

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



**Ministry of Environment
Lands and Parks
Geographic Data BC**

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PREFACE

The following document is the fourth published version of the document ***British Columbia Standards, Specifications and Guidelines for Resource Surveys Using Global Positioning System (GPS) Technology***. As part of its mandate to provide an effective and accessible geo-spatial reference in British Columbia, Geographic Data BC (GDBC) continues to build “GPS friendly” infrastructure in the province in support of applications requiring centimetre-level to few tens of metres level positioning. Standards, specifications and guidelines for utilizing GPS are an important part of this infrastructure. While GDBC maintains standards for higher precision GPS use by professional engineers and surveyors, this document addresses the more general GPS use at the sub-metre to few tens of metres use. As such, significant effort is made to provide detailed guidelines. GPS is a very democratic tool, as may be often heard. Anyone can walk into a general store and buy a GPS receiver for a few hundred dollars. Together with desktop publishing tools or other software available on a personal computer, one can easily produce a “map” showing the location of a stream or trail or points of interest. As is demonstrated by the specifications and guidelines herein and well understood by professional geomaticians, GPS is far from being a “black box” technology.

GPS technology is one of the few advanced technologies that is dramatically impacting government programs at all levels. Millions of dollars worth of data collection continue to occur and various databases or maps updated or overlaid with GPS derived information. The removal in year 2000 of Selective Availability (i.e. the intentional downgrading of civilian use of GPS by the U.S. military) and GPS modernization efforts currently underway by the U.S., will no doubt increase the utilization of GPS in the coming years. Further, the advent of other Global Navigation Satellite Systems (such as the European Galileo program), the maturation of augmentation systems (such as real-time wide-area corrections and integrity channels), the Internet and wireless communications will all blur the interface between the positioning source and the user. We need to maximize the GPS and other technologies potential and yet guard against its improper use and “pollution” of government/industry databases. As well, in this transition to a seamless and robust positioning source, some clarity is needed and a coordinated response to the opportunities and challenges posed by this exciting technological revolution need to be created. In all these regards, the Public Sector GPS Users Committee (PSGUC) provides one means for GDBC and other interested parties to collaborate.

The PSGUC Terms of Reference (ToR) are:

- To provide a forum for public sector GPS users to exchange experiences and concerns with the use of GPS technology.
- To promote the development, adoption and maintenance of common standards for GPS technology and data gathering, including issues pertaining to GPS/GIS integration.
- To avoid the duplication of effort in the establishment of GPS Reference Stations, standards, formats, processing methodologies, data communications, and other related concerns.
- To promote the use of GPS technology for increased efficiency and effectiveness in existing, and potentially new, application areas.

- To communicate government needs related to GPS technology to GPS, GIS and communications technology vendors.

The committee is open to any interested public sector body and we invite participation from any member or bodies from industry. Nationally, on these and other geo-spatial reference matters, GDBC collaborates with other provincial and federal agencies through the Canadian Geo-Spatial Reference System Committee (CGRSC). For more information about the PSGUC, CGRSC or the GPS interests at Geographic Data BC, please write to the under-signed or visit our web-site.

The Standards, Specifications and Guidelines contained herein continue to represent one of the key deliverables of the PSGUC and GDBC. As well, since 1998 and with the support of the Resource Inventory Committee (RIC) within the provincial government, the PSGUC and GDBC have successfully developed and implemented GPS Training and Certification in order to assist users gain the skills necessary to implement these Standards. Though voluntary, certification provides contracting agencies an effective way to ensure that GPS operators have the necessary skills in place. To date, over 300 people have undertaken the training and obtained RIC Certificates attesting to their ability to collect GPS data in conformance with these Standards.

As with any standards and specifications, feedback received from actual use is very important in ensuring that the standards and specifications are practical and serve their intended purpose. No doubt the document herein will continue to evolve for these and other reasons (such as evolving technology). Though these standards, specifications and guidelines have been written to fill the specific needs in the public sector, there are no reasons why private agencies may not utilize them for their own purposes. In fact, industry use should and is encouraged. It is important to note that these standards have been endorsed by the provincial Resource Inventory Committee (RIC) and are recognized for programs such as TRIM 1:20,000 mapping updates.

Changes under this release (Release 3.0) are largely tied to the impact of Selective Availability removal on May 2, 2000. The following section entitled Release Revisions outlines the changes made. Many of the changes are also administrative, arising from the amalgamation of the previously published specification (March, 1988; Release 2.1) with its follow-up Amendment document (published July 1999).

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RELEASE AMENDMENTS

This section summarizes the Release 3.0 (March 2001) changes to the previous Release 2.2 of the PSGUC/RIC Standards (including the Addendum issued July 31, 1999). See *Section A* for a short history of this document's Release versions. This revision cycle incorporates recent changes in GPS and other satellite positioning systems, standardizes all accuracies to the 95% confidence level, and attempts to rectify errors and/or omissions. Previous references to the *Guidelines* section of the document are now referred to as the *DGPS Guidelines*. This is to avoid confusion with the new Section E that is titled: *Autonomous GPS Guidelines*. Changes in the RIC GPS training course are also being updated through this Release. The table below identifies document sections that have been changed from the previous Release (minor spelling or grammatical changes are not noted).

Section	Comments
Preface	Updated by PSGUC Chair
Acronyms	Expanded to reflect GPS modernization, and other new developments
Section A	Updated (GPS modernization, new Section E, etc.)
Section B	Minor updates (figures, examples, significant figures, etc.)
Section C	All of the <i>Specification (Section C)</i> incorporates changes made in the addendum (July 1999). This includes changing must to highly recommended or should .
C-1	Clarification of applicable accuracy classes
C-2	Clarification of compliance levels
C-5.1	Expanded to include "High Significance" and "Standard Significance" feature identification
C-5.4	Change "semi-permanent markers" to "physical markers"
C-5.7	Now includes 5.8 & 5.9 and clarifies accuracy definitions
C-6.3	Removed reference to Static and Dynamic
C-6.6	Removed reference to speed and logging interval
C-6.7	Added reference to PoC and PoT
C-6.12	Added reference to PoC and PoT
C-6.13	Change "semi-permanent markers" to "physical markers", added N/A as an option
C-6.14	As above, plus allowed specifying "High Significance" or "Standard Significance"
C-6.15	Added SNR specification, with option to relax for linear features
C-7.4	Removed range rates and latency references
C-7.5	Clarification of Total Correction Age, and allows this value to be specified
C-9.3	Changed hardcopy delivery from required to optional
Section D	Changed section title from <i>Guidelines</i> to <i>DGPS Guidelines</i>
D-2.1	Clarification, update
D-2.3	Clarification, update, references to new <i>Section E</i>
D-2.4	Clarification, update, consistent terminology
D-2.5	New section: GPS modernization and other GNSS (GLONASS, GALILEO, WAAS, etc.)
D-3.1	Clarification
D-3.2	Clarification
D-3.3	Clarification
D-3.4	Updates
D-3.6	Updates
D-4.0	Clarification
D-4.1	Clarification

D-4.1.1	Clarification, updates
D-4.1.2	Clarification, updates
D-4.1.3	PSGUC/RIC course updates
D-4.2	Clarification, simplification, updates
D-4.2.1	Clarification
D-4.3.1	Updates
D-4.3.2	Clarification, updates
D-4.3.3	Updates
D-4.3.4	Updates
D-5	Clarification
D-5.1	Clarification
D-5.2	Update provided by MoELP, CLRS/OSG
D-5.3	Clarification
D-5.5	Clarification
D-6.1	Clarification, updates
D-7.1	Clarification
D-7.1.1	Clarification
D-7.1.2	Clarification, updates, significant figures
D-7.1.3	Clarification
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D-7.1.5	Clarification
D-7.1.6	Clarification, added magnetic variation, updated offset uncertainty table
D-7.1.7	Clarification
D-7.2.1	Clarification, updates
D-7.2.2	Clarification
D-7.2.3	Clarification
D-7.2.3.1	Clarification, significant figures, example consistency
D-7.2.3.2	Clarification, significant figures, example consistency, updates
D-7.2.3.3	Update, corrected & clarified table D-10
D-7.2.3.4	Clarification
D-7.2.4	Clarification
D-7.2.5	Clarification, summarizes SNR testing, new guidelines for SNR masks
D-7.3	Clarification
D-8.1	Clarification
D-8.2	Clarification
D-8.3	Clarification
D-8.4	Clarification
D-8.5.1	Clarification, Table D-11 clarifications
D-8.5.2	Clarification, updates (post SA), total correction age suggestions Vs target accuracy
D-8.6	Clarification
D-9	Clarification
D-9.1	Clarification, update
D-9.2	Clarification, update
D-9.3	Clarification
D-11.2	Clarification
Section E	New section: <i>Autonomous GPS Guidelines</i>
Appendix A	Update, corrections
Appendix B	Update
Appendix C	Update
Appendix F	Update

LIST OF CONTRIBUTORS

The following list identifies those Agencies, Companies, and individuals, in alphabetical order, who have provided feedback in one form or another (i.e. complete sections; additional information; corrections, etc.). This list also includes those who, in the past, contributed to the first version of this document through written form, or through participation on the Public Sector GPS Users Committee (PSGUC). The publication of this document would not have been possible without them. **Note, however, that mention of contributors is not intended to portray such individuals' endorsement of the contents herein. GDBC remains exclusively responsible for the end results as represented by the contents herein.**

Over the years and of special note is the significant input and data provided by the Ministry of Forests and the forests industry, as a result of the extensive use of GPS in forestry related operations. Contributions from MoF branches, regions and districts, as well as GPS consultants, have helped to identify operational issues and challenges and thereby assisted the PSGUC and GDBC to produce effective guidance for GPS use.

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LIST OF ACRONYMS

1D, 1-D	One-dimensional
2D, 2-D	Two-dimensional
2DRMS	Twice the distance RMS (Root Mean Square)
3D, 3-D	Three-dimensional
A-S	Anti-Spoofing (encryption of the P- code to the Y- code)
BC	British Columbia
BC ACS	British Columbia Active Control System
BCGS	British Columbia Grid System
BCGSR	British Columbia Geo-Spatial Reference
B.C.L.S.	British Columbia Land Surveyor
C/A	Coarse/Acquisition GPS signal (civilian)
CACS	Canadian Active Control System
CAD	Computer Aided Design
CCG	Canadian Coast Guard
CEP	Circular Error Probable (50% confidence)
CSRS	Canadian Spatial Reference System
CVD28	Canadian Vertical Datum 1928
CDGPS	Canada-wide Differential GPS (via Global Surveyor service, GDBC)
CLS	Canada Lands Surveyor
DGPS	Differential GPS
DOP	Dilution Of Precision
DRMS	Distance Root Mean Square (see 2DRMS)
DXF	Drawing eXchange Format (AutoCAD's open format)
ECEF	Earth-Centered, Earth-Fixed
EDOP	East DOP
FPC	Forest Practices Code
FRBC	Forest Renewal BC
GALILEO	Proposed European satellite navigation system
GCM	Geodetic Control Monument
GDBC	Geographic Data BC, Ministry of Environment, Lands and Parks
GDOP	Geometric DOP (3D plus Time)
GIS	Geographic Information System
GLONASS	GLObal NAVigation Satellite System (Russian GPS counterpart system)
GPS	Global Positioning System (also called NAVSTAR)
GRS	Geodetic Reference System
GSD	Geodetic Survey Division, Natural Resources Canada (NRCan)
GSD95	Geodetic Survey Division 95 geoid model for NAD83 ellipsoid to CVD28 orthometric height conversion
GSR	Geo-Spatial Reference
GSRU	Geo-Spatial Reference Unit, Geographic Data BC, Ministry of Environment, Lands and Parks
HDOP	Horizontal DOP (2D)
HT97	Modified geoid model based on GSD95

Hz	Hertz (1/second)
IERS	International Earth Rotation Service
IGDS	Interactive Graphic Design System
INCOSADA	INtegrated CORporate Spatial and Attribute DAtabase (MoF)
I/O	Input/Output
ISA	Integrated Survey Area
ITRF	International (IERS) Terrestrial Reference Frame
L1	GPS L-band signal 1 (1575.42 MHz)
L2	GPS L-band signal 2 (1227.6 MHz)
L5	GPS L-band signal 5 (1176.45 MHz)...planned new civilian frequency & code
LAAS	Local-Area Augmentation Service
LADGPS	Local-Area Differential GPS
L-band	L-band frequency (about 1-2GHz) of the electromagnetic spectrum
MGSR	Municipal Geo-Spatial Reference
MoELP	Ministry of Environment, Lands and Parks
MoF	Ministry of Forests
MSL	Mean Sea Level
NAD27	North American Datum 1927
NAD83	North American Datum 1983
NANU	Notice Advisory to NAVSTAR (GPS) Users
NAVD88	North American Vertical Datum 1988
NAVSTAR	NAVigation Satellite Timing And Ranging (original acronym for GPS)
NDOP	Northing DOP
NRCan	Natural Resources Canada
OEM	Original Equipment Manufacturer
P-code	Precise code – provided for military GPS users and selected others
PDOP	Position DOP (3D)
PoC	Point of Commencement
PoT	Point of Termination
PPM	Part Per Million (i.e. 1mm per 1km)
PPS	Precise Positioning Service (military)
PR	Pseudorange
PRC	Pseudorange Correction
PRN	Pseudo Random Noise (unique code for each satellite)
PSGUC	Public Sector GPS Users Committee
QA	Quality Assurance
QC	Quality Control
RIB	Resources Inventory Branch, Ministry of Forests
RIC	Resource Inventory Committee
RINEX	Receiver INdependent EXchange format
RMS	Root-Mean-Square
RTCA	Radio Technical Commission for Aeronautical services
RTCM	Radio Technical Commission for Maritime services
RT-DGPS	Real Time Differential GPS
RTEB	Resource Tenure and Engineering Branch, Ministry of Forests
RRC	Rate of the Range Correction (broadcast by RT-DGPS systems)
Rx	Receiver (i.e. GPS Rx)
SA	Selective Availability (removed 2 nd May, 2000)
SAIF	Spatial Archive and Interchange Format (GDBC-MoELP)

SEP	Spherical Error Probable (50% confidence)
SNR	Signal to Noise Ratio
SPS	Standard Positioning Service (civilian)
TDOP	Time DOP
TRIM	Terrain Resource Integrated Management
UTC	Universal Time Coordinated
UTM	Universal Transverse Mercator
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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**British Columbia
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Technology

*Release 3.0***

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. Yet, GPS is not “black-box” technology and it does not replace the need to understand the measurement sciences of surveying and mapping. Attractive and useful as it may be, there are risks involved with using GPS. These risks are best understood *and avoided* by ensuring appropriate levels of education, training and experience by everyone involved with these projects. This includes government staff overseeing GPS contracts. To date, 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. 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 taken 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 referred to as the *PSGUC/RIC Standards*). Keeping in mind that the audience for these specifications was very broad and emerging from non surveying and mapping practitioners, the PSGUC and GDBC found it necessary to expound more deeply those aspects of GPS technology, surveying and mapping principles, and surveying and mapping techniques, in order to mitigate the risk of mis-interpretation of the specifications. Hence the introduction of the Standards and Guidelines. For experienced geomatics professionals well versed with GPS and the measurement sciences, the short Specifications section will suffice for their application of GPS and attainment of the Standards.

The PSGUC/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, and a clarification addendum issued in July 1999. This latest Release 3.0 consolidates the Release 2.1 and subsequent (1999) Addendum, generally brings the document up to date, and adds an additional section related to autonomous GPS. The changes in this Release, i.e. beyond the consolidation mentioned above, are described further below.

The removal of Selective Availability (SA) on May 2nd, 2000 was a significant event for GPS users. This has a positive impact on navigation users, but also affects GPS surveying and mapping. The PSGUC/RIC Standards have references to SA throughout the document, and these were updated to reflect the current status. The removal of SA particularly benefits Real-Time DGPS users, and studies were done to quantify accuracy levels for different correction ages. The study results are incorporated throughout this Release 3.0. The removal of SA also prompted many resource users to consider using autonomous GPS. A new section was added to this Release 3.0 (*Section E – Autonomous GPS Guidelines*), to advise users of both the potential and of the risks of using autonomous GPS.

Other issues that are addressed in this Release 3.0 include:

- Signal to Noise Ratio (SNR) testing results and recommendations.
- Update on the modernization of GPS.
- Update on other Global Navigation Satellite Systems (GLONASS, GALILEO).
- Post-SA Real-Time positioning accuracy testing results and recommendations (i.e. RTCM Age setting).

This document particularly targets GPS surveys where the required project accuracies are in the 1m to 10m accuracy class (95%), although the Specifications herein may be applied to lower accuracy requirements. 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 Geographic Data BC (GDBC), Ministry of Environment, Lands and Parks. 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, interpretative accuracy values and GPS Reference Station categories. The information provided within this section of the *PSGUC/RIC Standards* is an extension of the developing document **British Columbia Accuracy Standards for Positioning Version 1.0 (targeted for release April, 2001)**; which identifies accuracy standards for all provincial positioning independent of the instrumentation used.

Section C outlines *DGPS Specifications*. The *DGPS 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 *DGPS 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 *DGPS 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 GPS Guidelines*. This section was added with Release 3.0 of this document, in light of the increased accuracies available with the removal of SA, and is intended to provide guidelines for those considering use of autonomous GPS for surveying and mapping of non-critical features.

Geographic Data BC (GDBC) 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 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 the Geo-Spatial Reference Unit, Geographic Data BC, Ministry of Environment, Lands and Parks (see *Preface* or *Appendix B* for contact numbers).

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

*Release 3.0***

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 directly derived from the Accuracy Standards developed for all positioning methodologies as outlined in the document entitled document **British Columbia Accuracy Standards for Positioning Version 1.0 (targeted for release April, 2001)** published by Geographic Data BC (Ministry of Environment, Lands and Parks). The Standards presented here are no different than the Standards presented in the aforementioned document; rather they 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.

This section is intended to evolve (in the future) to incorporate standards that address more than geometrical accuracy per se. Standards related to GPS receivers, data formats, and other aspects of GPS use need to be established as an over-arching framework over the rules-based specifications and explanatory guidelines. Meanwhile, the specifications and guidelines herein do fill this gap at the implementation level.

2. GENERAL CONCEPTS and DEFINITIONS

These Standards refer to the Geo-Spatial Reference (GSR) - 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 unknown value. Because the true value is not 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 root-mean-square (RMS), 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.

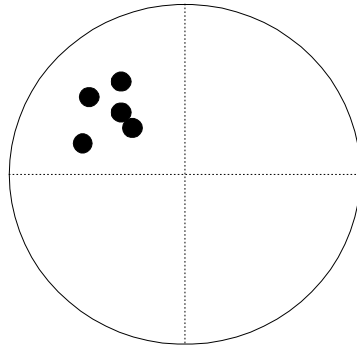
Precision measures are relatively simple to compute and are often used to estimate accuracy. They provide useful estimates of accuracy only if the data is unaffected by biases due to blunders or uncorrected systematic effects. Without some assurances that such errors do not exist, a precision measure 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 would be in 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” (say the 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.

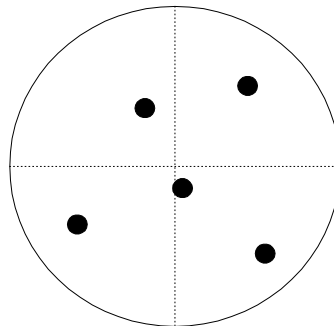
In summary, precision plus reliability, or precision without bias, results in true accuracy. In constructing the accuracy tables below, it is assumed that such true accuracy is being referred.

These standards are based on two types of accuracy that can be estimated for the geodetic coordinates of latitude, longitude (horizontal coordinates) and ellipsoidal 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.

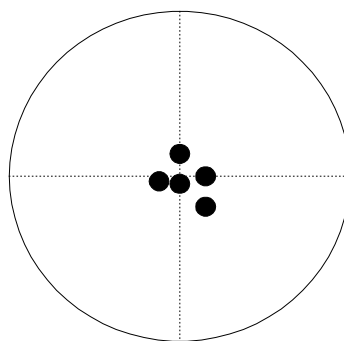
Figure B- 1 Network Accuracy vs. Local Accuracy Analogy

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



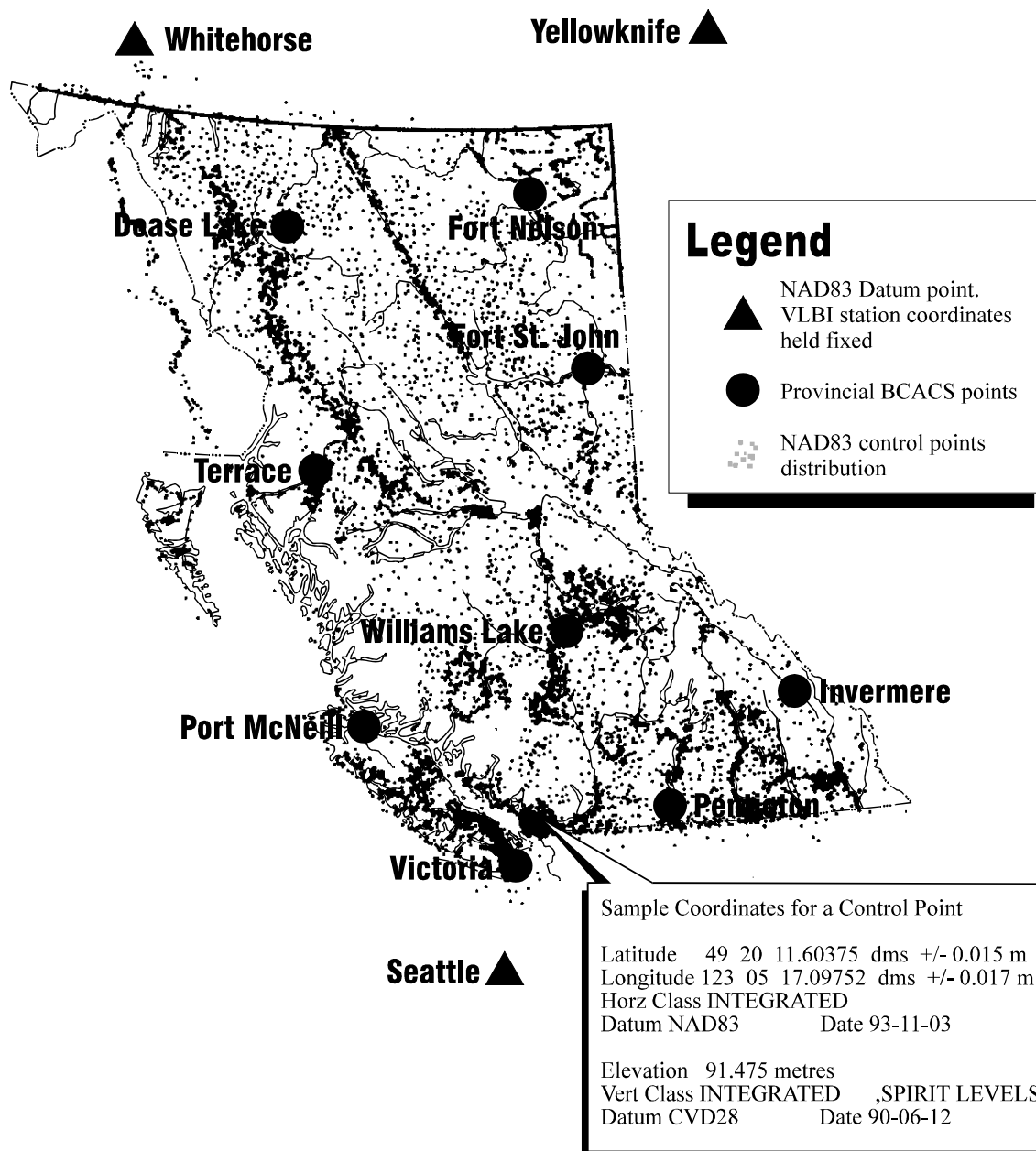
● Blunder/Outlier

*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 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 GDBC 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.

For more information on Network and Local Accuracy, the reader is referred to the Geodetic Survey Division (GSD) document: ***Accuracy Positioning Standards (Version 1.0)***.

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 Interpretative Accuracy of features being mapped as well as categorizing GPS Reference Stations. The final section looks at the practical application of the Standards to resource surveys.

ACCURACY CLASSIFICATION STANDARDS

ACCURACY CLASS	CLASS RANGE
1 millimetre	≤0.001 metres
2 millimetre	0.0011 - 0.002 metres
5 millimetre	0.0021 - 0.005 metres
1 centimetre	0.0051 - 0.010 metres
2 centimetre	0.0101 - 0.020 metres
5 centimetre	0.0201 - 0.050 metres
1 decimetre	0.0501 - 0.100 metres
2 decimetre	0.1001 - 0.200 metres
5 decimetre	0.2001 - 0.500 metres
1 metre	0.5001 - 1.000 metres
2 metre	1.0001 - 2.000 metres
5 metre	2.0001 - 5.000 metres
10 metre	5.0001 - 10.000 metres
20 metre	10.0001 - 20.000 metres
50 metre	20.0001 - 50.000 metres
100 metre	50.0001 - 100.000 metres
200 metre	100.0001 - 200.000 metres
500 metre	≥ 200.0001 metres

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 (BC GSR). Network Accuracy can be computed for any positioning project that is connected to the BC GSR (see *Figure B-3 Network Accuracy and Resource GPS Surveys*).

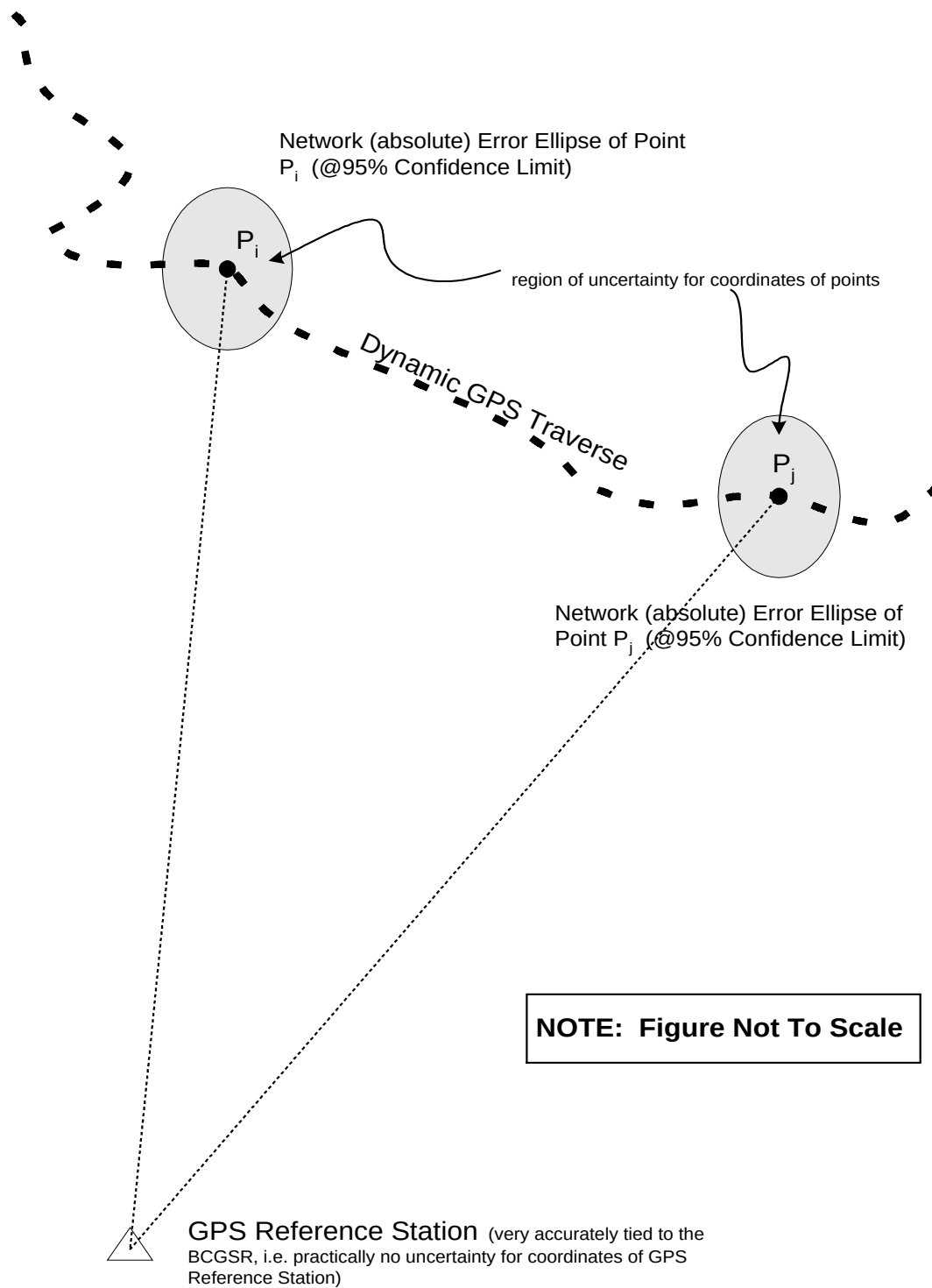
The BCGSR horizontal datum is physically marked on the ground by a system of approximately 50,000 accurately positioned geodetic control monuments placed throughout the province; and more recently, also through the GPS data products derived from the British Columbia Active Control System (BC ACS). The BC ACS is defined by a network of continuously operating GPS Reference Stations, known as Active Control Points (ACPs), distributed throughout British Columbia. These positions define the North American Datum of 1983 (NAD83) in the province. Accuracies of these coordinates are at the few centimetres level (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 BC ACS ACP error) to your 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 whose published horizontal error is 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 BC ACS (i.e. surveys tied to a GPS Reference Station that is rigorously integrated into the NAD83 datum) or various base mapping (i.e. surveys tied to features clearly defined on the NAD83 based mapping).

For general spatial referencing applications, the points in the British Columbia Active Control System (BC ACS) 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 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 *relative 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).

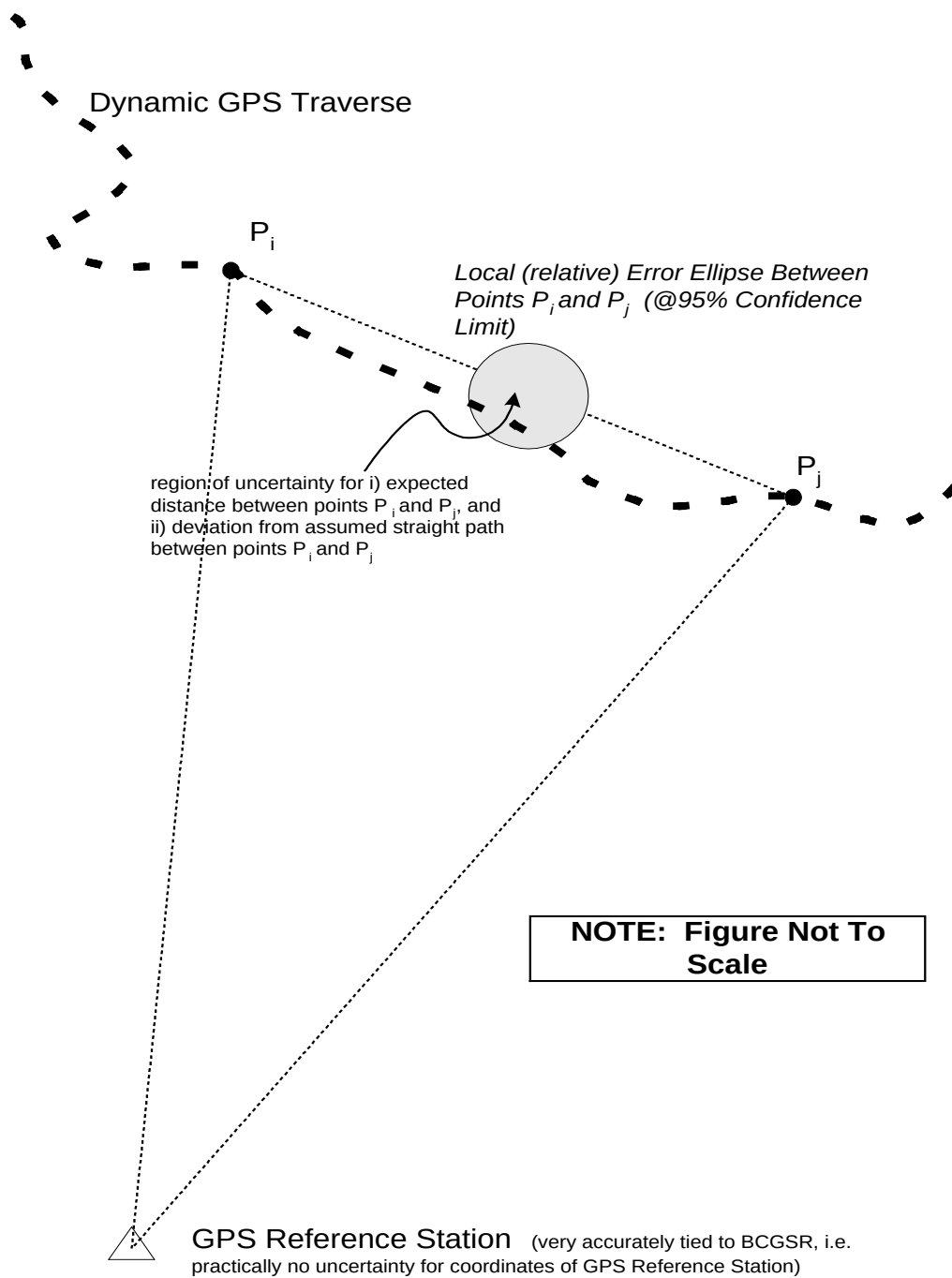
The Network and Local Accuracy values at a point provide two very different pictures of positioning accuracy. Network Accuracy indicates how accurately a point is positioned with respect to the reference system, and is therefore dependent upon the connection to the BCGSR. For a positioning project connected 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 Interpretative Accuracy

If the Interpretative 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 Interpretative 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 Interpretative Accuracies (all features sharply defined), or to assign a single Interpretative 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 Interpretative Accuracy.

Horizontal Interpretative Accuracy Class	Accuracy Range	Examples
1 millimetre	≤0.001m	fixed-centering monumentation (i.e. pillar)
2 millimetre	0.0011m - 0.002m	survey control marker – center punched
5 millimetre	0.0021m - 0.005m	iron pin - no center punch
1 centimeter	0.0051m - 0.010m	well defined urban facilities (e.g. hydrant)
2 centimeter	0.0101m - 0.020m	edge of pavement – sidewalk
5 centimeter	0.0201m - 0.050m	edge of pavement - no sidewalk
1 decimetre	0.0501m - 0.100m	center of utility pole, centerline of RR tracks
2 decimetre	0.1001m - 0.200m	edge of lake or gravel road
5 decimetre	0.2001m - 0.500m	center of gravel road, overhead line crossing
1 metre	0.5001m - 1.000m	intersection of seismic lines
2 metre	1.0001m - 2.000m	edge of clearing (cut)
5 metre	2.0001m - 5.000m	edge of marsh
10 metre	5.0001m - 10.000m	edge of clearing (natural)
20 metre	10.0001m - 20.000m	center of buffer strip
50 metre	20.0001m - 50.000m	river channel in marsh/delta
100 metre	50.0001m – 100.000m	center of small lake/swamp

Table B- 2 Horizontal Interpretative Accuracy Classification

Vertical Interpretative Accuracy Class	Accuracy Range	Examples
1 millimetre	≤0.001m	fixed-centering monumentation (i.e. pillar)
2 millimetre	0.0011m - 0.002m	survey control marker or BM
5 millimetre	0.0021m - 0.005m	supplemental control (i.e. hub))
1 centimeter	0.0051m - 0.010m	well defined “street furniture” (e.g. hydrant)
2 centimeter	0.0101m - 0.020m	water level - calm lake
5 centimeter	0.0201m - 0.050m	water level - calm seas & crown of road
1 decimetre	0.0501m - 0.100m	water level - rough lake
2 decimetre	0.1001m - 0.200m	Natural Boundary or Ordinary High Water Mark (OHWM)
5 decimetre	0.2001m - 0.500m	water level - rough seas
1 metre	0.5001m - 1.000m	top of bank
2 metre	1.0001m - 2.000m	summit of hill
5 metre	2.0001m - 5.000m	
10 metre	5.0001m - 10.000m	
20 metre	10.0001m - 20.000m	
50 metre	20.0001m - 50.000m	
100 metre	50.0001m - 100.000m	

Table B- 3 Vertical Interpretative Accuracy Classification

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

3.4. GPS Reference Station Accuracy

In most cases, GPS surveys in the resource sector utilize GPS Reference Stations (such as the BC ACS 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 Reference Station. It is generally considered good survey practice to ensure that the datum related positional accuracy (i.e. Network Accuracy) is at least one order of magnitude (i.e., 10 times) better than the highest equivalent accuracies sought in any particular project. This ensures the affect of GPS Reference Station positional error on the project survey will be negligible.

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

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

GPS Reference Station Category	Proposed Project Horizontal Network Accuracies	Reference Station Horizontal Network Accuracy	Proposed Project Vertical Network Accuracies	Reference 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 B- 4 GPS Reference 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 Reference Station Categories are more difficult to meet than their Horizontal counterpart due to the following:

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

A GPS Reference Station, classified as above, may support all lower categories but not higher categories. For example, if a GPS Reference 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 Reference 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 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 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 (BC ACS) 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 Geographic Data BC (GDBC) 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 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
Interpretative Horizontal Accuracy	0.5m
Local Ellipsoid Height Accuracy	2.0m
Network Ellipsoid Height Accuracy	5.0m
Interpretative 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 Reference Station is used.

In summary, for a typical resource GPS survey only the **Network Horizontal Accuracy**, the **Interpretative Horizontal Accuracy**, the **Network Orthometric Height Accuracy** and the **Interpretative 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)
Interpretative Horizontal Accuracy	0.5m	(i.e. Class = 5 decimetres)
Network Orthometric Height Accuracy	6.0m	(i.e. Class = 10 metres)
Interpretative Vertical Accuracy	0.5m	(i.e. Class = 5 decimetres)

This confirms that, for this example:

- the road centerline is horizontally integrated onto the BCGSR (i.e., NAD83) 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 against Mean Sea Level (i.e., CVD28) at the 6.0m accuracy level, and
- the road centerline crown is vertically discernible at the 0.5m level

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Global Positioning System (GPS)
Technology
*Release 3.0***

SECTION C - DGPS SPECIFICATIONS

SECTION C - DGPS SPECIFICATIONS

1. APPLICATION

These *DGPS 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 *DGPS Specification* will facilitate standardization and quality control for land related information collected for government databases using GPS technologies. The *DGPS Specification* are supported by two documents: the *Standards* and the *DGPS Guidelines*.

The *Standards* document outlines geo-spatial referencing categories in a standardized and uniform manner. Using the *DGPS Specification* document, one may specify the target accuracies to be achieved based on the standardized categories established within the *Standards* document. As well, the *Standards* document establishes standards for GPS Reference Station accuracies within the provincial geo-spatial reference framework.

The second supporting document is the *DGPS Guidelines* document. The *DGPS Guidelines* document provides relevant background information in order to complete those areas of the *DGPS Specification* 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 *DGPS Specification*. Also, see Appendix C for a sample *DGPS Specification* document completed for a typical resource survey requiring 10m 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 Geographic Data BC (GDBC) of the Ministry of Environment, Lands and Parks. Publications by other provincial and Federal agencies also describe procedures for using GPS for high accuracy surveys.

2. INTERPRETATION

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

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

Agency	Ministry, Department or other entity administering the Contract.
BCGS	British Columbia Grid System defining the map graticule breakdowns within the province at various scales.
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.
GDBC	Geographic Data BC, Ministry of Environment, Lands and Parks, Province of British Columbia.
Geoid	The equipotential surface approximating Mean Sea Level. Consult GDBC for provincial standard geoid model.
GPS	Global Positioning System as operated by the United States Department of Defense (US DoD). Also called NAVSTAR.
GPS Event	A GPS Event is a single position instead of a group of positions averaged to a single position (i.e. Static survey). Events are typically used when the antenna cannot, or need not, be stationary over a point.
GPS Reference 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 basestation.
MoELP	Ministry of Environment, Lands and Parks, Province of British Columbia.
NAD27	North American Datum of 1927, based on the Clarke 1866 ellipsoid.
NAD83	North American Datum of 1983, based on the Geodetic Reference System 1980 (GRS80) ellipsoid and as defined by the GRS in British Columbia.
PSGUC	Public Sector GPS Users Committee as established by Geographic Data BC
RIC	Resource Inventory Committee
Static-mode	Collection of GPS data at a discrete point while remaining stationary.
Supplemental Traverse	Supplemental Traverses are conventional traverses (e.g. compass and tape) that are integrated with GPS surveys.
UTM	Universal Transverse Mercator projection (map projection system).

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

highly recommended	Used to describe tasks that are deemed necessary and are good practice. Exceptions are possible, but only after careful consideration by the contracting Agency.
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.
- 3.3. To qualify GPS Systems (i.e. equipment, processing methods, and personnel) by a Contractor GPS System Validation survey to establish the accuracies achievable under various conditions.

4. PRE-QUALIFICATION AND VALIDATION

- 4.1. Total System - It is **highly recommended** that any Contractor expecting to undertake GPS data collection be prepared to fulfill the requirements of the full “System”, including: GPS hardware and software for field and office; field and GPS Reference Station receivers; and reporting techniques. All parts of the System are to be capable of meeting the contractual specifications below.
- 4.2. Field Operator Training – It is **highly recommended** that Field Operator(s) be qualified through the RIC sanctioned GPS 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 RIC sanctioned GPS course: *"Comprehensive GPS Training for Resource Mapping"*, or the defined Challenge Process.
- 4.4. It is **highly recommended** that any GPS System used be proven to meet the accuracy requirements through a GPS Contractor System Validation survey as outlined in *Section D-4.2* of the *DGPS Guidelines* document. The accuracy levels established during the validation and the conditions under which they were established **should** apply for all subsequent projects.
- 4.5. It is **highly recommended** that all GPS Reference 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 Reference Stations.

5. PRE-FIELDWORK PROCEDURES

- 5.1. The Contract Administrator **should** conduct a pre-fieldwork conference for all potential and qualified 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 interpretative 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.
- 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 (e.g. the Forest Practices Code guidebooks for forest road engineering and boundary marking).
- 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 = _____)
Interpretative Horizontal Accuracy =	_____ m	(Class = _____)
Network Orthometric Height Accuracy =	_____ m	(Class = _____)
Interpretative Vertical Accuracy =	_____ m	(Class = _____)

For clarification, the definition of meeting the above accuracy class is that for GPS point features, at least 95% of the individual position fixes are within the above-specified accuracies (horizontal linear measure) of the true position of the point. 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.

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 (sometimes known as “3D” positioning mode).
- 6.2. The *minimum* satellite elevation angle/mask for the field GPS receiver is 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.
VDOP limits need be followed only in surveys where accurate elevations are required

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

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

- 6.5. It is **highly recommended** that position fixes 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) on dynamic traverses **should** be accurate to at least _____ seconds.
- 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* distances for point offsets are _____ metres, and _____ 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 supplemental traverses meet these following rules:
- a) The supplemental 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 supplemental traverse is to close between the GPS PoC and PoT by _____ of the linear distance traversed.
 - d) The supplemental traverse is to be balanced between the GPS PoC and PoT by an acceptable method (i.e., compass rule adjustment).
- 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 **STANDARD** / **HIGH** (*circle one*) Significance points.
- 6.15. It is **highly recommended** that the 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 REFERENCE STATIONS

- 7.1. All GPS Reference 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. Physical reference marks are to be left and the station referenced using adjacent features (i.e. road intersections, sign posts, bearing trees, etc.) to assist in the future location, and in determining that it has remained undisturbed. Suitable markers include iron bars driven into the soil, spikes in asphalt or concrete, or other markers 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 Reference Station and field receivers be less than _____ kilometres, or the separation distance used during Validation, whichever is less.
- 7.3. The *minimum* elevation angle/mask of the GPS Reference Station **should** be 10 degrees.
- 7.4. If real-time corrections are used, it is **highly recommended** that they be from a GPS Reference Station validated according to Geographic Data BC, MoELP procedures.
- 7.5. If real-time corrections are used, it is **highly recommended** that the *Total Correction Age* of the rover GPS system not exceed _____ seconds. See *Section D-8.5.2 of the DGPS Guidelines* for information on correction ages appropriate for various accuracies.

8. PROCESSING AND QUALITY CONTROL

- 8.1. All GPS positions are to be corrected by standard differential GPS methods (pseudorange or navigation corrections). If navigation corrections are used, the same set of GPS satellites are to be used at the GPS Reference Station as at the field receiver for all corrected positions.
- 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 operator or vehicle, and the software versions and filter settings are to be noted in the project returns. If filtering is applied to GPS Reference Station data, this is also to be noted.
- 8.3. The Contractor **should** 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, a project name (if available), and a project identifier (e.g. provincial government's ARCS/ORCS number, etc.).
 - A brief description of the project work (i.e. purpose, target accuracy, location, etc.).
 - A key map showing the project area and a description of any GPS Reference Stations used.
 - A schedule of events showing key dates/milestones (i.e. contract award; field data acquisition; problems encountered; data processing; delivery of results; etc.).
 - A listing of all personnel (Contractor and Subcontractors) involved in this project detailing their particular duties and background (i.e. their educational background; formal GPS training details (courses with dates); their experience on similar projects, etc.) - this could be a copy of what was provided with the pre-qualification package.
 - A list of all hardware and software used on the project; including but not limited to:
 - GPS hardware (i.e. receiver model, antenna, 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.)
 - Detail regarding the GPS Reference Station used (i.e. private, local and/or government, validation status, etc.).
 - A summary of the project including planning, field data collection methods and parameters (i.e. GPS receiver settings/defaults), data processing methods and parameters (i.e. post-processing settings/defaults), any project problems, anomalies, deviations, etc.
 - An explanation of deliverables (digital and hard copy) including data formats, naming conventions, compression utilities used, media, etc.).
 - A copy of all field-notes (digital or hard copy).
 - A list of all features that have been mapped or surveyed.
- 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	Datum	Notes
GPS Reference Station Data	Proprietary or RINEX	WGS84	Merged if possible
Raw Field GPS Data	Proprietary or RINEX	WGS84	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 GPS data is to be provided in a digital format to be specified by the contracting Agency, and a hard copy map/plan may also be required. Map hard copies are to conform to Agency cartographic standards.

The following map submission is provided as a suggested minimum:

- Map Surround which includes the following project information: Project Title; Project Number/Identifier (e.g. provincial government’s ARCS & ORCS identifier); contracting Agency name; Contractor name; and date of survey.
- Plan datum (e.g. NAD83) and the Map Projection (e.g. UTM).
- Plan scale (e.g. 1:20,000) with BCGS map identifier.
- Plan orientation, (e.g. north arrow annotating True North, Magnetic North and Grid North).
- Geographic (e.g. latitude/longitude) and/or Mapping Projection (e.g. UTM) graticule as requested.
- Source of any non-project information (i.e. TRIM backdrop, Forest Cover data, etc.).

- 9.4. Final data (i.e. Original Corrected GPS data and Final Interpreted GPS Data) is to be reduced and presented referenced to the NAD83 datum. If the Contract Agency requires data to be provided on the NAD27 datum, then 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 are 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 (e.g. provincial government's ARCS/ORCS number, etc.).
- Type, model and version number of hardware used to collect and store data.
- GPS Reference Station used to correct field data (include coordinates and validation information).
- Details of post-processing conversions used.
- Software used in calculations and conversions and version number.
- Any non-standard data handling method, technique or principle used.

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 any significant changes in the Contractor's GPS system components (i.e., hardware, firmware, software, methodology, etc.) or personnel during the period of the contract, the Contractor **should** consult with the Contract Administrator. A decision will be made as to whether the Contractor GPS System Validation; the personnel qualification, and/or the GPS Reference Station Validation survey are required to be repeated.
- 10.2. The Contractor and the Contract Administrator **should** ensure that the most current versions of the PSGUC/RIC Standards are used.

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SECTION D - DGPS GUIDELINES

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1. INTRODUCTION

This portion 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 portion of the document 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 (i.e. equipment, measurement techniques, etc.).
- ii) Contract Management
- iii) Validation Concepts (i.e. GPS Contractors and GPS Reference Stations).
- 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 *DGPS Specification* 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 *DGPS Specification* section.

Release 3.0 of the PSGUC/RIC Standards includes a new Section (Section E) intended as a guideline for those considering use of autonomous GPS positioning for *non-critical* features.

Geographic Data BC (GDBC) 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.

2. GPS BACKGROUND

2.1 What is GPS?

The Global Positioning System (GPS) is a US military satellite system that provides continuous, accurate and instantaneous positioning 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 28 as of January, 2001) that

orbit the earth with a period of about 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 in the USA. The control stations monitor satellite performance, determine their orbits, model the atomic clock behavior, 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 (pseudorange), 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 *pseudorange* 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 (latitude, longitude and height). 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 *single-point* 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 has now exploded to the level where civilian users 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.

2.3 GPS Positioning Techniques

The mode of positioning described above (autonomous pseudorange) 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 (L1 & L2) which can produce instantaneous autonomous horizontal accuracies of ~5m (95%) using a single receiver. Civilian users have access to the SPS (Standard Positioning Service) via tracking of the C/A (Coarse Acquisition) code transmitted on 1 frequency (L1). Up until 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 overnight the SPS accuracy levels improved by an order of magnitude. Depending on the GPS receiver type used, horizontal accuracies of approximately 10m (95%) are now available autonomously under clear tracking conditions (accuracies typically degrade by a factor of 2–3 under forest canopy). Note that autonomous (single-point) GPS has low positional integrity (see *Section E* of this document for an explanation of positional integrity). It should be noted that vertical accuracies are typically 1.5–2.5 times worse than horizontal accuracies.

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

Differential GPS (commonly known as DGPS) is a technique based on a receiver operating at a previously surveyed location to allow measurement of instantaneous errors, and then make these available as differential corrections to other GPS receivers working within the local area. DGPS can produce 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. blockages, multipath, etc.)
- GPS field (rover) receiver type
- GPS Reference Station (base) receiver type
- GPS Reference Station and field receiver separation distance

DGPS surveys can be processed post-mission by merging the raw GPS data recorded at both the Reference Station (i.e., base) 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 Reference Station and rover (i.e. radio, satellite, cellular phone, etc.). 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 often 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 positional correction calculated at the Reference Station (corrections to latitude, longitude and height) which were then applied to the rover’s computed position. This methodology is also known as “spatial”, or “position-based” DGPS. This method provides reasonable accuracies *only* when the Reference Station and rover are tracking the *identical* set of satellites.

By the mid 1980s a more rigorous DGPS technique was developed by calculating the individual corrections to each pseudorange at the Reference Station, and applying these corrections to the rover’s measured pseudoranges before solving for the position. This marginally increased the accuracy and also relaxed the operating restrictions as it was no longer required for the Reference Station and the rover receivers to track the identical set of satellites. Note that some manufacturers still use a modified form of spatial DGPS in their current post-processing software, however, all receivers using real-time DGPS corrections are based on individual pseudorange corrections.

In the never-ending quest for improved accuracies, some early researchers recognized the possibility of using the GPS signal in a similar manner to VLBI (Very Long Baseline Interferometry). In this technique, the GPS phase angles of the carrier waves are tracked and recorded at a number of receiver sites, and is then processed together post-mission using software to form interferometric differences. This results in precise relative “baselines”, or vectors (3 dimensional coordinate differences) between each receiver 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 30 - 120 minutes of static observations being typical. The precision of these measurements range from a few millimetres to a few decimetres, and is usually expressed as a PPM (Part Per Million) of the baseline length. 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. GPS receivers that can track and record accurate carrier phase observations are generally classified as geodetic instruments.

Dual frequency receivers can take advantage of the “wide lane” technique (a numerical combination of phase measurements on the two 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 geomagnetic 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 accuracies possible nearly instantaneously. Kinematic solutions require the receiver to maintain phase lock on at least 4 or 5 satellites at all times. The original method for kinematic surveys was post-mission, but this quickly 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 accurate 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.

2.4 GPS Hardware and Software

This section is intended to give guidelines for evaluating GPS receivers and software, either for in-house use or for contractor validation. 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 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 is estimated to be over 500 GPS receiver models available from over 100 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 (January, 2001).

Use	Size	Best case accuracy (95%)	DGPS capable	Carrier Phase	Data Recording	Price Range
Recreational - Hiking, hunting, etc.	Hand-held, palm sized, watch	10+ m	Some	-	-	\$150 - \$700
General Navigation - Marine, aircraft, land vehicles etc.	Compact, external antenna	10+ m	Most	-	-	\$250 - \$2000
Low-End Mapping - standard-correlation code	Compact, external antenna	3-5m	Yes	Some	Yes	\$1500 - \$10,000
High-end Mapping - narrow-correlation code	Backpack, external antenna	1-2m	Yes	Most	Yes	\$7500 - \$20,000
Geodetic Surveying - single frequency	Backpack, external antenna	sub cm	Yes	Yes	Yes	\$7,500 - \$20,000
Geodetic Surveying - dual frequency	Backpack, external antenna	sub cm	Yes	Yes	Yes	\$15,000 - \$40,000

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 meet resource accuracy specifications, but are not considered here because of their lack of GIS/mapping functionality (e.g. data dictionary) and their poor 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 (\$):	\$1500 - \$10,000	\$7,500 - \$20,000
Accuracy (95%, best case):	3 - 5m	1 - 2m
Channels:	5 - 12	Usually “all in view” (≥8)
Tracking:	Parallel (some multiplexing)	Parallel
Carrier-Phase Smoothing:	Usually not	Usually
Other attributes:	Standard-correlation	Narrow-correlation with better multipath detection & rejection
Examples:	Magellan ProMark X CMT MC-GPS Trimble GeoExplorer III	Ashtech Reliance NovAtel GISMO Trimble ProXR

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 8 or more parallel channels will usually out-perform others. The receiver will be able to dedicate a hardware channel to each satellite in view. Measurements are made simultaneously and if a signal is interrupted (for example by a tree

stem), it can be used immediately upon re-acquisition. Some Low-End GPS receivers will use four parallel channels dedicated to four satellites, and one or more channels multiplexing, or rapidly sequencing between the other available satellites. This is an acceptable tracking scheme for open conditions, but the receiver's performance will not be as good under more difficult conditions.

The Signal Tracking Characteristics. 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 under forest canopy. These receivers will give better productivity and accuracy in most conditions.

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 2m - 3m. Carrier phase smoothing is a technique used by some High-End receivers to smooth the epoch-to-epoch range changes and thus produce "quieter" positioning (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 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 an effect on the 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 Reference 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 input from an external antenna, and often this produces better tracking performance than the built-in antenna.

Receiver Design. Some of the most accurate receivers may not be well suited for resource GPS work because of their layout. The receiver-antenna-controller combination must be designed for the type of work encountered. Most of the High-End receivers have a separate receiver, antenna, and data logger/controller connected by cables. These tend to be heavier and more awkward than Low-End receivers that typically integrate all three components in one unit. Generally, the integrated approach is good for projects where the GPS is a small portion of the total job, such as geo-referencing sample plots. The separate units are usually the best choice for projects where

the majority of the work involves GPS positioning. Of course, the accuracy performance is paramount when deciding which receiver type to use.

Robustness and Reliability. Forestry surveying 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.

Memory and Battery Capacity. It is important that the data collector be able to log all the data that can be recorded in a day – with some to spare as well. Less expensive receivers may have a fixed amount of memory, and perhaps are suited for only intermittent use rather than non-stop GPS data collection. Be aware that some GPS system prices may be quoted with inadequate memory, and the cost of additional memory should be considered. 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 corrections or the modified position corrections (see *Section D-8.1*). The software must be capable of importing reference station files in RINEX format if planning to utilize different manufacturer’s Reference 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 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 Bad 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 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 support, fax-back FAQ, web help, email, 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 Satellite Systems

GPS is an evolving system, and modernization announcements made during the late 1990s and early 2000 are worth noting here. Civilians currently have direct access to only the C/A code on 1 frequency (L1). This will change to 3 distinct frequencies (L1, L2 and a new frequency called L5). The C/A code will be added to L2, and an enhanced civilian code will be broadcast on L5. Broadcast power levels will also be increased from current levels. Collectively, these improvements will offer increased signal availability, reliability, integrity, accuracy, and resistance to radio interference. This modernization is phased over time, with the initial impacts likely beginning after 2003. Full impact, including a complete constellation of satellites with C/A code on L2 and enhanced civilian code on L5, is estimated at around 2010. It has been argued

that the removal of SA was in fact the first stage of GPS modernization, in which case we have already begun to experience its impacts.

GPS users should also be aware of other satellite positioning systems and augmentations that may be useful. GLONASS is a Russian system that is similar in design to GPS. Some receivers can track both GPS and GLONASS, which improves the available satellite coverage. This typically requires operating a dedicated Reference 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 has been degrading to the point where there were less than 10 operational satellites in 2000 (currently there are 9 operating satellites as of January 2001).

The European Union is planning to build a Global Navigation Satellite System (GNSS) to be called GALILEO. It is likely that this system will be structurally compatible with GPS, and dual system receivers will be possible. If GALILEO proceeds, it is likely that the system would be fully available sometime between 2005 and 2008.

There are also a number of regional systems designed to 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 the differential correction and integrity messages to end-users. This system utilizes Reference Stations across North America to compute a rigorous wide-area solution. WAAS signals are currently available, but the system has not yet been declared operational. The European and Japanese aviation authorities are building similar augmentation systems for their regions. Some WAAS capable receivers are now available, and this is expected to expand widely in the next few years. WAAS will be tested before it can be accepted for resource surveys in BC.

3. GPS OPERATIONS and CONTRACT MANAGEMENT

The entity 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:

- 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 some instruction and guidance provided by the 2-day RIC Field Operator training course, or by equivalency (i.e., direct supervision and training by a RIC Comprehensive GPS course Certificate holder 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, and training in the use of modems and communication software.

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 5-day RIC 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), 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 phases 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, interpreted, presented, and archived. As well, they are usually responsible for project planning, implementation, and completion. The GPS Project Manager should have taken the 5-day RIC Comprehensive GPS Training course, as well as have suitable 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 MoF 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 comfortable 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 send the raw data via modem to the GPS 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 - especially if the validation survey is completed - is intended to ensure that contractors (and Agency personnel) are at least competent to perform basic resource GPS surveys. Specific experience, expertise, equipment, past performance, cost and other factors (e.g. location, availability, emergency conditions, etc.) should be considered in evaluating potential contractors.

A list of validated GPS Contractors is maintained by Geographic Data BC and available on their Web page (<http://home.gdbc.gov.bc.ca/gsr>). It is recommended that this list be consulted as part of the RFP/ITQ review as certain information about the Contractors may already be recorded. Public Agencies should require potential Contractors to register (pre-qualify) with GDBC through the RIC GPS certification process.

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., monumentation to be used, distribution of monumentation, methods of demarcating features, information to be supplied on the physical markers, etc.).
- Deliverables, schedules, and work quality.
- Payment schedule.
- Other relevant contract issues.

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

3.6 Contract Specifications

This particular section of the document 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 F). 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 initialed 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 Contractor equipment and validation	D-2.4, D-4, D-4.2, D-7.2.1, D-8.6.1
C-4.5	GPS Reference 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 must start and 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 Reference Station	D-4.3.2, D-5.5
C-7.2	Reference Station rover separation distance	D-7.3, D-8.5
C-7.3	GPS Reference 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 reduced to NAD83	D-9.1
C-9.5	Vertical data reduced to CVD28	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 and re-Validation	D-4, D-11.1
C-10.2	The use of the current document versions	D-1, D-3

4. **PRE-QUALIFICATION & VALIDATION CONCEPTS**

The Public Sector GPS Users Committee (PSGUC) along with various government agencies (i.e. GDBC, MoF Resource Inventory Branch, etc.) has approached the issue of Quality Assurance (QA) for GPS resource surveys with a balanced effort to ensure quality with a minimum of additional bureaucracy. With this in mind, two general approaches deemed appropriate are by means of Training and by a Validation survey.

PSGUC in cooperation with the Resource Inventory Committee (RIC) has recently completed and implemented standardized GPS Training for the resource sector in support of the PSGUC/RIC Standards. ***It is highly recommended that Contractor personnel doing GPS-based resource mapping surveys in the province should have completed one of the formal, standardized RIC GPS courses (or has challenged the course) relevant to their duties.***

It is the vision of the aforementioned agencies that a series of Validation Test Ranges be established at approximately three to six sites around the province. The Validation Test Ranges would be set-up in typical forest canopy environments for a particular ecological region and attempt to replicate most, if not all, the typical GPS surveying tasks/features that are currently encountered by contractors. The Validation Test Ranges would be accurately surveyed horizontally and vertically and would thus serve as a benchmark for comparisons. However, at this time there are no GPS Validation Test Ranges easily accessible in the province. Therefore, the Contractor GPS System Validation procedures detailed below provide an interim solution.

Note: Experimental Test Ranges are currently being piloted in the Kamloops and Cowichan Lake area by the Ministry of Forests and in the Maple Ridge area by the Forest Engineering Research Institute of Canada (FERIC) and the University of British Columbia. Experience gained from these pilot sites, as well as other sources, will be used to guide the establishment of an appropriate validation program.

Also detailed below are the procedures for categorizing a GPS Reference Station and acquiring validation accreditation by Geographic Data BC, such that the GPS Reference 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. MoF 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 provincial government (e.g. MoF 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, validation surveys, and GPS Reference 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 Agencies satisfaction for the current field season before awarding contracts. Pre-qualification consists of appropriate training for all personnel and successful completion of a Contractor GPS Validation survey as outlined in Section D-4.2 below.

4.1.1 Training Requirements For GPS Contractors

For purposes of pre-qualification and validation, GPS Contractors should submit to the PSGUC Chair at Geographic Data BC, MoELP; a list of all GPS personnel in the 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 personnel is considered 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 Validation* survey (described below) may help in identifying potentially incompetent contractors - both to themselves and to contracting agencies.

It should be noted that there has been very little formal requirements of people providing the GPS training. In the past, having a GPS training course approved requires simply submitting a proposed syllabus to an Agency representative who may have minimal knowledge or experience with the essential topics. There was no test that that material would be presented competently or even correctly. It has been observed over the years that misinformation is being spread through these types of courses.

The PSGUC in cooperation with the Resource Inventory Committee (RIC) has completed contracting services to address and rectify most of these training issues. Currently, two standardized GPS Training courses for the resource-sector in support of the PSGUC/RIC Standards have been completed. The complete process (i.e., distribution, currency issues, certification, etc.) has been finalized and is administered by the Forestry Continuing Studies Network (FCSN). Information regarding these courses can be obtained from the following two sources:

Course Content Administrators

Public Sector GPS Users Group (PSGUC)

Attn: Amin Kassam, P.Eng., Chair

c/o Ministry of Environment Lands and Parks, Geographic Data BC

PO Box 9355 STN PROV GOVT
1st Floor, 810 Blanshard Street, Victoria, BC, V8W 9M2
Phone: 250-387-9157 Fax: 250-356-0969
<http://home.gdbc.gov.bc.ca/gsr/psguc/psguc.htm>

Course Administration/Facilitator

Forestry Continuing Studies Network Society (FCSN)
2665 East Mall, Vancouver, BC, V6T 1W5
Phone: 604-222-9157 Fax: 604-222-1730
<http://www.fcsn.bc.ca>

British Columbia provincial GPS standards require specific levels of expertise for Data Processors and Project Managers submitting data to the provincial government. It is **highly recommended** that all GPS operators successfully complete the appropriate course or successfully challenge the course through the GPS Challenge Process (see below for information on the Challenge Process).

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 RIC GPS training courses for all levels of GPS operations personnel. Similar 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. MoF 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 RIC GPS Training courses and delivered on-site by RIC-approved instructors who have completed higher levels of training and who have extensive GPS experience. An essential component of that training would be fieldwork on actual 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 RIC GPS 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 Standardized RIC GPS Training Courses

This section of the *DGPS Guidelines* provides a brief overview of the two current RIC GPS training courses. Thirteen core modules were developed that provide the information necessary to form the two existing RIC GPS training courses. Future course may also be developed from these modules. The core modules are listed below:

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	RIC 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	
	Participant Evaluation & Practical Exercises	

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 time, field exercises, data interpretation exercises, and 3 separate competency evaluations for all participants (passing grade is 75% in all evaluations). Students will also be required to complete an independent GPS validation survey within one month after the course. Provincial RIC certificates will be issued by FCSN upon meeting all requirements.

The audience for this course is typically industry personnel, consultants and government employees responsible for the design, implementation 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 and QA.

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 time, 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. Provincial RIC certificates are issued by FCSN 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.

4.2 GPS Contractor Validation Survey

Errors in GPS surveys are not as intuitively obvious as conventional surveys such as compass and chain surveys. There is no “magic” closure formula or balancing procedures that 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. The concept of a GPS Validation survey can be very useful in the pre-qualification process for GPS Contractors.

To objectively evaluate the abilities of a GPS Contractor, a validation survey is required. A validation survey tests the operator’s results against a benchmark. The ideal benchmark would be a true Validation Test Range. A Validation Test Range is an area with marked point, line, and area features with accurately known coordinates. Such a range would have canopy conditions and feature scales chosen to simulate actual surveys in that area. A less ideal validation survey could be performed on existing survey monuments, and point coordinates compared.

Validation Test Ranges should be designed by personnel with extensive knowledge of the forest canopy conditions and the types of resource surveys performed in the area (specifically forestry surveys). The design of the Test Range should closely mimic actual field conditions in order to be useful. Qualified personnel well versed in geodetic methods should perform the initial survey of the range. Assessment of validation results should be strictly controlled, and statistically and scientifically defensible in order to ensure fair trials for all GPS Contractors. The locations of the Validation Test Ranges and the work required of Contractors to complete the validation surveys should also be carefully considered. It has been suggested that an ideal Validation would take one day to observe - this would include expected travel time and the field survey time spent on the Validation Test Range.

The purpose of the *Contractor GPS System Validation* is to quantify the levels of accuracy achievable from a contractor’s particular “GPS System” and to qualify the separate components of the Contractors GPS System. The GPS System includes not only the hardware (i.e. receivers, antenna, etc.) and software, but also the Contractor personnel that plan the survey, manages the data collection and process and presents the results. Once a Contractor’s GPS System is validated to a certain level of accuracy, future projects with similar accuracy targets can be undertaken with confidence in the accuracy achievable. It should be noted that the GPS Validation Survey is a baseline model for the Contractors themselves to use as a standard for comparing hardware or software innovations, or comparing different GPS receivers. It should be a Contractor’s tool as much as a Contract Administrator’s tool.

The conditions under which a *Contractor GPS System Validation* is conducted form the basis for future project work (e.g. DOP limits - refer to *Section D-7.2.3* of the *DGPS Guidelines*). The contractor has the freedom to set the conditions under which the validation is performed, with the understanding that these conditions define future working limits. The GPS System and conditions that should be consistent between validation and production surveys include:

- key Personnel (Project Manager, Data Processor)
- type of rover hardware
- type of GPS Reference Station receiver (e.g., narrow-correlation)
- processing software (type and version number)
- observational parameters such as DOPs, SNR, and elevation masks
- separation distances between Reference Station and rover
- number of epochs (fixes) averaged at static points

The specific requirements for the *Contractor GPS System Validation* survey will vary according to the desired level of accuracy to be achieved for the project and operational constraints. The following steps are suggested:

- Contractor should attempt to simulate the actual project conditions (see factors listed above)
- Contractor should collect data while occupying at least 2 different provincial NAD83 geodetic control monuments (GCMs)
- GCMs should have a known accuracy of better than 0.1m corresponding to projects requiring 1m or 2m accuracies; and GCM accuracies of better than 1.0m corresponding to projects requiring 5m or 10m accuracies (all values at 95% confidence).
- the Validation Survey must statistically show absolute agreement (horizontally and/or vertically) with the geodetic control at the target accuracy level(s).

A sample *Contractor GPS Validation Survey* report has been supplied in *Appendix D* of this document. This report and the information provided within, will assist those GPS Contractors in providing a *Contractor GPS Validation Survey* report, and will reduce the turn-around time from time of validation survey to time of acceptance. This report contains the minimum amount of information required. Contractors providing more information for analysis are encouraged to do so.

Provincial geodetic control information may be obtained from GDBC, MoELP, at their Web-site: <http://home.gdbc.gov.bc.ca/gsr> (follow the link to MASCOT).

4.2.1 GPS Contractor Equipment

The GPS equipment (i.e. hardware and software) used by the Contractor will affect how accurately and how productively they can perform their job. 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 certain types of receivers in a document of this scope.

Certain equipment, such as older inexpensive hand-held or PCMCIA based receivers meant for general navigation are not appropriate for resource GPS surveys. These are precluded by the requirement in the data capture specifications that position fixes be determined from at least four simultaneous pseudoranges. Older navigation receivers usually do not have four parallel channels and thus cannot perform simultaneous measurements.

However, some receivers with four or more parallel channels may also not be appropriate for resource GPS. It is very difficult for Agency personnel to assess a contractor's equipment without extensive independent testing. It should be left to the Contractor to choose a receiver that

will meet the accuracy requirements of the survey. The quality assurance process outlined in *Section D-11*, or a *Contractor Validation Survey* as discussed above, will ensure that the equipment and software meets the project requirements.

One indicator of whether or not the equipment will meet the requirements is if the receiver and software are being used successfully elsewhere in the industry. Currently, most of the resource GPS surveys in the province is done with one type of receiver, a “High-End” system that performs well under forest canopy. Although this does not mean other manufacturer’s receivers are not appropriate (it may even be that some will perform as well or even better), it does give an indication for Agency personnel evaluating a new contractor’s receivers and software.

Most government resource Agencies will be acquiring GPS receivers and in-house expertise over the next few years. These receivers will be used to perform small projects or sensitive projects, which should not be done by industry. They will likely also be used to provide quality assurance on work submitted by contractors. The guidelines in *Section D-2.4* give some qualities to look for in evaluating equipment. It is preferable that each Agency centrally evaluates appropriate receivers and publishes (for internal use) a report recommending certain specific hardware and software, along with training and implementation guidelines.

4.3 GPS Reference Station Validation

GPS rover data collected in the field should be corrected using data from a high quality GPS Reference Station (or a valid real-time DGPS service) in order to meet the accuracy requirements of this document. The Reference Station should use appropriate GPS equipment, and have an accurately surveyed location. Many of the issues regarding Reference Stations are discussed in the next section. Geographic Data BC of the Ministry of Environment, Lands and Parks has undertaken to perform validation of temporary and permanent GPS Reference Stations in the Province

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

Some contractors maintain their own network of permanent Reference Stations across BC. When properly established, this is an acceptable method of generating differential corrections. These GPS Reference Stations may result in improved rover accuracies when the distance from the project site is less to a contractor’s Reference Station than it is to a BC ACS site. The three primary concerns for contractor Reference Stations are:

- i) Establishing accurate NAD83 coordinates for the GPS Reference Station antenna.
- ii) Ensuring that the site does not experience gross multipath effects.
- iii) Utilization of a good quality GPS receiver system and knowing the limitations of the system for the users.

Any error in the GPS Reference Station coordinates (latitude, longitude or ellipsoidal height) will be directly transferred to the differentially corrected rover’s position. Establishing these

coordinates must be done using a survey method that is an order of magnitude more accurate than the DGPS methods that will be used from this Reference Station.

4.3.1 Permanent GPS Reference Station Validation

As of January, 2001, the validated GPS Reference Stations in BC include 10 BC ACS, 4 Canadian Coast Guard (real-time only), and 11 private GPS Reference Stations. From a data quality standpoint, these GPS Reference Stations can be considered equivalent for resource GPS surveys at the 2-10 m level. The status of validated Reference Stations can be checked at: http://home.gdbc.gov.bc.ca/gsr/gsr_standards.htm

One significant factor that should be considered when choosing a GPS Reference Station is the atmospheric conditions for the project. One of the main sources of error remaining in GPS observations is the perturbation of the signals as they travel through the atmosphere (ionosphere and troposphere). Projects in areas subject to bad ionospheric conditions (e.g. Northeast BC) should use a Reference Station located in similar local conditions. Likewise, projects in the warm humid climate of the Queen Charlottes and much of Vancouver Island should use a Reference Station located in similar conditions.

4.3.2 Temporary GPS Reference Stations

On some projects it may be desirable to establish a temporary GPS Reference Station. Reasons for this are described here. The highest accuracies can only be reliably achieved with relatively small separations between base and rover (~100 km). Surveys with a high relative accuracy requirement may benefit from a local GPS Reference 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 Reference Station may be the most effective way of implementing real-time DGPS. Finally, in remote project areas a local GPS Reference Station may be the only way of obtaining timely correction data due to unavailable, unreliable, or expensive data communication facilities.

The general procedures for validating permanent or temporary GPS Reference Stations are listed below in the next section. In essence, the position of the temporary GPS Reference Station must be surveyed with an accuracy one order of magnitude better than the DGPS surveys that use the Reference Station required. This can be achieved in the simplest form by occupying an existing GSR control monument; or processing L1 pseudorange data from at least three existing, validated GPS Reference Stations; or to the most complex method of executing a local GPS survey with phase data processing.

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 Reference Station position. The adopted position may be from an averaged autonomous solution resulting in horizontal accuracies <10m and vertical accuracies < 15m (95%). Any rover positions differentially corrected with these adopted Reference Station coordinates can not be considered accurately referenced to NAD83. If the rover data is to be integrated into a mapping database at some later time, a better solution for the temporary GPS Reference Station position must be made. This could involve establishing an accurate NAD83 position for the Reference Station and re-processing all the rover data. Alternatively, the coordinate shifts (3D) between the initial adopted coordinates and the accurately surveyed coordinates could be simply applied to all rover positions. In either case, it is especially important to observe sufficient map ties in the field, to document all steps well, and to carefully manage the resulting data so that only the final coordinates are used.

4.3.3 GPS Reference Station Validation Procedures

GPS Reference 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 Reference Station that must be used. These categories are shown in the following table (also refer to Section B-3.4 of the Standards):

GPS Reference Station Category	Proposed Project Horizontal Network Accuracies	Reference Station Horizontal Network Accuracy	Proposed Project Vertical Network Accuracies	Reference 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 Reference 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 ellipsoid heights. Orthometric heights are referred to the Canadian Vertical Datum of 1928 (CVD28). Vertical Reference Station Categories are more difficult to meet than their Horizontal counterpart due to:

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

A GPS Reference Station, classified as above, may support all lower categories but not higher categories. For example, if a GPS Reference 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 Reference Station Validation process also includes an evaluation of a long GPS data set (minimum 24 hours) processed against data from one or more BC ACS stations. These data are to be collected using the same GPS system that will be permanently installed at that GPS Reference 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 in time). An acceptable GPS Reference 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.

The following subsections provide some typical procedures, issues, survey methodologies, and survey returns for the validation of all categories and types of GPS Reference 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 – Geographic Data BC will entertain alternative proposals as well.*** This document also provides a sample GPS Reference Station Validation report, which has been included in *Appendix E*.

The *GPS Reference 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 Reference Station (i.e. conventional or GPS); and
- B) Validation of the actual control survey of the GPS Reference Station.

The submission of a GPS Reference Station Validation should clearly define which GPS Reference Station Category (e.g., Horizontal I, II, or III) is being applied for. The basic differences between the GPS Reference Station categories are:

- i) the accuracy of the Geodetic Control Monuments (GCMs) used;
- ii) the survey methodologies used in the control survey process; and
- iii) the GPS receiver/antenna utilized for the GPS Reference Station (see discussion of GPS Reference 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 Reference 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 compass/tape traverses to geodetic GPS receivers); and lastly the quality of the GPS equipment (i.e. receiver, antenna, firmware, etc.) used for GPS Reference Stations varies.

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

A. Survey Equipment Validation Phase

A.1 Survey Design

- i) *If conventional equipment is used (i.e. theodolite and EDM) to survey the GPS Reference 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 Geographic Data BC (GDBC) - 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 GDBC, who will then process the data through specialized software.
- ii) *If GPS equipment is used to survey the GPS Reference Station then; depending on what GPS Reference Station category is being applied for; a GPS Validation must be performed either on one of the GPS Basenets throughout Canada, or on accurate/precise local geodetic control monuments (GCMs).*
 - A GPS Validation survey plan to the GDBC indicating how you plan to perform the validation survey (i.e. which stations you will occupy, sessions, baseline lengths, etc.).
 - GDBC staff will examine the design and 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 Reference Station is going to be surveyed to Category I Standards using static GPS methodologies from local geodetic control monuments within 30km of the proposed Reference Station - then the GPS Validation survey should attempt to replicate this survey on the GPS Basenet
 - Depending on which GPS Reference 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.
 - One important aspect of both the Equipment Validation survey and the Reference Station survey is the concept of 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 GDBC supplied form.
- ii) GPS Validation returns consist of the following items (these items vary depending on what category GPS Reference 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; 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 Reference Station Control Survey Validation Phase**B.1 Survey Design**

- i) Provide a survey plan to the GDBC indicating how you plan to perform the GPS Reference Station survey (i.e. which geodetic control monuments you will occupy, survey methodology, etc.).
- ii) GDBC staff will examine the survey design and 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 Reference Station.
 - Although the Control Survey Specifications refer to orders of surveys (i.e. 1st-order, 2nd-order, etc.) versus Network and Local coordinate accuracies; the procedures and guidelines provided are still relevant for the Category I, II and III GPS Reference Station surveys.
- ii) It will be evident from the procedures taken and the final adjustment results whether the GPS Reference Station Validation supplied will be acceptable for the category of GPS Reference Station being applied for.

- iii) One important aspect of both the Survey Equipment Validation survey and the GPS Reference Station survey is the concept of reliability; specifically, in the form of double occupations of all pillars/control monuments 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 Reference 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 Reference Station survey (i.e. observation scheme); equipment used; software used; hardware used; personnel used; problems, etc.
 - Intermediate GPS processing results (i.e. baseline, sessional adjustments, etc.) and adjustment results (i.e. adjustment input/output files).
 - Digital GHOST-format files (i.e. GPS baseline/sessional observations and covariance/correlation information).
- iii) GPS Reference Station details, will include (but not be limited to):
- A final survey report (see Appendix E).
 - Multipath analysis sample data set (minimum 24 hours).
 - GPS Reference Station location details (i.e. pictures, diagrams, proximity to obstructions, etc.).

As noted above, a sample *GPS Reference Station Validation Report* has been supplied in *Appendix E* of this document. This report and the information provide within, will assist those GPS Reference Station operators in providing a *GPS Reference Station Validation* and will reduce the time between submission of the validation survey to the time of acceptance. This report is 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 Reference Station categories:

Phase	Category I	Category II	Category III
A. EQUIPMENT VALIDATION	<ul style="list-style-type: none"> GPS Static Survey 	<ul style="list-style-type: none"> Phase-GPS or Conventional 	<ul style="list-style-type: none"> GPS (code & phase) or Conventional
a.1 Survey Design	<ul style="list-style-type: none"> GPS Basenet 	<ul style="list-style-type: none"> GPS Basenet, or GCMs standard deviations of 0.25m EDM baseline 	<ul style="list-style-type: none"> GCMs with standard deviation of 1.0m (or better) GPS Basenet EDM baseline
a.2 Survey	<ul style="list-style-type: none"> GPS Static 	<ul style="list-style-type: none"> EDM Validation Guidelines GPS occupation to replicate control survey (i.e. same settings and methodology) 	<ul style="list-style-type: none"> EDM Validation guidelines GPS occupation to replicate control survey (i.e. same settings and methodology)
a.3 Deliverables	<ul style="list-style-type: none"> Report GPS Validation Format see Control Specifications 	<ul style="list-style-type: none"> Report GPS Validation Format see Control Specifications 	<ul style="list-style-type: none"> Report GPS Validation Format see Control Specifications
B. CONTROL SURVEY VALIDATION	<ul style="list-style-type: none"> GPS Static Survey 	<ul style="list-style-type: none"> GPS Survey or Conventional Survey 	<ul style="list-style-type: none"> GPS Survey or Conventional Survey
b.1 Survey Design	<ul style="list-style-type: none"> Submitted to GDBC before survey for approval 	<ul style="list-style-type: none"> Submitted to branch before survey for approval 	<ul style="list-style-type: none"> Survey design not required, but suggested
b.2 Control Survey	<ul style="list-style-type: none"> Static GPS methods Tie to at least 3 surrounding precise local control points (0.025m or better) 	<ul style="list-style-type: none"> Static GPS (phase), or Conventional Survey Ties to at least 3 surrounding GCMs (0.025m or better), or Ties to at least two BC ACS stations and one local GCM 	<ul style="list-style-type: none"> GPS (code & phase) or Conventional Ties to at least 3 surrounding GCMs (0.05m or better), or Ties to at least two BC ACS stations and one local GCM
b.3 Deliverables	<ul style="list-style-type: none"> Report Network Adjustment 24hour data set see Control Specifications 	<ul style="list-style-type: none"> Report Network/Coordinate Adjustment 24 hour data set 	<ul style="list-style-type: none"> Report Network/Coordinate Adjustment 24 hour data set

Table D- 4 General Procedures for Various GPS Reference Station Categories

4.3.4 Other Issues

There are a number of new or emerging technologies for spatial positioning (e.g. WAAS, GLONASS, GALILEO, Global Surveyor™, CDGPS (based on GPS*C), US National DGPS, etc.). More information can be found in *Section D-2.5* and at the internet references listed in Appendix B. These technologies and their impact on resource surveys will be monitored as they develop.

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 neither practical nor desirable 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 interpretative boundaries. 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 most definite “natural” features and one of the easiest to follow it is easy to see where errors can be introduced into the survey.

Realistically, an interpretative uncertainty surrounding most natural features should be expected (*Section B - 3.3* of the *Standards* gives some examples of interpretative accuracies). The feature’s position data should be considered no more accurate than this interpretative 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 interpretative uncertainty, and the

feature can be mapped to the accuracy limitations of the GPS receiver (which depends, of course, on equipment, methods, multipath environment, etc.).

One example of a Ministry providing boundary definitions is provided below - the following information is provided from the Ministry of Forests, Resource Inventory Branch documents currently being developed:

- *Pre-harvest boundary traversing: pre-established ribbons or painted marks on tree trunks (e.g. 1 metre from the painted trees toward the inside of the polygon);*
- *Post-harvest boundary traversing: drip-line (line connecting perimeters of tree crowns that are projected to the ground), or line of disturbance (if no standing trees);*
- *Silviculture treatment: stump line (line connecting all identifiable tree stumps within the cutblocks), or line of disturbance;*
- *Burnt, selective logging, and windfall areas: drip-line (defined above) if affected trees are standing, and stump line if affected trees are fallen or removed;*
- *Forest service roads and recreation trails: centre-line (or a constant offset line for safety reasons).*
- *Other boundary lines: roadside lines, stream lines, edges of a lake, river, marshy area, swamps 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 Interpretative 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 datum (assuming an approved GPS Reference Station was used). These positions can be transformed to other datums such as NAD27 using specific transformation software.

Unfortunately, some existing maps in BC are not based on any accurate mathematical datum. 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 15 metre buffer.

Map ties are features that are identifiable on the map or other base (e.g. orthophoto) and which have GPS positions observed. 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 the existing map may be shifted to fit GPS. If sufficient map ties exist, or if the mapsheet has a known relationship to NAD83, 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 Reference 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 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 are established by ground survey where the corners and boundaries are physically marked on the ground or they are 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 where they do not coincide with a cadastral boundary.

5.4.1 Determining Cadastral Boundaries

Only a British Columbia Land Surveyor (BCLS) 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 a legal opinion on the location of a cadastral boundary.

The location of a cadastral boundary must be determined on the ground, where the limit of a forest tenure boundary lies within 150 metres of the cadastral boundary as depicted by Crown Land Registry Services spatial data.

The contractor and the ministry representative must consult a BCLS if all or part of a project is defined by cadastral boundaries where the condition of the survey evidence or the method in which the cadastral boundaries were defined is in doubt. The BCLS will advise if establishment or reestablishment of certain boundaries is recommended or required.

A survey technician may find and use survey evidence so long as the survey technician has adequate previous experience and training by a land surveyor in locating legal survey evidence. A survey technician may use such survey evidence to relate the location of features relative to a line intended by the technician to represent the cadastral boundary and to locate and mark a licensee's cut line to the limits described below. It should be noted that a line intended to represent a cadastral boundary that is determined by a technician is not necessarily the true cadastral boundary. Cadastral survey boundaries may only be legally located on the ground by a British Columbia Land Surveyor (B.C.L.S.). **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.**

Where the limits of a previously surveyed cadastral boundary must be determined and **all original posts are found** in place, the licensee may cut to a line located and marked by a technician and situated no closer than 20 metres from the intended cadastral boundary. The licensee may cut to the boundary where the cadastral boundary is certified by a British Columbia Land Surveyor (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, the licensee may cut to a line calculated, located and marked by a technician and situated no closer than 30 metres from the intended cadastral boundary. The licensee may cut to the boundary where the cadastral boundary is defined by a British Columbia Land Surveyor (B.C.L.S.).

Where a B.C.L.S. is engaged, he or she 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.

Questions regarding requirements for surveys of cadastral boundaries should be directed toward the Office of the Surveyor General of the Crown Land Registry Services of the Ministry of Environment, Lands and Parks. Plans and notes of district lots, sections and blocks are available from the Office of the Surveyor General.

5.4.2 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 BCLS regarding the establishment of that boundary.

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

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.).

The spacing of reference markers is determined by the operational requirements of the survey. For example, the **Forest Practices Code Guidebooks** for Forest Road Engineering and Boundary Marking have specific requirements for spacing and establishment of reference markers. Other survey requirements should be established in advance of the GPS survey.

All reference markers should be captured as static point features (see *Section D-7.1.1*), and offsets 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.

It should be noted that there may be discrepancies between contract accuracies required, and the definition of Network Accuracy in this document. For example, the FPC Boundary Marking Guidebook requires ... “Where global positioning systems are used, each ground reference point should be within 5 m of its mapped location.” However, the FPC Guidebook does not state a statistic to be used (i.e. is this 5m accuracy value expressed at 50%, 68%, 95% or some other confidence level?). It is recommended that discrepancies such as these be identified and resolved in advance to avoid confusion and the application of inappropriate standards.

The MoF Resources Tenure and Engineering Branch (RTEB) have defined one example for the

establishment and methodology of semi-permanent markers. This Branch has established standards for block layout traverses that are used for tenure definition (known as “Exhibit A”). These standards apply to conventional surveys as well as GPS surveys...

Example:

- (1) *The semi-permanent reference markers shall be established at least every 100 metres along the line being surveyed.*
- (2) *PoC (Point of Commencement) shall be taken from the nearest:*
 - *surveyed corner of a Lot, Block, Sublot, Section, Legal Subdivision or Indian Reserve (corners of T, TL, STL, or Timber Berth are not acceptable);*
 - *existing geodetic control monument triangulation stations (horizontal ties); or*
 - *confluence of named creeks and rivers (when a confluence is used right or left bank must be specified, e.g. PoC 100 m north and 20 m east of the confluence of Ken Creek on the left bank thereof and the Anita River on the right bank thereof).*

If it is difficult to find a suitable PoC in a reasonable distance from the feature being surveyed, a “tie point” shall be established at the junction of the main and the access road. This point shall be tied to station 1 of the polygon (i.e. the first measurement point along the survey block).
- (3) *PoC shall be tied to station 1 on the block being surveyed.*
- (4) *The stations shall be marked with unique sequential number, the first station starting with number one.*

The location, type, and identifier of these markers must be included on 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 surveyor walks the boundary being mapped with GPS receiver continuously logging the position of the antenna. For each reference tree, for example, then GPS Operator must stop, write on an aluminium tag, place it on the tree, flag the tree, and stay for the amount of time required to capture a GPS static point feature. The time required doing 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 four satellites, and limits on the Dilution Of Precision (DOP) values.

With a full constellation available, GPS planning is not as crucial as it once was. Users can generally assume there will be at least four satellites with reasonable geometry at most times of the day. This does not necessarily mean that the GPS coverage is balanced throughout the day. Typically there will be periods of the day that are more productive than others, and satellite prediction planning will identify these periods. In difficult project areas such as under heavy forest cover or mountainous areas with many terrain obstructions, it is important to plan fieldwork 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 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 widely available and are included with most commercial receiver/software packages. Also, there are free programs available on the Internet (downloadable versions, and on-line predictions). The more sophisticated planning packages will allow a user to apply variable satellite elevation thresholds, disable / enable individual satellites, simulate local obstructions, and generate detailed reports and PDOP, HDOP, and VDOP plots.

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

The U.S. Coast Guard's NAVCEN is the official source of civilian information for GPS (<http://www.navcen.uscg.mil/gps/default.htm>). The NAVCEN publishes daily GPS status messages known as NANUs (Notice Advisories to NAVSTAR Users), which alert users of planned satellite outages (e.g. down time for maintenance), as well as unplanned satellite outages. NANO 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 is helpful to give the field crews satellite visibility plots for specific times and they can adjust their schedules in the field accordingly.

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 requires 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 sub-sections, guidelines are provided for identifying possible features that will be mapped/positioned with GPS. The methodology of defining features in the field are 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 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 or cut block edge). These data collection methods are called "static" or "dynamic" modes respectively. 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 suggest 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 produce 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 antenna must be stationary during GPS 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.

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.

It must be noted that the values provided below are a guideline only that is based on both theoretical and empirical studies; for one particular GPS receiver (i.e. “High-End” narrow-correlation receiver); particular observational settings (e.g., PDOP better than 4.0) and specific site conditions (i.e. good horizon, “quiet” GPS environment, etc.).

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

Table D- 5 Static Data Collection – Suggested Duration and Number of Fixes

7.1.1.1 Standard and High Significance Static Point Features

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 also considering the additional time and costs this will cause). 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 Horizontal Network Accuracy = 10m; then the High Significance PoC/PoT point features should be surveyed to Horizontal Network Accuracy = 5m.

7.1.2 Linear Features - Dynamic Mode

Line features consist of a number of 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 antenna along the linear feature to be mapped while collecting GPS position fixes at a specified time interval. This time interval will be chosen based on the resulting distance between position fixes, which includes consideration of the 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 at all times. 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 35 km/hr (~10m/s), then the data collector must be capable of recording one fix per second. Note that some GPS systems claim a one-second recording rate, but can only sustain this when tracking less than 5 satellites.

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

Example Modes of Transportation	Speed (m/s)	Data Collection Rate (s) And corresponding Point Separation (m)
Walking	1.4m/s (5km/h)	@1.0s separation = 1.4m @5.0s separation = 7.0m
Bike	4.2m/s (15km/h)	@1.0s separation = 4.1m @5.0s separation = 21m
Vehicle – slow Helicopter – working	8.3m/s (30km/h) (16 knots)	@1.0s separation = 8.3m @5.0s separation = 42m
Vehicle – fast	17m/s (60km/h) (32 knots)	@1.0s separation = 17m @5.0s separation = 84m
Helicopter – ferrying	28m/s (100km/h) (54 knots)	@1.0s separation = 28m @5.0s separation = 139m
Aircraft - fast (fixed-wing)	83m/s (300km/h) (162 knots)	@1.0s separation = 83m @5.0s separation = 417m

Table D- 6 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. 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" (also referred to 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). 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.

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. By setting a 0.25-second (4 Hz) time requirement, these receivers will be precluded from using this survey mode.

For applications utilizing GPS Events, the speed of the GPS antenna, the data collection rate and the target accuracy must be taken into account.

It is recommended that the positioning of GPS Events must be accurate to one-half of the project accuracy specification, and thus, the timing accuracy is calculated based on this positioning accuracy. For example, if the accuracy specification is 10m and the travelling speed is 50km/h (14m/s), Event times must be accurate to one half of 10m divided by the speed (i.e. 5m divided

by 14m/s = 0.36 seconds).

Desired Network Accuracy	Receiver Speed	Required GPS Timing Accuracy
1.0 m	5km/h (1.4m/s)	0.36 seconds
	30km/h (8.3m/s)	0.06 seconds
	60km/h (17m/s)	0.03 seconds
	100km/h (28m/s)	0.02 seconds
	300km/h (83m/s)	0.01 seconds
2.0 m	5km/h (1.4m/s)	0.72 seconds
	30km/h (8.3m/s)	0.12 seconds
	60km/h (17m/s)	0.04 seconds
	100km/h (28m/s)	0.04 seconds
	300km/h (83m/s)	0.01 seconds
5.0 m	5km/h (1.4m/s)	1.80 seconds
	30km/h (8.3m/s)	0.30 seconds
	60km/h (17m/s)	0.15 seconds
	100km/h (28m/s)	0.09 seconds
	300km/h (83m/s)	0.03 seconds
10.0 m	5km/h (1.4m/s)	3.60 seconds
	30km/h (8.3m/s)	0.60 seconds
	60km/h (17m/s)	0.30 seconds
	100km/h (28m/s)	0.18 seconds
	300km/h (83m/s)	0.06 seconds

Table D- 7 Desired Point Accuracy vs. Speed & Timing Accuracy

7.1.6 Point and Line Offsets

Often it is desirable to use offsets from the GPS antenna to the feature being located 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.

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, 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 in the range of 0.3 to 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 best source of magnetic declination in Canada is GSC, and values can be computed using their on-line Magnetic Declination Calculator:

http://www.geolab.nrcan.gc.ca/geomag/e_cgfr.html

Magnetic variation 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 distortion 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.

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

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

Table 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 may be safer to survey this feature in a vehicle driving in the right-hand lane, with an offset of 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).

It is suggested that point offsets the following rules apply:

- Linear offset distances should be limited to 5m (since it is difficult to maintain a constant parallel offset for distances 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 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 between the GPS PoC and PoT can be stated as a ratio of the distance plus half the Network Accuracy requirement of the GPS survey. The following table provides some guidance on providing this specification. Any misclosure in the traverse must be balanced according to the contracting Agencies procedures.

Target Accuracy (Horizontal Network Accuracy)	Specification	Distance Traversed	Expected Closure	Specification Achieved
2.0m	1:100 + 1.0m	250m	2.5m + 1.0m = 3.5m	-
		500m	5.0m + 1.0m = 6.0m	-
		1000m	10.0m + 1.0m = 11.0m	-
	1:500 + 1.0m	250m	0.5m + 1.0m = 1.5m	Yes
		500m	1.0m + 1.0m = 2.0m	Yes
		1000m	2.0m + 1.0m = 3.0m	-
5.0m	1:100 + 2.5m	250m	2.5m + 2.5m = 5.0m	Yes
		500m	5.0m + 2.5m = 7.5m	-
		1000m	10.0m + 2.5m = 12.5m	-
	1:500 + 2.5m	250m	0.5m + 2.5m = 3.0m	Yes
		500m	1.0m + 2.5m = 3.5m	Yes
		1000m	2.0m + 2.5m = 4.5m	Yes
10.0m	1:100 + 5.0m	250m	2.5m + 5.0m = 7.5m	Yes
		500m	5.0m + 5.0m = 10.0m	Yes
		1000m	10.0m + 5.0m = 15.0m	-
	1:500 + 5.0m	250m	0.5m + 5.0m = 5.5m	Yes
		500m	1.0m + 5.0m = 6.0m	Yes
		1000m	2.0m + 5.0m = 7.0m	Yes

Table D- 9 Supplemental Traverse Closure Requirements

Example:

One example of a specification for a supplemental traverse is within the Ministry of Forests, Resource Inventory Branch Standard Procedures document, the specification of 1:100, plus 5 metres is provided (Target Requirement for GPS Surveys is 10m). In this example, a supplementary traverse of 300 metres must close to 8 metres (3m + 5m). The misclosure is balanced according to standard Ministry procedures (a compass rule adjustment).

7.2 GPS Equipment, Settings and Techniques

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

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 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 6 is considered a minimum (many new hand-held recreational receivers now have 12 parallel channels). GPS Reference Stations can typically track 10 or more satellites to ensure that all available measurements are recorded. The current GPS constellation (January, 2001) provides coverage across BC with between 6 and 10 satellites simultaneously above 10 degrees elevation. Any receiver with 10 or more channels can therefore be considered “all-in-view”, whereas receivers with less than 10 channels must select a sub-set of the available satellites to track. Some receivers automatically select the sub-set with the strongest fix geometry (e.g. lowest PDOP), while others require the operator to manually select the satellites they will track. Under conditions with intermittent satellite obstructions, a receiver with many channels will outperform one with fewer channels. Some manufacturers offer entry-level receiver configured with a limited number of channels, with an option to later upgrade to a higher number of tracking 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 improvement can be expected with the increased broadcast power and the enhanced civilian code on the modernized GPS satellites expected to be available after 2003.

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 Reference 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 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 multipath 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 surveyed by conventional methods under tree canopy.

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 Reference 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 Reference 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 of known location are required to solve for the antenna position (Latitude, Longitude, and Height) as well as the receiver clock offset. Regardless of whether or not the elevation is important to the specific GPS survey, accurate position fixes are only possible when four or more satellites are used. If the antenna's ellipsoidal elevation is known accurately, it is possible to fix this and compute only the latitude and longitude. However, this elevation must be known to at least three times the horizontal accuracy target in order for elevation fixing to be acceptable (e.g., must be accurate to <3m for 10m horizontal accuracy). This is very unlikely in most cases, considering that only orthometric (above mean sea level) elevations are available in most places in Canada. This orthometric height must be converted to the ellipsoid using a geoid model, and this will add errors as well. *In summary, 2D (fixed height) positions are not acceptable for any surveying or mapping tasks.*

Many receiver manufacturer's call a minimum four-satellite fix the "3D" mode. Most receivers can also be set to use "2D" mode, using three satellite measurements and a fixed height. Some receivers also offer an "automatic" mode in which 3D positions will be solved when four or more satellites are tracked, but 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 also be disabled during data collection since it constrains the solution using the last solved height.

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 also monitored during field data collection to ensure that the current solution will meet the project accuracy requirements and specifications. DOPs are also monitored during the Quality Control (QC) phase of a project by the Contractor to ensure quality position fixes were captured. Data not meeting the DOP specifications can be selectively excluded during post-processing. 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 appropriate DOP value to give an estimated accuracy of the final position. For example, if the 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: $(0.5\text{m} \times 2.0) = 1.0\text{m}$.

There are a number of different DOPs that can 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		Latitude	Long.	Height	Range Bias	Geometrical Meaning and Comment
Geometric DOP	GDOP	X	X	X	X	<ul style="list-style-type: none"> four dimensions latitude, longitude, height and time
Position DOP	PDOP	X	X	X		<ul style="list-style-type: none"> three dimensions latitude, longitude & height commonly used in 3D-positioning
Horizontal DOP	HDOP	X	X			<ul style="list-style-type: none"> two dimensions-horizontal latitude & longitude
Vertical DOP	VDOP			X		<ul style="list-style-type: none"> one dimension-vertical height
Time DOP	TDOP				X	<ul style="list-style-type: none"> one dimension - time rarely used (only for time transfer)
Northing DOP	NDOP	X				<ul style="list-style-type: none"> one dimension - Northing latitude “strength”
Easting DOP	EDOP		X			<ul style="list-style-type: none"> one dimension - Easting longitude “strength”

Table D- 10 DOP Components

Precise time is not generally of direct interest to surveyors, therefore the TDOP and GDOP are less applicable than the other DOP values that reflect only positional components. The PDOP is most commonly used both in pre-analysis of the available satellite coverage, and during monitoring of field operations. 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”.

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

$$\begin{aligned} \text{GDOP}^2 &= \text{PDOP}^2 + \text{TDOP}^2 \\ \text{PDOP}^2 &= \text{HDOP}^2 + \text{VDOP}^2 \\ \text{HDOP}^2 &= \text{NDOP}^2 + \text{EDOP}^2 \end{aligned}$$

In general, the HDOP is 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. Lower DOP values result in more accurate positioning. An example

of this concept is provided below.

Example - High-End Receiver

Narrow-correlation, phase-smoothing Receivers (i.e. Trimble ProXR, NovAtel Gismo, Leica GS50, etc.)

Pseudorange accuracy = 0.5m (i.e. narrow-correlation receivers with differential corrections from a reference station within 100km, clear tracking)

PDOP:	3.6
HDOP:	2.0
VDOP:	3.0

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

Positional (horizontal & vertical): $(0.5 \times 3.6)m = 1.8m$

Horizontal: $(0.5 \times 2.0)m = 1.0m$

Vertical: $(0.5 \times 3.0)m = 1.5m$

Example - Low-End Receiver

Standard-correlation code Receivers (i.e. Trimble GeoExplorer, Magellan ProMark X, CMT MC-GPS, etc.)

Pseudorange accuracy = 1.5m (i.e. standard-correlation receivers with differential corrections from a reference station within 100km, clear tracking)

PDOP:	3.6
HDOP:	2.0
VDOP:	3.0

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

Positional (horizontal & vertical): $(1.5 \times 3.6)m = 5.4m$

Horizontal: $(1.5 \times 2.0)m = 3.0m$

Vertical: $(1.5 \times 3.0)m = 4.5m$

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 January 1st, 2001. 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, typical GPS coverage using an elevation cut-off of 15 degrees shows between 4 and 10 satellites visible, with a PDOP range: 2.0 - 4.0, an HDOP range: 1.0 – 2.5, and a VDOP range: 1.5 – 4.0. Short-term spikes above these ranges are seen at intervals throughout the day, including a 10 minute period near 05:30 PST when only 4 satellites are visible and 3D positioning is weak with the PDOP near 10. Another weak period shows at approximately 21:00 PST with only 4 satellites and PDOP >20. These

short weak periods may change as the constellation is re-phased (satellites moved within their orbital planes), or new satellites are launched. Remember that the entire constellation advances ~4 minutes per day, therefore the spike near 21:00 PST on January 1st, will occur at 19:00 PST a month later on February 1st. The actual number of GPS measurements observed in the field is usually less than the theoretical maximum due to local obstructions. This is why it is important that Field Operators understand DOPs and monitor them carefully during data collection.

Figure D- 1 Sample GPS Predictions For Central British Columbia

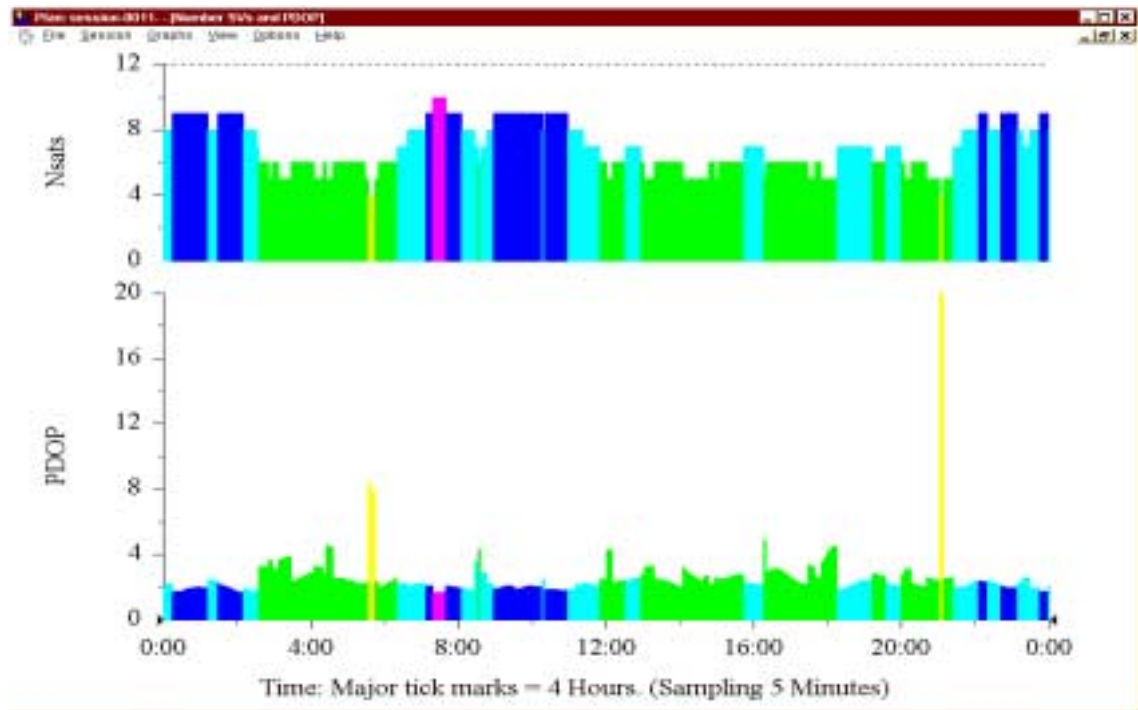
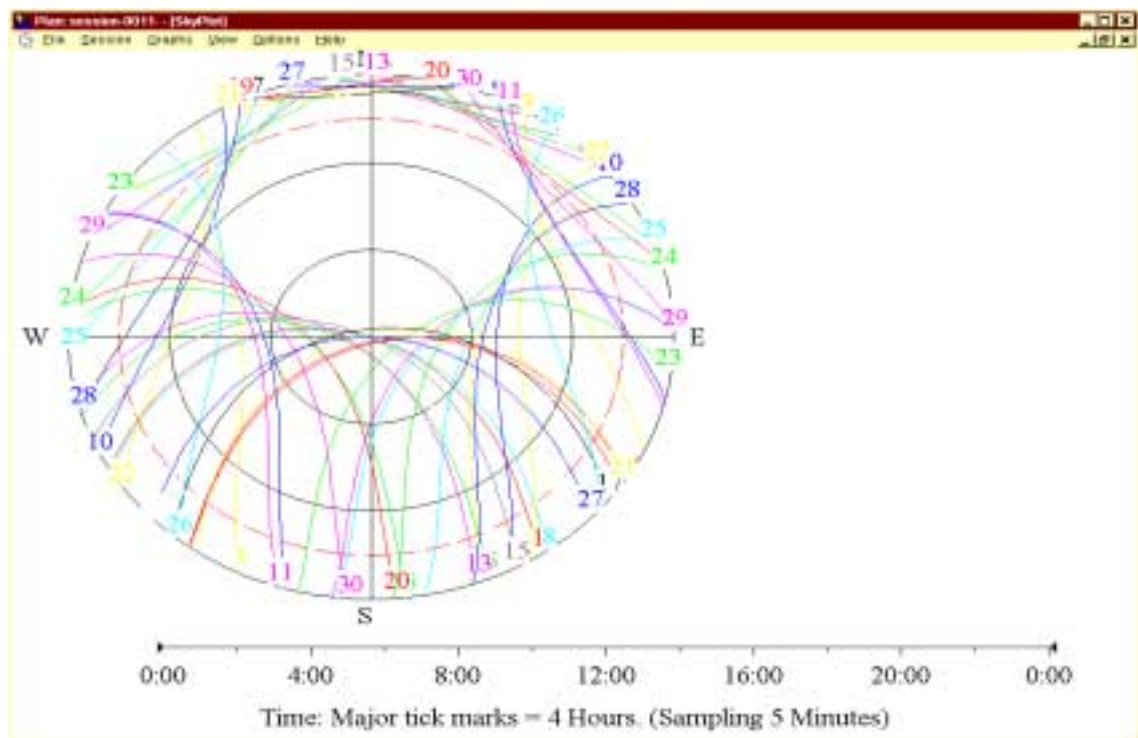


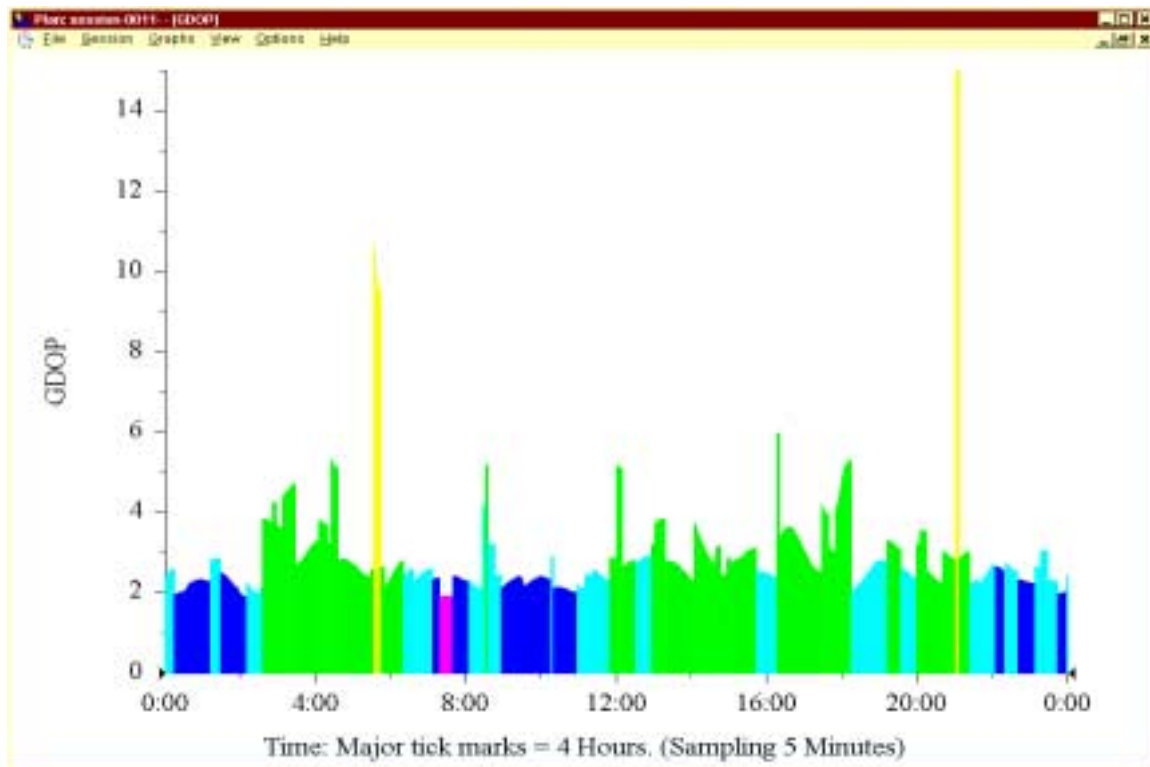
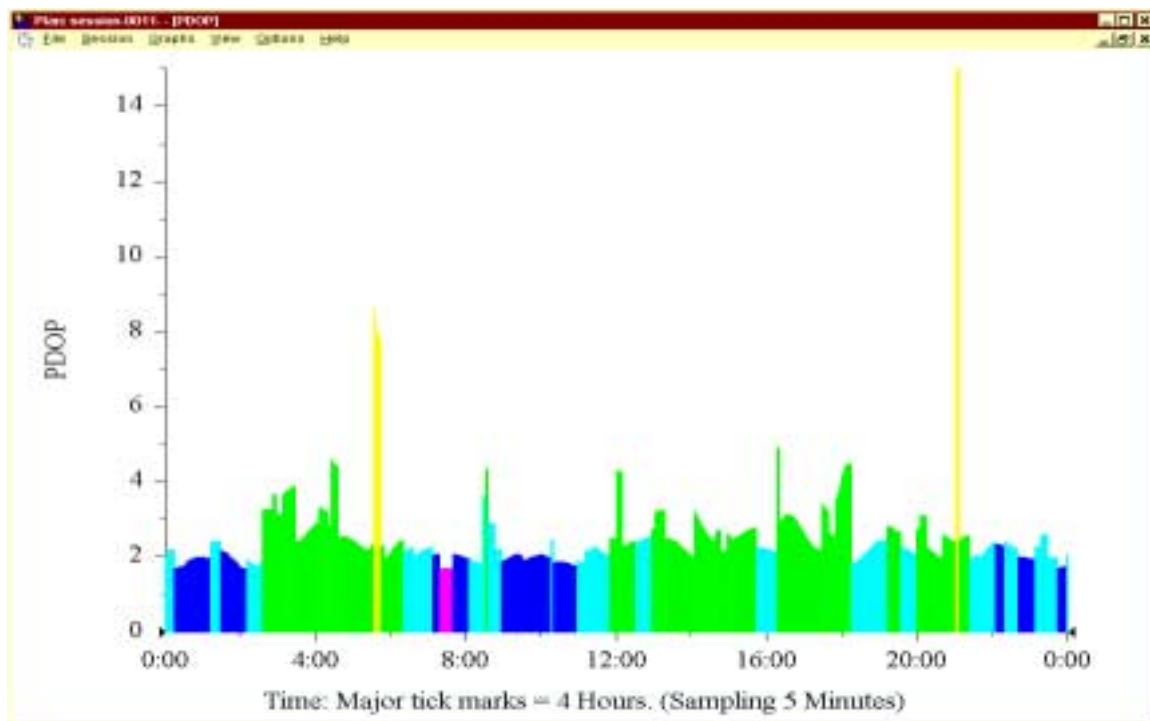
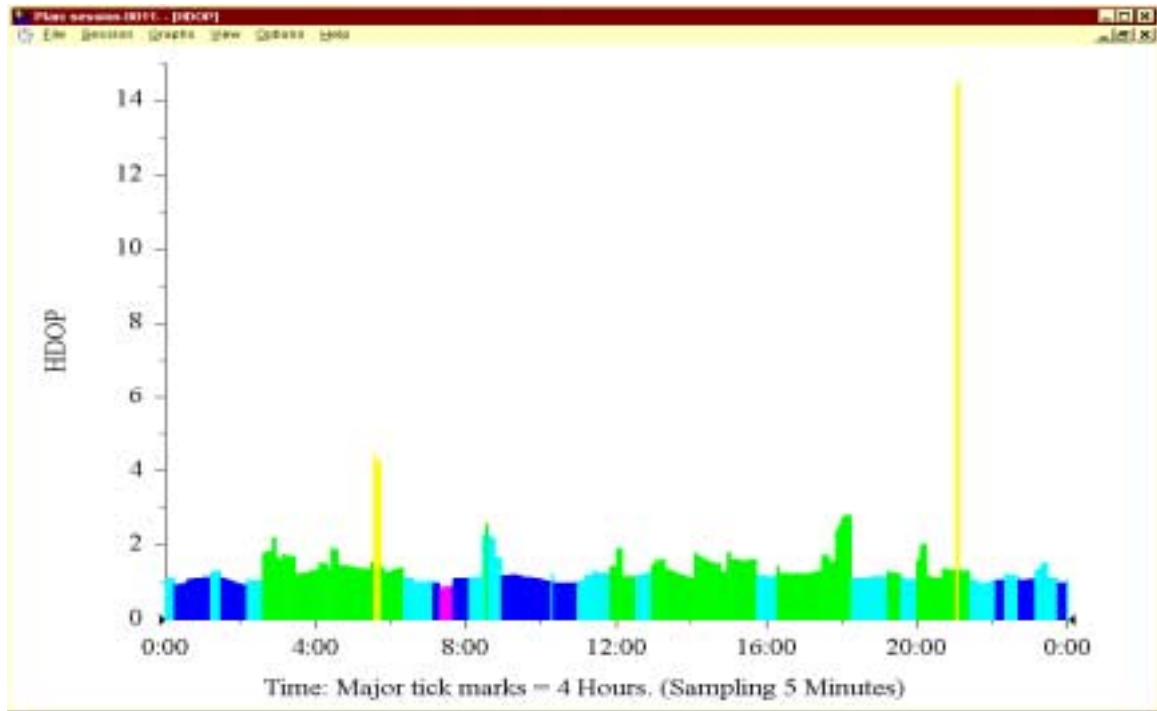
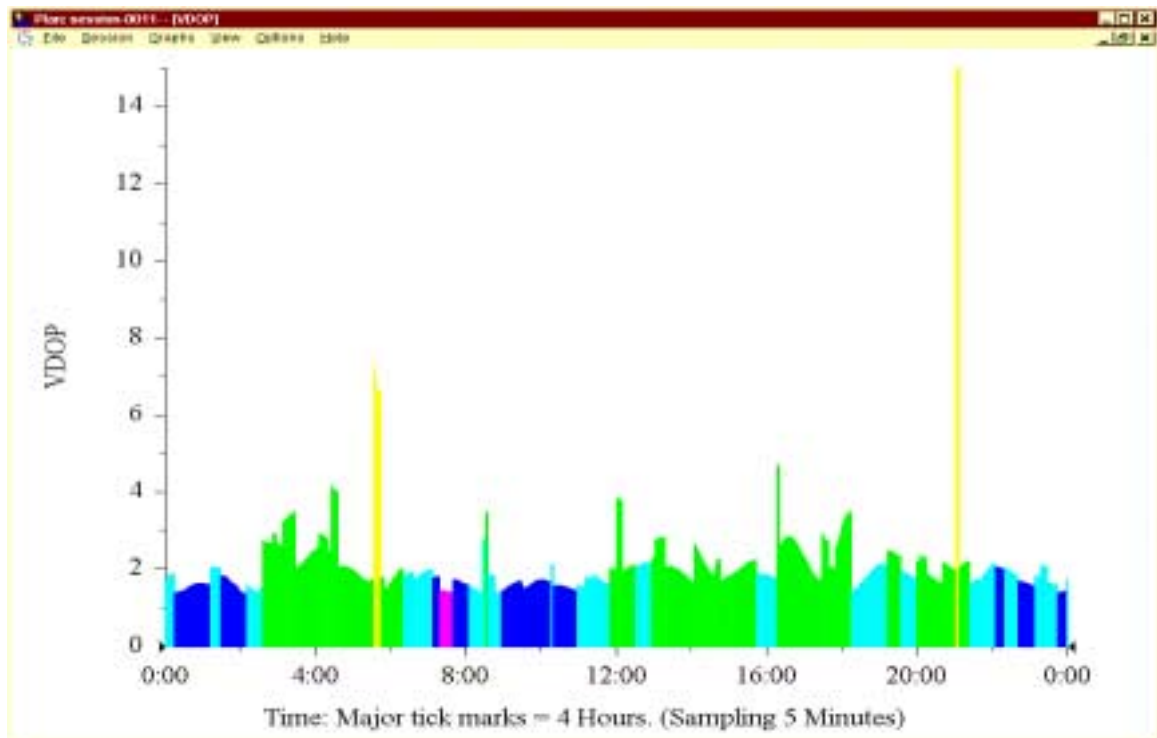
Figure Sample GPS Predictions For Central British Columbia (continued)

Figure 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), DOP values should be logged in the rover data collector as a QC / QA measure.

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, that 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 will be rejected.

Most resource GPS surveys will be 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 1m level of vertical accuracy is possible only within a localized area (i.e. 20 kilometres between the GPS Reference Station and field 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. GDBC should be consulted regarding use of an appropriate geoidal undulation model (e.g. HT97).

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 = 4.0 PDOP = 3.0 HDOP = 2.0 VDOP = 2.0	Not applicable	Narrow-correlation receivers only (with clear tracking conditions)
2m	GDOP = 5.0 PDOP = 4.0 HDOP = 3.0 VDOP = 3.0	Not applicable	Narrow-correlation receivers only (with mostly clear tracking conditions)
5m	GDOP = 8.0 PDOP = 6.0 HDOP = 4.0 VDOP = 4.0	GDOP = 5.0 PDOP = 4.0 HDOP = 3.0 VDOP = 3.0	
10m	GDOP = 10.0 PDOP = 8.0 HDOP = 5.0 VDOP = 5.0	GDOP = 8.0 PDOP = 6.0 HDOP = 4.0 VDOP = 4.0	Typical projects with 10m accuracy targets are done under difficult tracking conditions.

Table D- 11 Suggested Maximum DOP Values

7.2.3.4 Use of DOPs in Quality Control(QC)

The Dilution of Precision (DOP) is directly associated with the accuracy of the 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.

As with other sections of the *Specification*, the conditions under which a particular contractor has validated his GPS system may over-rule, or further restrict, the DOP guidelines suggested here. The Contract Administrator should use discretion when accepting a contractor's validation for a project situation that differs drastically from that observed during validation.

Example

A contractor validates their GPS system at the 5m Network Accuracy level with GPS Reference Station/Field Receiver separations of 50 to 200km and with PDOPs that range between 2.5 and 4.0. These same limits (separations

< 200km and PDOP < 4.0) would apply to any future works undertaken with this system at the 5m accuracy level. The Contract Administrator may accept longer separations and/or higher PDOP levels if a specific project has a less stringent accuracy requirement.

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 Cutoffs/Mask

A significant source of error in GPS observations is the error due to atmospheric propagation (i.e. how the signal is disturbed as it travels through the ionosphere and troposphere). This error increases significantly at low satellite elevation angles, and 15 degrees is considered a minimum for rovers during most surveying purposes. Elevation angles below 15 degrees can be accepted at the reference station (to ensure overlapping data). Satellites for which both the Reference 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 Reference Station satellites are used.

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 Reference Station is typically set to record satellites at lower elevations to ensure a data overlap with any rover receivers. Approximately 1 degree of elevation angle difference will result for every 100km of separation between GPS Reference Station and field receiver. The elevation mask for GPS Reference 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 an 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 most 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. In particular, the Trimble Pro-XL, XR, XRS models are widely used. 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, without a clear understanding of the impact on positional accuracy. A detailed study was done in heavy

forest cover conditions in BC during the fall of 2000 to isolate and understand the relationship between SNR and positional accuracy for static and dynamic positioning (with the Trimble ProXR receiver). This isolation of the test variable was possible because of the use of one antenna feeding two receivers via an antenna splitter. Testing was done at the FERIC Test Range near Maple Ridge. The full study is available on the GDBC website at: <http://home.gdbc.gov.bc.ca/gsr>. The study showed that under heavy 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 allows 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 are less accurate than those made with strong SNR values. 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 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. Static Point Accuracy
(Trimble Pro-Xx and Heavy Bush Conditions)

Note that the accuracies above indicate only the GPS error components of feature mapping. Interpretative errors in the field will also contribute to the combined total errors in feature mapping.

The above suggests that point feature positioning under heavy 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 “truth” routes established by accurate conventional surveys. This comparison was done based on the linear interpretation of the GPS data that an experienced “competent” 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” SNR 6 receiver, 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. Again, the most accurate linear results were

from the “control” SNR 6 receiver. The reduced SNR receiver collected approximately twice as many fixes as the SNR 6 receiver. During two 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 two 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 for Trimble Pro-Xx receivers, static point features appear to 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 **will likely 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 *CDGPS Specifications* establishes whether reduced SNR masks are acceptable for a contracted project. ***The 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 behavior can not be directly related to other receivers. However, the principle that low signal strength measurements are less accurate than measurements 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 Validation are to be done with the same receiver parameter settings.

7.3 GPS Reference 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 Reference 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 Reference Stations exists in British Columbia, most of which provide public access. Using a single GPS Reference 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 Reference Stations.

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

It is recommended that GPS Reference Stations have a GPS receiver that incorporates advanced signal processing technologies to ensure the best possible base data. 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 basestation operation with a ground plane or choke-ring to minimize multipath reflections.

It is recommended that GPS Reference Stations have at least ten 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 Reference Station. Elevation masks at the GPS Reference Station should be set to 10 degrees to ensure overlapping satellite coverage with GPS field rover receivers.

The GPS Reference Station logging interval is an issue requiring further discussion. Some processing software will interpolate between reference epochs. For example, if the GPS Reference 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 Reference 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 Reference 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 manufacturer’s interpolation algorithm is not accurate enough, this should be apparent from the results of the validation survey.

It may be that accurate interpolation over longer intervals (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 (*GPSPace*), which uses post-computed precise clock and orbit corrections and an ionospheric grid model to correct field data to the metre-level. The PSGUC and GDBC will investigate both of these technologies, as use of them will perhaps increase the accuracy available in some remote areas far from existing Reference Stations.

There are a number of new or developing technologies available for correcting GPS data in real-time. These include WAAS (Wide Area Augmentation System) and changes in the Global Surveyor™ service to a Wide Area solution based on GPS*C corrections from the Geodetic Survey of Canada (Canada-wide DGPS Service). These real-time technologies and their impact on resource GPS surveys will be investigated by PSGUC, GDBC and other Agencies as they develop.

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 uses data from a GPS Reference Station fixed over a known point to correct data collected at a roving field receiver. An extensive network of suitable permanent Reference Stations exists in British Columbia, most of which provide public access.

The Geo-Spatial Reference Unit (GSRU) of Geographic Data BC (GDBC), Ministry of Environment, Lands, and Parks (MoELP) is tasked with validating GPS Reference Stations and other GPS correction services in the Province. Information on approved services and methods can be obtained from GDBC (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 positional correction calculated at the reference 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 "spatial" DGPS. By the mid 1980s a more rigorous DGPS technique was developed based on calculating the individual corrections to each pseudorange, and applying them to the rover's measured pseudoranges before solving for the position. This increased the positioning accuracy and further reduced the operating restrictions (i.e. it was no longer required for the GPS Reference Station and the rover receivers to track the identical set of satellites). Note that at least one manufacturer is still using a form of spatial DGPS in their current software.

The contractor must be able to demonstrate that any change in processing software, including a change in versions of the same software suite, must be able to produce the same or improved levels of accuracy as the software used during validation. This does not necessarily require a full re-validation. Instead, the original validation data can be re-processed with the new software and results compared.

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. Some software is clearly not based on a least-squares solution as it can utilize only four pseudoranges (i.e. no over-determined solution and therefore no residuals or variance factor). 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 navigation DGPS solutions are acceptable only if the same set of satellites is used at the Reference Station as at the roving receiver. Wide area clock and orbit corrections from the Canadian Active Control System (CACS) may be used by the positioning public without prior consultation with GDBC. However, before utilizing other wide-area solutions the user should consult and obtain prior approval from GDBC.

8.2 **Advanced GPS Data Processing**

Simultaneous pseudorange observations to four satellites are the minimum required for calculating positions with DGPS. In most cases, more than four satellites are available for use by the receiver. Most current receivers used in resource surveys will track eight or more satellites simultaneously. If more than the minimum four observations are available, the extra information is “redundant” and an “over-determined” solution can be made.

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 method of differential corrections.

Two useful statistical parameters which can be generated from an over-determined position fix are the solution variances and the observation residuals. 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 receiver position to the computed satellite position) to the actual observation (the range measured by the receiver to the satellite). Any difference between these values is the observation residual, or what is left over. In good observing conditions, all residuals will be reasonably close in size to each other, with as many negatives as positive numbers. If, however, the observation to one satellite is very poor (for example, signals travelling through very thick canopy), then that satellite’s residual may be significantly larger than the others. Some software will allow designating this observation as an “outlier”, and then allow its removal from the solution and a new, more reliable and accurate position can be computed.

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). However, some manufacturers have implemented these features into 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 come back to proper training and experience.

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 as “least squares collocation”. The common “Kalman filter” is an example. 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 termed “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!). Obviously this is an outlier, or GPS “zinger”, and should be detected and rejected.

Software with this capability will usually have a receiver dynamics setting which can be set in the field 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 Reference 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) will be 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 a removing a noisy 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 somehow. This is done to smooth out the noise common to GPS data (especially under forest canopy), and so that the final lines have a reasonable number of points in them. In the case of dynamic linear surveys, a “best-fit” line is often drawn over the GPS position fixes (heads-up digitizing), with the Mapping Technician deciding the location of the generalized line. Other GPS operators connect individual position fixes (using object snap functions) to create a new line, and still others will delete

position fixes they deem too far out or unnecessary. It is also possible to perform some automatic smoothing of these line features using best-fit and line smoothing algorithms available in many GIS programs.

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 traverse line.

Whichever method is chosen, this involves some subjective analysis by the Mapping Technician and/or the GPS Data Processor. They must decide which fixes are outliers, and how to best smooth out the general noise in the data. 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 more, this is an issue of proper training and experience.

8.5 GPS Reference Station Issues

GPS data collected in the field must be corrected using data from a known GPS Reference Station in order to meet the accuracy and integrity requirements of this document. The GPS Reference Station must use appropriate equipment and have an accurately known location. Many of the issues regarding GPS Reference Stations have already been 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 Reference Station.

8.5.1 Accuracy Versus Separation Distances

Local area DGPS is based on the principle that errors observed at the Reference Station are applicable at the rover. This principle is valid when the rover is reasonably close to the Reference Station, but 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 Reference Station. Beyond this distance rover accuracies will degrade. Note that this de-correlation applies to only Local Area DGPS, as Wide Area techniques model system errors differently.

Contributing factors to the de-correlation of differential corrections between the GPS Reference 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 Reference Station and rover change the tropospheric and ionospheric errors affecting each pseudorange.
- Large differences in meteorological conditions.
- Large change in elevation (>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 are “best case”, and are obtainable only under favorable 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 Reference Station, and that the DGPS processing software is rigorous.

Rover Receiver Type	Base/Rover Receiver Separation Distances	Approximate “Best Case” Horizontal Accuracies (95%)
Low-End Receiver <i>approx. accuracy = 1.5m+2PPM</i>	100km	1.7m
	250km	2.0m
	500km	2.5m
High-End Receiver <i>approx. accuracy = 0.7m+2PPM</i>	100km	0.9m
	250km	1.2m
	500km	1.7m

Table D- 13 Separation Distance vs. “Best Case” Accuracies

The GPS Reference Station/rover separation distance used during a contractor’s validation should generally serve as the upper limit for future projects with the same accuracy target. However, this may be relaxed under some circumstances **and only upon careful evaluation**.

8.5.2 Real Time Corrections

Real-Time DGPS (RT-DGPS) is based on correction data from the GPS Reference Station being transmitted to the roving receiver by a radio telemetry link in “real-time”. RT-DGPS utilizes the pseudorange correction methodology (as opposed to the “spatial” methodology used in some post-mission software). Advantages to 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 Reference 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 of BC, the correction radio link is typically based on a geo-stationary communication satellite. This transmission method gives wide coverage, but it is disrupted by local obstructions, and suffers from low “look angles” at Northern latitudes. However, with the elimination of SA in May, 2000, the effects of such disruptions have been dramatically reduced. Real-time DGPS is thus more viable than ever. The Global Surveyor™ service is an example of a satellite communication RT-DGPS system.

RT-DGPS surveys should use a third-party service or a user-established GPS Reference Station validated by GDBC (temporary GPS Reference Stations must meet the requirements established by GDBC). Only the pseudorange correction method is acceptable for RT-DGPS. RT-DGPS

correction messages usually comply with the current international standard RTCM format (in the future the RTCA format will likely also be accepted). 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 Reference 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 Reference 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 (especially in the presence of S/A or high ionospheric noise).

The description of latency above corresponds to a Local Area RT-DGPS system with a single Reference Station. Wide area RT-DGPS (WADGPS) systems may have longer latencies as the measurements from many Reference 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 (the reader must check with the receiver manual).

RT-DGPS is always based on an extrapolation of the corrections computed at the Reference Station at some time in the past. This extrapolation leads to an accuracy loss when compared to post-mission DGPS which is based on corrections that are either exactly time synchronised between base and rover, or surrounding base corrections are used to interpolate corrections for an intermediate rover fix time. This RT-DGPS accuracy loss is small if the latency is kept small, and *this effect has also 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 quickest changing. This required that RT-DGPS systems have low latencies (and RTCM Age settings) in order to preserve pseudorange accuracies. With SA active, pseudorange corrections typically changed a metre every few seconds, and correction ages were typically limited to 10-30 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 (i.e. multipath errors, atmospheric errors, etc.). 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 (although the likelihood of this is very low). Details can be seen in papers available on the GDBC website at:

http://home.gdbc.gov.bc.ca/gsr/gsr_standards.htm. Taking into account these additional error components, the following table gives suggested maximum **RTCM correction ages** 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 RTCM Correction Age Settings

Note that these numbers are suggested based on a conservative interpretation of the testing results seen to-date. It is also interesting to note that one of the receiver manufacturers has just recently changed the maximum RTCM Age setting in their receiver from 50 seconds to 250 seconds.

8.6 Quality Control and Reporting

Quality Control (QC) and Quality Assurance (QA) 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 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 Quality Control (QC) starts before the GPS survey with the validation of the GPS Contractors system. During and after the field data collection, the GPS Contractors should review the data quality and completeness using a QC program. The following sections provide more information regarding these procedures.

8.6.1 Validation as Part of Quality Control

Validation is a key element in the program to ensure quality positioning results from GPS contractors. The validation submissions will show not only the technical capabilities of the hardware and software, but also the ability of the Contractor's personnel to comprehensively understand GPS and effectively plan a project, manage the data collection and process and present the results. A Contractor that submits poor validation results (i.e. data and reports) may treat production projects in the same way. See *Section D-4* for a complete discussion of this concept.

8.6.2 Quality Control (QC)

Many of the procedures for Quality Control (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, operators can help ensure (but not guarantee) that GPS data produced will be acceptable. GDBC can help ensure that GPS operators are qualified to perform and analyse GPS surveys through the pre-qualification process.

However, some specific QC procedures are essential to ensure that GPS surveys integrated into Agency geographic databases are reliable, accurate, and within project specifications. Some potential QC methods are provided below.

DOP Masks

The first, and most important, QC method is to ensure that the field data capture parameters 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 will not do that, 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.

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

Re-Observation

One additional 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 requirement should be carefully applied.

The nature of GPS errors typical to most resource surveys (positions are quite independent of each other) means that one really only has an indication of the accuracy of the GPS survey over the re-observed part. There is 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 by far the largest source of error. In open conditions without significant terrain features, re-observation can be more indicative of the overall quality. Re-observations can also be instructive when an operator is gaining experience with GPS surveys.

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:

Example:

Accuracy target: 5m

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

QC Test: 95% of the radial distances between separate observations at the same point 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. A cut-block survey can 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

Requirements to periodically check the GPS operator's system on existing, known locations (usually geodetic control monuments) are sometimes made. This requirement provides even less information about the quality of a GPS survey than re-observation. GPS systems do not require periodic "calibration". Perhaps the only information that can be derived from these checks is that the GPS operator has the correct coordinates for the GPS Reference Station in the processing operations - this can also be checked by verifying GPS map ties.

Redundant GPS Reference Station Data

It is also a good idea to assure reliability in the derived DGPS positions by using a networked GPS Reference Station solution. In the case of Local Area DGPS (LADGPS), the use of at least two GPS Reference Stations, located at opposite sides of the project to differentially correct the project data, may increase reliability in the coordinates and accuracy statistics. Other networked solutions, such as Wide Area Differential GPS (WADGPS) may offer increased accuracy and reliability (depending on project circumstances) and should be considered as valid survey methods that intrinsically provide greater quality assurance.

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 have become an essential tool for managing resource bases in the province. However, there are specific issues that must be considered when integrating 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 concept of geodetic datums (e.g. WGS84, NAD83, NAD27, etc.) and coordinate systems (e.g. Latitude/Longitude, UTM, etc.). Readers who need to familiarize themselves with basic concepts of geodesy are referred to the sources in *Appendix B*.

Positions derived from autonomous GPS are referenced to the World Geodetic System of 1984 (WGS84) datum. This datum is defined by the GPS control segment tracking stations around the world which are used to derive 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.

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 after approximately 1988. NAD83 datum realization on the ground is through geodetic control monuments. Coordinates for all survey monuments in British Columbia are published and distributed on the NAD83 datum. Since official adoption in 1990, NAD83 realization through the monuments continues to be refined and enhanced. Thus, users need to be aware of "versions" of NAD83, although most refinements are generally at the few centimetre to 2 m level across the Province. The latest adjustment of the survey monuments (and BC ACS stations) in BC offers a 1998 version of NAD83 and has a long-form identification of: NAD83(CSRS98). 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).

The NAD83 datum is almost equivalent to WGS84. The differences are either very local or are so small as to be inconsequential for all but the most precise surveys (e.g. continental drift surveys). Coordinates for all validated GPS Reference Stations in BC are referenced to the NAD83 datum, and by using a GPS Reference Station for differential corrections, all computed rover coordinates will also be on the NAD83 datum. This applies to both real-time and post-mission DGPS as long as the Reference Station coordinates have been accurately tied to the NAD83 datum.

Some older mapping products in BC are referenced to the North American Datum of 1927 (NAD27) (e.g. existing forest resource inventory mapping). Great care must be taken in transforming GPS-derived NAD83 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 transformation methods are usually based on three or seven parameter transformations, Molodensky transformations, and USGS NADCON (amongst others). Errors of over 10 metres are common if these transformation methods are used in BC, and this is clearly not acceptable.

In BC the acceptable method for transforming between the NAD83 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 the Geo-Spatial Reference Unit, Geographic Data BC, of the Ministry of Environment, Lands and Parks (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 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 (often 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. The preferred solution is to rigorously convert all mapping bases to accurate NAD83 coordinates (e.g. the Ministry of Forests has now substantially completed this task for the forest cover series).

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, any discrepancies between the local map base and accurate NAD83 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. 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, but it then becomes a local “in-house” 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 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 uses Universal Transverse Mercator (UTM) map projection coordinates. Small-scale mapping covering large areas will often use a different map projections 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 defined mathematically.

The UTM projection is defined with standard parameters worldwide, 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 ~500km 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, be aware that some 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). This is expected to change to the North American Vertical Datum of 1988 (NAVD88) sometime in the future. The vertical transformation from CVD28 to NAVD88 will likely be as problematic as the horizontal transformation from NAD27 to NAD83. Potential problems will not be dealt with in this document, as NAVD88 has not yet been implemented.

There are other issues, however, with the height reference of GPS-derived elevations. GPS calculations are based on purely mathematical ellipsoidal heights, while most users and maps use orthometric heights. Orthometric heights are referenced to the geoid, which 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 not required. However, there are reasons why elevations may be important for some surveys, and almost exclusively, these elevations are required to be orthometric (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. 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.

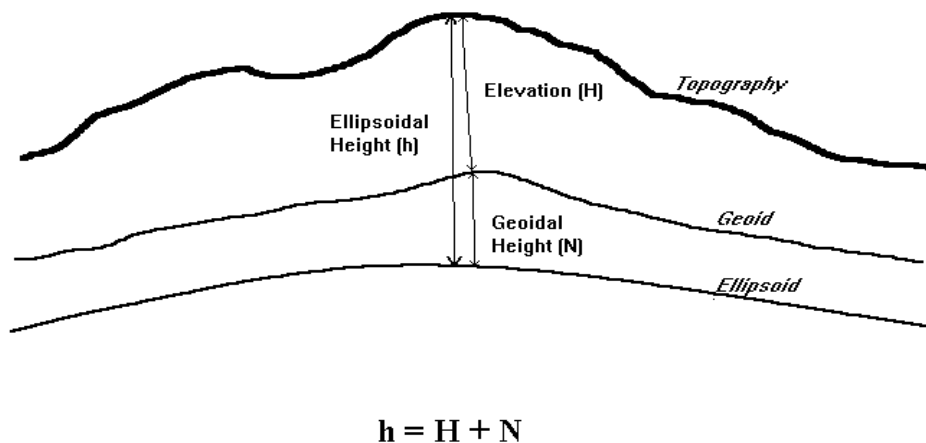


Figure D- 2 Relationship Between Ellipsoid and Orthometric Height

The accepted method of computing orthometric elevations from GPS is to use the Canadian national geoid model known as the Geodetic Survey Division 1995 geoid model (GSD95, or a related model, for example HT97). The GSD95 geoid model is accurate to approximately 0.5m throughout BC (there will be exceptions to this especially in the mountainous and very remote regions). This geoid model is available from Geomatics Canada (see *Appendix B* for references) either as executable software, or as an on-line conversion on their Internet website. It is recommended that users receive instruction in applying geoid corrections before attempting to derive orthometric elevations with GPS.

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. 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 *Specifications*.

One potential solution to this problem is the *Spatial Archive and Interchange Format* (SAIF) developed by GDBC, 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 a variety 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. Research is ongoing on this topic to provide a pragmatic solution.

As an example, the following information has been provided to demonstrate how the Ministry of Forests is attempting to standardize the submission of GPS data.

Example

The final interpreted data must be in IGDS (Intergraph Version 8.0 or later, or Microstation Version 5 or later) digital format on the NAD83 datum or in the format or datum specified by the ministry representative. The following IGDS file format is recommended as a temporary working format that can easily be transferred to the FRGIS database format (or INCOSADA standards).

- Level 1: All original (unedited) corrected GPS data points
- Level 2: All edited, corrected GPS data points
- Level 3: All polygonal shapes collected as line strings as positional data only, including attribute data for each feature. This level must be vector and polygon clean
- Level 4: All linear features captured as line strings as positional data only, including attribute data for each feature
- Level 5: All point features as positional data only, including associated attribute data for each feature
- Level 6: Legend and any representational information regarding the positional data provided
- Level 7: Data dictionary table, if required
- Level 9-63: As specified by the ministry representative.

All digital and hardcopy map products must adhere to the existing Ministry of Forests FRGIS mapping standards as specified in **The Preparation and Creation of F.R.G.I.S. Data Files**, published by the Resources Inventory Branch, March 1996, or the INCOSADA database standards. Examples are:

- All features must be displayed using the colour, weight, line style, text size, etc. as specified in the above document.
- Complex shapes are not acceptable.
- All files must be delivered in NAD83, georeferenced to 1:20,000 BCGS mapsheets with MoF global origin and set to MoF working units (km/m).

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 (e.g. Arc/Info, NAD27 datum, data provided on 8mm DAT tape, etc.). 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 (if available) and a project identifier (e.g. provincial government's ARCS/ORCS number, etc.).
- A listing of all personnel (Contractor and Subcontractors) involved in the project detailing their particular duties and background (i.e. their educational background; formal GPS training details (courses with dates); their experience on similar projects, etc.). This could be a copy of what was provided with the pre-qualification package.
- A key map showing the project area and a description of any GPS Reference Stations used.
- A description of the GPS Reference Stations used.
 - If using a temporary GPS Reference Station the issue of validating the GPS Reference Station will also have to be resolved (i.e. a GPS reference Station validation will have to be submitted).
- A schedule of events showing key dates (contract award, field data acquisition, data processing, and submission of the results, etc.).
- A list of all hardware and software used on the project; including but not limited to:
 - GPS hardware and particulars (i.e. models, receivers numbers, data loggers, antennas, firmware versions, etc.);
 - GPS software and particulars (i.e. name, version number, settings, etc.);
 - mapping software (i.e. name, version number, settings, etc.); and
 - utility software (i.e. name, version number, settings, etc.).
- A summary of the project including planning, field data collection methods and parameters (i.e. GPS receiver settings/defaults), data processing methods and parameters (i.e. post-processing settings/defaults), any project problems, anomalies, deviations, etc.
- A summary of the results, including repeatability test details.
- An explanation of the deliverables (digital and hard copy) including formats, naming conventions, compression utilities, media, etc.
- A copy of all field notes (digital or hard copy).
- A list of all features that have been mapped or surveyed.

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 (e.g. the Forest Practices Code guidebooks).

The following submission is provided as a suggested minimum:

- Map Surround which includes the following project information: project title; project number/identifier (e.g. provincial government's ARCS & ORCS identifier); contracting Agency name; Contractor name; and date of survey.
- Plan datum (e.g. NAD83) and, 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 Reference 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 Reference 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 the RINEX (version 2) format.

GPS Reference 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 Reference 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 Reference 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 currently 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 Reference 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. Reference 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. recordable CD-ROM). 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 (QC) and Quality Assurance (QA) procedures are essential to performing reliable GPS surveys by GPS operators, and to managing them by Agency personnel (e.g. Licensees). 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 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 traverses. This is especially relevant for provincial government agencies (e.g. Ministry of Forests Region and District offices). *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.

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 masks, DOP limits, 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

As previously stated, 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 for people to have confidence in data sets, and entire mapping programs can be questioned by users. 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 point fixes from this survey are

usually edited somehow 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 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.

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. MoF is currently developing detailed GPS QC/QA procedures which may include automated programs (January, 2001).

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 (which represents approximately a 95% level of significance), but not less.

It should be noted here that a low standard deviation, or apparent spread of aggregated position fixes, does not guarantee accurate point features. Local site multipath is usually the largest error source in resource GPS surveys. Multipath on C/A code can average out over 5-10 minutes. However, over a short time period (e.g. a 30 second point feature), multipath can have a very systematic effect. That is, the individual position fixes will seem to have a low spread (low standard deviation), but they can be significantly out from the true position. Multipath effects on a dynamic traverse tend to be more random.

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, and so on. 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 should be aware of what proportion of their work will be audited, and the audit procedures and targets for accuracy and performance. 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 for a Quality Check Audit would be to verify that all materials called for have been submitted, to verify the contractor has followed the 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 could perform it reliably.

This would be applied to a relatively large portion of the GPS contracts and involve reading of the project report, check of the field notes and digital returns, and visual and/or quantitative quality assurance procedures as outlined in the section on quality assurance and quality control. It is basically a thorough check of the contract's returns and compliance checks on the data capture parameters. No GPS processing software is necessary, only mapping software for which the GPS data were collected.

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 interior 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; which have been mentioned above; 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 masks, DOP limits, 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, must 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. The Auditor 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 probably must be used. Note also, that the most common receiver manufacturer in forestry does not store pseudorange data so cannot be processed with standard GPS processing software.

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 Reference Station as used by the Contractor should be used to avoid confusion caused by GPS Reference Station errors. However, the auditor should also process the data using an alternate GPS Reference Station to check for multipath, improper coordinates, and other possible GPS Reference 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 one 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.

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

*Release 3.0***

***SECTION E - AUTONOMOUS GPS
GUIDELINES***

SECTION E – AUTONOMOUS GPS GUIDELINES

1. INTRODUCTION

The removal of Selective Availability (SA) on May 2nd, 2000 was a significant event for GPS users. Autonomous (single-point) 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). 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 GPS positioning that must be understood before choosing this methodology.*** This *Section E* was added to the PSGUC/RIC Standards with release 3.0 (March, 2001) to improve understanding of both the *potential* and the *risks* of using autonomous GPS.

2. AUTONOMOUS GPS 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 GDBC, Ministry of Forests, Parallel Geo-Services and others. The knowledge from these sources has contributed to the results presented in this Section. It is expected that many 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.cnde.iastate.edu/staff/swormley/gps/gps.html>
<http://sparkie.nrri.umn.edu/saoff/results.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 web sites.

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. These horizontal and vertical results were obtained under controlled conditions with a static antenna and clear observing conditions (free of obstructions). The maximum autonomous horizontal error reported was 86m (3rd URL listed above). However, note that in testing done by Parallel Geo-Services with one particular 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 also extrapolate the direction and velocity for up to 60 seconds if adequate GPS satellites tracking (i.e. 4 or more) becomes 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, velocity and direction).

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”.

Of course accuracy gets worse when the tracking environment is changed from open to under canopy, and this 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 (3rd URL listed above) show a particular recreational receiver’s horizontal accuracy degrading by a factor of 2.8, i.e. to 16.5m (95%), 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 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 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 accuracies ranging 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 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)

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 know 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 position. Similarly, major ionospheric disturbances can cause unpredictable distortions in the pseudorange measurements which will affect autonomous 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 system that makes-up the full GPS system. This is evidenced by unplanned satellite outages that occur on average a few times per month. 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 labeled 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 Reference 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 Reference 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 rigorously report error statistics with features positioned in this mode. Thus, there is a level of risk that the accuracies obtained are not defensible in the usual 95% confidence statistics. Nevertheless, certain measures can be taken to mitigate some of these risks. In the case of large errors - say tens or hundreds of metres (or more) - map ties and other check measurements may be performed to catch the "blunders". ***As has been explained, autonomous (single-point) positioning should also not be utilized for critical points features, i.e. not used where these risks are unacceptable.***

As well and for further guidance on minimizing risk, the following Section 4 provides some suggestions for applications that may be appropriate for autonomous GPS positioning and Section 5 provides some general procedures and guidelines for data collection.

4. **SUGGESTED APPLICATIONS FOR AUTONOMOUS GPS**

Autonomous 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 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 all GPS methodologies used for GIS data collection. Unfortunately, this metadata may be ignored, as there is a tendency to treat feature positions as "perfect" 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 (within reason).

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).

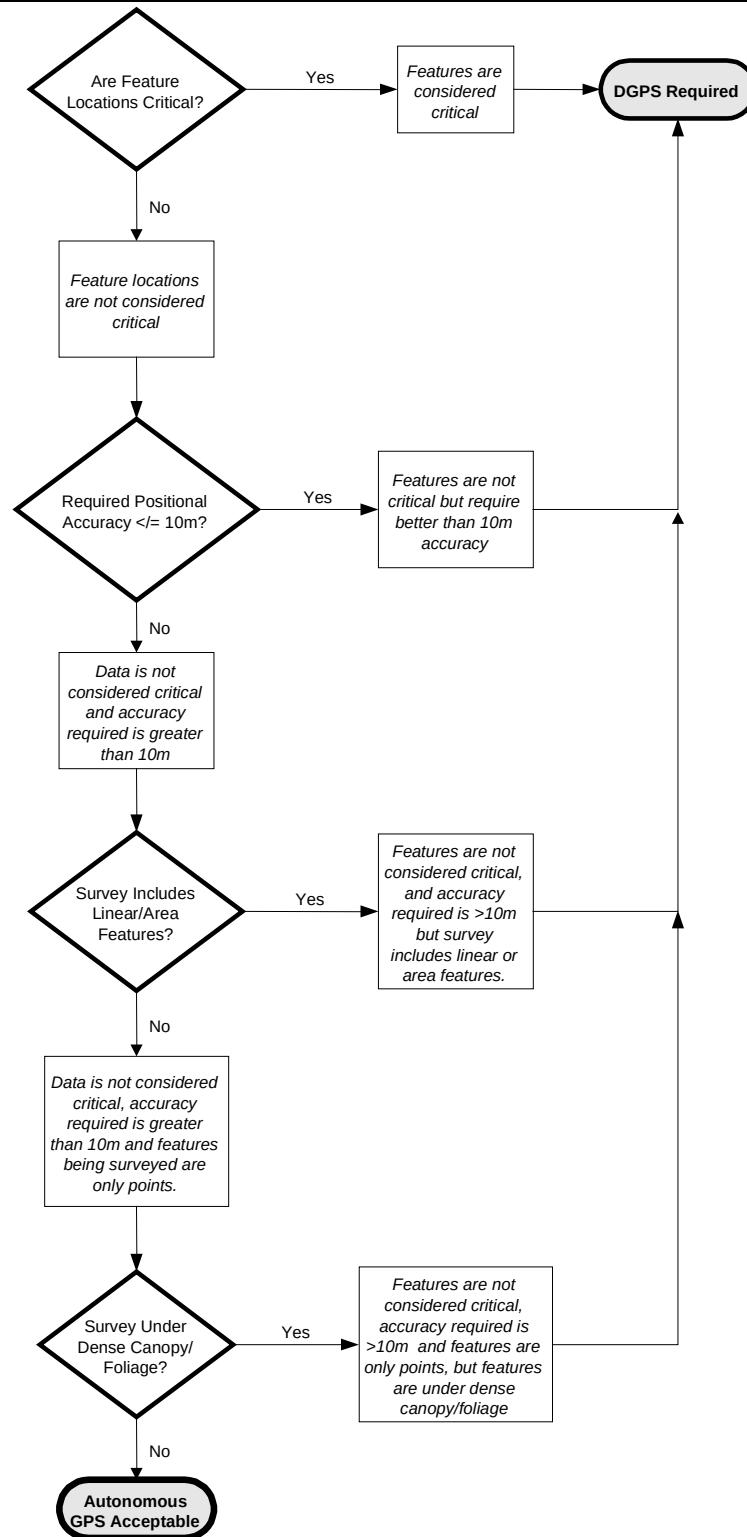


Figure E- 1 Decision Tree For Autonomous GPS Positioning

5. SUGGESTED PROCEDURES FOR AUTONOMOUS GPS DATA COLLECTION

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 checklist 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 into the map/database.
- 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, 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 “jumping” 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 (e.g. “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 in an overly “jagged” definition of the feature. The “dead reckoning” of recreational receivers is also a major problem for linear feature capture. It is suggested that one should thoroughly test linear data capture if planning to use recreational receivers.

APPENDICES

APPENDIX A

GLOSSARY

APPENDIX A - Glossary

95 % Confidence Level

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

Accuracy

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

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

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

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

Almanac

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

Altitude

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

Analog

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

Anti-Spoofing (A/S)

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

Application Software

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

Attenuation

The reduction of signal strength.

Attribute

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

Automatic Vehicle Location (AVL)

A type of system using various technology to track or locate a vehicle.

Availability

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

Azimuth

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

Baseline

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

Base Station

See GPS Reference Station

Bandwidth

The range of frequencies in a signal.

Bearing

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

Block I, II, IIR, IIR-M, IIF, III Satellites

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

Broadcast Message

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

C/A Code

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

Cadastral Boundary

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

Carrier

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

Carrier-Aided Tracking

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

Carrier Frequency

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

Carrier Phase Measurement

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

Channel

A channel of a GPS receiver consists of the circuitry necessary to receive the signal from a single GPS satellite.

Chip

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

Chip Rate

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

Circular Error Probable (CEP)

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

Civilian Code

See C/A code.

Clock Bias

The difference between the clock's indicated time and true universal time.

Clock Offset

Constant difference in the time readings between two clocks.

Code Division Multiple Access (CDMA)

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

Codeless Receiver

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

Code Phase GPS

GPS measurements based on the C/A code.

Computer-Aided Dispatch

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

Control Segment

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

Confidence Level

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

Course

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

Course Made Good (CMG)

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

Course Over Ground (COG)

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

Coverage Window

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

Cross Track Error (XTE)

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

Cycle Slip

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

Data Message

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

Datum

Any quantity or set of such quantities that may serve as a reference or basis for calculation of other quantities. In particular a geodetic datum, chart datum, or tidal datum. With respect to GPS, a convention using ellipsoid to model the earth in an area (local or global); usually defined by monuments on the ground.

Dead Reckoning (DR)

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

Differential GPS (DGPS)

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

Digital

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

Dilution of Precision (DOP)

A description of the purely geometrical contribution to the uncertainty in a position determination, given by the expression

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

where ... $\mathbf{A}$ is the design matrix for the solution (dependent on satellite/receiver geometry).

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

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

Distance Root-Mean-Square (DRMS or 2 DRMS)

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

Dithering

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

Doppler-Aiding

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

Doppler Shift

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

Dynamic Traverse

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

Earth-Centred Earth-Fixed (ECEF)

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

Elevation

Height above mean sea level. Vertical distance above the geoid.

Elevation Angle

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

Ellipsoid

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

Ellipsoid Height

The geometrical height of a point above a reference ellipsoid measured along the normal of the reference surface. Not the same as elevation above sea level. GPS receivers output position fix height in the WGS-84 datum.

Ephemeris

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

Ephemeris Message Block

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

Epoch

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

Fast-Multiplexing Channel

See Fast-switching channel

Fast-Switching Channel

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

Fiducial Point

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

Field Receiver

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

Frequency Band

A particular range of frequencies.

Frequency spectrum

The distribution of signal amplitudes as a function of frequency.

Geodesy

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

Geodetic Datum

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

Geodetic Control Monument (GCM)

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

Geoid

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

Geoid Height

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

Geostationary

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

Global Navigation Satellite System (GNSS)

A generic term describing space-based positioning systems (includes GPS, GLONASS, GALILEO, etc).

Global Positioning System (GPS)

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

GPS ICD-200

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

GPS Reference Station

A GPS Reference Station is a GPS receiver that has been situated over a known point and is used to differentially correct rover GPS data.

Great Circle

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

Hand-over Word (HOW)

The word in the GPS message that contains synchronization information for the transfer of tracking from the C/A- to the P-code.

Hardware

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

Heading

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

Health Word

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

Hybrid Traverse

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

Independent Baselines

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

Independent Observing Sessions

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

Integrity

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

Interface

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

Ionosphere

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

Ionospheric Delay

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

Ionospheric Refraction

The change in the propagation speed of a signal as it passes through the ionosphere. A signal

traveling through the ionosphere experiences a propagation time different from that that would occur in a vacuum.

Kalman Filter

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

L-band

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

L1 Signal

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

L2 Signal

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

L5 Signal

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

Line Feature

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

Linear Offset

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

Magnetic Bearing

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

Magnetic Declination

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

Magnetic Heading

Magnetic Heading is the heading relative to magnetic north.

Magnetic Variation

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

Mask Angle

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

Measurement Error Variance

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

Mobile Data Terminal (MDT)

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

Modem

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

Monitor Stations

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

Multi-channel GPS Receiver

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

Multipath

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

Multiplexing Channel

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

North American Datum 1927 (NAD27)

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

North American Datum 1983 (NAD83)

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

Nanosecond

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

NAV Message

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

Observation

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

Observing Session

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

Outage

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

Parallel Receiver

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

P-Code

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

Phase Lock

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

Point Feature

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

Point Offset

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

Point Positioning

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

Point-to-Point Traverse

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

Polygon Feature

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

Position Fix

A GPS calculated position from four or more simultaneous pseudoranges.

Post-Processing

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

Precise Positioning Service (PPS)

The highest level of military dynamic positioning accuracy provided by GPS, using the dual-frequency P-code.

Pseudolite

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

Pseudo-Random Noise (PRN)

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

Pseudorange

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

Quality Assurance (QA)

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

Quality Control (QC)

Data quality checks and procedures implemented by the Contractor during and after the GPS survey.

Radio-Navigation

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

Range Rate

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

Real-Time DGPS (RT-DGPS)

The method by which Differential GPS (DGPS) corrections are transmitted from a GPS Reference Station to a field receiver during the field survey (i.e. in “real-time”) for which the positions are corrected on-site.

Relative Navigation

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

Relative Positioning

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

Reliability

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

Residual

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

RINEX

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

Root-Mean-Square (RMS)

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

Route

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

Rover

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

Satellite Configuration

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

Satellite Constellation

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

Selective Availability (SA)

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

Sequential Receiver

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

Sigma

See Standard Deviation.

Signal-To-Noise Ratio (SNR)

A measure of the signal strength.

Simultaneous Measurements

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

Space Segment

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

Spheroid

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

Spread Spectrum

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

Spherical Error Probable (SEP)

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

Squaring-type Channel

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

Standard Deviation (sigma)

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

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

Standard Positioning Service (SPS)

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

Static Positioning

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

Supplementary Traverse

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

SV

Satellite vehicle or space vehicle.

Three-dimensional Coverage

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

Three-Dimensional (3D) Navigation

Navigation mode in which altitude and horizontal position are determined from satellite range measurements.

Time-To-First-Fix (TTFF)

The actual time required by a GPS receiver to achieve a position solution. This specification will vary with the operating state of the receiver, the length of time since the last position fix, the location of the last fix and the specific receiver design.

Track

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

Track Made Good (TMG)

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

Trivial Baseline

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

True Bearing

The bearing relative to true north.

True Heading

The heading relative to true north.

Two-Dimensional (2D) Coverage

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

Two-Dimensional (2D) Navigation

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

Undulation

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

Universal Time Coordinated (UTC)

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

Universal Transverse Mercator (UTM)

A universal globally defined system of mapping projection.

Update Rate

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

User Interface

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

User Range Accuracy (URA)

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

User Segment

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

Waypoint

A reference point on a track.

World Geodetic System (WGS)

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

World Geodetic System 1984 (WGS84)

The mathematical ellipsoid used by GPS since January 1987.

Y code

The encrypted version of the P-code.

APPENDIX B

REFERENCES

APPENDIX B - References

Accuracy Standards for Positioning (Version 1.0). Natural Resources Canada, Geomatics Canada, Geodetic Survey Division, Ottawa, ON. September 1996.

British Columbia Accuracy Standards for Positioning (Version 1.0). Province of British Columbia, Ministry of Environment, Lands and Parks, Geographic Data BC, Victoria, BC. To be published April 2001.

British Columbia Control Surveys Standards, Specifications and Guidelines for Control Surveys (March 1991). Province of British Columbia, Ministry of Environment, Lands and Parks, Geographic Data BC, Victoria, BC. March 1991.

British Columbia Standards, Specifications and Guidelines For Resource Surveys Using GPS Technology (Release 2). Province of British Columbia, Ministry of Environment, Lands and Parks, Geographic Data BC, Victoria, BC. **March 31, 1997.**

British Columbia Standards, Specifications and Guidelines for Control Surveys Using GPS Technology (November 1990). Province of British Columbia, Ministry of Environment, Lands and Parks, Geographic Data BC, Victoria, BC. November 1990.

GPS Positioning Guide. A Users Guide to the Global Positioning System. Natural Resources Canada, Geomatics Canada, Geodetic Survey Division, Ottawa, ON. January 1995.

Mapping Systems General Reference. Trimble Navigation Limited, Sunnyvale, California. March 1994.

PFINDER Software Reference. Trimble Navigation Limited, Sunnyvale, California. August 1995-2001.

Reliance Office User's Guide. Ashtech, Inc. Sunnyvale, CA. April 1996.

The Forest Practices Code Guidebooks. Province of British Columbia, Ministry of Forests, Victoria, BC.

The Ministry of Forests Standard Procedures for Georeferencing Field Sample Plots Using GPS Technology. Province of British Columbia, Ministry of Forests, Resource Inventory Branch, Victoria, BC. February 1996.

The Ministry of Forests Standard Procedures for Line and Polygon GPS Surveys. Province of British Columbia, Ministry of Forests, Resource Inventory Branch, Victoria, BC. March 1997.

RECOMMENDED INFORMATION SOURCES

A Source for All Listed Materials:

Navtech Seminars Inc.

2775 S. Quincy Street, Suite 610
Arlington, VA 22206 USA

Tel: 1-800-NAV-0885

Fax: (703)931-0503

URL: <http://www.navtechgps.com>

A mail-order bookstore. A source for almost all GPS-related publications, software, hardware and training. The best starting place for any GPS-related product.

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.

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:

GIS World Inc.

155 E. Boardwalk Drive, Suite 250

Fort Collins, CO 80525, USA

Tel: (970)223-4848

Fax: (970)223-5700

URL: <http://www.geoplace.com>

Subscription US\$72

Monthly magazine. A mix of news about GIS and GIS products, technical information, and general interest articles. Advertising from many sources.

GPS World

P.O. Box 6148

Duluth, MN 55806-6148, USA

Tel.: (218)723-9477 or (800)346-0085

URL: <http://www.gpsworld.com>

Subscription \$117 US.

Monthly magazine. A mix of news about GPS and GPS products, technical information, and general interest articles. Advertising from many sources.

Navigation, Journal of the Institute of Navigation

1800 Diagonal Road

Alexandria, VA 22314, USA

Tel: (703)683-7101

Fax: (703)683-7177

Email: publications@ion.org

URL: <http://www.ion.org>

Membership fees \$55 US.

Quarterly journal. Technical articles, mostly dealing with DGPS for navigation, also new techniques and developments.

Internet Sites:

Geographic Data BC, Ministry of Environment, Lands, and Parks

- maps, coordinates, BC ACS GPS Reference Station data, geodetic utilities
<http://home.gdbc.gov.bc.ca>

Geodetic Survey Division, Natural Resources Canada

- online geoid heights and NAD conversions
<http://www.geod.nrcan.gc.ca>

Navigation Information Service

- official source of GPS information and notices
<http://www.navcen.uscg.mil/gps/default.htm>

University of Calgary Geomatics Engineering

<http://www.ensu.ucalgary.ca>

University of New Brunswick Geodesy and Geomatics Engineering

- good starting point with many GPS links
<http://www.unb.ca/gge>

University of Colorado (materials originally developed at University of Texas)

- online tutorial
- excellent learning resource for GPS, datums, map projections
http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html

Government and Other Information Sources:**Geo-Spatial Reference Unit, Geographic Data BC, MoELP**

1st floor, 810 Blanshard Street
Victoria, BC
V8W 9M2 CANADA
Tel: (250)387-3164
Fax: (250)356-7831
URL: <http://home.gdbc.gov.bc.ca/gsr>

The GSRU provides coordinates for geodetic survey monuments in BC, and administers the Active Control System in BC (BC ACS).

Geodetic Survey Division, Geomatics Canada

615 Booth Street
Ottawa, Ontario
K1A 0E9 CANADA
Tel: (613)995-4410
Fax: (613)995-3215
E-mail: information@geod.nrcan.gc.ca
URL: <http://www.geod.nrcan.gc.ca>

The GSD provides many technical papers, software for datum and coordinate transformation, geoid models, as well as coordinates for survey monuments.

Ministry of Forests - GPS Steering Committee

c/o MoF Resource Inventory Branch

722 Johnson Street

Victoria, BC

V8W 3E7 CANADA

Tel: (250)387-1314

Fax: (250)387-5999

URL: <http://www.for.gov.bc.ca/isb/gps>

RIB has developed some standard procedures, using this document, for GPS survey for the Ministry of Forests.

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 Standard = 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 Reference Station separations; etc.). Also, provide some mechanisms for guaranteeing 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 - DGPS SPECIFICATIONS

1. APPLICATION

These *DGPS 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 *DGPS Specification* will facilitate standardization and quality control for land related information collected for government databases using GPS technologies. The *DGPS Specification* are supported by two documents: the *Standards* and the *DGPS Guidelines*.

The *Standards* document outlines geo-spatial referencing categories in a standardized and uniform manner. Using the *DGPS Specification* document, one may specify the target accuracies to be achieved based on the standardized categories established within the *Standards* document. As well, the *Standards* document establishes standards for GPS Reference Station accuracies within the provincial geo-spatial reference framework.

The second supporting document is the *DGPS Guidelines* document. The *DGPS Guidelines* document provides relevant background information in order to complete those areas of the *DGPS Specification* 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 *DGPS Specification*. Also, see Appendix C for a sample *DGPS Specification* document completed for a typical resource survey requiring 10m 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 Geographic Data BC (GDBC) of the Ministry of Environment, Lands and Parks. Publications by other provincial and Federal agencies also describe procedures for using GPS for high accuracy surveys.

2. INTERPRETATION

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

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

Agency	Ministry, Department or other entity administering the Contract.
BCGS	British Columbia Grid System defining the map graticule breakdowns within the province at various scales.
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.
GDBC	Geographic Data BC, Ministry of Environment, Lands and Parks, Province of British Columbia.
Geoid	The equipotential surface approximating Mean Sea Level. Consult GDBC for provincial standard geoid model.
GPS	Global Positioning System as operated by the United States Department of Defense (US DoD). Also called NAVSTAR.
GPS Event	A GPS Event is a single position instead of a group of positions averaged to a single position (i.e. Static survey). Events are typically used when the antenna cannot, or need not, be stationary over a point.
GPS Reference 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 basestation.
MoELP	Ministry of Environment, Lands and Parks, Province of British Columbia.
NAD27	North American Datum of 1927, based on the Clarke 1866 ellipsoid.
NAD83	North American Datum of 1983, based on the Geodetic Reference System 1980 (GRS80) ellipsoid and as defined by the GRS in British Columbia.
PSGUC	Public Sector GPS Users Committee as established by Geographic Data BC
RIC	Resource Inventory Committee
Static-mode	Collection of GPS data at a discrete point while remaining stationary.
Supplemental Traverse	Supplemental Traverses are conventional traverses (e.g. compass and tape) that are integrated with GPS surveys.
UTM	Universal Transverse Mercator projection (map projection system).

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

highly recommended	Used to describe tasks that are deemed necessary and are good practice. Exceptions are possible, but only after careful consideration by the contracting Agency.
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.
- 3.3. To qualify GPS Systems (i.e. equipment, processing methods, and personnel) by a Contractor GPS System Validation survey to establish the accuracies achievable under various conditions.

4. PRE-QUALIFICATION AND VALIDATION

- 4.1. Total System - It is **highly recommended** that any Contractor expecting to undertake GPS data collection be prepared to fulfill the requirements of the full "System", including: GPS hardware and software for field and office; field and GPS Reference Station receivers; and reporting techniques. All parts of the System are to be capable of meeting the contractual specifications below.
- 4.2. Field Operator Training – It is **highly recommended** that Field Operator(s) be qualified through the RIC sanctioned GPS 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 RIC sanctioned GPS course: "*Comprehensive GPS Training for Resource Mapping*", or the defined Challenge Process.
- 4.4. It is **highly recommended** that any GPS System used be proven to meet the accuracy requirements through a GPS Contractor System Validation survey as outlined in *Section D-4.2* of the *DGPS Guidelines* document. The accuracy levels established during the validation and the conditions under which they were established **should** apply for all subsequent projects.
- 4.5. It is **highly recommended** that all GPS Reference 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 Reference Stations.

5. PRE-FIELDWORK PROCEDURES

- 5.1. The Contract Administrator **should** conduct a pre-fieldwork conference for all potential and qualified 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 interpretative 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.
- 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 (e.g. the Forest Practices Code guidebooks for forest road engineering and boundary marking).
- 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 =	<u>10.0</u> m	(Class = <u>10 metre</u>)
Interpretative Horizontal Accuracy =	<u>10.0</u> m	(Class = <u>10 metre</u>)
Network Orthometric Height Accuracy =	<u>N/A</u> m	(Class = <u>N/A</u>)
Interpretative Vertical Accuracy =	<u>N/A</u> m	(Class = <u>N/A</u>)

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.

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 (sometimes known as “3D” positioning mode).
- 6.2. The *minimum* satellite elevation angle/mask for the field GPS receiver is 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)	8.0
Horizontal DOP (HDOP)	5.0
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. During Static (point-mode) surveys, occupations will adhere to the minimum values below, or the values used during the Validation survey, which ever is higher.

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

- 6.5. It is **highly recommended** that position fixes 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.
- 6.7. It is **highly recommended** that position fixes for linear features mapped dynamically (i.e. dynamic traverse) be no more than **5** 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) on dynamic traverses **should** be accurate to at least **0.25** seconds.
- 6.10. It is **highly recommended** 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* distances for point offsets are **50** metres, and **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 **highly recommended** 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 **highly recommended** 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 **5.0 metres+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).
- 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.
- 6.16. It is **highly recommended** that static point features be collected at all physical reference markers. These static point features are to be collected as **STANDARD** / **HIGH** (circle one) Significance points.
- 6.17. It is **highly recommended** that the 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 REFERENCE STATIONS**

- 7.1. All GPS Reference 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. Physical reference marks are to be left and the station referenced using adjacent features (i.e. road intersections, sign posts, bearing trees, etc.) to assist in the future location, and in determining that it has remained undisturbed. Suitable markers include iron bars driven into the soil, spikes in asphalt or concrete, or other markers 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 Reference Station and field receivers be less than **_ 800 _** kilometres, or the separation distance used during Validation, whichever is less.
- 7.3. The *minimum* elevation angle/mask of the GPS Reference Station **should** be 10 degrees.
- 7.6. If real-time corrections are used, it is **highly recommended** that they be from a GPS Reference Station validated according to Geographic Data BC, MoELP procedures.
- 7.7. If real-time corrections are used, it is **highly recommended** that the *Total Correction Age* of the rover GPS system not exceed **_ 90 _** seconds. See *Section D-8.5.2* of the *DGPS Guidelines* for information on correction ages appropriate for various accuracies.

8. **PROCESSING AND QUALITY CONTROL**

- 8.1. All GPS positions are to be corrected by standard differential GPS methods (pseudorange or navigation corrections). If navigation corrections are used, the same set of GPS satellites are to be used at the GPS Reference Station as at the field receiver for all corrected positions.
- 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 operator or vehicle, and the software versions and filter settings are to be noted in the project returns. If filtering is applied to GPS Reference Station data, this is also to be noted.
- 8.3. The Contractor **should** 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, a project name (if available), and a project identifier (e.g. provincial government's ARCS/ORCS number, etc.).
 - A brief description of the project work (i.e. purpose, target accuracy, location, etc.).
 - A key map showing the project area and a description of any GPS Reference Stations used.
 - A schedule of events showing key dates/milestones (i.e. contract award; field data acquisition; problems encountered; data processing; delivery of results; etc.).
 - A listing of all personnel (Contractor and Subcontractors) involved in this project detailing their particular duties and background (i.e. their educational background; formal GPS training details (courses with dates); their experience on similar projects, etc.) - this could be a copy of what was provided with the pre-qualification package.
 - A list of all hardware and software used on the project; including but not limited to:
 - GPS hardware (i.e. receiver model, antenna, 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.)
 - Detail regarding the GPS Reference Station used (i.e. private, local and/or government, validation status, etc.).
 - A summary of the project including planning, field data collection methods and parameters (i.e. GPS receiver settings/defaults), data processing methods and parameters (i.e. post-processing settings/defaults), any project problems, anomalies, deviations, etc.
 - An explanation of deliverables (digital and hard copy) including data formats, naming conventions, compression utilities used, media, etc.).
 - A copy of all field-notes (digital or hard copy).
 - A list of all features that have been mapped or surveyed.
- 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	Datum	Notes
GPS Reference Station Data	Proprietary or RINEX	WGS84	Merged if possible
Raw Field GPS Data	Proprietary	WGS84	
Original Corrected GPS Data	DXF	NAD83	Unedited
Final Interpreted GPS Data	DXF	NAD83	Edited

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

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

The following map submission is provided as a suggested minimum:

- Map Surround which includes the following project information: Project Title; Project Number/Identifier (e.g. provincial government’s ARCS & ORCS identifier); contracting Agency name; Contractor name; and date of survey.
- Plan datum (e.g. NAD83) and the Map Projection (e.g. UTM).
- Plan scale (e.g. 1:20,000) with BCGS map identifier.
- Plan orientation, (e.g. north arrow annotating True North, Magnetic North and Grid North).
- Geographic (e.g. latitude/longitude) and/or Mapping Projection (e.g. UTM) graticule as requested.
- Source of any non-project information (i.e. TRIM backdrop, Forest Cover data, etc.).

- 9.4. Final data (i.e. Original Corrected GPS data and Final Interpreted GPS Data) is to be reduced and presented referenced to the NAD83 datum. If the Contract Agency requires data to be provided on the NAD27 datum, then 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 are 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 (e.g. provincial government's ARCS/ORCS number, etc.).
- Type, model and version number of hardware used to collect and store data.
- GPS Reference Station used to correct field data (include coordinates and validation information).
- Details of post-processing conversions used.
- Software used in calculations and conversions and version number.
- Any non-standard data handling method, technique or principle used.

- 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 any significant changes in the Contractor's GPS system components (i.e., hardware, firmware, software, methodology, etc.) or personnel during the period of the contract, the Contractor **should** consult with the Contract Administrator. A decision will be made as to whether the Contractor GPS System Validation; the personnel qualification, and/or the GPS Reference Station Validation survey are required to be repeated.
- 10.2. The Contractor and the Contract Administrator **should** ensure that the most current versions of the PSGUC/RIC Standards are used.

APPENDIX D

SAMPLE GPS CONTRACTOR VALIDATION REPORT

GPS CONTRACTOR VALIDATION REPORT

ABC GPS Ltd.

March 31, 2001

1. Company/Agency Information:

Company/Agency: ABC GPS Ltd.
• see Company Dossier attached in Annex A

Contact: John Doe, RPF
123 Main Street
Victoria, BC V8V 1X4
Phone: (250)123-4567
Fax: (250)123-4567
Email: jdoe@abcgps.com

2. Validation Purpose:

Validation Purpose: **Specific Purpose:** To qualify for GPS positioning of ground water wells for the Water Rights Branch's (MoELP) - Ground Water Well Location Program.

- Required Network Horizontal Accuracy = 5 metre
- Required Network Orthometric Height Accuracy = 2.5metre

General Purpose: Validation requested for all other government GPS surveys with similar requirements as above.

3. "GPS System" Being Validated:

GPS Field Operator: John Doe (see particulars below)

GPS Data Processor: Jane Smith, RPF (see particulars below)

Field GPS Manufacturer/Model: Acme Pro-GX (see particulars below)

Field GPS Processing Software: Acme Pro-GX Office - Version 1.01
GSD's QUAD Software (HT97 model)

Field Presentation Software: Microsoft Excel - Version 7.0
Bentley's MicroStation - Version 2

GPS Reference Station Used: BCACS - Summerland and BCACS-Williams Lake
(see particulars below)

4. Field Operator Information:

Field Operator Name: John Doe

Company/Agency: ABC GPS Ltd.
123 Main Street
Victoria, BC V8V 1X4
Phone: (250)123-4567
Fax: (250)123-4567
Email: jdoe@abcgps.com

Formal Credentials: Diploma in Forestry Technology - BCIT (1987)

Experience: 10 years working in Forest Industry
3 years GPS Surveys for Forest Industry

Certificates: RIC 5-day Comprehensive Course (April, 2000)
GPS/GIS Integration Workshop - GIS96 Symposium

5. Data Processor Information:

Data Processor's Name:	Jane Smith, RPF
Company/Agency	XYZ Digital Mapping Ltd. 123 Main Street Victoria, BC V8V 1X4 Phone: (250)123-4567 Fax: (250)123-4567 Email: jsmith@xyzmap.com
Formal Credentials:	<ul style="list-style-type: none">• see Company documents in Annex A B.Sc. Forestry - UBC (1994) Registered Professional Forester - 1996
Experience:	<ul style="list-style-type: none">• see Diploma & Licence attached in Annex B 2 years working in Forest Industry 1 years GPS Surveys for Forest Industry
Certificates:	GPS/GIS Integration Workshop - GIS'96 Symposium GPS Introduction (3 day) by GPS Training Ltd.

6. Field GPS Receiver Information:

FIELD GPS RECEIVER - GENERAL INFORMATION

GPS Rx Manufacturer/Model:	Acme Pro-GX
Field GPS Rx Specifics:	13-channel parallel, digital SuperDuper Technology (i.e. code-carrier) L1 carrier and C/A code data logging
Field GPS Rx Firmware:	1.0.1
Field GPS Rx GPS Antenna Specifics:	Acme Pro-GX Microstrip antenna

FIELD GPS RECEIVER - DATA COLLECTION SETTINGS

Data Rate Used:	1.0 seconds
Data Format:	Internal *.RAW Format
Data Observables/Stored:	L1 phase (L1); C/A code (C1); and Doppler (D1)
Satellite Elevation Mask:	15 degrees
PDOP Mask:	PDOP = 6.0
Minimum Number of SVs:	Minimum 4 SVs (3D-mode)
Filter Settings:	Static
SNR Mask:	Manufacturers Default = 8
Other Settings:	Nil

7. GPS Reference Station Used:

GPS REFERENCE STATION - GENERAL INFORMATION

Reference Station Location:	BCACS - Summerland BCACS - Williams Lake
Reference Station Operator:	Geographic Data BC, MoELP.

Reference Station Information:

- See Appendix B for attached details
- See <http://home.gdbc.gov.bc.ca/bcacs>

Validation Date:

Validation Date: September 15, 1995

- See the following webpage:
http://home.gdbc.gov.bc.ca/gsr/specifications/resource_gps/validations/base_val.htm

8. Validation Survey Particulars:

Validation Location:

Kelowna Region

Survey Ties:

GCM#1123, #3447 and #8872

GPS Reference Station Separation:

Penticton 65km (average)

Survey Methodology:

- Occupied each GCM as a Standard Significance Point and a High Significance point
- Standard Significance Point = 15 epochs/45 seconds
- High Significance Point = 50 epochs/150 seconds
- Each GCM was double occupied with approx. 20 minutes separating occupation times.
- Results from each occupation were averaged.

Accuracy Achieved:

Horizontal Network Accuracy at ...

GCM#1123 = 1.263m

GCM#3447 = 0.857m

GCM#8872 = 0.303m

Orthometric Height Network Accuracy at ...

GCM#1123 = 2.445m

GCM#3447 = 1.843m

GCM#8872 = 1.654m

- See Annex C for GPS processing results and spreadsheet results
 - See Appendix D for GPS software plots
 - See Appendix E for Microstation plots
-

10. VALIDATION RETURNS

Item	Hard Copy	Digital Copy	Format	Comments
Project Report; includes: Report GPS Ref. Station Validation Field Notes/Logs Post-processing Output	1 copy	1 copy	WORD and ASCII files	This report
GPS Reference Station Data	N/A	see notes	RINEX	<ul style="list-style-type: none">digital data available upon requesthourly data files have been merged using Acme RINMERGE utility (v2.1)WGS84
Raw Field GPS Data	N/A	1copy	*.RAW (Acme)	WGS84
Original Corrected GPS Data	1 copy	1 copy	*.MID and *.FIN	<ul style="list-style-type: none">Acme format filesAudit/Log files includedHard copy printouts providedWGS84
Original Corrected Digital File	1 copy	1 copy	DXF NAD83	<ul style="list-style-type: none">All individual positions suppliedAveraged position colour and symbology is differentNAD83
Final Interpreted Digital File	1 copy	1 copy	DXF	NAD83
Final Coordinate List	1 copy	1 copy	MS Excel (ver7)	Horizontal: NAD83 UTM Zone 10 Vertical: Mean Sea Level (calculated using HT97 geoid model)

SUMMARY:

ABC GPS Ltd. is requesting that the above described system be Validated for Resource Surveys for all Province of BC GPS survey contracts requiring Network Horizontal Accuracies = 5.0m or greater.

Please see the attached Annexes listed below for supporting documentation:

- Annex A Company Information (Business Licences, Experience and Marketing material).
 - Annex B GPS Reference Station Validation Confirmation (GDBC Web page).
 - Annex C GPS Processing Reports (Intermediate & Final Processing Documentation).
 - Annex D GPS Survey Plots (Intermediate and Final results).
-

APPENDIX E

SAMPLE GPS REFERENCE STATION VALIDATION REPORT

GPS REFERENCE STATION VALIDATION REPORT

**For
ABC GPS Ltd.**

March 31, 2001

Operator Information:

Owner:	ABC GPS Ltd.
Operator:	ABC GPS Ltd. <ul style="list-style-type: none">• 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: jdoe@abcgps.com

Station Information:

Reference Station Location:	Victoria, BC, Canada
Reference Station Structure:	Steel mast attached to concrete block building. Control point is the GPS Antenna phase centre.
Reference 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, long, construction level; and was subsequently checked for verticality by 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 Reference 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 Reference Station location and surrounding area
- Multipath analysis

Reference Station Hardware / Software Information:

GPS Receiver Manufacturer/Model:	Acme Pro-GX <ul style="list-style-type: none">• see GPS Receiver Information in Annex C
GPS Receiver Specifics:	13-channel parallel, digital SuperDuper chip technology L1 carrier and C/A code
GPS Receiver Firmware:	1.0.0
GPS Antenna Specifics:	Remote choke-ring antenna 30m cable

GPS Reference Station Software:	Acme Base Station (ABS) software (for OS/2) Version 3.7
GPS Reference Station Computer:	Pentium P4 1.5 GHz c/w 256Mb RAM 40.0 Gb Harddisk SVGA Monitor Colorado backup tape
GPS Reference Station Communications:	Internet (TCP/IP) connection via digital modem.
Additional Information:	TrippLite UPS (approx. 2 hours backup power). Power system has surge protection and filters.

GPS Reference Station Settings:

Operating Times:	Every day: 6:00 - 20:00 PST
Data Rate:	1.0 seconds
Data Format:	Acme *.RAW format Synchronized (GPS Time) RINEX available upon request
GPS Observables/Stored:	C1, P1, P2, L1, L2, D1, and D2 Positions
Filter Settings:	Static
Satellite Elevation Mask:	10 degrees
PDOP Mask:	PDOP = 99 (not applicable)

Reference Station Survey:

GENERAL INFORMATION

Survey Agency:	XYZ Surveys Ltd. <ul style="list-style-type: none"> see Company Information in Annex A
Survey Contact:	Jane Doe, BCLS, P.Eng. 123 Anywhere Street Victoria, BC V8V 1X4 Phone: (250)123-4567 Fax: (250)123-4567 Email: jdoe@xyzsurveys.com

SURVEY SYSTEM VALIDATION:

Validation Location:	Greater Vancouver GPS Basenet and Self validation via BCACS stations
Accuracy Achieved:	Second-order
Survey System Validated:	Two Survey X-12 receivers Survey X-12 L1/L2 antennae Survey DELTA software (version 3.12)
Validation Report>Returns:	<ul style="list-style-type: none"> see included information in Annex D

GPS REFERENCE 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
---------------------------	--

<i>Survey Methodology:</i>	Static GPS Ties
	<ul style="list-style-type: none"> • occupation times = min. 53 minutes. • Two session seperated by 6 hours • All GCMs double occupied
<i>Survey Ties:</i>	<ul style="list-style-type: none"> • GCM#1123, #34478 and #887290 • BCACS Stations: Esquimalt, Port Hardy & North Saancih • WCDA Stations: ALBH and CHWK
<i>Survey System Used:</i>	Two Survey X-12 receivers Survey L1/L2 antennae Survey DELTA software (version 3.12)
<i>Survey Report>Returns:</i>	<ul style="list-style-type: none"> • see included reports in Annex E

Summary:

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

Please see the attached Annexes listed below for supporting documentation:

Annex A Company Information (Business Licences, Experience and Marketing material)

Annex B GPS Reference Station Information

Annex C GPS System Validation (GPS Basenet Survey Results and Report)

Annex D GPS Reference Station Survey Report (Intermediate and Final Results included)

APPENDIX F

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APPENDIX F - INDEX

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