data collectors it applies the pseudorange correction methodology. Be aware however that when this system is used with real-time DGPS corrections it always applies these as pseudorange corrections, regardless of the version of data collector used. A final complication…it is possible to post-process data that was initially collected with real-time corrections applied. In this case, positions computed with older data collectors will then switch from being pseudorange corrected to position-shift corrected.

Contractors should understand their complete GPS System well, including the DGPS methodology that is being applied in different situations. If the data collection and/or processing software changes, the full system performance should be confirmed before being applied on projects. A GPS Validation Range is an ideal way to confirm performance.

The DGPS processing software supplied with commercial systems is simplified to be user friendly and require limited training to operate. Advanced processing options are not offered, and this is acceptable to most general users. Unfortunately, most commercial software has only limited Quality Control / Quality Assurance outputs (QC/QA), if any at all. The Contract Administrator will need to look to other means of QC/QA.

All GPS positions must be corrected by standard differential GPS methods either in real-time or by post-processing. Simple position-shift DGPS solutions are acceptable *only* if the same set of satellites is used at the Base Station and at the Rover. CDGPS is an acceptable wide-area real-time DGPS method. Other DGPS methods may be acceptable, but only after comprehensive testing under real-world conditions, and following approval by CRGB.

8.2 Advanced GPS Data Processing

Simultaneous pseudorange observations to four satellites are the minimum required for calculating positions with DGPS. In BC most of the time there are more than four satellites available to track. Most current receivers used in resource surveys can track and use ten or more satellites simultaneously. If more than the minimum four pseudorange observations are available, the extra redundant information can be used in an over-determined solution.

Redundant observations are desirable for many reasons. The computed position will usually be more accurate, since errors can be distributed using least-squares adjustment procedures. Perhaps more important, statistical quality control information can be generated for an over-determined solution. This is only possible, however, using the pseudorange correction method of DGPS.

Two useful statistical parameters which can be generated from an over-determined position fix are the observation residuals and the solution variances. Solution variances will give standard deviations of the computed position (an indicator of how well the data fit together to compute the position). Variances are not always a reliable indicator of the absolute accuracy of any given fix, but they can give a relative indication of the quality. For example, points under forest canopy would be expected to have a higher standard deviation than those in the open. Note that this is different from the internal standard deviation computed from multiple fixes during a static point survey.

Observation residuals are generated after the adjusted position is computed by comparing the theoretical observation (range from the computed Rover position to the computed satellite position) to the actual observation (the actual range measured by the receiver to that satellite). The difference between these 2 values is the observation residual. In good observing conditions, all residuals will be reasonably small and close in size to each other, with as many being negative as positive. If, however, the measurement to one satellite is very poor (e.g. multipath), then that satellite's residual will usually be significantly larger than the other residuals. Some software will detect this observation as an outlier, and then compute a new fix location with this measurement ignored.

The statistical and mathematical basis for these analyses is beyond the scope of this document (for more information referred to the texts outlined in *Appendix B*, or search for the term: RAIM). However, some manufacturers have implemented these features within their processing software, and hidden the more complex concepts from the average user. Some manufacturers have derived their own quality estimator from variances, residuals, DOPs, and other information. These may be valid indicators of the overall quality of the solution, but they must be assessed by comparing them to data of known quality before relying on them. Again, this comes back to proper training, experience, and confirmation (e.g. not relying only on manufacturer's claims).

There are particular cases where the best possible accuracy and quality control information is required. For example, audits of the work of others should be statistically defensible and have some quantitative indication of the solution quality. In these instances, pseudoranges should be stored in the field receiver, and processing done by experienced personnel using sophisticated processing software. For special circumstances (and using sophisticated processing software), project specifications could be written giving expected statistical values which must be met. This may be the case for audit surveys or surveys investigating alleged violations that may be challenged in the courts or appeal boards.

8.3 Filtering and Smoothing Schemes

Some manufacturers use various interpolation, filtering and estimation schemes on the GPS data, generally known (e.g. Kalman filtering). Again, the concepts behind these methods are beyond the scope of this document; however, their effects on the processed data should be discussed. For discussion terms, these methods will be defined as filtering.

All filtering schemes use knowledge of previous and/or future positions and usually some knowledge of the dynamics of the Rover receiver in computing GPS position solutions. For example, when walking with a Rover receiver, the solution should not be able to move 50 metres North, and then 50m South over 10 seconds (that would be 40 km/h!).

Software with this capability will usually have a receiver dynamics setting which can be changed in the field Rover or in the post-processing software. Other manufacturers may apply such filters, but not allow the user control over the settings. If possible, dynamics parameters should be set to match the platform dynamics - stationary, walking, driving, flying, guided missile, etc. Properly set dynamics filters can also aid in the signal tracking in the field, as explained in the equipment section. Some manufacturers also apply filtering to the GPS Base Station data to smooth observation noise (typically not required if a High-End receiver is used at the Base).

Software with the filters described above can provide more accuracy than standard processing schemes, but the filters must be applied appropriately. In many cases, the application of the filters is not under the user's direct control. Care must be taken that the platform dynamics are appropriate to the situation. For example, if walking dynamics are applied to a helicopter-based aerial traverse, legitimate movement can be filtered out inadvertently, leading to an inaccurate and unreliable traverse. Any dynamics settings and filters applied should be noted in the project report.

8.4 Data Editing, Smoothing and Generalizing

The positions originally computed by the DGPS processing software (or by the Rover receiver if real-time corrections are being applied) are considered the original corrected GPS data. This original corrected data shows the level of noise in the GPS traverse as well as any major errors. This data should be archived as an indicator of the quality of the GPS survey.

In some instances, special-processing controls may be applied to the data, either before any processing takes place or after a preliminary run. Examples might be a new elevation mask, specific outlier rejection criteria, or removing a specific satellite from the solution. If any of these controls (other than the software defaults) are used to generate the original corrected GPS positions - these must be noted. This can be done by including the processing options file (most programs will provide this) or by noting them in a written report.

Most maps made from GPS traverses are edited or generalized. This is done to smooth out the noise common to GPS data (especially under forest canopy), and so that the final lines are made up of a reasonable number of points. In the case of dynamic linear surveys, a best-fit line is often drawn over the GPS position fixes (heads-up digitizing) to create a generalized line. This should be done by somebody with an understanding of both GPS errors under canopy, and also the characteristics of the feature being mapped. It is possible to perform some automatic smoothing of these line features using best-fit and line-smoothing algorithms available in the GIS program, but this looses the intelligence that a human operator brings.

Point-mode traverses and static point features are also usually edited. This may be done automatically by the software program that averages the position fixes to one single point feature. In some cases, the GPS processor may delete individual position fixes when they are obviously much different than the majority of the fixes. Statistical tests on the standard deviation are also common, as outlined in the section on Quality Control. In the case of a point-to-point GPS traverse, the edited and averaged point features are connected to form a linear feature using CAD / GIS tools.

It is clear from the above that GPS interpretation involves some subjective analysis by the Mapping Technician and/or the GPS Data Processor. They must decide which fixes are outliers (rejecting gross and systematic errors), and how to best smooth the remaining random position fix noise. Often they must interpret sections where there may be questions as to a linear feature's location, especially if the feature has a complex shape and the GPS data is noisy. If the data is too difficult to interpret with confidence, they must be prepared to require a re-survey of this section. Many errors in GPS traverses are due to inadequate interpretation and analysis of the corrected GPS data. *Once again, this is an issue of proper training and experience.*

8.5 GPS Base Station Issues

GPS data collected in the field must be corrected using data from a known GPS Base Station in order to meet the accuracy and integrity requirements described in this document. The GPS Base Station must use appropriate equipment and have an accurately known location. Many of the issues regarding GPS Base Stations are discussed in *Section D-4.3* and *Section D-7.3* and will not be repeated here. The following sub-sections are specific to the processing aspects (both post-mission and real-time) of the GPS Base Station.

8.5.1 Accuracy Versus Separation Distances

Local area DGPS is based on the principle that errors observed at the Base Station are applicable at the Rover. This principle is valid when the Rover is reasonably close to the Base Station, but this breaks-down (becomes de-correlated) as the separation increases. Many manufacturers recommend a maximum separation of 500km, although this figure should be used with caution. The best Local Area DGPS accuracies are obtained within ~100km of the Base Station; beyond this distance Rover accuracies will degrade. Note that this de-correlation applies to only Local Area DGPS, as Wide Area DGPS techniques model system errors differently.

Contributing factors to the de-correlation of differential corrections between the GPS Base Station and Rovers are:

- Geometric de-correlation of ephemeris & other errors as the spatial separation grows.
- Differences in the observed satellite elevation angles between GPS Base Station and Rover change the tropospheric and ionospheric errors affecting each pseudorange.
- Large differences in local meteorological conditions.
- Large change in elevation (e.g. >1000m).

The DGPS processing software may also have an impact on the de-correlation of errors. Early versions of a particular commercial spatial software package showed a large error growth with increasing separation. This growth was over 10PPM, resulting in additional errors of over 5m with a separation distance of 500km. Later versions of this same software package (after ~1995) reduced the error growth to <2PPM (through more rigorous atmospheric modeling).

The following table provides a rough indication of the possible accuracies attainable from the two typical GPS receiver types over varying separation distances. The accuracies indicated in the table below may be obtained only under favourable observation conditions (i.e. low DOPs, good observing environment, etc.). Both types of Rover receiver accuracies shown in the table assume that a High-End receiver is used at the Base Station, and that the DGPS processing software is rigorous.

Rover Receiver Type	Base / Rover Separation Distances	Favourable Horizontal Accuracies (95%)
Low-End Receiver *approx. accuracy = 1.5m + 2PPM*	100km	1.7m
	250km	2.0m
	500km	2.5m
High-End Receiver *approx. accuracy = 0.5m + 2PPM*	100km	0.7m
	250km	1.0m
	500km	1.5m

Table D-13 Separation Distance Vs. Favourable Accuracies

8.5.2 Real Time Corrections

Real-Time DGPS (RT-DGPS) is based on correction data from the GPS Base Station being transmitted to the Rover receiver by radio telemetry link in real-time. RT-DGPS utilizes the pseudorange correction methodology (as opposed to the position-shift methodology used in some post-mission software). Advantages of RT-DGPS include better accuracy in the field allowing precise navigation and layout, availability of derived results (distances, areas), and improved quality control of field positioning. There are also time and cost savings with RT-DGPS as there is normally no post-mission DGPS processing required. The difficulty with RT-DGPS is usually establishing a reliable radio link between the Base Station and the Rover. In coastal areas of BC, many users choose the Canadian Coast Guard service as the low-frequency radio link is generally not affected by local obstructions, and the service is reliable, accurate and free. In the interior parts of BC, the correction radio link is typically based on a geo-stationary communication satellite. This transmission method gives wide coverage, but it can be disrupted by local obstructions, and suffers from low angles at Northern latitudes. CDGPS is an example of a satellite communication RT-DGPS system.

RT-DGPS surveys should use GPS Base Stations that have been validated by CRGB. The 4 Canadian Coast Guard stations along the BC coast are validated for local-area use, but the only wide-area service that currently meets this requirement is CDGPS (mainly because the core GPS tracking stations that form these corrections are the Federal Government CACS stations that also define the NAD83(CSRS) survey datum in Canada). RT-DGPS correction messages applied from a local Base Station usually complies with the current international standard RTCM format. Either RTCM Type-1 or Type-9 messages are acceptable. Both messages send the computed pseudorange correction, plus the range rate (see below) for all visible satellites. Type-9 messages are shorter and more likely to be useable under difficult radio reception conditions, and the overall correction latency is typically less than for Type-1 messages.

Data-link latency and RTCM-Age (i.e., time since last RTCM message) are issues in real-time GPS, although this is less critical since the removal of SA. Pseudoranges are observed at the GPS Base Station, corrections are computed for each satellite, and this information is then formatted, sent to a radio modem, modulated, and transmitted (perhaps through a number of repeaters). This signal is then received at the Rover radio modem, de-modulated, sent to the GPS receiver, re-formatted, and finally applied to the individual pseudorange measurements made at the Rover before computing a position fix. The time it takes to do all of this is called the overall ***latency*** of the RT-DGPS system. During the latency period, the error conditions for each satellite may have changed, and therefore the corrections being applied at the Rover are no longer completely valid. Range rates are usually transmitted by the GPS Base Station (always the case with RTCM standard messages), and these are used to minimize the inaccuracy caused by correction latency. However, these range rates are only valid for a relatively short time period.

The description of latency above corresponds to a Local Area RT-DGPS system with a single Base Station. Wide area RT-DGPS systems may have longer latencies as the measurements from many Base Stations must be transmitted to a central processing facility where the wide area corrections are modelled. These extra steps require additional time for communications and processing.

Most Rover GPS receivers have a user-controllable setting, typically called the ***RTCM Age*** or ***Age of Corrections***, which sets the time limit up to which the last received corrections will be used for RT-DGPS positioning. Note that this receiver setting may not correspond to the full latency of the corrections, as it may exclude the delays before the correction message was received at the Rover (check your equipment manual).

RT-DGPS is always based on an extrapolation of the corrections computed at the Base Station at some time in the past. This extrapolation leads to a marginal accuracy loss when compared to post-mission DGPS which is based on corrections that are either exactly time synchronised between Base Station and Rover, or surrounding corrections are used to interpolate corrections at a Rover fix time. This RT-DGPS accuracy loss is negligibly small if the latency is kept small (this effect has greatly diminished with the removal of SA).

Prior to May 2nd 2000, Selective Availability (SA) was the largest single error affecting GPS, and it was also the fastest changing. This required that RT-DGPS systems have low latencies in order to preserve pseudoranging accuracies. With SA active, pseudorange corrections typically changed a metre every few seconds, and correction ages were typically limited to ~10 seconds. Without SA, the remaining errors cause pseudorange corrections to change at a much slower rate of a metre every few minutes, and therefore the correction ages can be much longer. RT-DGPS testing has been done in BC since the removal of SA to determine accuracy performance at different latencies. Aged corrections affect positioning accuracies in different ways depending on the satellite elevation angles, atmospheric conditions, and the GPS system generating the corrections. Remember that errors from aged corrections are *additional* to all other errors contributing to GPS inaccuracies. Also note that any satellite anomalies will be undetected by the Rover until the next correction is received. Longer age limits increase the risk of accepting corrupted data without detection. Further details of this testing is available from CRGB. The following table gives suggested maximum correction latencies for different target project accuracies, and can be used to complete *Section 7.6* of the *Specifications.*

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

Table D-14 Suggested Maximum Correction Age for Various Target Accuracies

Some GPS systems allow data to be corrected in real-time, and also allow the same data to be post-mission corrected. In this case, the correction age setting is not important as long as final results are all post-mission corrected.

8.6 Quality Control, Quality Assurance, and Reporting

Quality Control and Quality Assurance procedures are essential to performing reliable GPS surveys (by GPS Contractors), and to managing them (by Agency personnel). For the purposes of this document, Quality Control (QC) is defined as the procedures undertaken by the GPS Contractor during the project to ensure that the final products are complete, correct and accurate. Quality Assurance (QA) is the procedures undertaken by the contracting Agency to ensure the final products are complete, correct, and accurate; and also to ensure that they are properly integrated into the existing map databases (see *Section D-11*).

The concept of QC starts before the GPS production survey with the training of personnel and the Contractor GPS System Validation. During and after the field data collection, the GPS Contractor should review the data quality and completeness using a QC program. The following sections provide more information regarding these procedures.

8.6.1 Training and Validation as part of the Quality Control Program

Quality Control of GPS data can *only* be done by staff with appropriate training. Without an understanding of the important GPS concepts, there can be no effective QC.

GPS System Validation should be part of a Contractor's QC program to ensure reliable and accurate GPS positioning. See *Section D-4* for more information.

8.6.2 Quality Control

Many of the procedures for QC have been detailed in *Sections D-4, D-7, and D-8 (Operator Pre-Qualification, Field Data Collection, and GPS Post-Processing and Interpretation).* By following the field procedures and specifications and the post processing methods outlined, Contractors can help ensure (but not guarantee) that GPS data produced will be acceptable.

Additionally, some specific QC procedures are important to ensure that GPS surveys integrated into Agency databases are reliable, accurate, and within project specifications. Some QC methods are listed below.

DOP, Elevation, and SNR Masks

The first QC/QA method is to ensure that the field data capture specifications have been followed. Some GPS receivers allow the user to set DOP masks to ensure that the receiver does not collect any data when DOP values exceed certain values. Other receivers will issue a warning, but continue logging data. If maximum DOP values are specified, there must be some way of ensuring that they were not exceeded. It is preferable to log DOP values directly with each position fix or change in satellite constellation used. If the receiver can not do this, DOPs can be computed after the fact, usually in the manufacturer's software. Other parameters should be noted either in the project reports or in a file generated by the receiver or software. Note that some processing software includes utilities that can quickly extract all receiver control settings from the raw files (any time the Field Operator changes a setting a record is written to this binary file). This allows a quick confirmation of all receiver settings that affect data quality (e.g. position mode, DOP type and mask value, elevation mask, SNR mask, etc).

Scientific-level DGPS processing software allows many QC/QA parameters to be output (i.e. solution standard deviations, residuals, variance factors, etc.). However, the capabilities of most commercial software for offering these outputs are generally limited.

Re-Observation

Another method of assessing the quality of a GPS survey is to re-observe portions of the survey. By comparing the observations, an indication of the accuracy of the survey can be determined. However, this method should be carefully applied.

The nature of GPS errors typical to most resource surveys (positions are quite independent of each other) mean that a re-survey will give an indication of the accuracy only over the re-observed portion. There is usually very little relationship between the accuracy of a portion of a survey and the rest of the traverse or static GPS points, especially under forest canopy where site-specific multipath effects are the largest source of error. An exception to this would be systematic errors caused by using wrong coordinates for the Base Station. In open conditions without significant obstructions, re-observation can be more indicative of the overall quality. Re-observations can also be instructive when an operator is gaining experience with GPS.

When executing re-observations, the repeat observations should be as independent as possible from the original observations. A second GPS observation immediately following the initial observation is highly correlated, and is not a good indicator of positioning accuracy. The time separation between observations should be as great as possible (i.e. at least 1 hour). When two field crews are working on a project, crew #2 should make the repeat observations if crew #1 did the original observations.

The project report should contain a table or spreadsheet showing the repeat measurements, with a summary indicating the percentages that were within the accuracy test level. Typically, 95% of the repeat measurement distances are required to be within the square root of twice the accuracy target squared. This concept is defined in the following example:

Project horizontal accuracy target: 5m

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

QC Test: 95% of the horizontal radial distances between separate observations of the same point feature must be less than 7.1m.

This test is applied to the radial distances between repeat observations, not individual coordinate component comparisons.

A dynamic survey should also include repeat segments. As a suggestion, a cut-block survey could include an overlap of approximately 5% of the perimeter distance. A road survey can include repeated segments (preferably run in the opposite direction from the original survey). These dynamic repeats can be compared graphically by plotting at a scale that allows clear confirmation of the accuracy levels.

Ties to Known Coordinated Points

Some contracts require a periodic check of the GPS system on existing, known locations (usually geodetic control monuments). This requirement does not provide much real information about the quality of a GPS survey (GPS systems do not require periodic calibration). Perhaps the only information that can be derived from these checks is that the Data Processor used the correct coordinates for the GPS Base Station during post-processing.

Redundant GPS Base Station Data

In some circumstances, DGPS processing from multiple GPS Base Stations can improve accuracy and reliability. An example is a project covering a large area (or a long linear project such as a transmission powerline). Some DGPS processing software will accept and use data from multiple Base Stations when correcting Rover GPS positions. If this is not supported, then 2 or more processing runs can be done using different Base Stations, and the Rover results manually compared. Wide Area Differential GPS (WADGPS) is by definition based on many GPS Base Stations networked together, and this may offer increased accuracy and reliability (depending on project circumstances).

9. DIGITAL MAPPING and GIS INTEGRATION

GPS is a powerful tool for feature capture, updates and integration into existing digital mapping databases. Geographic Information Systems (GIS) and digital mapping has become an essential tool for managing provincial resources (as well as many other non-resource applications). However, there are specific issues that must be considered when integrating GPS data within existing digital mapping bases.

Agencies may use a number of different digital mapping and GIS software and hardware platforms. Existing digital map bases may be referenced to different datums and use different coordinate systems depending on the original purpose, age and accuracy of the mapping. Digital attribute data may also be in different formats for much the same reasons.

The following sections discuss the issues of integrating GPS data within existing digital mapping and GIS systems.

9.1 Horizontal Datums and Coordinate Systems

It is assumed here that the reader is familiar with the concepts and practical application of geodetic datums (e.g. WGS84, NAD83, NAD27, etc.) as well as coordinate systems / map projections (e.g. Latitude/Longitude, UTM, etc.). More information on basic geodesy concepts are referenced in *Appendix B*.

Positions derived from autonomous GPS are referenced to the WGS84 datum. This datum is defined by the GPS control segment tracking stations around the world which are used to create the broadcast ephemeris messages describing satellite positions. These satellite positions are used, along with 4 or more pseudorange observations, to compute the user's position, and therefore this Rover position is also inherently referenced to the WGS84 datum. WAAS positioning is also referenced to the same WGS84 datum.

The current standard datum for mapping and geodetic use in Canada is the North American Datum of 1983 (NAD83). This is the datum used by TRIM and other mapping products compiled in BC after approximately 1988. Coordinates for all survey monuments and BCACS Base Stations in BC are published and distributed on the NAD83 datum. In 1998, following a Canada-wide network re-adjustment and alignment, a new version of NAD83 was released and given the full identifier NAD83(CSRS). The initials CSRS refer to the Canadian Spatial Reference System which is a Canada-wide framework that is closely aligned to the highest-order international reference frame (ITRF: International Terrestrial Reference Frame). This 1998 datum re-alignment resulted in up to metre-level position shifts between the original NAD83 and NAD83(CSRS), but future network re-adjustments should now be very small (accounting for plate tectonics, local distortions, etc).

The NAD83(CSRS) datum is similar to the native GPS datum of WGS84, but it is not identical. In BC the differences are at the metre-level. Coordinates for all validated GPS Base Stations in BC are referenced to the NAD83(CSRS) datum, and by using a GPS Base Station for differential corrections, all computed Rover coordinates are then also on the NAD83(CSRS) datum. This applies to both real-time and post-mission DGPS.

Some older mapping products in BC are still referenced to the North American Datum of 1927 (NAD27). Great care must be taken in transforming GPS-derived NAD83(CSRS) coordinates to NAD27 to fit existing mapping bases. These conversions are not trivial, although most commercial software packages make little mention of the issues involved.

Most commercial GPS and geographic calculation software apply datum transformation methods which are only approximate, and are appropriate in only specific regions. These approximate methods are usually based on 3 or 7 parameter mathematical transformations. Errors of over 10 metres are common if these transformation methods are used in BC, and this is clearly not acceptable.

In BC the only acceptable method for transforming between the NAD83(CSRS) and NAD27 datums is the Canadian model known as the National Transformation (NT). The latest version of this transformation software should be used (currently NTv2). This method provides transformation accuracies of better than 1m throughout BC. This software is available from CRGB as well as from GSD of NRCan (see *Appendix B*). This transformation has been implemented in some commercial GIS and mapping packages, however, users should ensure that the latest version of NT transformation is being applied.

Another datum which will be introduced here is the concept of a local map datum. There are many existing maps that are not referenced to either of the two North American datums. This may be because the original mapping was poorly controlled, or not controlled at all (some maps were produced for a local area and were not tied to independent survey control). Also, some maps in BC, especially forest inventories maps, may have been incorrectly transformed and are not properly referenced to either NAD27 or NAD83(CSRS). The preferred solution is to rigorously convert all mapping bases to accurate NAD83(CSRS) coordinates (e.g. the Ministry of Forests has now substantially completed this task for the forest cover maps).

One practical way of transforming GPS surveys to a local map datum is to perform a simple linear shift. By making suitable map ties during the GPS survey, the discrepancies between the local map coordinates and accurate NAD83(CSRS) can be resolved (see *Section D-5.3*). The differences in Northing and Easting at the map tie points can be computed and averaged if they are in reasonable agreement (of course this will not work if the original map datum was not aligned to North). The entire data set can then be shifted by these average amounts. This method can be effective and relatively accurate within a local area, but should be used only after carefully quantifying and analyzing the possible errors, and after discussions with all appropriate data users and owners.

Additionally, there may be apparent errors due to the scale of the original mapping (e.g. difficulty in seeing a feature on high altitude aerial photographs). An example is a cut block boundary that appears to cross a creek on the original map, when it actually was established with a 15-metre buffer away from the creek. The problem may be in the original mapping of the creek, or it may be that the creek has changed course since the map was compiled. Regardless, the problem must be resolved to make the map base consistent. This may involve additional map ties to determine if the entire map has coordinate biases, or it may require a re-survey of the creek to define its new location.

Some Agencies are transforming their mapping base on an ad-hoc basis, as GPS information comes in. This creates a more accurate map base, and considered a local map base which can not be easily shared with other Agencies that continue to use the original source mapping. For this reason it is important that NAD83(CSRS) coordinates always be submitted, regardless of the final datum the GPS-derived map is provided in. It is also important that the method and parameters of any transformations be submitted with the data for future use with more accurate mapping.

Coordinate systems and map projections used in GPS projects will vary depending on the project. Medium and large-scale (1:20,000 or larger) mapping in BC generally use Universal Transverse Mercator (UTM) map projection coordinates. Small-scale mapping covering large areas will often use a different map projection such as the Lambert conformal or Polyconic projections. Other projects, particularly if GPS is used as a basis for navigation, will utilize geographic coordinates (latitude and longitude). GPS satellite positions and receiver positions are internally computed using a 3D Cartesian coordinate system with its origin at the centre of the earth. Unlike transforming between datums, commercial GPS and GIS software can be used to perform conversions between Cartesian, geographic, and map projection coordinates without any loss of accuracy. The difference is that this operation is a purely mathematically coordinate conversion, whereas datum transformations involve modelling of local distortions that can not be simply or completely defined mathematically.

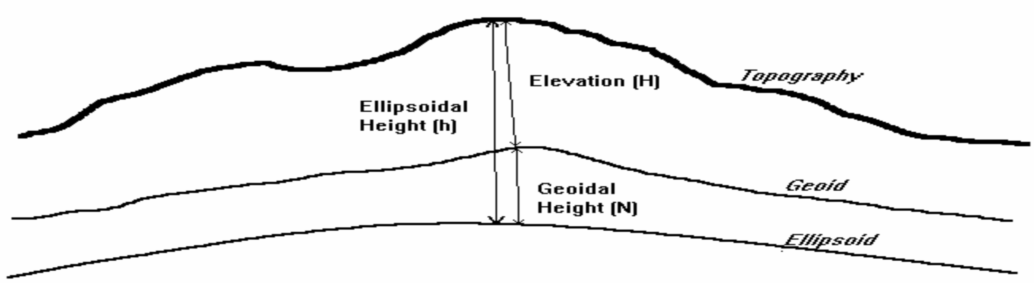
The UTM projection is defined with standard parameters world-wide, and is probably the most widely used map projection in the world. UTM is defined in zones which are six-degrees of longitude wide (3 degrees either side of the central meridian). British Columbia is covered by UTM zones numbered 8, 9, 10 and 11, with central meridians at 135, 129, 123, and 117 degrees respectively. Care must be taken with UTM calculations at the zone boundaries (meridians 132, 126, and 120 degrees in BC). Some conversion programs will automatically switch UTM zones based on the longitude of each point. In this case, a polygon straddling the UTM boundary will have coordinates in 2 different zones, and the mapped polygon shape will not appear correctly (the Easting values will be different by hundreds of km in the different zones). When a project is near or crosses a UTM zone boundary, a decision should be made to *force* all coordinates to be computed in only one zone. This method of forcing coordinate calculations is valid for up to ~1/2 degree outside of the zone boundary (about 50 km). However, there are existing maps with neatlines at a UTM zone boundary will not match at the edges. These situations must be resolved before GPS coordinates can be imported. It is assumed that Agencies working in these areas have resolved the zone boundary problems operationally. The forcing of coordinate calculations does not reduce positional accuracy, and the GIS system can convert these to a different UTM zone if required with no loss of accuracy.

9.2 Vertical Datum and Height References

Just as there are different horizontal datums, there are also different vertical datums in use throughout the world. The current vertical datum used in BC is the Canadian Vertical Datum of 1928 (CVD28). Work is being done on a new vertical datum, and this is expected to become available ~2010.

There are other issues to consider for GPS-derived elevations. GPS calculations are based purely on mathematical ellipsoidal heights, while most users and maps use orthometric heights which have a different vertical reference surface called the Geoid. The Geoid is a geophysical equipotential surface (a surface with equal gravitational attraction) equivalent to Mean Sea Level (MSL). The Geoid is a complex surface due to the earth's variable topography and density. The separation between the ellipsoid and the Geoid must be known in order to use GPS to derive orthometric elevations. This separation is known as the Geoid height or the Geoidal undulation, and can be computed from various Geoid models.

Many resource GPS surveys require only horizontal (planimetric) positions, and elevations are ignored. However, there are reasons why elevations may be important for some surveys, and almost exclusively, these elevations are required to be orthometric (i.e. above MSL). Similar to horizontal datum transformations, many commercial software packages provide a method for computing orthometric elevations from GPS ellipsoidal elevations. Be aware, however, that the Geoid models used for this derivation may be from a coarse global model that is locally inaccurate in BC. Users should also keep in mind that GPS-derived elevations are usually 1.5 to 2 times less accurate than horizontal coordinates, even before the conversion from ellipsoidal to orthometric referencing.



$$\mathbf{h = H + N}$$

Figure D-3 Relationship between Ellipsoid and Orthometric Height

The accepted method of computing orthometric elevations from GPS measurements is to use the latest Canadian national Geoid model produced by GSD of NRCan. The current Geoid model is called CGG2000 (released in the year 2000), and this is the basis for a height transformation model called HT2_0 that is used to relate GPS-derived ellipsoidal elevations to CVD28 orthometric elevations. Both the pure CGG2000 Geoid model and the HT2_0 height transformation are available from GSD NRCan (see *Appendix B* for contact information). It is expected that a new height transformation (and a new vertical datum) will be released ~2010.

9.3 GIS and Map Integration

The details of integrating GPS data within digital maps or GIS software is beyond the scope of this document.

Both the software products and the individual Agency requirements vary greatly. Only a brief discussion is provided below.

The appropriate archival, presentation and data exchange formats used in CAD and GIS systems will depend on the system used by the contracting Agency, thus specific formats can not be imposed by the GPS Specifications. DXF is an exchange format common to many systems; however, users should be aware of DXF shortcomings including an inefficient storage format resulting in large file storage and transfer requirements, and limitations with respect to transferring attributes.

One potential solution to this problem is the *Spatial Archive and Interchange Format* (SAIF) developed by CRGB, which is a data-modeling paradigm with a published coding specification. This gives it flexibility to handle different kinds of data yet the specification ensures that the resulting data format is rigorous enough to remain constant across Agencies and projects. Further to this format, a software tool has been developed by SAFE Software Inc. called the Feature Manipulation Engine (FME™). The FME is a powerful, easy to use, configurable spatial data translator that can move the data quickly between varieties of systems. The FME can also be used to perform a variety of geometric and attribute operations while it translates - operations that may be awkward and costly to perform using other software.

10. DELIVERABLES and DATA MANAGEMENT

GPS projects can generate enormous amounts of data, and managing this data is essential to its future usefulness. Some data will be transmitted as part of the normal returns from a GPS project. Some other data may not be delivered, but must be archived until it is no longer required (which can be seven years or more). The many temporary and derived files from a typical GPS project need not be archived or submitted.

This section describes the deliverables from a GPS contract in terms of file format, and media. It also describes requirements for managing and archiving data. Some Agency personnel, especially at the local level (i.e. District/Regional offices), may have other specific requirements. In any event, these guidelines should be followed as closely as possible.

10.1 Project Report

The Contractor should 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 and ID# (if available).
- 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.).
- A key map showing the project area and a description of any GPS Base Stations used.
- A description of the GPS Base Stations used.

- If using a temporary GPS Base Station the issue of validating the GPS Base Station will also has to be resolved (i.e. GPS Base Station validation).

- 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 and particulars (i.e. models, receivers numbers, data loggers, antennas, firmware versions, etc.);
  - GPS software and particulars (i.e. name, version number, key 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).

10.2 Hard Copy Plans

The Agency may require a final hard copy map in a specific format. The media, scale, datum, surround, etc. must conform to Agency cartographic standards as specified and attached to the contract. Different standards may apply according to each Branch, Region, or District preferences or existing Agency guidelines.

The following submission is provided as a suggested minimum:

- Map Surround which includes the key project information: project title; project number/identifier
- Contracting Agency name; Contractor name; and date of survey.
- Plan datum (e.g. NAD83(CSRS)) and, if relevant, the map projection (e.g. UTM).
- Plan scale (e.g. 1:20,000) with BCGS map identifier.
- Plan orientation, (e.g. North arrow annotating True North and Magnetic North).
- Geographic (e.g. latitude/longitude) and/or map projection (e.g. UTM) graticules as requested.
- Source of any non-project information (i.e. TRIM backdrop, Forest Cover data, etc.).

Coordinates and observed data reported ***must*** indicate the accuracy of the survey using appropriate significant figures and the association of accuracy estimates alongside the data or in the surround.

10.3 GPS Data and Processing Deliverables

It is essential that all raw GPS data be kept for archive and Quality Assurance (QA) purposes. This includes all data from each GPS Base Station and each field receiver used on the project. The data should be archived in the format originally downloaded from the field receiver and from the GPS Base Station operator - in other words, the most original form of the data possible. Raw GPS data may be in the manufacturer's proprietary format or in RINEX format.

GPS Base Station data is often supplied in one-hour blocks. If possible, merged files should be submitted giving continuous coverage of each field file or session.

Data from the field receivers usually have GIS feature and attribute information (see *Section D-7.1*). This information is not supported by the current RINEX format, and therefore it is preferable to store field data in the manufacturer's proprietary format.

An important submission in digital and hard copy formats is the original corrected GPS data. The original corrected GPS data is the file from the original DGPS processing (or directly from RT-DGPS), before any averaging, generalizing, or editing is done. It must be the same as if a third party corrected the raw data from the GPS Base Station and field files submitted. The original corrected GPS data must be delivered for Quality Assurance (QA) procedures (see *Section D-11*).

The final interpreted information is averaged, generalized, and edited from the original corrected GPS data to create the final map or database. This will be compared to the original corrected GPS data using QA procedures.

10.4 Data Ownership

All data files and other items submitted in *Sections D-10* are the property of the Agency and access to them by the Contract Manager or their designate must be made available upon request. All the documents submitted to the provincial government will be subject to the disclosure provisions of *The Freedom of Information and Protection of Privacy Act*.

10.5 Data Management and Archiving

Data from GPS projects are often used for a variety of functions within the Agency, or among other Agencies, and the original data may be required for Quality Assurance (QA). GPS projects can generate an enormous amount of data and it is essential for the Contract Manager to archive and manage this reliably and efficiently. Each Agency office must establish a system for managing and archiving the data.

Certain materials must be archived so that a GPS survey can be re-evaluated if any questions arise as to boundaries, positions, etc. For example, this is especially important in the case of a cut-block layout traverse, where the block may not be harvested for five or more years and the license not retired for a few more years. If there is a boundary dispute, one of the first questions asked will be if the original GPS traverse was accurate and interpreted correctly. Without the original data (i.e. raw GPS Base Station and Rover files), it is difficult to assess the original GPS traverse. It is recommended that the Agency archive all GPS data since they will likely have more secure facilities and efficient recovery procedures than the individual GPS operators.

RINEX (Receiver INdependent EXchange) is a structured format to allow exchange of raw GPS data (pseudoranges, carrier phase measurements, ephemeris data, etc) from different manufactures. However, some field receivers do not store raw GPS observation data, and instead store only the derived positions. Rover files from these receivers can not be converted to RINEX format. Also, the RINEX format does not support feature and attribute records and other essential data structures for a GIS-capable GPS receiver. For these reasons, it is preferable to archive the field observation files in the manufacturer's original format. If the data is to be re-evaluated, the manufacturer's software can be used or they can be converted to another format at that time. If the Rover files support creation of RINEX format files, and this is chosen as the archive format, then a copy of the RINEX conversion software should also be archived along with the data. This will ensure that the project can be re-constructing following the original processing steps.

GPS Base Station files typically are supplied in one hour blocks. All hours used to correct the field survey must be archived - either in the original hour blocks, or merged into a single file for each day. Base Station data can be archived in the original supplied format, or in RINEX format.

Raw field data should be archived in the manufacturer's original format, regardless of whether or not RINEX files can be created. The most important reason is to ensure that these are the files directly downloaded from the receiver or datalogger, and have not been edited in any way. Some receiver manufacturers, on downloading the data files, re-format them for use by the software program - in at least one important case, these files can be easily edited using tools supplied by the manufacturer. The file that should be archived is the original file stored on the downloading computer before any changes of format. This will be different for each manufacturer.

10.6 Digital Media

The GPS archive data should be stored on stable media (e.g. CD / DVD). The Agency office should institute a file management system so that data can be retrieved efficiently. The system should be structured to accept vital project information such as: project name, contracting agency, Contractor, map reference, file names, formats, significant dates, physical storage location, etc.

The Agency representative in the branch, region, or district office contracting the GPS services will specify the transmission medium according to their needs and the Contractor's capabilities. The Agency representative is responsible for transferring the data to archive-quality media (e.g. for Internet submissions) if necessary.

11. QUALITY ASSURANCE and AUDIT

Quality Control and Quality Assurance procedures are essential to performing reliable GPS surveys by GPS operators, and to managing them by Agency personnel. For the purposes of this document, Quality Control (QC) is defined as the procedures undertaken by the GPS operator (i.e. Contractor or Agency personnel) during the GPS project to ensure that a the final product is correct, complete, and accurate. Quality Assurance (QA) is the procedures undertaken by a Contract Administrator, or other personnel with responsibility for accepting the products of a GPS project, to ensure the final product is correct, complete, and accurate and that it is properly integrated into corporate mapping and attribute databases.

Detailed QA and Audit procedures are Agency specific activities and beyond the scope of these Guidelines, and will require training for all Agency personnel administering contracts and auditing them. However, the information presented below will provide a basis for some QA procedures and assist in the QA and auditing phase of a GPS contract.

Detailed QA procedures must be developed by the Contracting Agencies if field and mapping personnel are to have confidence in GPS surveys. This is especially relevant for provincial government agencies. *Section D-10 (Deliverables and Data Management)* discusses standard formats to ensure all returns from GPS contracts and in-house surveys are consistent and complete. *Section D-11.2* below discusses some potential procedures and methodologies for assessing the correctness and accuracy of the GPS data. These discussions are not comprehensive by any means, but serve to inform the reader what is involved in implementing quality control procedures.

It is recommended that all Agencies (particularly the larger provincial government Ministries) develop and implement some comprehensive and practical procedures for QA of GPS data. As suggested below, they need not be overly technical and would require minimal training of existing personnel. For larger projects, some data would be subject to more rigorous QA, and qualified independent consultants or Agency personnel (or some combination of the two) would likely do this.

11.1 Acceptance of Returns

It is important that returns from contracts be managed and archived efficiently. In many cases this will be done by Mapping Technicians (with the guidance of appropriate resource professionals in the organization). The form of the returns is explained in *Section D-10.* Below are some procedures that should be followed to help ensure the returns are complete and appropriate to the project, and are integrated and archived appropriately.

Suggested Procedures for Managing Returns

- Verify completeness of returns.
  - verify all files, reports, field notes, etc. are submitted
- Verify Agency qualification status of GPS Contractor.
- Create project directory on computer workstation.
- Upload digital files and verify file formats, naming conventions, etc.
- Review project report.
  - verify data capture parameters (i.e. elevation, DOP, SNR masks, etc.).
  - note any anomalies for review.
- Integrate submitted CAD/GIS files into mapping database.
- Review CAD/GIS files.
  - verify position and general configuration of GPS survey.
  - verify appropriate attribute information is integrated.
- Review submitted hardcopy maps for completeness and presentation.
- Archive digital files and hardcopy as appropriate.

11.2 Quality Assurance & Accuracy Requirements

Quality Assurance (QA) is the process of assuring the data accepted from a GPS operator and integrated into corporate mapping databases are complete, correct, and meet the accuracy requirements. Without QA processes in place, it is difficult to have confidence in GPS datasets, and entire mapping programs can be questioned. In the best case, the users will perform some quality assurance checks of their own (incurring additional expense) - in the worst case entire mapping programs may be re-done.

An essential component of any QA program is to define the target standards the data must meet. In this instance accuracy targets are given and the data are expected to be submitted in standard formats, datums, media, and so on. Referring to the *Specifications, Sections C-5.7* the statements of target accuracy are repeated below, and discussion follows:

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. If statistical methods are used to reject outliers, 2 sigma* ***should*** *be used for the minimum level of significance.*

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.

Currently in BC most GPS traverses are done in the dynamic linear mode, as discussed in *Section D-7 (GPS Field Data Collection Methods*). The individual fixes from this survey are usually edited to smooth and generalize the line (described in *Section D-8, GPS Data Processing and Interpretation*). By overlaying the final, best-fit line on the GPS position fixes, an assessment of the data quality and the interpretation can be made. Under noisy GPS conditions, some points may be in error by tens of metres.

This assessment can be done, as is usually the case, visually. This visual quality control will usually be done by overlaying the two files on a computer screen, since to plot the files out at a suitable scale over an entire traverse would be wasteful of material and of time (1cm represents 10m at 1: 1000 scale). There are different methods by which this can be done visually on a computer screen including moving around a scale bar representing the target accuracy (e.g. 10m); or creating parallel offsets of the final line. The Mapping Technician can pan around the project and visually inspect the noise level of the GPS data, and the interpretation creating the smoothed lines.

It is possible to develop an automatic method of checking for deviations in GPS traverse data. A program could be written to compute perpendicular offsets from all GPS position fixes to the final line. Another approach would be to build a buffer, equal to the target accuracy, around a traverse line and use GIS point-in-polygon overlay functions to test the data. If an Agency is dealing with many traverses submitted in a short time, it might be more efficient to develop programs and macros to perform these tasks.

Another problem with interpreted GPS data is that the Mapping Technician may have interpreted certain features incorrectly. This can be the case if the Field Operator makes map ties or ties to cruise strips which are not directly on the boundary. In this case the Mapping Technician may mistakenly connect the interpreted boundary to the off-boundary feature. The potential for this error is minimized with careful field notes and naming of features. By visually inspecting the final map and the GPS position fixes, an experienced Project Manager or contract administrator should recognize these errors.

As with linear features, quality assurance of point features is usually done visually. However, automatic methods can be easily developed as well, as long as the position fixes comprising the point feature can be identified (by time or attribute).

There are standard statistical methods for editing aggregated positions. The average coordinate is computed, as well as the standard deviation of the individual position fixes. The individual fixes are examined and if any are more than two standard deviations (2 sigma) away from the mean, it is rejected and the average and standard deviation re-computed. This procedure is followed until no outliers remain. The operator may choose levels greater than 2 sigma, but not less.

It should be noted here that a low standard deviation, or apparent spread of aggregated position fixes, does not always guarantee accurate point features. Local site multipath is usually the largest error source in resource GPS surveys. Multipath on the C/A code can average out over 5-10 minutes; however, over a short time period multipath can display a systematic effect. That is, the individual position fixes may seem to have a low spread (low standard deviation), but they may have significant actual error. Multipath effects on a dynamic traverse tend to be more random. Note that high end GPS receivers with narrow-correlator tracking are much better at rejecting multipath than low end receivers, and during times when they are affected, they tend to display a particular fix trend pattern that serves as an indicator that multipath is present. This pattern is specific to each GPS system, and demands careful attention from the Data Processor (experience is important). Note also that static point features are much more susceptible to multipath when the SNR mask is reduced to let in weak GPS measurements.

11.3 Quality Assurance

Audits and quality checks of the work of GPS contractors are perhaps the most important part of Quality Assurance (QA) procedures. There are different levels of audits possible, and their frequency will depend on factors such as the workload of Agency staff, availability of independent outside consultants, number of active GPS contracts, etc. This document breaks the Audit procedures into three classes: i) Quality Check Audit; ii) Detailed Audit, and iii) Complete Audit.

At present, most contracts with a GPS component are for cut-block traversing (pre or post-harvest), where there will likely be many individual traverses in one contract. For contracts such as these, individual GPS traverses from the larger project can be identified for audit. In other circumstances (e.g. a large road network survey), representative portions of the project can be identified for audit. For smaller contracts, a proportion of all contracts submitted should be chosen. Individual offices may choose to audit a contractor without a local performance record more frequently.

The proportion of the surveys to be audited will, as stated above, depend on the resources available. For example, reasonable starting proportions might be 15%, 4%, and 1% for Quality Check Audits, Detailed Audits, and Complete Audits, respectively. The GPS Contractor can be advised that their work will be audited, but of course the Contracting Agency retains the right to audit any work submitted by any Contractor. The GPS Contractor should not, of course, be made aware of the specific individual traverses or portions to be subjected to audit. These should be selected by a fair process which is as random as possible (following standard sampling procedures) while still being broadly representative of the project (i.e. traverse type, forest cover, etc.).

11.3.1 Quality Check Audit

The purpose of a Quality Check Audit is to verify that all materials have been submitted, to verify the Contractor has used correct field parameters and has met the accuracy specifications, and to review the mapping interpretation and any datum issues. This check is designed so that mapping technicians and others with limited GPS background can perform it reliably. This would be applied to a relatively large portion of the GPS contracts and involve reading the project report, check the field notes and digital returns, and visual and/or quantitative QA procedures as outlined in the section on quality assurance and quality control. It is basically a thorough check of the contract returns and compliance checks on the data capture parameters. No GPS processing software is necessary.

Agency staff could easily do this task after limited training, and following the Quality Check Audit procedures below. The time required would obviously depend on the amount of information, but for a single, typical cut-block traverse should take 30-60 minutes. Much of this is overhead such as loading and converting digital files and so on. For projects where a Contractor will submit many individual traverses as part of a contract, much of this overhead is spread out and thorough checks could easily be done in less than 30 minutes per traverse. With automated QA routines, this would be further reduced.

Automatic QA routines could provide accuracy checks by comparing individual position fixes with the final interpreted lines or averaged points. It would also be able to verify some data collection parameters such as maximum distance between position fixes, number of position fixes per point feature, etc.

The procedures below give the details of a Quality Check Audit. Portions of these procedures (without the more detailed reviews of the files) should be performed on all GPS data submitted. These procedures are outlined above under contract management.

Quality Check Audit Procedures

- Assemble all materials.
- Create check directory on computer workstation.
- Load digital files to check directory; convert format if necessary.
- Review project report.
  - generally note dates of milestones (i.e. field survey, post processing, mapping).
  - generally note equipment, personnel, etc.
  - specifically note data capture parameters (i.e. elevation, DOP, and SNR masks, data collection duration, etc.).
  - note any anomalies.
- Review field notes.
  - note any anomalies that may not have been caught in mapping.
  - generally note established reference markers, map ties, etc.
- Review digital files visually.
  - overall view looking for large blunders.
  - verify accuracy standards for point and line features.
  - verify spacing of reference markers, etc.
  - verify spacing or number of position fixes on line and point features.
  - verify offsets and supplemental traverses.
  - 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).

11.3.2 Detailed Audit

The Detailed Audit is designed to verify the quality of the Contractor's GPS survey by performing the same Quality Control checks that the contractor will, or should, have performed. It is basically an office re-processing of the Contractor's field data, with a thorough review of the data collection parameters and other Quality Assurance specifications.

Personnel, or consultants, who have much experience and understanding of GPS concepts and practical surveying and data processing, should do the Detailed Audit. People performing the audits should be independent of the Contractors in the area. The auditor must be familiar with the nature of the errors inherent in GPS surveys as practised in the resource industry (i.e. especially in the forest industry with under-canopy effects). The auditor should be very familiar with the manufacturer's data format and processing software, and should also be familiar with the type of resource survey involved (e.g. forestry layout, forestry road deactivation survey, etc.).

This procedure requires that post-processing software and appropriate CAD or GIS software is available, as well as analysis tools such as spreadsheets or statistical analysis programs. It is desirable that the software used has some Quality Control statistics available. However, since RINEX conversion does not transfer GIS-style data structures, the receiver manufacturer's proprietary software may have to be used.

Many of the procedures of a Detailed Audit will follow the Quick Check Audit procedures detailed above. To verify the data collection parameters, the auditor should examine the raw data files or other information files produced by the receiver. The processing should be done according to procedures described in *Section D-8 GPS Data Processing and Interpretation*. For the processing, the same GPS Base Station as used by the Contractor should be used to avoid confusion caused by GPS Base Station errors. However, the auditor may also process the data using an alternate GPS Base Station to check for multipath, improper coordinates, and other possible GPS Base Station errors.

A Detailed Audit will take between 2 and 4 hours to do for a single traverse (e.g. typical interior cut-block traverse). If significant problems are noticed, a longer time should be expected, and discussions initiated with the Agency Contract Administrator and the GPS Contractor involved.

11.3.3 Complete Audit

A Complete Audit is an entire re-survey of the Contractor's work. This should be done on a very small proportion of GPS surveys due to the cost involved. However, Complete Audits are valuable not only as a Quality Control measure, but as a relevant repeatability test, as opposed to having the Contractor repeat a portion of each survey. Another advantage of Complete Audits is that they will provide easy to understand accuracy comparisons by repeatability. These statistics can be used to demonstrate the accuracy (or inappropriate application to some cases) of GPS to the courts, appeal boards, and other non-technical personnel and agencies.

As with the Detailed Audit, the Complete Audit must be performed by qualified personnel or independent consultants. If there is a discrepancy between the auditor's survey and the Contractor's, the Ministry must have confidence in the auditor's survey. Preferably these audits would be done using superior equipment, software, and methodology to the Contractor's production survey. However, not all receivers are appropriate to resource GPS surveys (e.g. geodetic-level receivers, for example, will not yield good results under forest canopy), and many Contractors use state-of-the art equipment and methods themselves. Surveys for audit, then, must use the best equipment possible that is appropriate to the task and the processing subject to rigorous Quality Control procedures - at least to the level of a Detailed Audit.

11.3.4 Other Audit Procedures

There is also the possibility to implement other audit procedures that would utilize other survey methods for field checks. The advantage of these procedures is that Agencies can use existing personnel, equipment, and other products if they do not have sufficient GPS equipment and experience, rather than going to an outside source.

Field audits could also be performed using conventional equipment such as chain and compass surveys. However, over more than about 1000 linear metres, GPS techniques are likely to be more accurate than most conventional methods. Naturally, the field traverse personnel should be very careful in their methods (i.e. careful tight chaining, forward and backward bearings, etc.).

Another form of a field audit would be to re-survey only certain portions of a traverse or certain reference markers. This could be done with GPS technology - including, perhaps geodetic receivers in some instances. It could also be done using high accuracy conventional means such as theodolites and distance meters or laser range finders. This is perhaps more applicable to open areas (e.g. for example in post-harvest cut blocks).

The GPS survey in some cases could be compared to information from remote sensing and photogrammetric techniques. The increased use and availability of digital orthophoto products is well suited for this. Use of these products would provide area and boundary comparisons, and a check on the datum accuracy of both the GPS survey and of the original mapping base.

Comparisons using these other audit procedures must consider the varying accuracy and error propagation characteristics of the methods. If a GPS survey is more than, say, 1% out in area from a conventional compass and chain survey, that does not mean that one is wrong and the other is right. The conventional techniques would not usually provide any geo-referencing (i.e. coordinate) information, but may provide good relative comparisons (especially for area surveys).

A Detailed Audit (above) could be performed in conjunction with these other audit procedures. Qualified personnel or consultants (or teams) who understand the errors inherent in each type of surveying or remote sensing method should do analysis of the results of these checks.

SECTION E - AUTONOMOUS (UNCORRECTED) GPS GUIDELINES

SECTION E – AUTONOMOUS (UNCORRECTED) GPS GUIDELINES

1. INTRODUCTION

The removal of Selective Availability (SA) on May 2nd, 2000 was a significant event for GPS users. Autonomous (uncorrected) horizontal accuracies improved overnight by an order of magnitude from approximately 100m to 10m (95%). Vertical accuracies improved in a similar manner from approximately 150m to 15m (95%). High-End mapping and survey-grade GPS receivers tend to produce the best accuracies in autonomous mode, however, even the least expensive recreational receivers appear to produce reasonable accuracies (see *Section E-2* below).

These new accuracy levels are tempting for projects with lower positioning accuracy targets (e.g. 20m, 50m @ 95%). This could include projects with final map scales of 1:20,000 or smaller. Savings can be realized by replacing GPS equipment costing many thousands of dollars with simple handheld receivers costing a few hundred dollars. Additional savings in time and money result from eliminating differential GPS (reduced field equipment and/or no post processing). ***However, there are risks inherent in autonomous (uncorrected) GPS positioning that must be understood before choosing this methodology***. This *Section E* was added to the Standards with release 3.0 (March, 2001) to improve understanding of both the *potential* and the *risks* of using Autonomous (uncorrected) GPS.

Update with version 4.0 (2008): there have been incremental improvements in both the GPS system itself (better clocks and broadcast orbits), and in the positioning algorithms within some GPS receivers since this *Section E* was initially written in 2001. This has resulted in marginal improvements in SPS autonomous accuracies. Most of the agencies currently monitoring GPS performance use dual-frequency geodetic equipment with large choke-ring antennas, and this is not representative of the achievable performance of consumer recreational receivers. The values shown below may now be marginally pessimistic, but the same considerations described below apply today. Also, since 2001 there have been several events triggered by satellite failures which caused **gross** positioning errors (**tens of km**) for autonomous receivers, and these events lasted for hours before the offending satellite was shut-off. Differential GPS users were not affected during these periods *(this is a clear demonstration of the low positioning integrity of autonomous GPS).*

2. AUTONOMOUS ACCURACY PERFORMANCE

The accuracy performance of autonomous GPS has been widely monitored since the removal of SA. This monitoring has been reported by agencies and individuals from all around the world, and much of this information is available via the Internet. Within BC, detailed monitoring has been done by CRGB and others. The knowledge from these sources has contributed to the results presented in this Section. It is expected that most potential users of autonomous positioning will be using inexpensive recreational receivers, and this is described in the *Section 2.1* below. *Section 2.2* summarizes the accuracy performance of High-End survey and mapping receivers. *Section 2.3* compares these two receiver classes and lists some of the reasons for accuracy differences.

2.1 Recreational Receivers

The accuracy performance of low cost recreational handheld GPS receivers has been studied and reported since the removal of SA. Detailed information can be found at the following URLs:

http://www.erols.com/dlwilson/gps.htm
http://www.edu-observatory.org/gps/gps.html

Testing includes popular recreational receivers including Garmin, Magellan, Eagle, Lowrance and others (some testing was done with both internal and external antennas). Results are summarized in the paragraphs below, for more in-depth results see the websites.

The reported instantaneous horizontal position accuracies for recreational GPS receivers varied between 7m and 12m (95%). Corresponding vertical results ranged between 12m and ~20m (95%). Some vertical results indicate a bias on the order of ~10m that appears to affect elevations computed by particular receivers (e.g. Garmin 12xl, an older model no longer in production). These horizontal and vertical results were obtained under controlled conditions with a static antenna and clear observing conditions (free of obstructions). However, note that in testing done by Parallel Geo-Services with a recreational receiver, 2 short time periods showed errors over 150m, and another period of ~30 seconds showed errors over 67km horizontally and 12km vertically. Some recreational grade receivers will extrapolate positions using the velocity for up to 60 seconds if adequate GPS satellites tracking (i.e. 4 or more) become impossible due to forest canopy or other blockage. This results in the GPS track showing a straight line for 60 seconds, regardless of the true track being followed (i.e. dead-reckoning based on the last known position and velocity).

Some accuracy improvement was seen using the averaging feature found on many recreational receivers. The amount of improvement varied with different receivers, and with the averaging time used. Averaging may be useful in real-world tracking environments to help minimize transient effects causing position spikes.

Accuracy gets worse when the tracking environment is changed from open skies to under canopy, and this environment likely affects recreational receivers more than other receiver classes (see *Section 2.3* below). Reports from the US National Resources Research Institute at the University of Minnesota show a particular recreational receiver's horizontal accuracy degrading by a factor of almost 3 when comparing moderate canopy tracking to open tracking. These results were from 1 minute position averaging in 3D mode. It would be expected that the typically heavier canopy cover found in BC would cause even more degradation than the moderate canopy experienced in the Minnesota tests.

Overall, recreational GPS receivers can be expected to produce horizontal positions with an accuracy of approximately 10m (95%) under clear tracking conditions. Positioning under canopy will likely reduce this accuracy to ~30m (95%), or worse, depending on tracking conditions. Corresponding vertical results would be expected to be approximately ~15m (95%) in the open, and ~45m (95%), or worse, under canopy. All of these figures assume that the receiver is operating in 3D mode (see notes in the comparison *Section 2.3* below).

2.2 High-end Surveying and Mapping receivers

Autonomous GPS accuracy performance studies have also been done for High-End surveying and mapping receivers. A good source of information is the US National Geodetic Survey web site at:

http://www.ngs.noaa.gov/FGCS/info/sans_SA

This site contains comparisons of controlled single and dual frequency receiver results, with a number of different approaches to modelling propagation errors. The results from a normal configuration (single frequency, broadcast ephemeris and ionospheric model) show horizontal accuracy range between 5.5m and 8.2m (95%). Dual frequency receivers can directly determine the ionospheric delay, but add "noise" by introducing measurements on the second frequency (L2). The net impact on autonomous positioning is that dual frequency horizontal results are not substantially different from single frequency results, except when apparent disturbances on L2 can cause much larger errors.

Tests in BC during May 2000 and November/December, 2000 confirm the autonomous position accuracy of a High-End single-frequency receiver with NAD83(CSRS) horizontal comparisons of between 6m and 8m and vertical ellipsoidal elevation comparisons of between 9m and 12m (95%). Maximum errors seen in these tests (40,000 fixes) were 20m horizontal and 52m vertical. This testing was done under controlled observing conditions with minimal tracking obstructions and multipath conditions. These results would become worse under difficult tracking conditions (canopy), although it is likely that this degradation would not be as sharp as for recreational receivers because of the better tracking and positional control parameters available on High-End receivers (i.e. ability to filter positions based on SNR, PDOP/HDOP/VDOP settings, satellite elevations, etc.) as described in the following section.

2.3 Autonomous accuracy comparisons of Recreational and High-End GPS receivers

Table E-1: Expected autonomous accuracies (95%) of Recreational and High-End GPS receivers (open tracking conditions)

GPS receiver "class"	Horizontal accuracy (m)	Vertical accuracy (m)
Recreational	7 - 12	12 – 20
High-End	6 - 8	9 – 12

The factors that contribute to better performance of High-End receivers include:

- better antenna design (better gain pattern / increased sensitivity)
- better pseudorange resolution and multipath rejection (advanced signal processing)
- better modelling of propagation errors (height bias seen in some recreational receivers)
- user control of tracking SNR (allows rejecting weak / inaccurate pseudoranges)
- user control of satellite elevation angle (allows rejecting low elevation pseudoranges which are susceptible to large propagation errors)
- user control of DOPs (preventing weak geometric fixes)
- user control of positioning mode (preventing 2D positioning / extrapolation)

These factors contribute to the better overall accuracy as seen in the table above, and it is also expected that they are key in reducing the worst-case results. The user control parameters available on High-End receivers are likely the main reason that the maximum horizontal error seen was 20m, while the recreational receivers showed maximum errors of over 100m (and even as much as 67km).

3. AUTONOMOUS GPS RISKS

Autonomous positioning is the basic mode of working with GPS signals to derive the user's position. This mode relies on having high-quality broadcast ephemeris information in order to known the instantaneous satellite locations with high accuracy. It also relies on having extremely stable clocks on each satellite, as well as having predictable errors along the signal paths from the satellites to the user's receiver. If the broadcast ephemeris or an individual satellite clock experiences an undetected error, this will cause errors in the user's derived Autonomous (uncorrected) position. Similarly, major ionospheric disturbances can cause unpredictable distortions in the pseudorange measurements which will affect Autonomous (uncorrected) positioning as well.

The GPS control segment has established an excellent record in the daily operation of GPS, particularly since the system was declared fully operational in 1995. However, it must be recognized and understood that failures do occur within the complicated mechanical / electrical systems that make-up the full GPS system. This is evidenced by unplanned satellite outages that occur. The control segment has a stated goal of detecting and correcting system errors within 15 minutes of their occurrence. An autonomous GPS user may have grossly distorted positions during these periods, and these distortions may be unrecognized and undetectable. This is why autonomous positioning is labelled as having ***low positional integrity*.**

Differential GPS techniques were developed to improve the user's positional integrity by detecting and/or correcting anomalous errors, as well as to enhance overall accuracies. The basis for Local Area DGPS is that any errors observed at the Base Station are formed into corrections for the Rover to apply. It does not matter what caused or contributed to the observed errors, only the end result being the total error is important. During normal operations, differential GPS enhances accuracies by correcting the small residual errors as measured at the Base Station. During a period with system problems (anomalous satellite clock or ephemeris errors), differential GPS instantly detects these problems and prevents them from corrupting the Rover's positions.

An analogy can be made with a conventional survey traverse (measured bearings and distances). Autonomous GPS can be compared with an open traverse. The project's target accuracies may be met by the open traverse; however, this can not be stated with confidence unless the traverse is closed. Closing the traverse can then be compared to differential GPS. Traverse accuracies are improved by balancing the observations, but more importantly, the *integrity* of the traverse is improved by detecting any blunders through a closure check.

The lack of positional integrity with autonomous GPS means that it is not possible to confidently report error statistics with features positioned in this mode. This is also the reason that autonomous positioning can not be accepted as a valid methodology under the RISC Standards. This does not mean that there is no place for autonomous positioning. The following *Section 4* provides some suggestions for applications that may be appropriate for autonomous positioning.

4. SUGGESTED AUTONOMOUS GPS APPLICATIONS

Autonomous GPS positioning has clear and obvious application for navigation, safety, and production efficiency issues. This has been greatly improved since the removal of SA. These uses of autonomous positioning are not considered surveying or mapping applications as they are not based on recording feature positions and attributes for integration in a map or database. This section provides suggested survey and mapping applications that could be considered for autonomous positioning.

It is recognized that not every feature on a map or in a database needs high positional integrity. A position of a feature is required if it is to be used in a GIS, but the coordinates may be of low importance. An example may be wildlife trees near a transmission corridor. It may be desirable to know that a wildlife tree exists, and to understand its attributes (e.g. importance for different birds and animals), but the coordinates of the tree may not be considered *critically* important. This may be an appropriate decision if the end-use of the database is to generate general information such as the number of wildlife trees within the entire transmission line circuit (typically many kilometres in length). A small-scale map (e.g. 1:50,000) may be produced to show the distribution of each type of wildlife tree. If it is clear that these end-uses can accept the tree's positions as *non-critical*, then autonomous GPS positioning could be used. Of course a danger with this is the possibility that the database may be used for a different purpose some time in the future, and this new use may require that positions have higher accuracy and integrity. Continuing with the same example, utility companies are concerned with trees that can impact the transmission line if they fall (referred to as a hazard tree). This requires high relative accuracy of the spatial positioning of both the transmission line and the hazard tree. It would be incorrect to try to use the wildlife tree database (derived from autonomous positioning) to determine if individual wildlife trees were a potential hazard to the transmission line. GIS databases should include metadata describing the survey methodologies and associated accuracies. This is strongly recommended for <u>all</u> GPS methodologies used for GIS data collection. Unfortunately, this metadata may be ignored as there is a tendency to treat feature positions as ideal once they are in a database or map. In addition, whether the metadata is available or not, analyzing whether the accuracy (positional *or* attribute) of individual features in the database is suitable for any application is probably beyond the abilities of many end-users of the data. Therefore, when considering if the feature positions are *critical* or *non-critical*, it is important to not only think about the current use, but also of potential future uses of this database.

The examples used in the last paragraph are intended only to represent *critical* and *non-critical* positioning. There may be surveys of wildlife trees that have a *critical* positioning requirement and this survey would then not be appropriate for autonomous positioning (e.g. wildlife trees within or near a cut block border).

Once a decision has been made to consider the coordinates of a feature *non-critical*, there are a number of procedures that can be followed to help ensure the best accuracies from autonomous positioning. This may seem contradictory, but just because feature coordinates with low integrity can be accepted in the database, it does not exclude trying to get the best accuracies with a given methodology. The following suggestions are provided for recreational receivers operating in autonomous mode. Note that not all suggestions may apply to a particular project.

- Read the receiver manual, especially sections dealing with coordinate systems and datums. Check the important configuration settings daily. A check-list will be helpful for field crews.
- Pre-planning GPS surveys applies to autonomous positioning as well as differential GPS. Satellite predictions should be updated weekly.
- Setup procedures for recording GPS waypoints with links to manually recorded field notes. Test these procedures fully before doing production works. Also test the procedures for downloading waypoints from the receiver to a PC and linking with the field notes.
- Wherever possible, GPS observations should be made in the open to get the best accuracy from strong satellite signals. Offset measurements can be made from the GPS point to the feature being surveyed. Make sure that field crews are competent with offset measurements (compass observations, declination, horizontal distance measurements, etc). See *Section D-7.1.6* for more information on point feature offsets. If observations must be made under canopy, better tracking may result from the use of an external antenna.
- Check the satellite status / positioning mode screen to ensure that at least 4 satellites are being tracked with good signal strengths and the positioning mode is 3D. Be aware that most recreational receivers will

automatically revert to a 2D fix using 3 satellites (or worse), even if configured for 3D positioning. 2D fixes should be avoided as they can be grossly corrupted. Also note that some recreational receivers will continue to position along the previous vector (i.e. dead reckon) if an insufficient number of satellites are being tracked.

- Most receivers display a form of fix quality indicator (various terms used on different receivers) that may be used as an accuracy guide during field surveys. Different manufacturers compute these indicators in different ways with the aim of simplifying complex considerations into a single number. It is suggested to first read the appropriate sections in the receiver manual to understand what is being displayed, and then do field testing to see if the displayed quality indicator is a useful accuracy guide.
- For point data collection, averaging should be used if available. One minute of position averaging should be enough for most applications. The averaging screen should be watched, and if the coordinates are still changing significantly at the end of the averaging period it suggests that the tracking conditions are marginal. It may be better to move to a different spot and try again. If this continues to be a problem (i.e. all the locations are equally poor), then the only option may be to average for a longer period. Note any data collection and tracking irregularities in the field notes (e.g. jumping between 4 and 6 satellites; elevations fluctuating wildly; etc.).
- Additional information recorded in the field notes may help with later interpretation at the mapping stage such as; ‘50m South of tower #3-12’, or ‘on the North side of access road’, or ‘100m West of the last wildlife tree’, etc). If possible, reference autonomous GPS fixes using some independent means, for example, to features visible on maps or aerial photos, or previously located with more precise methods. This will help identify gross errors.

The above comments apply to positioning point features. Linear and area features are not as easy to capture with most recreational receivers as the sampling rate is often not user-controllable (or if it is, the finest resolution is still coarse), and storage is limited. This can result with a jagged definition of the feature. The dead reckoning of recreational receivers is also a major problem for linear feature capture. It is suggested to thoroughly test linear data capture if planning to use recreational receivers.

5. TRAINING MATERIALS

In the past years, CRGB has observed the need to provide freely available educational or training materials with different levels of GPS knowledge. In a response to this need, CRGB has created materials based on the popular RISC GPS Training materials.

5.1 Recreational GPS Navigation Training (1 – Day Course)

This course is for those interested in using GPS for recreational navigation purposes. The course is structured as a 1-day delivery using both classroom and outside hands-on practice for groups of up to ~10 people. An Adobe PDF version of presentation slides are provided with training (PowerPoint version may be requested for instructional purposes). Alternatively, the course can be self taught by downloading and viewing the slides from the 5-modules delivered:

1. Basic GPS concepts (classroom)
2. Introduction to Recreational GPS receivers (classroom & basic outside exercise)

3. GPS Applications and Methods (classroom)
4. Configuration and Operation of Recreational GPS receivers (classroom & advanced outside exercise)
5. Connecting to a PC and GPS Planning (classroom)

The recreational GPS navigation course does NOT provide an in-depth understanding of signal structure, measurement techniques, range errors and geodesy, DGPS data processing, interpretation, quality control, quality assurance, audits and data delivery formats. Please see the other RISC GPS courses for the in-depth program.

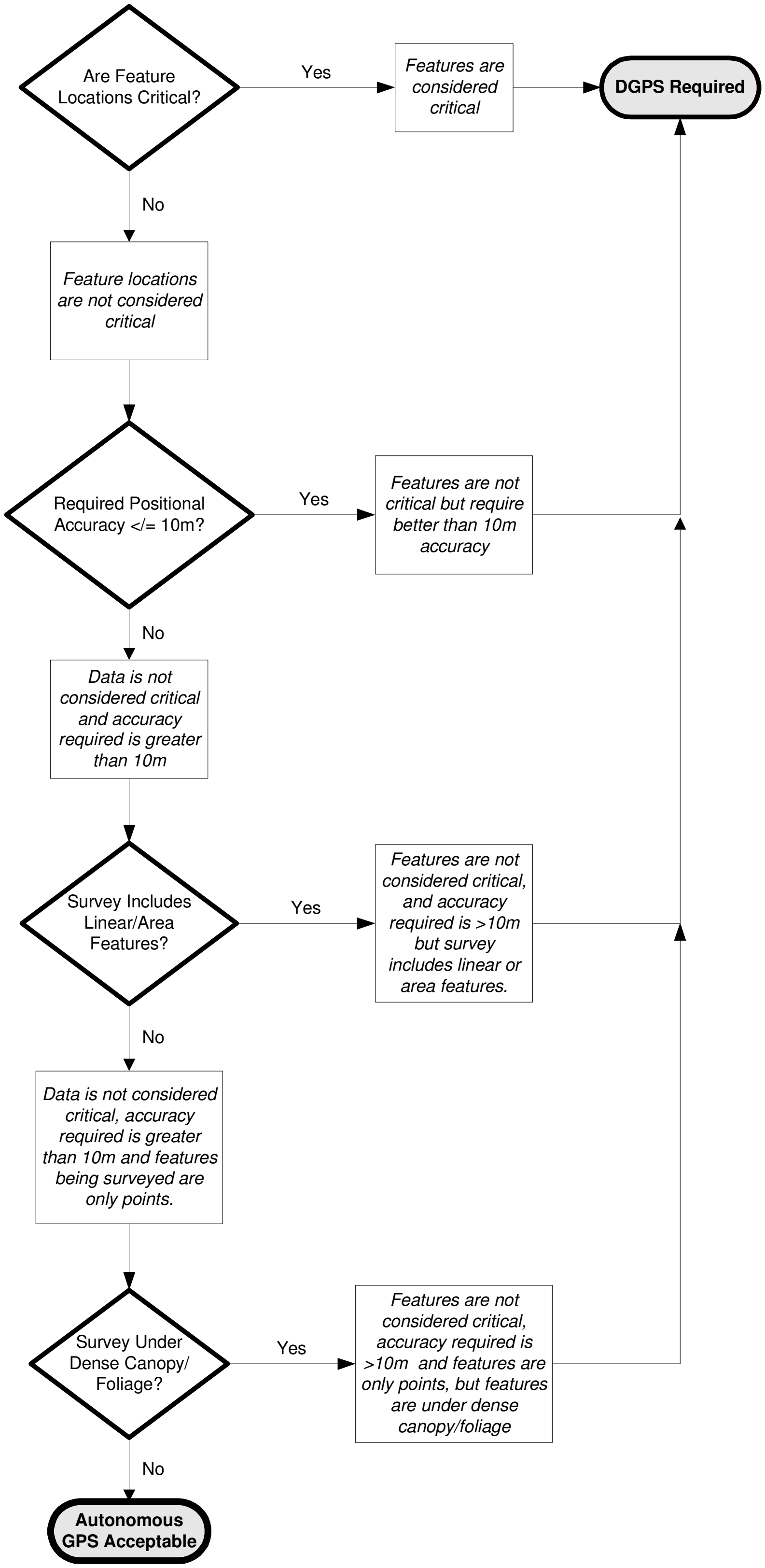


Figure E1 Decision Tree for GPS Selection

APPENDICES

APPENDIX B

REFERENCES

APPENDIX B - References

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RECOMMENDED INFORMATION SOURCES

Non-Technical Introductions:

Erickson, C. ***GPS Positioning Guide***. Geomatics Canada, Natural Resources Canada, Ottawa. 1993.
An excellent, non-technical introduction to GPS. Emphasis on Differential GPS techniques.

Smith, J.R. ***Basic Geodesy***. Landmark Enterprises, Rancho Cordova. 1988.
A very good introduction to the concepts of geodesy (including coordinate systems and datums), without the mathematical complexity behind those concepts.

Technical GPS and Geodesy:

Bomford, G. ***Geodesy.*** Oxford University Press, Oxford. 1980.

Hofmann-Wellenhof, B., Lichtenegger, H., and J. Collins. ***GPS Theory and Practice.*** Springer-Verlag, Wein. 1993.

Leick, A. ***GPS Satellite Surveying***. Second Edition Wiley, New York. 1995.

Kleusberg, Alfred and Peter J.G. Teunissen (editors). ***GPS for Geodesy (Lecture Notes in Earth Sciences).*** Springer, Berlin. 1996.

Wells, D.E., N. Beck, D. Delikaraoglou, A. Kleusberg, E.J. Krakiwsky, G. Lachapelle, R.B. Langley, M. Nakiboglou, K.P. Schwarz, J.M. Tranquilla, and P. Vanicek. ***Guide to GPS Positioning***. Canadian GPS Associates, Fredericton. 1987.

Seeber, Gunter. ***Satellite Geodesy*** Second edition, Walter de Gruyter GMBH, Berlin. 2003.

Snyder, John P. ***Map Projections - A Working Manual***. US Geological Survey, Washington. 1987.

Vanicek, P, and E.J. Krakiwsky. ***Geodesy, the Concepts***. North Holland Amsterdam. 1986.

Torge, W. ***Geodesy: An Introduction.*** deGruyter, Berlin. 1980.

Krakiwsky, E.J. ***Conformal Map Projections in Geodesy***. UNB Lecture Notes, University of New Brunswick, Fredericton. 1978.

Journals and Magazines:

GEO World
http://www.geoplace.com

GPS World
http://www.gpsworld.com

GPS Solutions
http://www.springer-ny.com

Inside GNSS
http://www.insidegnss.com

Navigation, Journal of the Institute of Navigation
http://www.ion.org

Internet Sites of Interest:

Base Mapping & Geomatic Services, Ministry of Agriculture and Lands
Maps, coordinates, BC ACS GPS Base Station data, geodetic utilities
http://ilmbwww.gov.bc.ca/CRGB

BC Municipal Active Control System Information
http://ilmbwww.gov.bc.ca/CRGB/gsr

National Geomagnetism Program, Natural Resources Canada
Online Geomagnetic Activity Reports
http://gsc.nrcan.gc.ca/geomag

Geodetic Survey Division, Natural Resources Canada
Online Geoid heights and NAD conversions
http://www.geod.nrcan.gc.ca

US Coast Guard Navigation Information Service
Official source of GPS information and NANU notices
http://www.navcen.uscg.gov

United States National Geodetic Survey, National Oceanic and Atmospheric Administration
GPS Antenna Calibration Results
http://www.ngs.noaa.gov/ANTCAL

University of New Brunswick, Fredericton,
Department of Geodesy and Geomatics Engineering
http://gge.unb.ca

University of Calgary, Calgary,
Department of Geomatics Engineering
http://www.geomatics.ucalgary.ca

Navtech Seminars and GPS Supply
All-round source of GPS equipment, software, texts, and seminars
http://www.navtechgps.com

APPENDIX C

SAMPLE CONTRACT SPECIFICATIONS

APPENDIX C
Sample Contract Specification
GPS Contract Requiring 10m Accuracy

The following sample Contract Specification has been directly taken from *Section C* of this document (i.e. *Specifications*). It has been completed (i.e. blanks filled out) using the information provided in *Section D - DGPS Guidelines* for a typical project requiring a horizontal accuracy of <10 metres at the 95% confidence level (i.e. Horizontal Network Accuracy class = 10 metres).

Some typical projects requiring this accuracy level are:

- Pre-harvest Boundary Traversing
- Post-harvest Boundary Traversing
- Forest Inventory Vegetation Sample Plot survey
- Environmental Contaminated Site Location

It must be noted that it may be difficult to obtain accuracies at the 1m or 2m level using GPS in typical British Columbia conditions (i.e. dense tree canopy; mountainous regions; etc.). Thus, when requiring accuracies at this level one should take into account the local conditions in which the GPS survey is taking place (i.e. open southern-interior pine, or dense coastal rain forest, etc.) and include in the Contract Specifications some safe-guards for acquiring the desired accuracy level (i.e. longer observation times, lower DOP masks, shorter GPS Base Station separations; etc.). Also, it is suggested to provide some mechanisms for ensuring the accuracy target has been achieved (i.e. independent occupations, better equipment, etc.).

Please note that the sample provided is only an example and probably does not reflect any actual project, nor actual values that would be used in the above noted project types.

SECTION C - SPECIFICATIONS

1. APPLICATION

These *Specifications* have been developed in response to a need for standardized Global Positioning System (GPS) data collection procedures for all GPS resource surveys in the province. In particular, the *Specifications* will facilitate standardization and quality control for land related information collected for government databases using GPS technologies. The *Specifications* are supported by two other sections in this document: the *Standards* and the *DGPS Guidelines*.

The *Standards* section outlines geo-spatial referencing categories in a standardized and uniform manner. Using the *Specifications* section, the project target accuracies can be specified based on the standardized categories established within the *Standards* section. As well, the *Standards* section establishes standards for GPS Base Station accuracies within the provincial geo-spatial reference framework.

The second supporting section is the *DGPS Guidelines*. The *DGPS Guidelines* section provides relevant background information in order to complete those areas of the *Specifications* that vary project by project. This *Specification* document, when completed using the *DGPS Guidelines*, will form the technical section of a GPS survey contract. Refer to *Section D-3.2* for a cross-reference table to assist the Contract Administrator in completing these *Specifications*. Also, see *Appendix C* for a sample *Specifications* document completed for a typical resource survey requiring 10m horizontal Network Accuracy.

This schedule is intended for use as an adjunct to all contracts for surveys undertaken in the Province of British Columbia using differential GPS techniques (DGPS), with accuracy requirements focused on the 1m to 10m horizontal accuracy classes (at 95% confidence) and the 5m to 20m vertical accuracy classes (at 95% confidence). These specifications can also be applied for the 20m and 50m horizontal classes and up to the 100m vertical accuracy class (at 95% confidence). The actual accuracies required for the project or application are to be entered under *Specification C-5.7.*

For higher accuracy requirements (millimetres to a few decimetres), refer to the document ***British Columbia Standards, Specifications and Guidelines for Control Surveys using Global Positioning System Technology*** as available from CRGB of the Ministry of Agriculture and Lands. Publications by other provincial and Federal agencies also describe procedures for using GPS for high accuracy surveys.

2. INTERPRETATION

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

Note that the term "GPS" can be exchanged with the generic term "GNSS" where appropriate. This is to allow use of systems that are more than just "pure" GPS (e.g. combined GPS / GLONASS / GALILEO systems). The period from 2007 onwards will see significant developments both within GPS, and with other GNSS, and these advancements can be applied during resource surveys where appropriate (of course following careful confirmation of new equipment / techniques / methods).

In this schedule, the following definitions and abbreviations are used:

Agency	Ministry, Department or other entity administering the Contract.
BCGS	British Columbia Grid System defining the map graticules within the province at various scales.
CRGB	Crown Registry and Geographic Base, Integrated Land Management Bureau, Ministry of Agriculture and Lands, Province of British Columbia.
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.
CVD28	Canadian Vertical Datum of 1928.
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 CRGB for the current provincial standard Geoid model.
GNSS	Global Navigation Satellite System (e.g. GPS, GLONASS, GALILEO, etc)
GPS	Global Positioning System as operated by the United States Department of Defence (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 Base 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 GPS Base Station.
NAD27	North American Datum of 1927 based on the Clarke 1866 ellipsoid.
NAD83 (CSRS)	North American Datum of 1983 (Canadian Spatial Reference System), based on the Geodetic Reference System 1980 (GRS80) ellipsoid and as defined by the GRS in British Columbia.
RISC	Resources Information Standards Committee
Static-mode	Multi-epoch collection of GPS data at a point while remaining stationary.
Supplemental Traverse	Supplemental Traverses are conventional traverses (e.g. compass and tape) that are integrated with GPS surveys.
UTM	Universal Transverse Mercator projection (map projection system).

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

highly recommended	Used to describe tasks that are deemed *highly* desirable and are good practice. Exceptions are possible, but only after careful consideration.
should	Used to describe tasks that are deemed desirable and good practice, but are left to the discretion of the Contracting Agency.

3. GOALS

3.1. 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.

3.2. To provide capability for integration of requirements across government agencies and to standardize those requirements where common standards are applicable.

4. PRE-QUALIFICATION AND VALIDATION

4.1. Total System - It is ***highly recommended*** that any Contractor proposing 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 Base Station receivers; and reporting techniques. All parts of the System are to be capable of meeting these contractual specifications.

4.2. Field Operator Training – It is ***highly recommended*** that Field Operator(s) be qualified through the RISC course: "Field Operator GPS Training for Resource Mapping".

4.3. Data Processor / Project Manager Training – It is ***highly recommended*** 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. It is ***highly recommended*** that they be qualified through the RISC course: "Comprehensive GPS Training for Resource Mapping".

4.4. It is ***highly recommended*** that all GPS Base Stations be validated according to the procedures outlined in *Section D-4.3* of the *DGPS Guidelines* document. This includes public, private, permanent, or semi-permanent GPS Base Stations.

5. PRE-FIELDWORK PROCEDURES

5.1. The Contract Administrator ***should*** conduct a pre-fieldwork conference for all potential contractors. The Contract Administrator ***should*** 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, a specimen layout for interpretive purposes ***should*** be provided. The Contract Administrator ***should*** 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.

5.2. The Contract Administrator ***should*** 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).

5.3. The Contract Administrator ***should*** 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. Adjacent information outside the contract area or station marking should be defined and negotiated prior to contract award.

5.4. If physical reference markers are required to be established, it is ***highly recommended*** that the interval and type of markers be stated in the contract, and be established according to existing Agency guidelines or requirements.

5.5. All projects ***should*** include sufficient map ties such as creek junctions, road intersections or other features to enable accurate geo-positioning and to provide reliability checks. The Agency representative ***should*** specify the number of tie points required, and ***should***, if possible, specify where and what these tie points should be.

5.6. ***Cadastral survey boundaries in British Columbia may only be definitively and legally located on the ground by a British Columbia Land Surveyor (B.C.L.S.) or, in specific cases, a Canada Lands Surveyor (C.L.S.). Non-qualified persons may misinterpret boundary marks when occupying legal survey monuments. This could result in legal action being taken against the Contractor or the Agency if damages occur on adjacent lands*** (see *DGPS Guidelines Section D-5.4).*

5.7. The required survey accuracies (i.e. target accuracies at 95%) for the project are:

Network Horizontal Accuracy =	**10** m	(Class = **10 m**)
Interpretive Horizontal Accuracy =	**10** m	(Class = **10 m**)
Network Orthometric Height Accuracy =	_______ m	(Class = ___________)
Interpretive 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. If statistical methods are used to reject outliers, 2 Sigma result ***should*** be used.

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

6. FIELDWORK

6.1. 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 (this mode is sometimes referred to as *3D* positioning mode).

6.2. It is ***highly recommended*** that the *minimum* satellite elevation angle/mask for the field GPS receiver is set to 15 degrees above the horizon.

6.3. It is ***highly recommended*** that the DOP not exceed the following values:

DOP Figure	Maximum DOP Value
Geometrical DOP (GDOP)	***10***
Positional DOP (PDOP)	***8***
Horizontal DOP (HDOP)	***5***
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

6.4. It is ***highly recommended*** that during Static (point-mode) surveys, occupations will adhere to the minimum values shown below:

Point Significance	Minimum Occupation Time (sec)	Minimum Number of Fixes
Standard-Significance Point	***45***	***15***
High-Significance Point	***150***	***50***

6.5. It is ***highly recommended*** that positions for linear features mapped statically (i.e. static or point-to-point traverses) be no more than ***25*** metres apart, with the traverse points defined as Standard Significance Points and established to the *Specification C-6.4* above.

6.6. It is highly recommended that position fixes for linear features mapped dynamically (i.e. dynamic traverse) be no more than 25 metres apart.

6.7. It is ***highly recommended*** 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)).

6.8. 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.

6.9. Times of GPS Events (i.e., interpolated points captured while moving) on dynamic traverses should be accurate to at least 0.25 seconds. It is mandatory that the Contractor do representative testing to prove that the GPS Event methodology produces results that meet the accuracy specifications.

6.10. It is ***mandatory*** that for point offsets, the following specifications be observed:

- e) 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.
- f) Magnetic Declination is to be applied to all compass observations before computing offset coordinates.
- g) The *maximum* distance for point offsets is ***50*** metres or 100 ***metres*** if offset observations are measured forward and backwards.
- h) Bearings are to be accurate to at least ***2*** degrees, and distances to at least ***1*** metres.

6.11. It is ***mandatory*** that for linear offsets, the following specifications be observed:

- d) The Field Operator is to record the following information: horizontal distance and the direction (left or right) perpendicular to the direction of travel.

e) The *maximum* linear offset (i.e. horizontal distance) allowable is ***5*** metres.
f) Linear offset distances are to be checked and adjusted periodically.

6.12. It is ***mandatory*** that supplemental traverses meet these following rules:
e) The supplemental traverse is to begin and end on physically marked High-Significance GPS static points (PoC and PoT).
f) The distance traversed is to be less than ***2000*** metres.
g) The supplemental traverse is to close between the GPS PoC and PoT by ***7.1m+1:100*** of the linear distance traversed.
h) The supplemental traverse is to be balanced between the GPS PoC and PoT by an acceptable method (i.e., compass rule adjustment or similar method).

6.13. Physical reference markers are to be established every 100 metres along linear features (enter N/A if not applicable). These markers must adhere to Contracting Agency standards, or be accepted before the work commences.

6.14. It is highly recommended that static point features be collected at all physical reference markers. These static point features are to be collected as HIGH / STANDARD (circle one) Significance points.

6.15. It is highly recommended that the field GPS receiver's default Signal to Noise Ratio (SNR) mask for high accuracy be used. This CAN / CANNOT (circle one) be relaxed during traversing of linear features. See Section D-7.2.5 of the DGPS Guidelines for more information on SNR masks and their effect on positional accuracy.

7. GPS BASE STATIONS

7.1. All GPS Base Stations established by the contractor are to be monumented (physically marked) to allow the Contracting Agency or other Contractors to re-occupy the same location. Reference marks are to be semi-permanent and the station referenced using adjacent features (i.e. road intersections, bearing trees, etc.) to assist during relocation, and in determining that it is undisturbed. Suitable markers include iron bars driven into the soil, spikes in asphalt or concrete, or other markers which the Contractor and Agency determine will remain stable during and, for a reasonable time, after project completion.

7.2. It is ***highly recommended*** that the separation distance between the GPS Base Station and field GPS receivers be less than ***500*** kilometres.

7.3. The *minimum* elevation angle/mask of the GPS Base Station ***should*** be **10** degrees.

7.4. If real-time differential corrections are used, it is highly recommended that they be from a GPS Base Station validated according to CRGB procedures.

7.5. If real-time corrections are used, it is highly recommended that the Total Correction Age of the field GPS receiver not exceed **90** seconds. See Section D-8.5.2 of the DGPS Guidelines for information on correction ages appropriate for various project accuracies.

8. PROCESSING AND QUALITY CONTROL

8.1. All GPS positions are to be corrected by standard differential GPS methods (pseudorange or position-shift corrections). If position-shift corrections are used, the same set of GPS satellites are to be used at the GPS Base Station as at the field Rover receiver for all corrected position epochs.

8.2. 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 Rover receiver, and the software versions and filter settings are to be noted in the project returns. If filtering/smoothing is applied to GPS Base Station data, this is also to be noted.

8.3. The Contractor ***should*** outline and 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).

8.4. The Contractor ***should*** be prepared to entirely re-survey those areas that do not meet the compliance standard at their own cost.

9. PROJECT DELIVERABLES

9.1. The Contractor ***should*** 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, and a project name (if available).
- A brief description of the project work (i.e. purpose, target accuracies, 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.).
- A list of all hardware and software used on the project; including but not limited to:
  - GPS hardware (i.e. receiver model, antenna, datalogger, 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.)
- Details regarding the GPS Base Station(s) 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.

9.2. The Contractor ***should*** submit the following digital deliverables in the indicated format and datum (see *Sections 9 & 10* of the *DGPS Guideline* for details).

Deliverables	Format	Notes
GPS Base Station Data	***RINEX – WGS84***	Merged if

		possible
Raw Field GPS Data	***Proprietary or RINEX***	Original downloaded
Original Corrected GPS Data	***Proprietary or RINEX – NAD83(CSRS)***	Unedited
Final Interpreted GPS Data	***Proprietary or RINEX – NAD83(CSRS***	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 QA/QC is applied (i.e. filtering, pruning, averaging, etc.). The second dataset must show the resulting GPS data that has been through QA/QC process (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.

9.3. The final Interpreted 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; Contracting Agency name; Contractor name; and date of survey.
- Plan datum (e.g. NAD83(CSRS)) and the Map Projection (e.g. UTM).
- Plan scale (e.g. 1:20,000) with BCGS map identifier.
- Plan orientation, (e.g. north arrows showing True North, Magnetic North and Grid North as appropriate).
- Geographic (e.g. latitude/longitude) and/or Mapping Projection (e.g. UTM) graticule as requested.
- Source of any non-project information (i.e. TRIM backdrop, Forest Cover data, etc.).

9.4. Final data should be presented referenced to the NAD83(CSRS) datum. If the Contract Agency requires data to be provided on the NAD27 datum, then the National Transformation algorithm (latest version) is to be used to create a ***copy*** of the data. If the Agency requires any other local datum, the methods used to transform the data is to be explicitly described in the project report and approved by the Agency.

9.5. If orthometric elevations are required for submission, vertical data is to be referenced to the CVD28 using the standard Geoid model for British Columbia - with local Geoid modelling if required (i.e. for high vertical accuracy projects).

9.6. 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 ***should*** be made available to the Contract Administrator or designate. The Agency ***should*** be responsible for storage or destruction of the data files in accordance with government standards.

9.7. The data provided ***should*** 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.
- Type, model and version number of hardware used to collect and store data.

- GPS Base 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.

9.8. Digital returns are to be submitted on the storage media and format as required by the Agency.

10. TECHNOLOGICAL/PERSONNEL CHANGE

10.1. If there are 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. The Contract Administrator may require confirmation that the new system will continue to meet the contract specifications.

10.2. The Contractor and the Contract Administrator ***should*** ensure that the most current versions of the RISC Standards are used.

APPENDIX D

SAMPLE GPS BASE STATION VALIDATION REPORT

GPS BASE STATION VALIDATION REPORT

For
ABC GPS Ltd.

April 23, 2008

Operator Information:

Owner:	ABC GPS Ltd.
Operator:	ABC GPS Ltd. • see Company Information in Annex A
Contact:	John Doe, RPF 123 Main Street Victoria, BC V8V 1X4 Phone: (250)123-4567 Fax: (250)123-4567 Email: mr_smith@abcgps.com

Station Information:

Base Station Location:	Victoria, BC, Canada
Base Station Structure:	Steel mast attached to concrete block building. Mark is the GPS Antenna phase centre.
Base Station Position:	Latitude = n48-23-01.12345 Longitude = w123-21-20.56789 Ellipsoid Height: 27.678m Orthometric Height: 41.456m

General Site Description:

The GPS antenna is mounted on the top of a steel mast that is attached securely to the west side of our office building. The building is concrete block construction. The mast was levelled utilizing a standard construction level; and was subsequently checked for verticality by a theodolite, for which the installation was good.

The GPS antenna is free and clear of any roof obstruction that would potentially cause satellite obstructions or multipath. A Microwave tower exists on a nearby building (one block, approximately 300 metres away); however, the Microwave drum is pointing away from the GPS receiver antenna location and we foresee no problems with signal interference.

The location has been checked for multipath by examining a 24-hour data set for multipath signature. No extraordinary noise has been noted in the data plots (included in Annex E).

As referred to above, the following information and supporting documentation regarding the GPS Base Station has been included within this report for your examination (see Annex C):

- General site sketch
- Detailed GPS antenna mounting diagram.
- GPS horizon diagram
- Photographs of GPS Base Station location and surrounding area
- Multipath analysis

Base Station Hardware/Software Information:

GPS Receiver Manufacturer/Model:	Acme Pro-GX • see GPS Receiver Information in Annex C
GPS Receiver Specifics:	20-channel parallel, digital SuperDuper chip technology Dual frequency Selectable update rate 1.0 - 15 seconds
GPS Receiver Firmware:	3.0.0
GPS Antenna Specifics:	Remote choke-ring antenna 30m cable
GPS Base Station Software:	Acme Base Station (ABS) software Version 5.7
GPS Base Station Computer:	IBM ThinkCentre A61 with Windows™ Vista Pro 300 GB Hard disk 3 GB RAM memory auto backup to network drives each evening
GPS Base Station Communications:	Available via FTP or WWW access
Additional Information:	TrippLite UPS (approx. 2 hours backup power). Power system has surge protection and filters.

GPS Base Station Settings:

Operating Times:	Continuous 24/7
Data Rate:	1.0 seconds
Data Format:	Acme *.RAW format Synchronized (GPS Time) RINEX available upon request
Data Observables/Stored:	L1 frequency: C/A code, carrier, doppler L2 frequency: L2C code, carrier, doppler Positions
Filter Settings:	Static
Satellite Elevation Mask:	10 degrees
PDOP Mask:	PDOP = 99 (not applicable)

Base Station Survey:

GENERAL INFORMATION

Survey Agency:	XYZ Surveys Ltd. • see Company Information in Annex A • see Personnel Information in Annex B
Survey Contact:	Jane Doe, BCLS, P.Eng. 123 Anywhere Street Victoria, BC V8V 1X4 Phone: (250)123-4567 Fax: (250)123-4567 Email: janedoe@xyzsurveys.com

SURVEY SYSTEM VALIDATION:

Validation Location:	Greater Vancouver GPS Basenet
Accuracy Achieved:	Network Horizontal Accuracy < 5 centimetre Network Ellipsoidal Height Accuracy < 1 decimetre Local Horizontal Accuracy < 2 centimetre Local Ellipsoidal Height Accuracy < 2 centimetre
Survey System Validated:	Two Survey X-12 receivers Survey X-12 L1/L2 antennae Survey DELTA software (version 3.12)
Reference Document:	BC Standards, Specifications and Guidelines For Control Surveys Using GPS Technology
Validation Report/Returns:	• see included information in Annex D

GPS BASE STATION SURVEY

Accuracy Achieved:	Network Horizontal Accuracy < 1 decimetre Network Ellipsoidal Height Accuracy < 2 decimetre Local Horizontal Accuracy < 2 centimetre Local Ellipsoidal Height Accuracy < 5 centimetre
Survey Methodology:	Static GPS Ties - occupation times minimum 33 minutes. All GCMs double occupied
Survey Ties:	GCM#1123, #34478 and #887290 BCACS ACP Lulu Island (LI)
Survey System Used:	Two Survey X-12 receivers Survey L1/L2 antennae Survey DELTA software (version 3.12)
Reference Documents:	BC Accuracy Standards For Positioning. BC Standards, Specifications and Guidelines For Control Surveys Using GPS Technology.
Survey Report/Returns:	• see included reports in Annex E

Summary:

ABC GPS Ltd. is requesting Horizontal Category II and Vertical Category II GPS Base Station status.

Please see the attached Annexes listed below for supporting documentation:

Annex A	Company Information (Business Licences, Experience and Marketing material)
Annex B	Personnel Information (Education Credentials; Resumes and Certificates)
Annex C	GPS Base Station Information
Annex D	GPS System Validation (GPS Basenet Survey Results and Report)
Annex E	GPS Base Station Survey Report (Intermediate and Final Results included)

APPENDIX E

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APPENDIX E - INDEX

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