Government of Alberta

Director of Surveys & Technical Services Branch

Standards, Specifications & Guidelines For GPS Surveys Of Alberta Survey Control

March 2001

Updated: March 2, 2010

TABLE OF CONTENTS

TABLES

1 INTRODUCTION

1.1 Background

The specifications and guidelines contained in this manual are intended for surveys of the provincial spatial referencing system using the Global Positioning System (GPS). The specifications and guidelines have been developed to provide the information necessary to achieve 2-dimensional and 3-dimensional second-order relative positioning using GPS. This manual is a primary reference for municipalities and contractors who wish to establish and integrate survey control into the provincial spatial referencing system. The manual is a recompilation of the previous *Specifications, Standards & Guidelines for Alberta Survey Control Chapter 5 (GPS Surveys) 1992-08-28*.

GPS is a satellite-based, worldwide, all-weather navigation and positioning system that has been implemented by the U.S. Department of Defence. GPS has gone beyond its military origins to become a worldwide information resource supporting a wide-range of civil, scientific and commercial functions. Since its inception in the early 1980's, GPS has become a key tool for the surveyor determining a position of a point on the surface of the earth. In 1996 GPS was declared fully operational by the United States government.

In Alberta GPS has been used to establish and enhance the provincial spatial referencing system in a variety of ways. Everything from replacement of destroyed Alberta Survey Control Markers (ASCMs) on a localized basis to the establishment and integration of the Canadian Base Network (CBN) pillars in Alberta, has been done via GPS. Additionally, differential GPS service providers are now available within the province to assist users in improving their positional accuracy while reducing the amount of traditional equipment needed to complete a survey.

GPS is seen as a corner stone of the *Spatial Reference Design Alternatives* (SRDA) initiative that has been developed for Alberta. Specifically, it will drive the move from the current monumented control system to a control network that takes advantage of technology via GPS and thereby evolving into a GPS-based spatial referencing system. The reasons for doing this are: the inability of the existing monumented control network to consistently meet the positioning capabilities of GPS; the cost of maintaining the density of the existing monumented control network; and the accuracy and quality limitations of the horizontal and vertical datums currently used. For further information on the SRDA initiative, please refer to the document *Spatial Reference Design Alternatives Issues, Roles & Strategies August 1998*.

In conjunction with the SRDA initiative, the Branch is no longer taking on the role of "project manager" as it did in the past when it came to establishment and/or extension of the provincial spatial referencing system. Instead, the Branch acts as the coordinator and facilitator for development of the spatial referencing system. As part of this role, this manual has been developed to provide contractors and municipalities with the tools to develop and use the provincial spatial referencing system as set out in the SRDA initiative.

1.2 Accuracy

The accuracy of coordinates derived from GPS observations can be exceptionally good. The accuracy is dependent upon two factors; the geometrical strength of the satellite configuration and the presence of unmodelled observational errors which may be systematic, random or both. While the effect of random errors associated with GPS observations is almost negligible, systematic errors (or biases) can affect the results significantly. Biases such as selective availability, incorrect antenna heights and improperly resolved cycle-slips may all contribute to an inaccurate GPS survey. This manual will help the user detect and reduce or eliminate these and other systematic biases.

The accuracy of height determination using GPS must be treated differently from that obtained via conventional surveying. Conventional methods provide orthometric heights (i.e., heights above the geoid) whereas GPS provides geodetic heights (i.e., heights above the ellipsoid). In order to integrate between these two systems, a precise knowledge of the difference between the geoid and ellipsoid (*geoidal undulation*) is required.

As with any surveying system, the variance-covariance (or covariance) information that results from an adjustment must be handled realistically. The covariance data is key to defining the quality of a survey based on statistical analysis. GPS surveys tend to be overly optimistic in their representation of the results because of the methodology used to process the data and the resulting covariance information. Therefore, it is necessary to scale the covariance information appropriately to properly define the results of the GPS survey.

1.3 The Manual

GPS surveying is a relatively complex process with many "equipment and procedure" combinations able to obtain 2nd order relative positioning. Rigidly defined specifications to address all of the potential GPS alternatives would be difficult to compose and would not readily take advantage of future changes in GPS positioning capabilities. It is the intent of the standards, specifications and guidelines not to restrict contractors to specific equipment and/or procedures, but instead take full advantage of present and future GPS capabilities. This manual de-emphasizes rigid design and field specifications and emphasizes strict specifications for the reporting /validation of results. Although strict specifications are de-emphasized for design and field procedures, they are not done away with completely. Instead, guidelines are included to assist the professional in their design, pre-analysis, data collection and analysis of their GPS surveys. This document provides the contractor with a reference for completing a satisfactory GPS survey. It also gives the Branch the information necessary to evaluate the contractor's results.

Specifications in this manual fall into three classes; requirements, recommendations and suggestions. Each of these are identified by the following words:

must	Indicates a condition that must be met by the contractor.
should	Indicates a recommendation to be taken under consideration and which, in the Branch's view, is necessary to achieve the required accuracy.
may	Indicates a suggestion which is left to the discretion of the contractor.

1.4 Terms Used Within This Manual

The following is a list of terms that are used throughout this manual and are provided here for reference:

ASRD .... Alberta Sustainable Resource Development
ALSA .... Alberta Land Surveyors Association
ASC .... Alberta Survey Control
ASCM .... Alberta Survey Control Marker
Branch .... Land Dispositions Branch, Lands Division, Alberta Sustainable Resource Development
CBN............ Canadian Base Network
Contractor .. Surveyor hired to carry out a GPS survey. Note that the term contractor and surveyor are used inter-changeably in this report.
CSRS .... Canadian Spatial Referencing System
DOD .... United States Department of Defence
GSD .... Geodetic Survey Division, Geomatics Canada, NRCan
GPS............ Global Positioning System
HPN............ High Precision Network
MASCOT ... Multipurpose Alberta Survey Control Operations and Tasks database.
NAD83........ North American Datum 1983
NRCan .... Natural Resources Canada
PDOP .... Precise Dilution of Precision
PPM .... Parts-per-million
Province ..... Province of Alberta
SA .... Selective Availability
SRDA .... Spatial Reference Design Alternatives
Surveyor ..... Contractor hired to carryout the GPS surveyor.
2D............... 2-Dimensional
3D............... 3-Dimensional

2 SYSTEM DESCRIPTION

2.1 GPS System – Satellites, Receivers & Software

GPS works by the principle of measuring the range on a satellite (or satellites) from the point of interest. To measure the range, each satellite transmits at two radio frequencies: 1575.42 MHz (or **L1** carrier frequency) and 1227.6 MHz (or **L2** carrier frequency). These carrier frequencies are modulated by different codes. The C/A-code is a 1.023 MHz code associated with the Standard Positioning Service (SPS) and is modulated on the **L1** carrier only. The P-code is a 10.23 MHz code associated with the Precise Positioning Service (PPS) and is modulated on the **L1** and **L2** carriers. A 50 bit-per-second message is also modulated on both the **L1** and **L2** carriers. This message contains information about the satellite's orbit (i.e., position), clock (i.e., timing) and health.

Both C/A-code and P-code can be used to measure the pseudo ranges between the satellites and the receiver antenna. When they are used in conjunction with the satellite orbital information to determine the 3D coordinates at the point of observation. The nominal measurement accuracy is typically 1% of the signal wavelength. This translates into an accuracy of 3 m for C/A-code and 30 cm for P-code. However, a much more precise range can be determined from measurements of the carrier phase. The carrier phase observation is derived from range measurements of the L1 and/or L2 carrier frequency instead of the codes. These measurements can be made to an accuracy of about 2 mm (at 1% of the signal wavelength) and do not necessarily require knowledge of the codes.

Equipment required by the GPS user consists of a receiver with antenna and data processing hardware and software. Virtually all GPS receiver manufacturers provide complete packages containing the hardware and software required to collect GPS data, process and determine a position. The various types of receiver hardware/software and processing software are not discussed in this manual. Users who require this information are encouraged to contact the supplier and/or manufacturer of their GPS equipment and software.

2.2 Errors Sources Associated with GPS

There are a number of random and systematic errors that impact the accuracy of a survey using conventional or GPS methodologies. However, there are some specific error sources associated with GPS. The most important of these are ephemeris errors, clock errors, tropospheric and ionospheric effects, cycle slips, multipath and antenna phase centre variations, and selective availability.

2.2.A Satellite Ephemeris Errors

Errors in the ephemeris refer to the error in the predicted position (i.e., orbit) of the GPS satellite as determined by the system operator (i.e., US DOD). Typically, these errors are small and are ignored by holding the orbit as fixed and errorless. Other solutions include relaxing the orbit by estimating or modelling the biases or by differencing your observational data. GPS surveying typically uses the

differencing approach. Consequently, the effect of a 20 m orbital error is reduced to 1 ppm or less on a baseline vector solution using the differencing technique.

2.2.B Clock Errors

Clock errors are a function of the precision of the oscillator used in the satellite and the receiver. GPS satellites typically use a cesium or robidium atomic clock. Most of the error in the satellite clock can be modelled using a polynomial approach with the resulting corrections included as part of the broadcast ephemeris. Modelling of the satellite clock error reduces the associated positional error to about 30 ns or 10 m. Conversely, a GPS receiver typically uses a quartz oscillator which results in a larger error than that for the satellites due to the lower accuracy. To reduce or eliminate the clock error at both the satellites and the receiver, the typical approach is to difference the observations. Precise clock information is also way in which to reduce the clock error.

2.2.C Tropospheric and Ionospheric Errors

The troposphere is the part of the atmosphere from the earth's surface up to an altitude of about 50 km. The effect of the troposphere on positioning accuracy is normally divided into separate wet (water vapour) and dry (all other) components, and is independent of frequency. The tropospheric error is usually modelled using surface meteorological measurements together with a mapping function that transforms the predicted zenith delay into a delay along the measured slant range from the GPS satellites that are between the horizon and 90 degrees above the horizon (i.e., 0 degrees zenith). Propagation of the error typically ranges between 2 m and 20 m. Hence, most GPS processing software uses an atmospheric model, such as Hopfield & Black, to reduce this error. Also, differencing of the observations will reduce and/or eliminate the tropospheric error.

The ionosphere is that part of the atmosphere ranging from approximately 50 km to 1000 km above the surface of the earth. In this zone, ionization is taking place due to ultraviolet radiation from the sun. Consequently, the GPS signal is effected by causing various problems related to group delay, polarized rotation, carrier phase advance, and angular refraction (*amplitude* and *phase scintillation*). The range of positional errors associated with the ionosphere may vary up to 50 m. Sunspot activity can also cause this error to increase dramatically. Sunspot activity runs on an approximately eleven-year cycle, going to a maximum in the summer of 2000. The ionospheric effect is magnified in northern regions, particularly in the auroral zone (i.e., 70^{o} north latitude to the polar cap).

Various problems can occur due to a *noisy* ionosphere including loss of lock on the GPS satellite signal and/or the collection of poor observational data. Two steps to reduce or eliminate these errors include use of dual frequency receivers and the avoidance of relative positioning on long baselines (i.e., greater than 100 km).

GPS users can obtain a forecast and a review of the daily mean hourly ranges of the geomagnetic activity (i.e., activity in the ionosphere) from Geological Survey of Canada (NRCan) via their web-site at www.geolab.nrcan.gc.ca/geomag (see *Appendix C* for more information).

2.2.D Cycle Ambiguities and Cycle Slips

The cycle (or phase) ambiguity is the uncertainty associated with measuring the number of cycles (or wavelengths) between each satellite and the receiver during observation of the carrier phase signal. When a GPS receiver starts to collect data broadcasted from a satellite, the receiver does not know exactly at what point within the first wavelength that it started to collect the data. The receiver counts the number of whole cycles from this start point to determine the range from the receiver to the satellite. Not knowing the exact point at which observations began creates an error (or ambiguity) which results in reduced accuracy of the derived position. Most commercial GPS software automatically tries to determine the cycle ambiguity by various modelling methods to either "fix" the ambiguity to one value or "float" the ambiguity. The optimum result is to fix the ambiguity to a single value. Some sophisticated GPS processing software will allow the user to try different approaches to resolve the ambiguity, but the result is still the same of either a fixed or float solution. The ambiguity can vary up to 19 cm for the L1 carrier frequency and 24 cm for the L2 carrier frequency. For further information, readers are encouraged to review the references given at the end of this manual (see *Appendix G*).

Over short baselines it is relatively easy to resolve ambiguity parameters to integer values and fix them in a subsequent adjustment. The situation is more difficult over longer baselines where the ambiguity parameter may absorb other effects such as orbit and atmospheric errors. In this case, caution should be used when processing the ambiguity parameters to fixed values so that the cycle ambiguities are resolved correctly.

Cycle slips are discontinuities in the series of carrier phase measurements caused by a loss of lock of the satellite signal(s) being tracked (due to forest canopy, for example). It causes the phase ambiguity to change by an integer number of cycles. Many different methods exist for detecting and correcting these cycle slips. Typically, dual frequency receivers are more easily corrected than single frequency receivers are. As with the ambiguity, most commercial GPS processing software automatically resolves cycle slips during processing. Some sophisticated GPS processing software will allow the user to resolve a cycle slip (or slips) manually.

2.2.E Multipath, Imaging and Antenna Phase Centre Variations

Multipath is caused by the interference of two or more signals emitted from the same source, but travelling along paths of different lengths. Under normal conditions the GPS signals travel a direct line-of-sight from the satellite to the GPS antenna. However, when a GPS antenna is set-up near a building (a *compressor shack*), the same GPS signal may also travel to the building, reflect off of it and then go to the antenna. This causes a distortion of the GPS signal in the receiver that degrades the positioning quality. Imaging is similar to multipath in that a large nearby object (again, a *compressor shack*) produces an image of the antenna that also degrades the positioning quality.

The effect of multipath is best avoided by selecting sites with no reflective surfaces in the area. If it is not possible to avoid an area suspected to cause multipath, it may be possible to average out some of its effect by collecting GPS data over a longer time period. The presence of multipath may then

be confirmed as a common trend in the observation residuals from the different baseline solutions. Most GPS antennas in use today are designed such that they greatly reduce and even eliminate multipath.

Variations in the phase centre of the receiver antenna are the characteristic of a particular antenna and its design. The variations are generally a function of viewing angle and can amount to 10 cm in some cases [Wells and Tranquilla, 1986], [Geiger, 1990]. Manufacturers have developed more stable antennas to reduce these effects. However, caution should be used when using older antennas as the effects due to phase centre location may be significant. Contractors can contact their GPS equipment provider to find out more information regarding the phase centre location of their antenna(s). Also, it is possible to account for these variations in most commercial GPS data processing software.

2.2.F Selective Availability

Selective Availability (*SA*) is the intentional degradation of the information carried by the GPS signal for the purpose of denying accuracy to the user. SA was implemented in March 1990 on the Block II satellites and has continued for all subsequent GPS satellites. SA is at a level consistent with the Standard Positioning Service, which is defined as 100 metres 2 DRMS (95%) absolute positioning accuracy [McNeff, 1990]. In a practical sense, this means that the accuracy of any single-point determination with GPS and SA is a horizontal position somewhere within a radius of 100 metres. SA is implemented through a perturbation of the satellite orbit which appears in the broadcast ephemeris and with an apparent dithering of the satellite clock [Kremer .al., 1990].

There are various methodologies employed to overcome the effect of SA. These include the differencing of observational data, use of post-computed (or precise) ephemeris and modelling techniques.

2.3 Orthometric Height Considerations

The heights derived from a GPS survey are with respect to the WGS-84 reference ellipsoid. Therefore, two factors must be considered when computing orthometric heights from the GPS-derived ellipsoidal (or geodetic) heights: The first is the accuracy attainable for GPS-derived heights; and the second is the relationship between geodetic and orthometric heights as well as the accuracy of this relationship.

2.3.A Accuracy of GPS-Derived Heights

Traditionally, vertical and horizontal accuracy specifications are treated and developed separately. This independence is due to the different methods employed in determining the individual parameters. For example, NRCan considers the second-order vertical standard to be met when the discrepancy between the forward and backward levelling does not exceed 8 mm / $\sqrt{K}$, (*84% confidence level*) where **K** is the distance, in kilometres, between two benchmarks as measured along the levelling route. For a line one kilometre in length, this gives an allowable discrepancy of

up to 8 mm. Conversely, horizontal second-order standards (see *Section 5.2.1*) result in an allowable error of up to 60 mm at the 95% confidence level over the same distance.

Therefore, even though GPS is intrinsically a 3-dimensional system, the desire is still to relate the accuracy qualifiers in terms of a 1-dimensional (*vertical*) or 2-dimensional (*horizontal)* survey with the qualifier derived from conventional surveying techniques. When comparing GPS heights to spirit levelling, it is difficult for GPS to meet the standards of spirit levelling. This is particularly true over short distances (*less than 1 km*). In situations that require accurate height determination, GPS-derived heights cannot be used to replace conventional spirit levelling techniques unless specific procedures and specifications are used. For further information on GPS levelling techniques, please contact the Branch.

2.3.B Orthometric and Geodetic Height Relationship

Relative GPS observations give only relative geodetic heights between two or more observed points. In order to determine relative orthometric heights, it is necessary to know the local variations of the geoid. This relationship is described in the following equation:

$$\Delta H = \Delta h - \Delta N$$

where

Δh = geodetic height difference
ΔH = orthometric height difference
ΔN = geoidal undulation difference

The accuracy of GPS orthometric height differences depends upon two factors: accuracy of observed geodetic height differences and accuracy of the estimated geoidal undulation differences. The latter factor implies knowledge of the relative geoid shape. However, if the geoid slope is small and the geoid smooth over short distances, then the geodetic height differences may be used in lieu of relative orthometric heights. The maximum amount of variation allowable before this method may be used is dependent upon the accuracy required for height determination. Care should be taken not to over constrain heights in the final adjustment if the heights are not well known as this error might propagate into horizontal positional errors.

The determination of "absolute" orthometric heights may be accomplished by including conventional vertical control points in the control network. The accuracy of heights so derived is then a function of both the accuracy of the GPS height differences and the accuracy of the vertical control. The relationship between orthometric (H) and geodetic (h) heights is given by the following expression:

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

where N = geoidal undulation
h = ellipsoidal height
H = orthometric height

Geoidal undulations, their differences and associated errors can be obtained from the Branch.

3 DESIGN

3.1 Principles

In designing an Alberta Survey Control project using GPS, surveyors are developing strategies that will allow them to maintain the existing network, establish new ASCMs or develop an HPN. The results from each of these tasks are different, but the basic principles remain the same. They help to develop and maintain a control network that is physically and *mathematically capable* of supporting GPS surveys. Mathematically capable means that the design meets the desired accuracy and precision of the survey.

<u>3.1.A</u> <u>Physical</u> <u>Characteristics</u>

The physical characteristics of a new or existing control marker to be used in a GPS survey are:

1. Making the marker accessible to all users entails establishing new control markers on public land or reserves (i.e., road allowance). Before to commencing the field reconnaissance for a project, a *title search* of all property involved in the survey should be done. This provides a contact with owners and occupants to either place markers or access property for purposes of making observations.

2. Absences of obstructions down to 100 above the horizon and is located in such a place as to reduce or eliminate the possibility of multipath and/or imaging. You can be facilitate this by completing horizon skyplot for each point to be surveyed using GPS. See Appendix B for a skyplot form.

3. No high-tension power lines within 200 metres of the marker. The electro-magnetic radiation from the power lines will interfere with the collection of GPS data. However, one-, two- or three-line regular power lines do not pose any significant problems for GPS data collection.

4. Adequate spacing (500 m) from a microwave transmission dish if it is in a direct line-of-sight of the dish. However, collection of GPS data is possible at a closer distance to the tower as long as the transmission dish is not in a direct line.

5. Demonstrated horizontal and vertical stability.

6. Adequate spacing for new control markers. The spacing from any existing ASCMs should be a minimum of 800 metres up to 1500 metres in urban areas. In rural areas, the spacing is mostly dependent on the users needs, but may vary up to 50 km.

<u>3.1.B</u> <u>Network</u> <u>Integration</u> <u>Characteristics</u>

There are a number of principles to obtain the desired level of network integration. It is important to note that the network configuration plays an important role in the optimization of reliability and

accuracy of a GPS survey. The following principles apply to all types of GPS surveys for Alberta Survey Control:

1. Ensure control markers used for integration of new control or maintenance have 2nd order or better horizontal integration. The existing control markers should also be chosen so that they are either roughly equidistant on the periphery of the network or well distributed throughout.

2. Each new or existing control marker must be occupied at least two separate times during the survey to allow for proper blunder detection (i.e., incorrect point set up, set up errors, incorrect antenna height measurements). A separate occupation occurs when the antenna setup has been taken down, re-centred over the point, and the receiver re-initialized.

3. Each new or existing control marker must be connected to at least two other points in the network in each of at least two different observing sessions.

4. At least two network-wide baselines, oriented roughly perpendicular to each other, should be included to improve the determination of scale and orientation.

5. Direct connections should be made between existing control markers to provide an additional check on the reliability as well as helping to resolve weaknesses in the existing control.

6. Vertical integration of any new or existing controls markers in urban areas will be carried out by differential spirit levelling. GPS heightening may be acceptable within an urban area when it is impractical to spirit level to or from a particular point (i.e., GPS rooftop base station). GPS heightening in rural areas is acceptable when spirit levelling is impractical due to the potential length of the spirit levelling (see Section 3.2 for further information).

7. The baselines in each session should approximately be equal in length. This may not always possible particularly when ties are made to the CBN markers. In this case it is quite likely that odd length baselines will occur.

8. A minimum of three GPS receivers must be used for any GPS survey of Alberta Survey Control. However, improved efficiency as well as increased station re-occupation and baseline repeatability can be gained by using four or more GPS receivers.

9. A minimum of four GPS receivers is used for HPN projects.

10. The maximum number of GPS receivers to be employed in any one session is restricted to five due to data management requirements within the Branch's database.

One of the most important principles relates to the direct connections between all of the new and/or existing control markers to be surveyed. Enough direct connections should be observed to ensure sufficient redundancy and strength in the network adjustment. The number of baseline connections to each marker should be kept as equal as possible to have a homogeneously connected structure throughout the network. The exception to this condition arises with the use of the fiducial point integration method where the fiducial point (*CBN marker or HPN marker*) may have many more connections than the rest of the surveyed control markers (see Section 4.2.C for further information). In this case, all master station points should have a homogeneously connected structure. The following criteria shall be used to determine when a direct connection between two points is required:

1. Adjacent points should be directly connected whenever possible unless the master station approach is used.

2. Two stations should be directly connected when the distance separating the two points is less than 25% of the total length of the shortest path through directly connected intervening points.

When it is deemed impractical to satisfy some or all of the above criteria for any particular GPS project, the surveyor is encouraged to contact the Branch for additional advice.

3.2 Accuracy

While the capability may exist to achieve higher accuracy surveys using GPS technology, unless otherwise requested, all Alberta Survey Control (ASC) projects using GPS technology shall be designed to meet three dimensional second order accuracy standards.

It should be noted that the given accuracy standards represent the attainable accuracy given the geometrical configuration of the network and the standard deviation of the observables. With these measures, no consideration is given to the reliability of the results, as indicated by the sensitivity of the network to the presence of outliers in the observables, as they are derived purely from the propagation of random errors. Network design should also consider reliability aspects (see Sections 4.2.D & 5.2).

3.2.A 2-Dimensional Accuracy Standard

Within Alberta the horizontal integration accuracy for any control markers (new or existing) is to a minimum standard geometric error of 2^{nd} order. This means that the maximum allowable size of the semi-major axis (i.e., r_{2d}) of the horizontal relative error ellipse at the 95% confidence level is:

$$r_{2d} = 50 \times k + 10 \text{ mm}$$

Where: k = distance between any two stations in kilometres.
r_{2d} = semi-major axis length in millmetres.

- Based on the Specifications and Recommendations for Control Survey and Survey Markers (1978) Energy, Mines and Resources (now Geomatics Canada, NRCan).

3.2.B 3-Dimensional Accuracy Standard

Recognizing the 3-dimensional nature of GPS, the maximum allowable geometical error at 95% confidence can be derived from the horizontal (2-dimensional) parameter given above using the appropriate expansion factors. By dividing by the 2-dimensional expansion factor of 2.447 and multiplying by the 3-dimensional expansion factor of 2.795, the maximum allowable semi-major axis (i.e., r_{3d}) of the 3-dimensional relative error ellipsoid at 95% confidence is:

$$r_{3d} = 57 \times k + 11 \text{ mm}$$

Where: k = distance between any two stations in kilometres.
r_{3d} = semi-major axis length in millmetres.

3.2.C Minimum Standard Geometrical Error

A more meaningful method of evaluating the precision of the derived coordinates is by using the *minimum standard geometric error* as derived from the 3-Dimensional accuracy standard in 3.2.B. By dividing through by the 3D 95% confidence level expansion factor (2.795), the minimum standard geometric error is:

$$r_{1d} = 20 \times k + 10 \text{ mm}$$

Where: k = distance between any two stations in kilometres.
r_{1d} = semi-major axis length in millmetres.

Note: 10 mm is used for the constant error versus the derived value of 5 mm. This is done to reduce an over-optimistic solution on short GPS baselines (*less than 1000 m*).

The *minimum standard geometric error* will be used for testing of all repeated baselines and loop misclosures. The results of the repeat baselines and loop misclosures will be documented as shown in Section 4.2.D.

3.2.D Vertical Accuracy Standard

For a GPS surveys it is important to make distinctions between the horizontal and vertical accuracies of GPS. Typically, the horizontal accuracy of a point surveyed using GPS is two to three times better than the vertical accuracy. As an example, a point that has been integrated horizontally to 0.01 m has a corresponding accuracy of 0.02 to 0.03 m in the vertical. Therefore, it is important to look at the accuracy of a GPS survey in terms of the 2-dimensional (*horizontal*) and 1-dimensional (*vertical*) components, as well as the 3-dimensional (*combined horizontal and vertical*) component.

In most urban surveying environments, surveyors are required to undertake spirit levelling for elevation determination because of the poor accuracy of GPS in the vertical component. The reason for this is that GPS heightening at existing urban densities is not a realistic alternative in replacing spirit levelled orthometric heights. In rural areas, GPS heightening may be viable the vertical accuracy of other heightening methodologies *(inertial survey system, trigonometric heightening, barometric levelling, contour intervals, etc*). Unless impractical, surveyors must carry out vertical integration of any new or existing control markers by spirit levelling methods in urban areas. Within rural areas, GPS derived heights are a realistic alternative to spirit levelling where the length of the spirit levelling lines make it impractical. All contractors are encouraged to contact the Branch to clarify their specific situation.

3.3 General Information

3.3.A Reconnaissance

ASCMs established by GPS techniques should not have a spacing less than 800 m or more than 1500 m in urban areas. It is assumed that most (if not all) ASC projects are being undertaken for HPN establishment and/or densification. Thus, 800 m is the minimal required spacing to facilitate an HPN. Where the proposed spacing is less than 800 m, the surveyor is encouraged to contact the Branch for further information.

In carrying out the reconnaissance, surveyors should refer to the information contained within *3.1.A Physical Characteristics* of this manual. Additional factors to be considered in selecting a location for a new ASCM includes:

- Marker stability
- Current and future access (placement on private versus public land)
- User safety
- Long term preservation of the marker(s)
- Presence of underground utilities
- Conventional surveying site lines (if applicable)

For safety and stability reasons, markers should not be located in travelled areas. The shoulder of a road grade in most cases is unstable and should be avoided. Also, control markers should be placed in public land to avoid the cost and encumbrance of formally dealing with landowners if possible. The location of existing ASCMs and level of densification is facilitated through the use of Survey Control Index Maps which are available from the Branch.

3.3.B Landowner Contact

While ASCMs are generally placed in public lands such as road allowances, road rights of way, parks, boulevards, streets, etc. there will be occasions where markers must be placed in private property. The surveyor must establish contact with the owner and/or occupant, explain the project, and the need to access the property to make survey observations and/or place a marker. Should the landowner not give consent to either placing a marker or access to the property for the purposes of obtaining survey observations, then the surveyor must alter the design of the survey.

3.3.C Utility Checks

To avoid property damage, injury or possible loss of life, all proposed locations for new markers should be marked and checked for underground utilities by the utility owner or Alberta One Call. If necessary the location should be changed to avoid underground utilities. The responsibility to carry out these duties rests with the surveyor carrying out the survey.

3.3.D Site Preparation

Markers should be placed (or selected) so that they are accessible by vehicle. As a matter of convenience the location should be chosen so that the receiver may be placed within 10-30 metres of the antenna depending on cable length. The marker should be located where the antenna can be mounted on a conventional or extended surveying tripod above the survey marker.

The proposed survey design shall reflect the actual field reconnaissance. The field reconnaissance will determine ground type and condition, terrain, horizon visibility, and ground cover. Each marker location must be prepared in advance of collection of survey observations to provide for access to the station, either airborne or by ground.

3.3.E Marker Condition Reports

Under the ALSA *Manual of Standard Practice*, Marker Condition Reports are required for all ASC markers used within the survey. The condition reports are then submitted to the Branch for processing and updating of the database. For details on the "Marker Condition Report" see Appendix D.

3.3.D Design Documentation

It is the responsibility of the surveyor to collect and carefully review the paper reconnaissance phase of the survey design. This should include a report outlining the desired results, spacing of markers, integration with existing control, and proposed GPS survey observations. Other factors such as ground conditions, ground cover, terrain, and access should also be discussed. The report should include the following information:

1. Access limitations.

2. Ground conditions.

3. Terrain and terrain cover (including GPS Horizon Skyplots).

4. Marker inter-visibility (if desired).

5. Description of marker type (proposed).

6. Nearest services available (if applicable).

7. Sensitive land owners.

8. Observation scheme, times, and schedules.

9. Documents showing that any underground utilities have been checked.

10. Marker Condition Reports.

11. Explanation of the accuracies expected.

12. Full explanation of error sources and proposed solution of the error sources.

3.3.F Approval

As discussed in the *Introduction*, the Director of Surveys Branch is no longer responsible for the approval of survey design proposals by surveyors or other parties. It is the responsibility of the municipality (or their designate) to review the design of the survey. If requested, the Branch can provide support during the review process and offer specific recommendations for improvements in the design if required. Once the survey design as been approved by the municipality, authorization will be given to install the new markers and/or start the integration survey. A successful GPS validation survey must be completed before any field data will be accepted by the Branch for the integration of any new and/or existing ASC markers using GPS surveying techniques. Please see *Section 6* for further information.

3.3.G Marker Location Descriptions

Following marker installation, a marker location description must be submitted to the approving agency as well as to the Branch. This information will then be used to update the database for inclusion of the new marker into the provincial spatial referencing system.

To obtain further information on ASCM specifications, descriptions and installation, please refer to the *Standards, Specifications & Guidelines for Alberta Survey Control 1993-06-01*. This manual contains valuable information and should be consulted by contractors. A copy of this manual can be obtained from the Branch or by contacting the Data Distribution

4 DATA ACQUISITION

Once the design stage has been completed the surveyor must implement the survey design to facilitate data collection. The following information is an outline of the equipment considerations and field procedures that should be employed by the surveyor.

4.1 Equipment Considerations

There are three general elements related to the equipment used for a GPS survey for Alberta Survey Control:

- GPS receiver/processor unit(s).
- Antenna(s).
- Data collection

4.1.A GPS Receiver/Processor Unit(s)

GPS receivers used for any ASC integration project shall in general be dual frequency and of geodetic surveying quality. Where it is anticipated that the baseline lengths are less than 20 km, single frequency geodetic quality GPS receivers (i.e., L1 with phase and code observable data) may be acceptable. Surveyors will be required to demonstrate the capability of the receiver to meet the survey specifications by completing a GPS validation survey (see *Section 6*) if they have not already done so. **Final approval of a GPS validation is at the discretion of the Branch**.

The GPS receiver(s) should be capable of displaying satellite health, elevation and orientation information, and *PDOPs* to verify proper operation and data quality. Further information on the functions and capabilities of GPS receivers can be obtained from receiver manufacturers.

All procedures for the operation, system checks and maintenance of GPS receivers should strictly follow the manufacturer's instructions. Also, to avoid potential multipath/imaging problems at the GPS receiver, access should be kept to a minimum during operation.

4.1.B Antenna(s)

To minimize inconsistencies such as phase centre variations and susceptibility to multipath, stability and quality are key factors to consider when choosing antennas. For ASC projects, the typical GPS antenna used is a dual frequency capable woppy-type geodetic antenna. Characteristics to be considered for an antenna are:

1. Avoid imaging or multipath problems; the antenna should be positioned such that these effects are reduced or eliminated.

2. Mount the antenna assembly (some receivers have an antenna on the top of the receiver unit) on a conventional tripod fixture such as a tribrach with a rotating optical plummet. The antenna must be accurately centred over the point.

3. Accurately centre the antenna over the marker. Check the optical-mechanical means of centring the antenna over the marker before and after the survey, every week for the duration of the survey, or whenever there is an indication that the error may exceed 1 mm.

4. Measure the height of the antenna's phase centre above the station marker to the nearest 1 mm using the manufacturer's suggested procedure. This measurement should be made at the beginning and end of each observation session. The contractor should also include a sketch showing how the height measurement was made.

5. All GPS antennas used in the project must be of the same type. This avoids incompatibilities related to the determination of the phase centre between the various sets of equipment used within the survey.

6. Where the same antenna is used to observe back-to-back sessions, the antenna must be repositioned, the height re-measured, and the recorded. This ensures the independence of each observing session.

4.1.C Data Collection

Data collection rates are dependent upon a number of factors such as the satellite configuration geometry change, cycle slip detection and baseline length. The general rule is baselines less than 20 km and for sessions less than 20 minutes; the data collection rate should be five seconds. For baselines longer than 20 km and sessions longer than 20 minutes; the data collection rate should be 15 seconds. It is noted that the higher the data collection rate the easier it is to detect cycle slips. However, to adequately resolve the satellite configuration geometry change, a low recording rate is sufficient. Surveyors are responsible to determine what data collection rate will give the best results.

The minimum criteria for the data collection time span is that period used for the observation collection during the contractor validation survey (See *Section 6*). However, the observation session must include continuous and simultaneous observations. Continuous observations are data collected that do not have any breaks involving the satellites being observed. Occasional breaks for individual satellites caused by obstructions are acceptable, however they must be minimized. A set of observations for each measurement epoch shall be considered simultaneous when it includes continuous data from a minimum of 3 receivers, or at least 75% of the receivers participating in the observing session when 4 or more receivers are used.

For HPN establishment and/or extension projects, there are desired data collection rates and session observation time periods to be used in order to obtain the optimal results. The recommended rates and time periods are as follows:

- Local integration of a new or existing Alberta Survey Control Marker into an HPN should have a data collection rate of 15 seconds over a 60-minute observation session.

- Integration of new or existing Alberta Survey Control Markers to Canadian Base Network markers should have a data collection rate 15 seconds over a 3-hour observation session. Based on the nominal baseline lengths in Alberta from the CBN to control markers, a minimum of two 3-hour sessions each is considered adequate for integration of an ASCM to the CBN.

Each marker should be occupied at least one-half hour before observing is to commence to ensure that each observing session meets optimum accuracy requirements. During this time, the equipment is set up and tested, and field notes recorded. The efficient utilisation of this half-hour will help to ensure that valuable data is not lost due to missing the start of the observing window as well as allowing coordination between operators at other stations.

4.2 Field Procedures

It is not the Branch's intention to advise enforcement of an arbitrary set of specifications for field procedures since different approaches are capable of achieving the required accuracy. Nevertheless, the contractor must apply the same field survey procedures, instrumentation, personnel, redundancy, etc. as used during the validation (see *Section 6*).

4.2.A Field Log

A detailed field log should be kept during each observation session at each station. The minimum amount of information that should be recorded is:

1. Date of observations, (Julian Day and YY, MM, DD format)

2. Station identification (ASCM number, tablet markings, etc.)

3. Session identification

4. Serial numbers of receiver, antenna, and data logger

5. Identification of tape/disk numbers (if applicable)

6. Receiver operator

7. Antenna height (to nearest 1 mm)

8. Station diagram illustrating location and deployment of equipment

9. Site condition details including Obstruction diagram showing any obstructions above 10^o Elevation (i.e., horizon skyplot).

10. Starting and ending time (UTC) of observations

11. Satellites observed (including time of changes)

12. General weather conditions at the time of observing

13. Any problems encountered during the observation session

4.2.B GPS Surveys in Built-up Areas

Obstructions to the satellite-antenna line of sight, which rise more than 10^o above the horizon, can degrade the satellite geometry and increase the likelihood of multipath biases to the extent that second-order survey standards might not be easily met. In urban areas, high rise structures make unobstructed control points difficult to find. In this case, the following two strategies may be adopted:

- GPS is not used in high rise areas. GPS surveys are extended into these areas by conventional surveying methods.

- GPS is used only partially in high rise areas. Only unobstructed sites such as in parks, parking lots, wide boulevards, etc. are considered. These points form a sparser than usual GPS network, may involve longer baselines, and might require longer observation periods. This sparse GPS network is then densified to the required station spacing by conventional surveying methods.

The strategy to follow should take into account the extent of the high rise area to be surveyed, the prevalence of unobstructed ground points to use for GPS observations, the end uses of the control, and the relative costs between GPS and conventional surveying methods. These same general rules can also be applied to GPS survey field procedures in rural environments where objects such as compressor shacks, trees and other potential line-of-sight obstructions may occur.

4.2.C Receiver Deployment Schemes

There are a number of receiver deployment schemes that are used in GPS surveys. Each one has advantages and disadvantages in accuracy and logistics (cost, time and manpower). Two of the more common methods are the leapfrog and monitor station.

The leapfrog method uses basically a traversing approach where each station is re-occupied only the required number of times (*a minimum of twice for Alberta Survey Control projects*). The monitor (*or master*) station approach makes use of a small number of markers within the project area called monitor stations that are frequently occupied during the campaign. These points, from which many baselines radiate, don't have to be existing ASC markers. They may be any points in the network so long as they are adequately tied to the existing ASC network. Although the monitor station method is logistically inferior, due to the need for simultaneous observations at three or more markers, it is thought to produce superior results when there are two or more simultaneous monitor stations.

Regardless of the method used, adequate connections between observing sessions must be maintained to obtain the best results possible. This is very important on short baselines (i.e., less than 500 m) where it is difficult to obtain 2^{nd} order specifications. On such baselines, it is best to directly observe them at least once (*a direct tie*) to meet the specifications.

4.2.D Reliability Confirmation

Reliability confirmation of the production survey by the contractor plays a crucial role in the evaluation of GPS surveys to ensure precise, reliable and repeatable results. Survey proposals and reports should provide details on the level of reliability and the method used to validate the GPS survey results. Reliability analysis is best done by doing repeated baseline comparisons and single baseline residual evaluation. A third step in the reliability verification process is to use loop closure analysis on all observed baselines. These validation checks should be carried out as frequently as possible, preferably daily during the field campaign. If misclosures or inconsistencies indicate that the desired accuracy is not being achieved, then the problem should be corrected. This may include re-observing one or more baselines if necessary. Where the validation results are inconsistent with the standards for the GPS survey, they must be resolved before the production survey data will be accepted.

4.2.D.1 Repeated Baseline Analysis

There must be at least one repeat baseline in each session. This does not require that the repeated baselines be session to session, but that at least one of the baselines in each session is repeated during one session or another during the project. The differences between the repeated baselines should not exceed 1 cm $\pm$ 20 ppm for the horizontal (*local geodetic*) and vertical (*height difference local geodetic*) parameters (See Section 3.2). The repeated baseline results must be included in the contractor's report to the Branch.

4.2.D.2 Baseline Residuals

The discrepancies between the final network solution and single-baseline solutions for each baseline observation should be included within the production survey report. Wherever available, baselines established by methods expected to provide superior results to the second-order GPS production survey (e.g., first-and special-order surveys) should be observed and the differences between the "known" baselines and those from both the GPS single baseline and network solutions compared and reported in the production survey report. Discrepancies must not exceed those specified by the minimum geometric standard error value with respect to baseline length (See Section 3.2).

4.2.D.3 Loop Closures

Single-baseline solutions, and/or single-session solutions must be combined to form loops and the closure error(s) reported. To form the loops at least two independent observing sessions should be represented in each loop and no more than 10 baselines should be combined to form a loop. At least 70% of all independent baselines should be represented in at least one loop and all stations should be included in at least one loop. Loop misclosures must not exceed those allowed by the minimum geometric standard error value with respect to the total loop length for 1 cm ± 20 ppm (See Section 3.2).

5 DATA HANDLING PROCEDURES

The data handling procedures consists of processing, evaluation and reporting the results of the GPS survey. This also includes the data return requirements of the Branch so that the observed data can be incorporated into the provincial spatial referencing system. The contractor is responsible for completing most of the tasks associated with data handling.

The first and most onerous task for the contractor is the data processing. This includes the decoding, pre-processing, and adjustment. The next task for the contractor is the evaluation and verification of both the internal and external consistency. Included in this step is the derivation of the geometrical precision estimates via relative confidence regions. The last task is the integration of the survey into the provincial spatial referencing system to generate final published values for the new and/or existing control markers. This step is the Branch's responsibility as it involves the appropriate weighting and treatment of the existing network to ensure a consistent set of control values.

5.1 Data Processing

Data processing is conceptually separated into data decoding, baseline processing and the least squares adjustment. These tasks may be approached in many ways as long as the quality of the results can be proven. However, the contractor must note any errors found during the data processing stage, the method used to rectify them, and report this information to the Branch.

5.1.A Data Decoding

Data decoding is concerned with the translation of the "raw" data recorded by the receiver into the format required by the processing software. It is dependent upon the type of receiver, recording system and processing software used. This is an automatic step using either the receiver manufacturer’s GPS processing software or a generic software package. During this stage it is important for the contractor to review the field log sheets to make sure that the hand written field notes are consistent with the data as inputted into the receiver at the time of data collection. This includes information such as the height of the antenna, station name and number, operator name and any other miscellaneous information. Also, it allows the data processor to review the field log sheets to see if any data collection problems (i.e., loss of power, line of sight obstructions, weather conditions, etc) were encountered during the GPS survey. This information is invaluable during the data processing stage.

In general, the following steps should be followed for data decoding of the raw GPS information:

1. Check all recording media (typically diskettes) and data files to make sure that the data exists, is usable and has been identified correctly.

2. Check the field log sheets for any missing information as well as comparing the

written data with that inputted into the receiver during the survey.

3. Review the field log sheets for any potential processing problems due to field conditions.

4. Note any errors that may occur when the raw GPS data is being loaded from the receiver (or recording media) into the data processing software.

5.1.B Baseline Processing

Virtually all GPS data processing software uses an automated approach to derive GPS. There are limited changes that the processor can make to the software to change the outcome of the processed baselines. For example, many software packages allow the user to choose the reference satellite, remove or add satellites that are observed during data collection, or include precise ephemeris and/or clock information during processing. Each of these parameters can impact the results of the derived baseline information. Regardless of the software used, it must be capable of producing results that meet the accuracy standards specified for the survey. It must also be capable of producing the full, formal covariance matrix of all the estimated parameters for each baseline. Further information can be obtained from the software manufacturer's processing manual.

The baseline solutions are usually processed at the end of each observing session (*when possible*) and are used to quickly ascertain if the observations meet the required standards for the survey. The baselines resulting from this process are inter-station baselines (*or position differences*) with associated covariance information. This data is then used within the least squares adjustment to derive coordinate data and statistical parameters. As previously mentioned, these baselines must be derived from observation sessions that include continuous and simultaneous observations involving all common stations and all satellites within an observation session.

One of the most important automatic features within the processing software is the automatic detection and correction of carrier phase cycle slips. Early GPS processing software required the processor to carry out extensive analysis in order to correctly detect and correct the cycle slips. However, with improvements in technology and use of dual frequency receivers, this job has been effectively eliminated. For further information on cycle slip detection and correction, contractors are encouraged to review their software manufacturer's processing guide.

In the early 90's, a number of commercial software packages were available to carry out session processing, as opposed to baseline processing, of the GPS observational data. The difference between the two methods is that session processing only processed the non-trivial baselines. Correspondingly, baseline processing typically involves the processing of the non-trivial and trivial GPS baselines. Session processing is seen as being superior to baseline processing because the inclusion of all baselines (trivial and non-trivial) significantly distorts the results by artificially increasing the redundancy in the adjustment in overly optimistic covariance information. This in turn results in a GPS survey solution that may statistically be much better than it actually is. Having said this, it is not the intent of this manual go into a rigorous explanation of the differences between session and baseline GPS processing. Since virtually all commercial GPS baseline processing software packages use some form of baseline processing, contractors are assumed to be using this method. Also, the Branch requires that all baselines (non-trivial and trivial) will be included in the network solution derived by the contractor anyway. If a baseline or baselines are rejected from the solution, then a detailed explanation must be provided as to why they were rejected and how the loss of the data is accounted for.

5.1.C Least Squares Adjustment

The generation of station coordinates shall be accomplished through a network adjustment of the processed GPS baselines and corresponding covariance information. A network adjustment constitutes a final solution (or best estimation) of the station coordinates and relative accuracies of the baseline adjustment data (i.e., position differences and covariance information)

The software used for the least squares adjustment must provide observation residuals (or equivalent) which must be examined to ensure that no systematic biases remain (i.e., undetected or wrongly corrected cycle slips). Typical packages include *GEOLAB* and *RASCAL* as well as built-in least squares programs such as *TRIMVEC* within Trimble's GPSurvey GPS processing software. Again, it is not the intention of this manual to specifically determine what least squares adjustment package should be used to derive the station coordinates and relative accuracies. Contractors are encouraged to investigate the different software programs available and obtain the one that will best suit their needs.

5.2 Data Evaluation

The data evaluation stage takes place when the contractor is ready to confirm the quality and reliability of the GPS survey. As discussed previously, with no reliable accuracy estimates available, some means is necessary to ensure that no significant random or systematic errors (biases) exist. Although a basenet validation will have been performed to demonstrate the "capability" of the contractor's GPS system (i.e., receivers, processing and adjustment software, and field staff and methodology), data evaluation is a further guard against undetected errors and biases existing in the production survey data. The evaluation consists of two distinct processes: a test of internal consistency and a test of external consistency.

5.2.A Internal Consistency of the GPS Survey

The internal consistency test is made up of tabulating the results from the observations made in support of the reliability confirmation (See Section 4.2.D). This includes repeated baseline analysis, baseline residual discrepancies and loop closures. Any discrepancies, closures or comparisons resulting from the minimally contained adjustment must not exceed the minimum geometric standard error value with respect to baseline length (See Section 3.2).

The internal accuracy of the network should also be examined by computing 95% relative confidence regions between all possible station combinations in a minimally constrained adjustment. There should be no unexplained in-homogeneities in relative accuracy throughout the network. Relative accuracies must not exceed second-order, three-dimensional standards with respect to baseline length. The results from this adjustment will indicate the geometrical precision of the observed network, but should not be used as an indication of the final accuracy of the network points. However, it is important to note that on short baselines (i.e., less than 500 m), it may be very difficult to meet this requirement in the vertical component of the three-dimensional standard because of the inherent errors associated with GPS. In this case, some relaxation of the standard may be necessary in order to obtain acceptable results (See Section 3.2).

5.2.B External Consistency of the GPS Survey

The external compatibility of the final GPS network solution with existing control may be determined by examining the coordinate discrepancies using various descriptive statistics, statistical tests and strain analysis. Any statistically significant parameters should be explicitly noted and explained within the production survey report. Local distortions at each existing control point in the GPS network may also be examined by performing a strain analysis of the GPS solution with respect to the existing higher-order control. Any strains or differential rotations larger than second-order standards should be explicitly noted and explained.

The preceding methodology can be a complicated and cumbersome way to evaluate the survey for many surveyors. It requires an in-depth knowledge of least squares adjustment and statistical analysis. However, a similarly effective approach to confirm external reliability may be carried out by performing a minimally constrained adjustment. The external reliability is then demonstrated through a tabulation of the coordinate differences at the unconstrained stations in the network.

5.3 Data Reporting and Returns

The production survey report is the main source of information for judging the satisfactory completion of the contractors work. It is the responsibility of the contractor to supply sufficient information in the report to facilitate verification by the Branch that the objectives of the GPS survey have been met. The summary of reported items and returns identified in Table 1 (see page 29) represent the minimum returns required for a GPS project. A checklist is provided in Appendix F that is used to check the content of the contractor's submitted returns. Depending on the GPS equipment or methodology used, additional information may be required. The onus for identifying and providing relevant information rests with the contractor executing the project. It is very important to note that one of the intents of both the data reporting requirements and the data returns is to provide sufficient information to enable re-processing of the raw data, if required.

5.3.A General Information Reporting

Each production survey report shall include a short description of the survey location, the aim of the survey and the number of markers positioned. A suitable plot/plan shall also be included detailing existing and new control markers. The plot shall be to scale and must show all baseline observations complete with the observation dates and times. This description shall also contain a summary of the project logistics including personnel involved and difficulties encountered.

There shall be a clear description of the survey procedures used in the field. Along with the field log information as identified in Section 4.2.A, the following information will also be provided:

1. Any conventional survey field notes (see chapter 2 of the *Standards, Specifications & Guidelines for Alberta Survey Control 1993-06-01* document) used in eccentric ties, along with an explanation of the need for an eccentric station.

2. Number of receivers used per session.

3. Receiver and antenna type(s) and serial numbers, and a brief description of characteristics and principal of operation.

4. Time, number and duration of sessions per day.

5. Summary of stations occupied per session.

6. Horizontal/vertical antenna offset determination (if required).

7. Description of data sampling rate.

8. Field data check procedures.

9. Logistics information including:

    a. Means of transportation.
    b. Equipment deployment scheme.
    c. Personnel involved and their duties.
    d. Difficulties encountered and how they were overcome.

10. Daily diary detailing all work accomplished.

There shall be a clear description of the procedures employed in the office. This includes, but is not limited to:

1. Computer and software used in processing and adjusting the observational data. This includes the version number and date of the software used.

2. Options used (if any) during processing.

3. Data editing performed.

4. Source and accuracy of the orbital data (i.e., broadcast or precise ephemeris).

5. Parameters adjusted and held fixed.

6. Results of reliability confirmation as outlined in Section 4.2.D.

7. Quality control checks performed and any difficulties encountered, including:

    a. Description of the cycle slip detection if manually correcting cycle slips. Outline the rectification procedure as well as which baseline(s) required cycle slip ambiguity resolution. When automatically detecting and resolving cycle slips, no description is required.

    b. Parameters used for any coordinate transformations shall be presented with worked examples.

    c. Scaling of the covariance matrix by the contractor must be described and justified in detail.

    d. Description summarizing any other data anomalies beyond those outlined above.

5.3.B Adjustment Results

The adjusted 3D coordinates of markers to the nearest millimetre must be presented in the production survey report. The coordinates must be based on a network adjustment constrained to the values published by the Branch for existing markers to which the survey is tied. To avoid datum transformation problems, position difference observations, as opposed to position observations, must be used in the adjustment. Proper attention must also be given to the geoidal undulation values so that appropriate orthometric heights can be derived. Geoidal undulation values as provided by the Branch, must be used for the derivation of orthometric heights (see Section 2.3). Even though the elevations of the markers may ultimately be determined by spirit levelling (see Sections 3.1.B & 3.2), orthometric heights must be derived using GPS.

A minimally constrained adjustment shall also be performed holding one of the known control markers fixed to its coordinate values as provided by the Branch. The full covariance matrix of the adjusted parameters (including nuisance parameters) must be included. If the covariance matrix has been scaled, the methodology for scaling must also be presented, and must be derived from the same procedure as that used in the validation survey (See Section 6).

The contractor shall provide statistical testing of the results of the GPS survey from the network adjustment. This includes analysis of variance factors, the semi-major axes for the 2-D (horizontal) and 3-D 95% relative confidence regions between all possible pairs of points (which must be less than the allowable specified in Section 3.2.), residuals, and residual outliers. Failed standardized residuals at the 95% confidence level may suggest a problem and require either an explanation or re-observation of the problem baseline(s). Further external accuracy evaluation will be carried out by the Branch applying the techniques described in Craymer et al [1989]. This can include the following tests on the coordinate discrepancies for:

1. Descriptive statistics (e.g. means, rms, etc.).
2. Statistical analyses of compatibility.
3. Strain analyses of local systematic distortions within the networks.

5.3.C Data Returns

The format of the data to be included in the information, provided by the contractor to the Branch, is detailed in Table 1 (Pg 29). This is the minimal amount of information required in order to successfully evaluate and integrate the GPS survey into the provincial spatial referencing system. Additional points to be noted when submitting data include:

1. Raw data must be provided on diskette (or CD), properly labelled and described. Data must also be provided in RINEX (Receiver Independent Exchange) format. The processing and results must be based on the on the data as provided to the Branch.

2. Processed baseline information provided to the branch (i.e., data input files) must be broken into the appropriate sessions for each grouping of baselines observed. See *Appendix E* for an example of the formatting requirements.

3. New and existing control markers must be identified by the ASCM number and not by the tablet markings or other contractor specific numbering schemes. The ASCM numbers will be used for all input and output data files, contractor plots or other reporting media.

4. Input data or the minimally constrained adjustment should be submitted in GHOST station and observation record format (see *Appendix E*).

5. GEOLAB Version 2 or 3 is alternative data format for the input data files. Contractors may supply their input data file for the minimally constrained adjustment in GEOLAB position difference observation format. Contact the Branch if further information is required.

Table 1: Contractor Data Submission Requirements for GPS Production Surveys

*Ephemeris information is required from the contractor for both the broadcast and precise ephemeris data (if used). The precise ephemeris data should be provided in SP3 format. For further information, contact the Branch.

DATA ITEM	FORMAT	
	Digital	Hard Copy
Geomagnetic Activity Reports	No	Yes
Daily Diary	No	Yes
Marker Condition Reports	No	Yes
Raw & RINEX Format GPS Observation Files *(includes ephemeris, site and observation data)	Yes	No
Baseline Solution Files	Yes	No
Input Data Files		
minimally constrained (Scaled and Unscaled)		
- GHOST format (or GEOLAB V2 or V3 format)	Yes	No
- Contractor adjustment	Yes	Yes
fully constrained		
- Contractor adjustment	Yes	No
All baselines divided into sessions		
Network Plot Showing Observed Baselines	No	Yes
Repeat Baselines & Loop Closure Analysis	No	Yes
Network Adjustment Output		
minimally constrained - adjustment coordinates - scaled variance covariance matrix - confidence regions - residual analysis - variance factor analysis	No	Yes
fully constrained - adjusted coordinates - confidence regions - residual analysis - variance factor analysis	No	Yes
Catalogue List of Data Files (explicit definitions of file content and usage)	Yes	Yes

6 VALIDATION

A GPS validation survey is very similar to a production GPS survey in that many of the functions completed (or to be completed) during a production survey are also done for a validation survey. The key differences are that the validation survey is usually completed out before the production survey and carried out on a network of precisely known points. Validation surveys are usually undertaken for one or more of the following reasons:

1. Any contractor who wishes to undertake a GPS survey to establish and/or maintain the provincial spatial referencing system, but has not previously completed a GPS validation survey for the Branch.

2. Contractor has previously completed a GPS validation survey, but has made significant changes in his/her GPS equipment, processing and/or adjustment software, field crew or methodology.

3. Contractor has not completed a GPS validation survey within the last 3 to 5 years. It is noted that the time limit of 3 to 5 years is somewhat arbitrary and can be reviewed on a case by case basis, contact the Branch for more information.

Much of the following information either repeats or is referred back to the previous sections within this manual. It is for this reason that the GPS validation surveys section has been placed at the back as opposed to the start of the manual. Most contractors will find that the first GPS survey they will undertake, before establishing/integrating new or existing control within the spatial referencing system, is a validation survey. Users of this manual are encouraged to carefully review all of the information before Chapter 6.

6.1 Purpose of GPS Validation Surveys

The purpose of a GPS validation survey is to test the contractor's GPS surveying system. The contractor's system consists of the GPS receivers, processing and adjustment software, the field crew to be employed in the production GPS survey and the integration methodology to be used in the production survey. The results of the validation are used by the Branch to determine whether the contractor has the capability to meet second-order standards for establishment and/or integration of new and existing control using the contractor's GPS system.

Evaluation of the validation is carried out by reviewing the internal and external compatibility of the GPS validation survey. The Branch will be responsible for all official analysis, but contractors may wish to perform the analysis as part of a self-validation exercise. A description of the evaluation process is outlined in the following sections. The Branch evaluates the contractor's data by using the NETVAL suite of programs for validating 3-dimensional network surveys. For further information on the NETVAL suite, please contact the Branch.

In Alberta there are two GPS validation networks. One network is situated in the

Edmonton region and the other is situated in the Calgary region. Both networks were established on a co-operative basis between the Province, GSD, and the Cities of Edmonton and Calgary. Each network consists of a set of forced centring pillars with baseline lengths varying from approximately 325 m to over 140 km. Consequently, almost any combination of baseline lengths can be accommodated on one or the other network. Long baseline lengths are particularly important for users who may need to evaluate their GPS survey system for integration ties to the Canadian Base Network. For further information on the GPS validation networks in Alberta, please contact the *Data Distribution Unit of Resource Data Division* (Ph: 780/427-7374) to obtain copies of the validation network manuals, (*Edmonton GPS Validation Network* and *Calgary GPS Validation Network*). They are available free of charge and explain in detail the location and purpose of the networks as well as giving scientific coordinate data with which a contractor can use to self-validate their GPS survey system.

The Branch is responsible for the evaluation and subsequent approval of the surveyor's GPS system for ASC projects. However, there are instances where the contractor wishes to do a self-validation of their GPS system. In this situation, the Branch is available to evaluate the surveyor's data if requested to do so. Please contract the Branch for further information.

6.2 The Validation Process

As previously discussed the steps to be completed for GPS validation surveys are very similar to those carried out for a GPS production survey. They involve the project design, data acquisition and data handling of the GPS survey information. The validation survey is to be designed such that it uses the same equipment, software and methodology as that proposed for the GPS production survey.

6.2.1 Project Design

The extent of the validation exercise will be a function of the station separation to be encountered in the production situation. The contractor must follow the procedures outlined in Sections 3.1 and 3.2 when designing the validation survey. In addition to *3.1* and *3.2*, contractors should note the following information when designing the validation survey:

1. Use the validation network that has baseline lengths that best reflect those to be encountered within the production survey. The Edmonton GPS Validation Network has the baselines ranging from 450 m up to 140 km. The Calgary GPS Validation Network has baselines ranging from 325 m to just over 41 km. With a typical HPN spacing of 1000 m (*minimum of 800/ maximum of 1500 m*), either baseline should meet any test requirements.

2. Validation surveys to be carried out at the Edmonton GPS Validation Network must include **ASCM 265959** as part of the evaluation process as this is considered by the Branch to be the "fixed" station within the network. Conversely, **ASCM 25320** is the "fixed" station within the Calgary GPS Validation Network

that must be included when submitting a validation survey for evaluation by the Branch (See the following information).

3. Design the validation survey to best reflect the GPS production survey for evaluation of the contractor's GPS surveying system.

6.2.1 Data Acquisition

The data acquisition stage will follow the same requirements as outlined in Section 4 of this manual. Again, it is a test of what, where and how the contractor plans to carry out the production survey.

The data collection rates are based on that required for the production survey. Typically, the production survey will involve integration and/or establishment of an HPN within a municipality. Therefore, the rate will likely be at a 15-second epoch for a 60-minute session. Nominally, for observed baselines of less than 20 km, the rate is 5 second epochs for 20 minutes, and 15 second epochs for more than 20 minutes for baselines over 20 km.

It is particularly important for the contractor to carry out the reliability confirmation of his/her validation survey through the repeated baseline analysis, baseline residual analysis and loop closures. This information is very helpful to both the contractor and the Branch in determining whether the desired precision and accuracy of the validation survey is met.

6.2.2 Data Handling

The processing, evaluation, reporting and the observational data returns to be submitted will be very similar to that described in Section 5 of this manual. In particular, data decoding and baseline processing will follow those steps as is proposed within the production survey. However, there are some differences with respect to the least square adjustment results and the data evaluation.

6.2.3.A Least Squares Adjustment

Specifically, the contractor will submit to the Branch their derived three-dimensional NAD83 coordinates for the validation basenet markers to the nearest millimetre. The adjustment will consist of an unscaled minimal constraint adjustment of the contractor’s GPS validation survey. From this adjustment, a full formal covariance matrix of the adjusted parameters must be supplied to the Branch for evaluation. The data to be included in the returns for the Branch are detailed in Table 3 within this section.

The minimally constrained adjustment must be performed through the use of horizontal and vertical constraint equations using either ASCM 265959 (*Edmonton validation network*) or 25320 *(Calgary GPS validation network*). The coordinate values to be used in the adjustment and the associated constraint equation information are provided by the Branch. Please see Appendix *E (GEOLAB Format Input file*) for information on the constraint equations to be used for the 2D/1D parameters.

6.2.3.B Data Evaluation

The evaluation of the internal and external accuracy is concerned with the assessment of both the strength of the network design, the influence of some of the errors and unmodelled biases which may affect the GPS survey results, and compatibility of the derived solution with “known” values. As with the GPS production survey, the data evaluation is divided into two distinct parts, the internal and external accuracy.

6.2.3.B.1 Internal Accuracy

The internal accuracy is evaluated using the covariance matrix from the resulting minimal constraint adjustment as well as comparisons between baseline and minimally constrained network results. To assess the internal accuracy of the final network solution, relative confidence regions must be determined from the network covariance matrix (i.e., the minimal constraint adjustment). Each of the semi-major axes of all possible 2D (horizontal) and 3D 95% relative confidence regions shall meet second-order standards with respect to baseline length. In addition, the single baselines shall be compared to the minimally constrained adjustment results for 3D standards.

6.2.3.B.2 External Accuracy

The external accuracy of the final GPS solution can be assessed by examining its compatibility with the *known* coordinates established by more accurate standards as well as evaluating the network-wide and local distortions between the known and unknown coordinates. Coordinate discrepancies between the GPS solution and existing basenet pillars are analyzed using various statistical tests and strain analysis. It is noted that reliability of the solution increases with the number of GPS network validation points included in it. For contractors this may result in a trade-off between cost efficiency (few basenet points) and reliability of the evaluation (more basenet points). However, the number of points observed at is ultimately dictated by the design of the GPS production survey. Contact the Branch for assistance if further information is required.

6.2.3.B.2.a Compatibility

Assessment of the external accuracy is carried out via evaluation of the coordinates from the GPS network solution for statistical compatibility with the *known* control points using the Chi-square test.

$$\Delta\mathbf{x}^{T}\mathbf{C}^{-1}_{)\mathbf{x}}\Delta\mathbf{x} \le \xi\chi^{2}_{u,1-\alpha}$$

The $\Delta\mathbf{x}$ vector is composed of differences between corresponding coordinates of the *known* control points. The $\mathbf{C}_{\Delta\mathbf{x}}$ matrix is the sum of the two covariance matrices associated with the coordinates from the GPS solution and the *known* control ξ is the abscissa of the Chi-squared distribution function for a significance level of α. u is the number of parameters being tested.

Various combinations of the coordinates may be tested together by defining $\mathbf{\Delta x}$ and $\mathbf{C}_{\Delta x}$ in different ways. The tests used include:

a. $\mathbf{\Delta x}$ containing only the 3D coordinate differences (x, y, z) at a single station (u = 3)

b. $\mathbf{\Delta x}$ containing only the x (north) coordinate differences (u = number of stations)

c. $\mathbf{\Delta x}$ containing only the y (east) coordinate differences (u = number of stations)

d. $\mathbf{\Delta x}$ containing only the z (height) coordinate differences (u = number of stations)

e. $\mathbf{\Delta x}$ containing only the differences in the 2D horizontal (x, y) components (u = 2 times the number of stations)

f. $\mathbf{\Delta x}$ containing all the 3D (x, y, z) coordinate differences (u = 3 times the number of stations)

The above Chi-square tests of parts of the total network coordinate vector (tests 1 to 5) are performed out-of-context from the other parameters; that is, they neglect the presence of the other parameters. These tests may also be performed in the context of the other complement tests so that the simultaneous probability of these tests is equal to the desired confidence level (see Vanicek and Krakiwsky [1986]).

The so called in-context tests are performed in exactly the same manner as the out-of-context ones except that the significance level α/m is used in place of α, where m is the total number of parameters divided by the number of parameters used in the test. For example, test 1 requires using α/p in place of α (p is the number of points in the network), tests 2, 3 and 4 use $\alpha/3$ and test 5 uses $2\alpha/3$. Test 6 uses all parameters and thus the out-of-context and in-context tests are the same for this case. This is summarized in Table 2 below:

In-Context Significance Levels for Simultaneous Confidence Level α

Table 2: In-Context Significance Levels

Test	Significance Level
1	α/p
2, 3, 4	$\alpha/3$
5	$2\alpha/3$
6	α

6.2.3.B.2.b Network-wide Distortions

A Helmert transformation of the GPS solution of all the existing control can be performed using seven parameters (3 rotations, 3 translations and scale). This determines any systematic network-wide differences in scale, rotation, and translation between the GPS and the existing network solution.

One purpose of this evaluation is to detect unmodelled biases in the GPS data, which often results in network-wide distortions. Another purpose is to identify the causes of failure of the statistical compatibility test in Section 5.5.2.3., which may be due to network-wide distortions in either the

GPS network (due to unmodelled biases), or in the existing network solution (for any number of causes).

6.2.3.B.2.c Local Distortions

Strain analysis can also be performed to detect any local distortions between the GPS solution and *known* control points. Local distortions are quantified in the form of strain ellipses and differential rotations. This analysis may be performed using the techniques described by Craymer et al. [1987].

6.2.3.C Data Returns

Either GHOST or GEOLAB (V2 or V3) format is acceptable to the Branch. The required formats for the data file to be submitted for a contractor validation are detailed in Appendix E. For contractor submitted validation data, all data must use the appropriate ASCM numbers to identify the basenet points for both the digital and hardcopy files. Table 3 (page 37) outlines the data submission requirements for the GPS validation surveys.

Of special note, the GEOLAB V2 or V3 extracted output file containing the adjusted coordinates and covariance matrix information from the minimal constraint run must be in position equation format. Please note that this requirement is different from that requested within the production survey where position differences and covariance are required.

6.3 Qualification of Contractors

A contractor will be considered to have successfully qualified for performing GPS surveys for the establishment and integration of control markers into the provincial spatial referencing system if the following conditions are met:

1. All 95% relative confidence regions meet second-order, two-and three-dimensional accuracy standards as defined for the internal accuracy (see above).

2. Final adjusted coordinates and covariance values of all points agree with the *known* values to within second-order three-dimensional standards as defined for the external accuracy (see above).

3. No significant pockets of local distortion exist within the network adjustment.

4. No failed standardized residuals at 95% confidence level, considering the validation scale factor applied to apriori standard deviations. In this case, scaling of the contractor's data may be required in order to obtain a passing solution. While all validation surveys typically require some additional scaling, the amount should be within a reasonable level of the estimated variance factor resulting from the minimal constraint adjustment.

As previously stated, a GPS validation survey is valid for three to five years provided the equipment, procedures, software and field personnel remain unchanged. If this is the case, the contractor is considered to have qualified as a potential contractor for future GPS surveys with station spacing similar to the validation test. However, if the equipment, procedures, software or personnel are modified or changed in any way then the Branch must be informed. If requested, the qualification test may be repeated at the request of the Branch. Acceptance or rejection of a GPS validation survey is the responsibility of the Branch.

Table 3: Contractor Data Submission Requirements for GPS Validation Surveys

* Ephemeris information is required from the contractor for both the broadcast and precise ephemeris data (if used). This precise ephemeris should be provided in SP3 format. For further information, contact the Branch.

DATA ITEM	FORMAT	
	Digital	Hard Copy
Geomagnetic Activity Reports	No	Yes
Daily Diary	No	Yes
Field Log Sheets	No	Yes
Raw & RINEX Format GPS Observation Files *(includes ephemeris, site and observation data)	Yes	No
Baseline Solution Files	Yes	No
Input Data Files minimally constrained (unscaled)		
- GHOST format (or GEOLAB V2 or V3 format)	Yes	No
- Contractor adjustment	Yes	Yes
All baselines divided into sessions		
Network Plot Showing Observed Baselines	No	Yes
Repeat Baselines & Loop Misclosure Analysis	No	Yes
Network Adjustment Output minimally constrained - adjusted coordinates - confidence regions - residual analysis - variance factor analysis	No	Yes
Validation Data File (Appendix E or alternate format) - adjusted coordinates - covariance matrix of parameters - observation connections	Yes	Yes
Catalogue List of Data Files	Yes	Yes

APPENDIX A - EXAMPLE - PROJECT DESIGN & DATA ACQUISITION

1 INTRODUCTION

The following example has been developed to give the user of this manual a guide to project design and data acquisition as it applies to the establishment and integration of new and existing control markers into the provincial spatial referencing system.

2 PROJECT

2.1 Background

Within the Town of Hyder and surrounding area there are approximately 111 existing ASCMs. Based on the desired HPN spacing (i.e., density) of 1000 m to 1500 m, eight control markers are going to be upgraded with high precision GPS ties to each other and to the CBN. Six of the markers have conventional ties to the surrounding ASCMs. Two other markers are also ASCMs with conventional integration ties as well as existing high precision GPS ties to the CBN. Table 4 shows the control markers that have been chosen for this project.

Table 4: Proposed HPN Markers for Town of Hyder

ASCM #	Horizontal Order	Vertical Integration Method	CBN Tie
13599	2	Spirit	No
21451	2	Spirit	No
25254	2	Spirit	No
34652	2	Spirit	No
138859	2	Spirit	Yes
150615	2	Spirit	No
220905	2	Spirit	No
223446	2	Spirit	Yes

The markers to be used for the HPN are typical for the ASCMs found within most municipalities in Alberta. They are integrated with respect to their surrounding control markers at the 2nd order level and all have been integrated vertically using differential spirit levelling techniques.

With respect to the physical location of the markers, they are located either in grassed boulevard or open areas. The skyplots (see Skyplots on pages 7 to 14 of Appendix A) show that the observation horizon is clear down to 10 degrees above the horizon except for either nearby light standards, 3-wire power lines (at one marker) or trees and bushes. These kinds of obstructions will only give intermittent blockage of the GPS signals and should not be cause for concern. During the data collection and processing stages, this information is useful to help obtain the best results. Based on the physical and mathematical constraints of the eight stations, all of these markers will provide a good base for the establishment of the HPN in Hyder.

2.2 Operational Requirements

The following operational requirements are in place for this project:

1. Carry out GPS integration ties between the eight control markers that will constitute the HPN.
2. Make two additional direct integration ties to the CBN at two markers other than the two existing CBN-tied markers. The additional ties are necessary in order to obtain the correct orientation and scale of the HPN in Hyder with respect to the CBN. This is important since the CBN forms the fundamental basis for any HPN in Alberta.
3. This project will employ the GPS baseline (leapfrog) approach for surveying as opposed to the monitor station method (see *Section 4.2.C*).
4. Four GPS receivers and antennas will be used for this project.
5. The surveyor contracted to do this work has never undertaken a GPS survey for control purposes. Therefore, the contractor must complete a GPS validation survey using his/her GPS surveying system (i.e., GPS receivers, baseline processing and adjustment software, field crew and methodology).
6. The survey is considered to be 3D and orthometric heights based on the GPS observational data will have to be solved for. Differential spirit levelling will not be required for this project since all control markers within the project already have good vertical coordinate values.

All the markers are located within public areas and the only utilities within the area of the markers are power lines and one gas wellhead (at ASCM 13599). Additionally, all of the markers are accessible by vehicle and/or by foot.

2.3 Proposal

2.3.A Project Design

This project can be divided into two pieces: the first involves the GPS observational ties between the proposed HPN markers; and the second involves the additional direct integration ties to the CBN from two control markers other than the two existing CBN integrated markers in Hyder.

2.3.A.1 HPN Integration Survey

To adequately integrate the HPN markers, five GPS sessions are being proposed using all four GPS receivers. Table 5 is a matrix of sessions versus markers that summarizes the proposed GPS survey. Figure 1 (see page 15 of Appendix A) shows the various proposed occupations for each session within the GPS survey. From both Figure 1 and

Table 5 it can be ascertained from this design:

1. Seven of the 30 baselines are repeated. Note that the baselines are not always repeated session to session, but are devised such there is at least one repeated baseline in each session.

2. Each marker within the design is occupied at least two times. In this case, half of the control markers are occupied twice and the other half are occupied three times.

3. All four receivers are used in each session.

4. All of the markers are directly integrated to their next nearest control marker. This is not always possible, but under most conditions within an urban environment this is advisable in order to get the necessary reliability into the survey.

5. Two baselines are approximately perpendicular to each other and run the full extent of the surveyed area (*Session C – ASCM 223446 to ASCM 13599 & Session D – ASCM 150615 to ASCM 34652*).

6. Baselines to be observed in each session are approximately of equal length. The shortest compared to the longest in any session is Session D with a 600-m baseline and a 3300-m baseline.

Table 5: HPN Survey - Session vs ASCMs Matrix

ASCMs/Sessions	A	B	C	D	E	Number of Occupations
13599	X		X		X	3
21451	X	X				2
25254	X	X				2
34652			X	X		2
138859			X	X		2
150615		X		X	X	3
220905		X		X	X	3
223446	X		X		X	3
Number of Receivers	4	4	4	4	4	

It is noted that when designing the GPS survey, use of the matrix showing the sessions and ASCMs makes it easy to visually see the repeated baselines as well as keep a tally of the number of occupations and the number of receivers used in each session. Contractors are encouraged to use this method when presenting their designs.

2.3.A.2 CBN Integration Survey

The CBN integration survey of the two additional control markers to the Hyder HPN is a simple exercise. Again, it is emphasized that the reason for doing this is that the two additional CBN-tied markers in Hyder will help to define both the scale and orientation of the HPN with respect to the CBN. Deciding on which additional markers to make direct ties to the CBN follows the same criteria as for any other marker to be included within the GPS-based provincial spatial referencing system. It is noted that these markers should, where possible, be located such that their longevity is guaranteed due to the cost of making ties to the CBN. For the purposes of this project, ASCMs 21451 and 25224 will have additional CBN ties made to them.

Though not discussed directly within this manual, there are 21 CBN markers within the province of Alberta with a nominal spacing of 125 km south of 56 degrees latitude and 300 km above 56 degrees latitude. For the Town of Hyder, the two nearest CBN markers are at Fox Creek (ASCM 398321) and Hinton (ASCM 351148). Typically, integration of an HPN project only requires direct ties to two CBN pillars. While there is some advantage to integrating to more than two CBN markers for determination of orientation and scale of an HPN, the cost versus benefit is not justified in most cases.

As with the HPN, the CBN integration survey is also summarized using a sessions versus ASCMs matrix. Table 6 below shows the sessions, number of occupations and number of receivers. Figure 2 is a diagram of the layout of the survey (see *pg 16 - Appendix A*).

Table 6: CBN Survey - Session vs ASCMs Matrix

Sessions ASCMs	A	B	Number of Occupations
21451	X	X	2
25254	X	X	2
351148	X	X	2
398321	X	X	2
Number of Receivers	4	4	

Again, all of the criteria with respect to repeated baselines, double occupation and number of receivers is met. The only problem with this survey is the disproportionate lengths of the observed baselines. Between the two markers within Hyder, the baseline length is approximately 1 km while for the two CBN markers it is approximately 135 km long. Unfortunately, since ASCMs 351148 and 398321 are the two closest CBN markers, the odd length baselines will have to be accepted. It is noted that during the validation portion of the project, it is possible to test this situation to verify that no significant impacts will occur.

2.3.B Data Acquisition

For the purposes of this project, only the physical constraints and data collection rates will be discussed as information such as reliability confirmation cannot be demonstrated without the collection of actual GPS observational data. However, once the surveyor has designed and collected the information, it is a natural process to follow for the evaluation and reporting of the results.

Within this project, four dual-frequency GPS receivers with geodetic quality antennas (e.g., woppy-type geodetic antennas) will be employed. Since the observed baselines vary from approximately to 1 km to over 130 km, the use of dual frequency receivers is a must. The same antennas types will be used to avoid any incompatibilities related to phase centre determination.

Physical constraints at each station are such that multipath and imaging problems are at a minimum. Field crews should be aware of the potential electro-magnetic interference from mobile radios and cell phones to the GPS receivers and antennas. Also, field crews should be cautioned regarding parking of vehicles in close proximity to the antenna as this might cause multipath problems to occur. Plummeting at each of the HPN points will be facilitated by using tripods with optical-plummet tribracs and checks of the optical-plummet made as required. The CBN stations are forced centring pillars and do not require optical plummeting. Also, each station within the survey will have complete independent sessions by re-positioning each unit before the start of a new observing session.

The data collection rates used in this survey are typical for HPN establishment and integration, including to the CBN. For the HPN integration survey, the sessions will be 60-minutes long (see *Section 4.1.C*) at a data collection rate of 15-seconds. Conversely, for the CBN integration survey, the sessions will be 3-hours long (see *Section 4.1.C*) at a data collection rate of 15 seconds. This level of data collection will meet the needs of the project.

2.4 Validation Survey

As previously noted, the contractor is required to validate due to a lack of experience with this type of project. The validation survey for this project must reflect as close as possible the GPS survey to be undertaken in the field to test the surveyor's GPS surveying system. The evaluation will be carried out at the Edmonton GPS Validation Network using a combination of short and long baselines in order to simulate the HPN and CBN integration surveys.

2.4.A Short Baseline Evaluation

The ASCMs to be used for the short baseline portion are 265959, 208595, 320424 and 814343. The baselines in this situation vary from approximately 1 km to 10 km in length. Table 7 and Figure 3 (*pg 17 - Appendix A*) demonstrate the layout of the short baseline observations.

Table 7: Validation Survey (Short Baselines) - Session vs ASCMs Matrix

ASCMs\Sessions	A	B	Number of Occupations
208595	X	X	2
265959	X	X	2
320424	X	X	2
814343	X	X	2
Number of Receivers	4	4	

2.4.B Long Baseline Evaluation

For the long baselines, the ASCMs to be used are 265959, 208595, 107797 and 483404. In this situation, the baseline lengths vary from approximately 1 km to over 140 km (ASCM 107797 to 4834040). As above, Table 8 and Figure 4 (*pg 18 - Appendix A*) demonstrate the validation survey portion for the CBN integration ties.

Table 8: Validation Survey (Long Baselines) - Session vs ASCMs Matrix

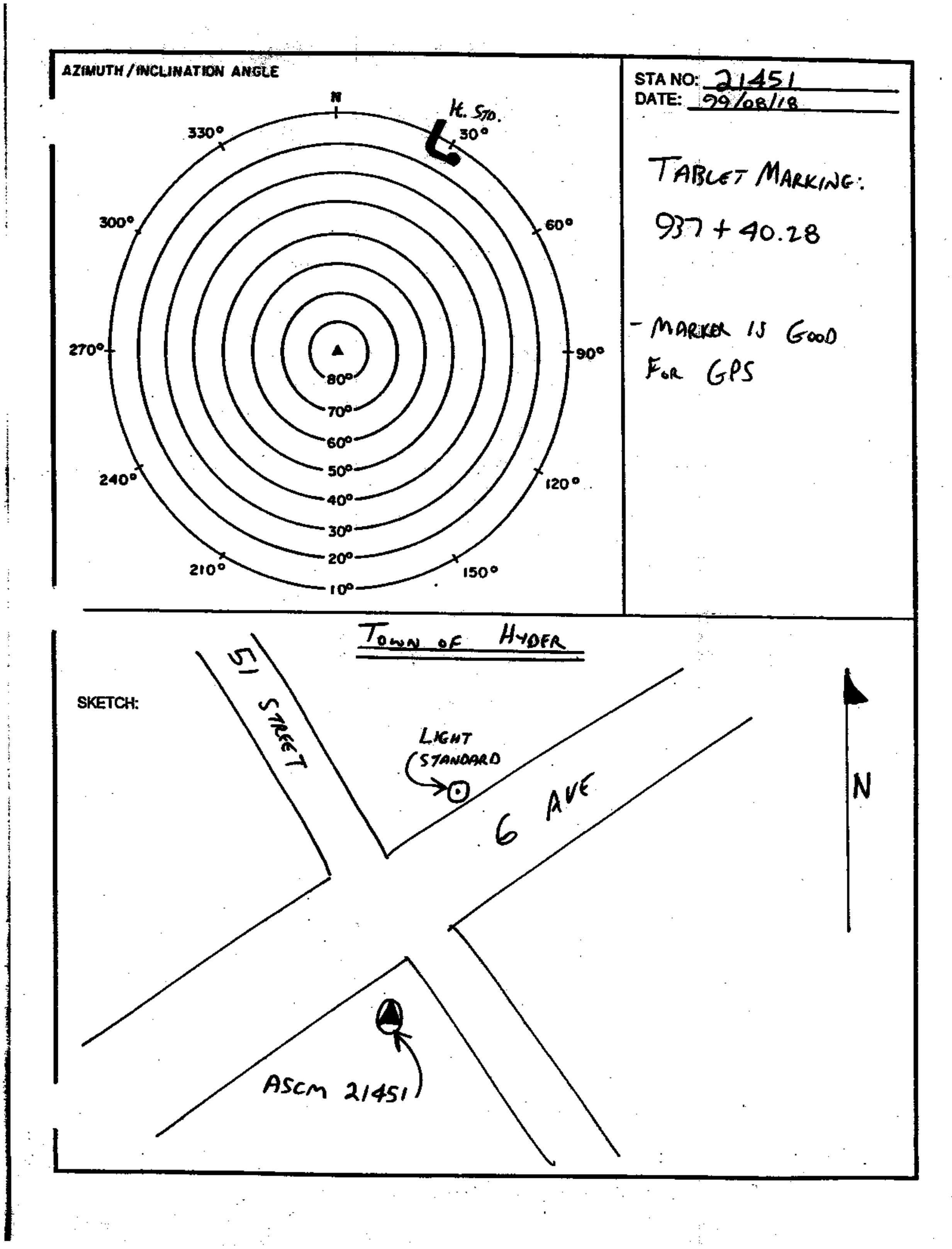
ASCMs\Sessions	A	B	Number of Occupations
107797	X	X	2
208595	X	X	2
265959	X	X	2
483404	X	X	2
Number of Receivers	4	4	

In either part of the validation survey, the requirements for occupation, number of receivers and repeated baselines are met. In these cases, the baselines are being fully repeated between each of the sessions. As previously discussed, this validation gives the surveyor the opportunity to evaluate the GPS surveying system, particularly when combining long baselines and short baselines.

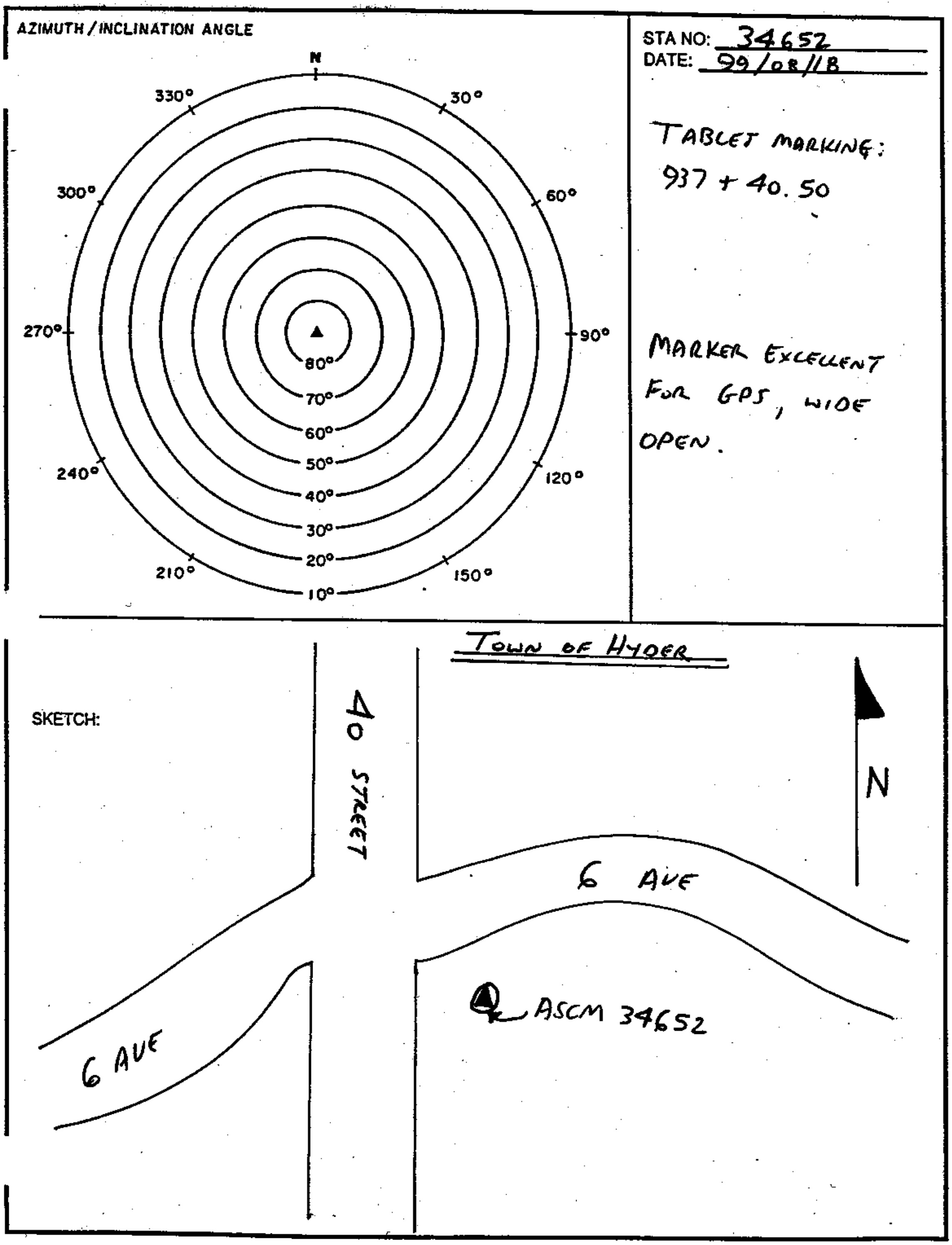
3 Summary

This example has briefly discussed some of the aspects related to GPS project design and data collection for an HPN establishment and integration project using existing ASCMs. There are a number of issues not discussed here including sight visits, access, utility searches, cost of the project, mobilization of the field crew, etc. A number of these issues are dependent on the type of survey being undertaken as well as the experience of the surveyor. What this example has shown is a typical HPN integration project that could be undertaken in any municipality within Alberta. The proposed equipment and methodology will meet the specifications as outlined previously within this manual.

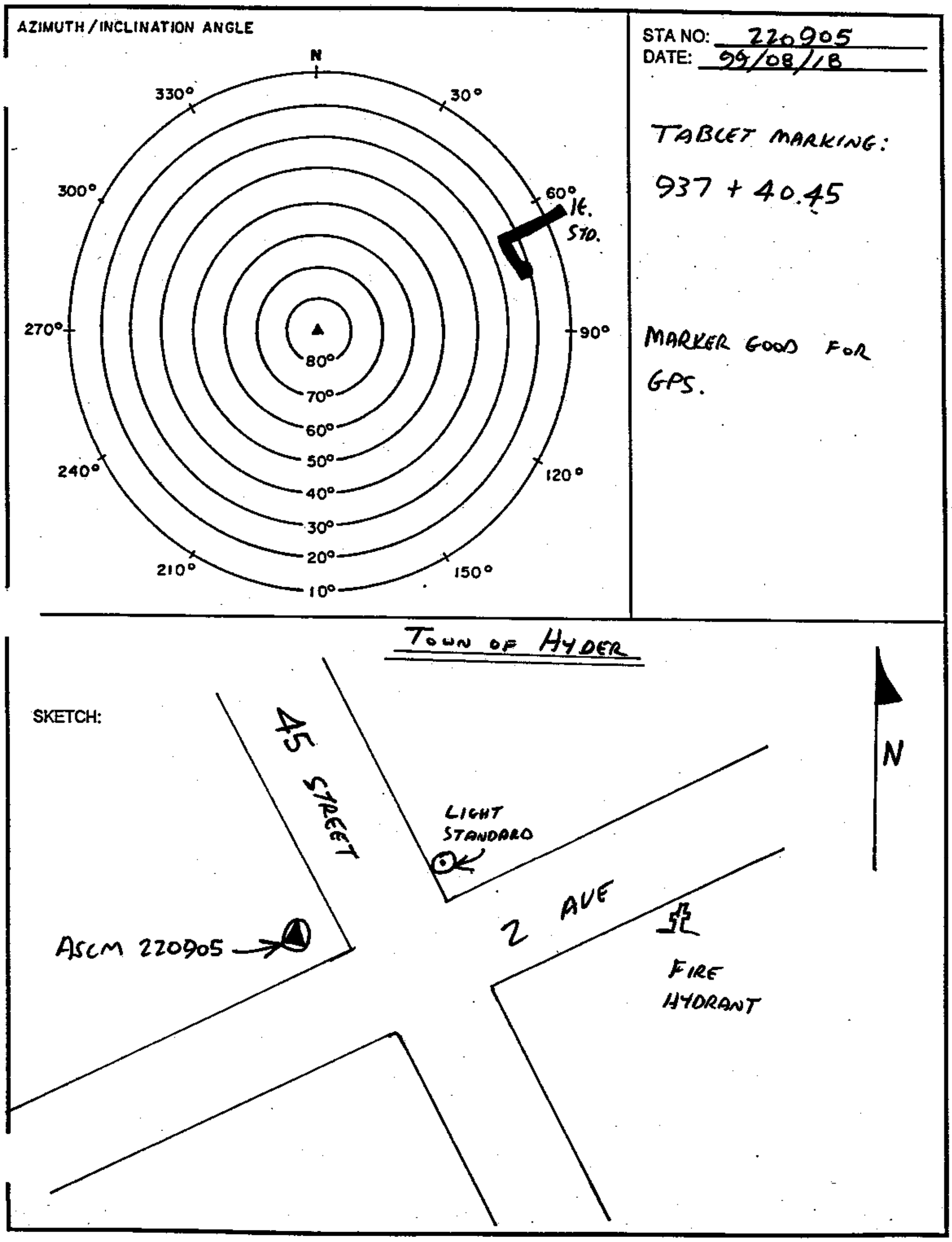
While it is no longer the responsibility of the Branch to approve integration projects for the Provincial spatial referencing system, the Branch is available to review potential projects and provide advice as to how best to design the GPS survey such that specifications will be met. For further information and/or comments related to this example, surveyors are encouraged to contact the Branch.



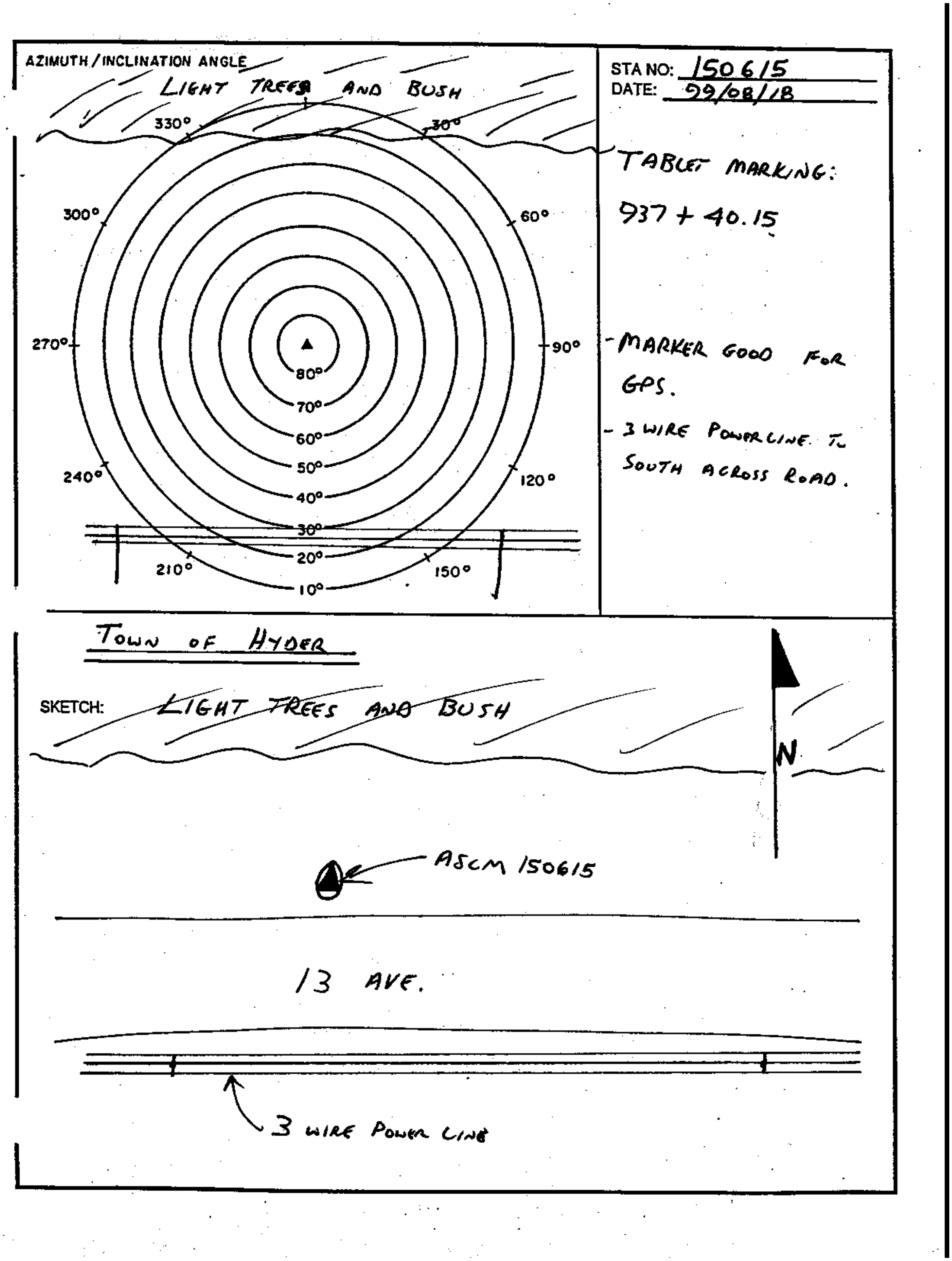
SKYPLOT 1 (ASCM 21451)



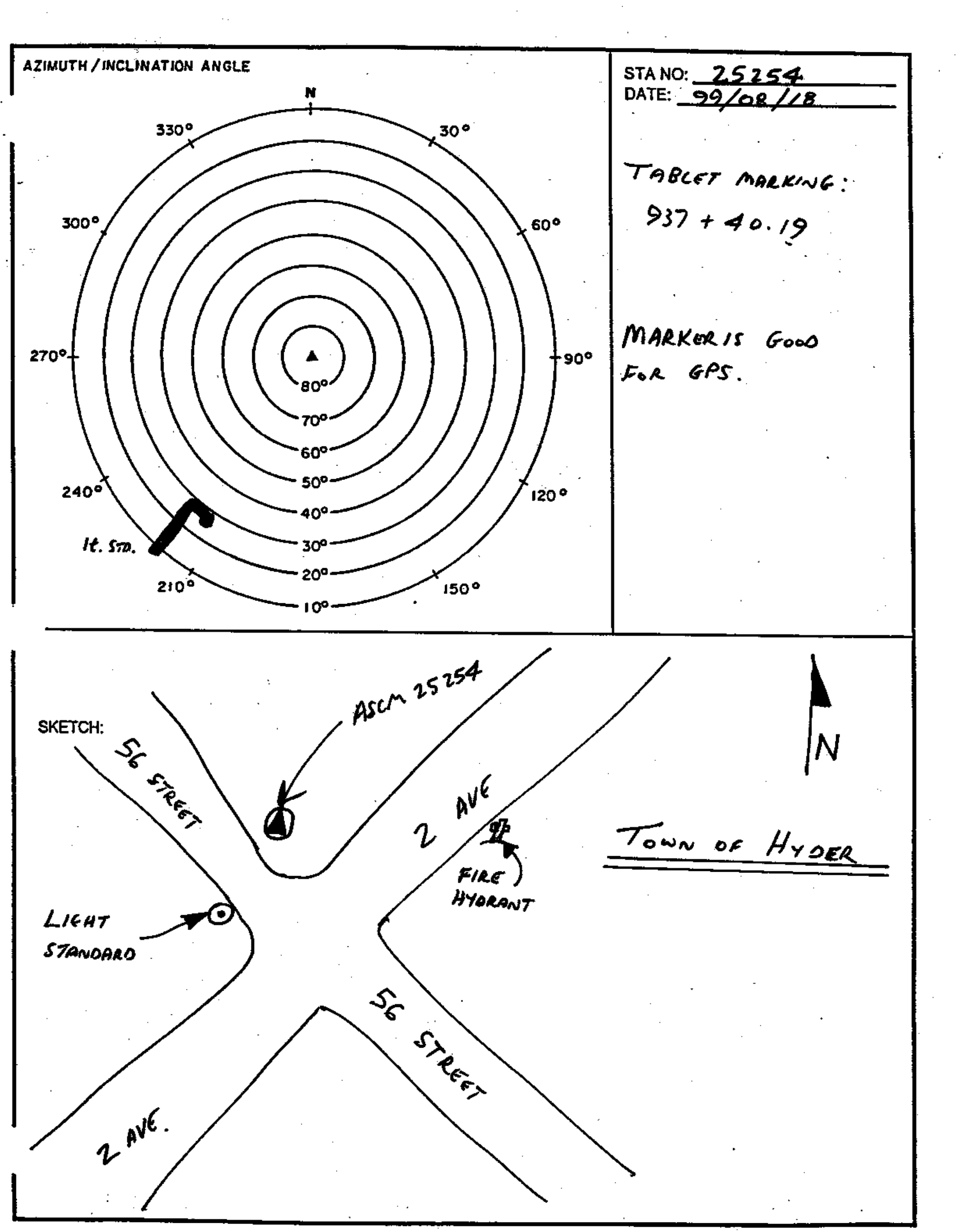
SKYPLOT 2 (ASCM 34652)



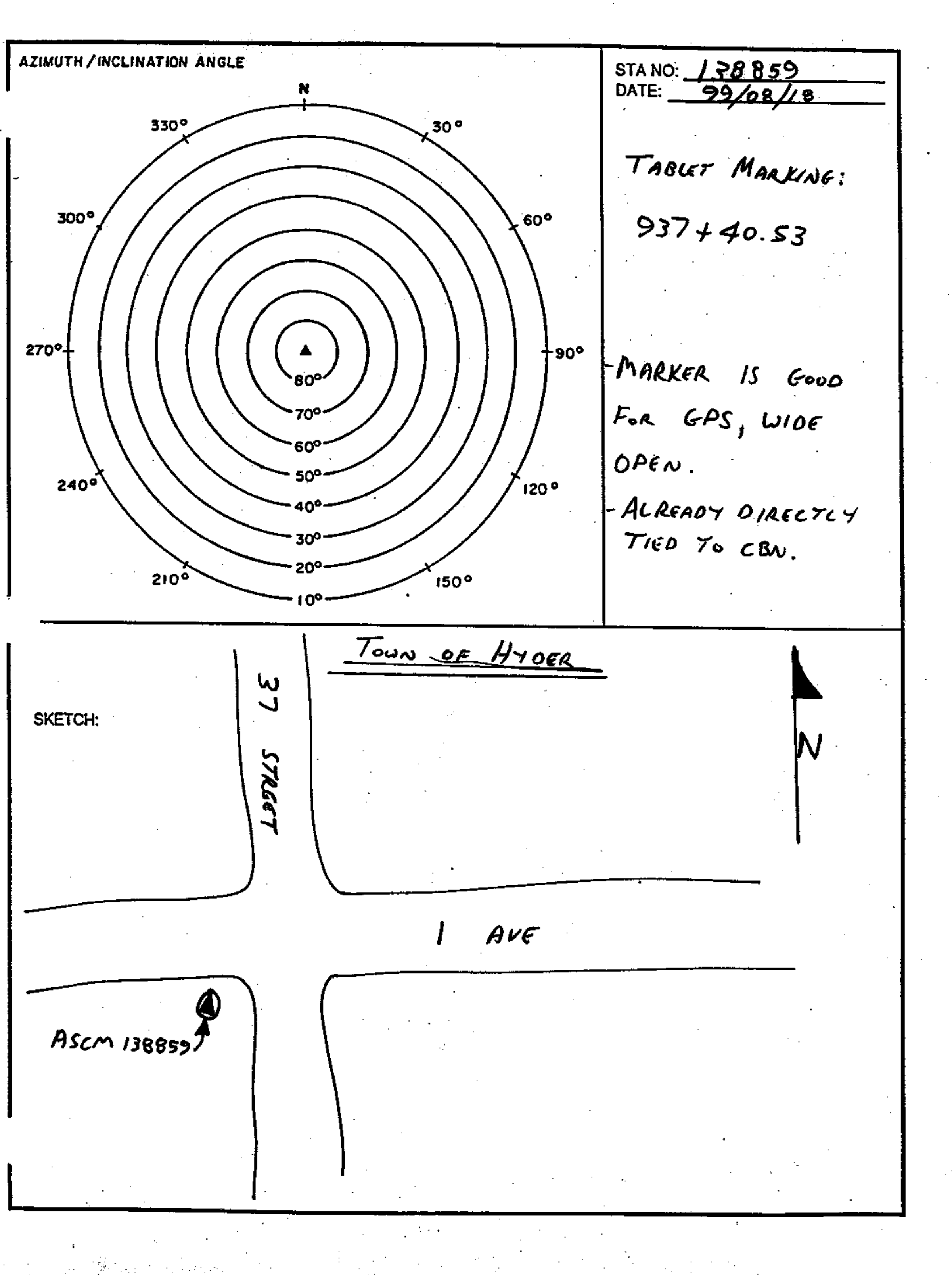
SKYPLOT 3 (ASCM 220905)



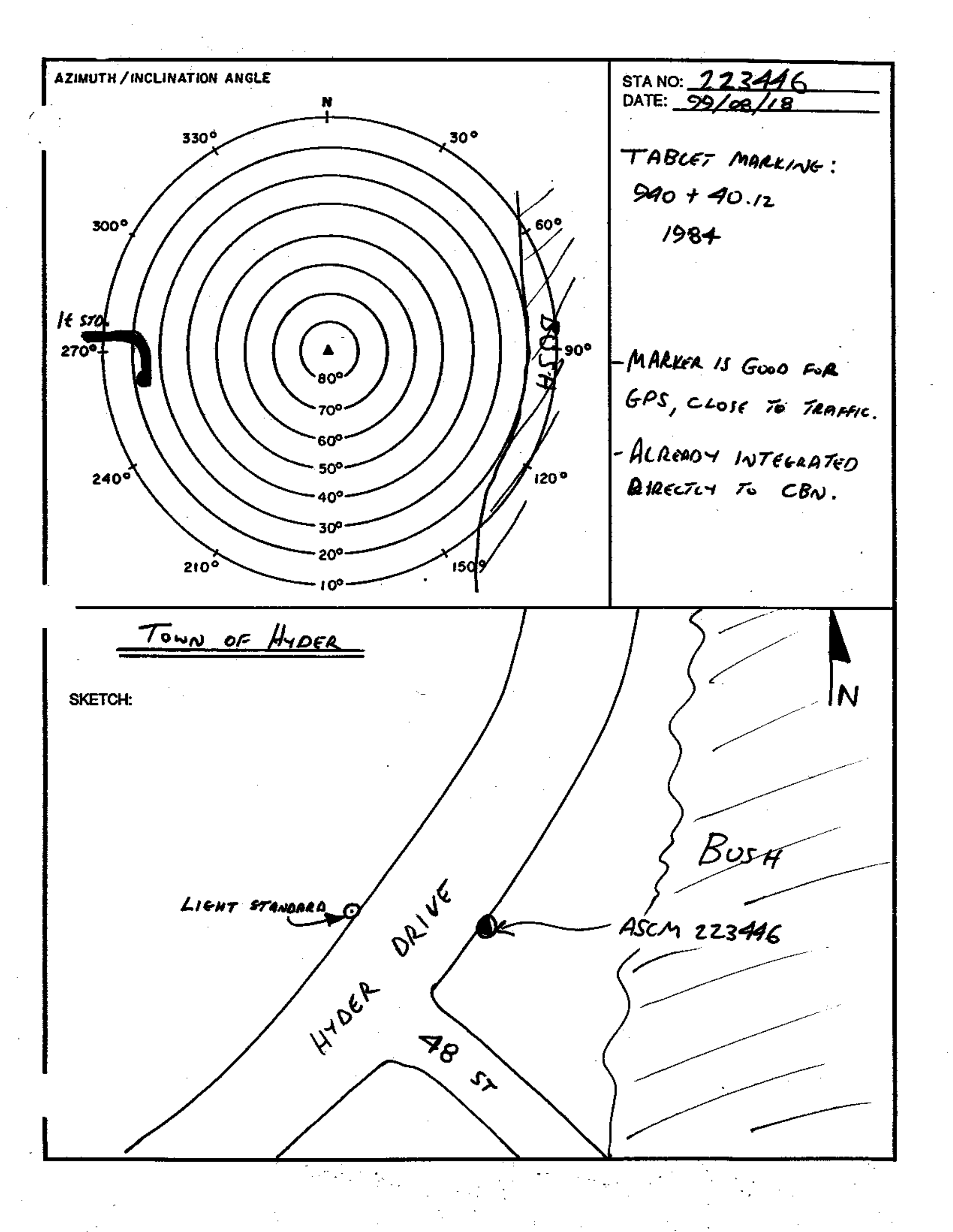
SKYPLOT 4 (ASCM 150615)



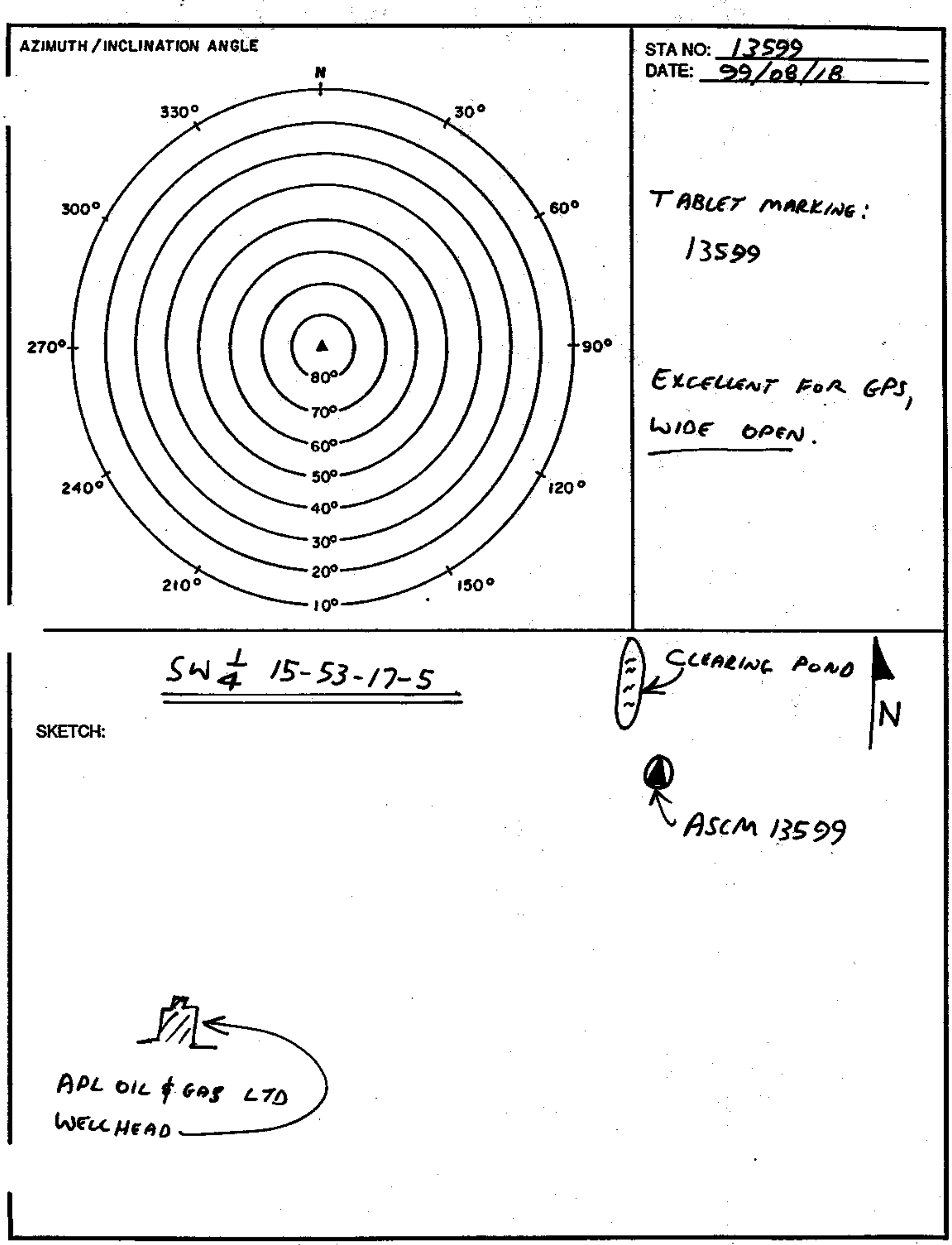
SKYPLOT 5 (ASCM 25254)



SKYPLOT 6 (ASCM 138859)

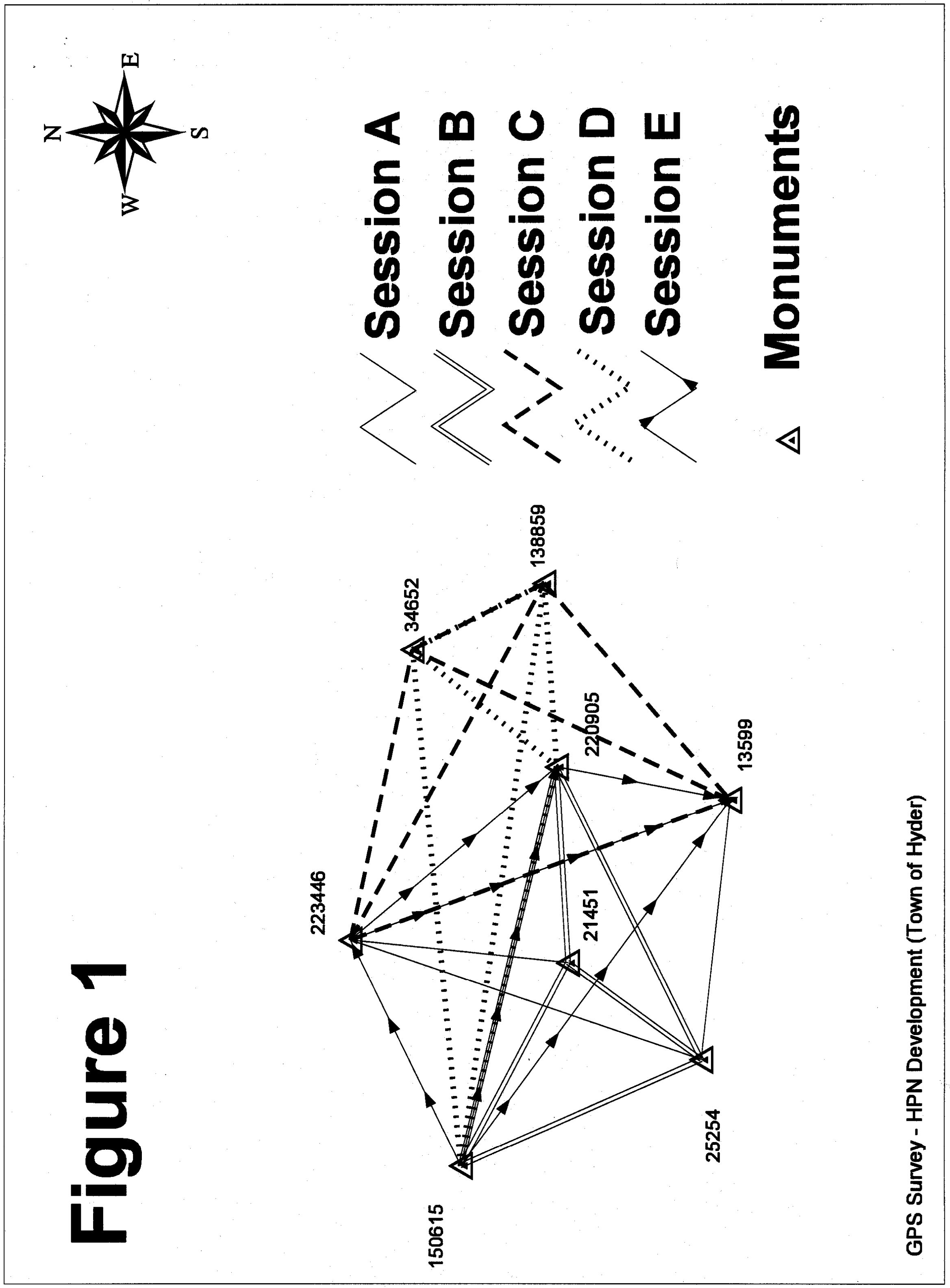


SKYPLOT 7 (ASCM 223446)



SKYPLOT 8 (ASCM 13599)

Figure 1



GPS Survey - HPN Development (Town of Hyder)

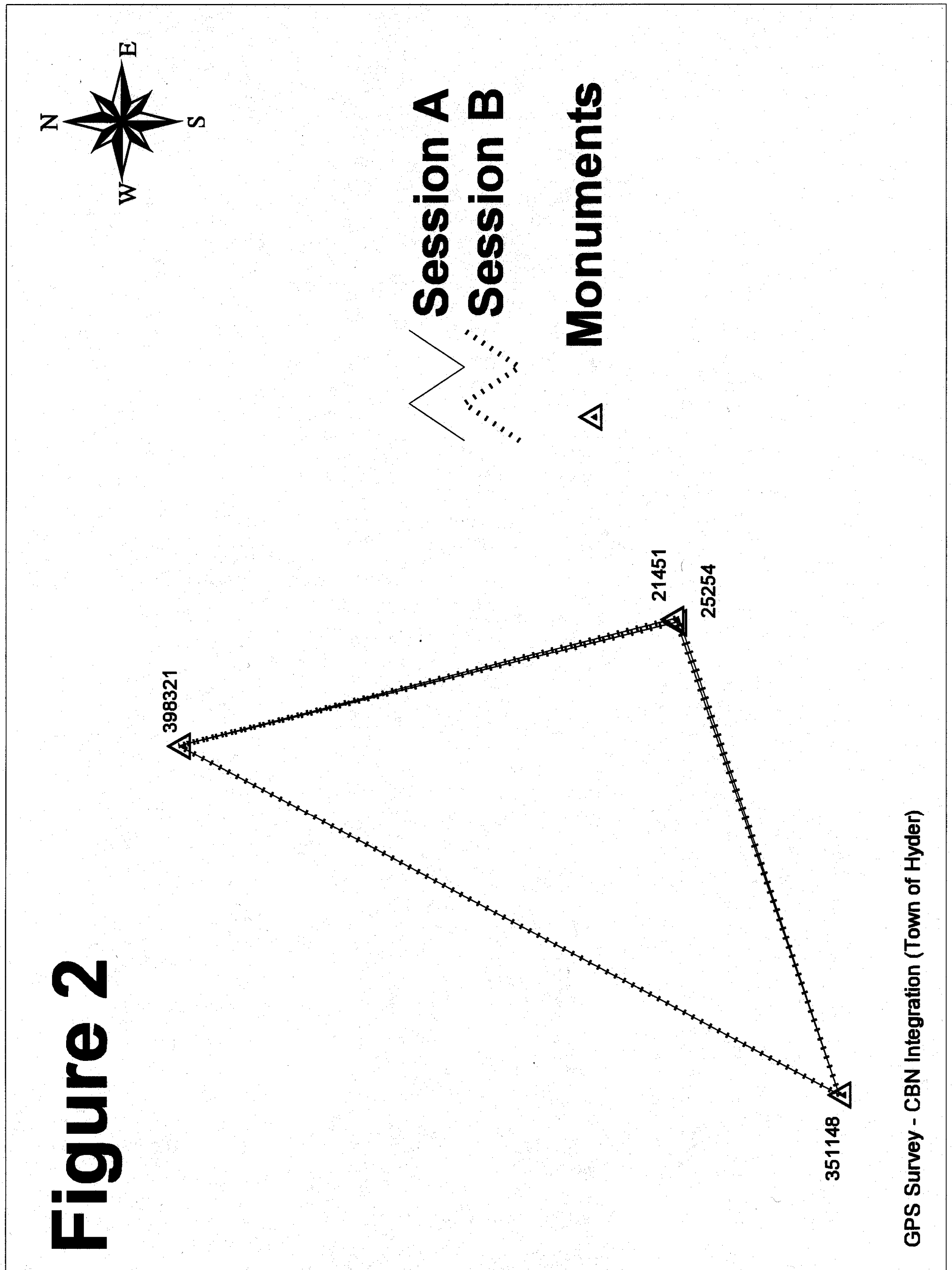


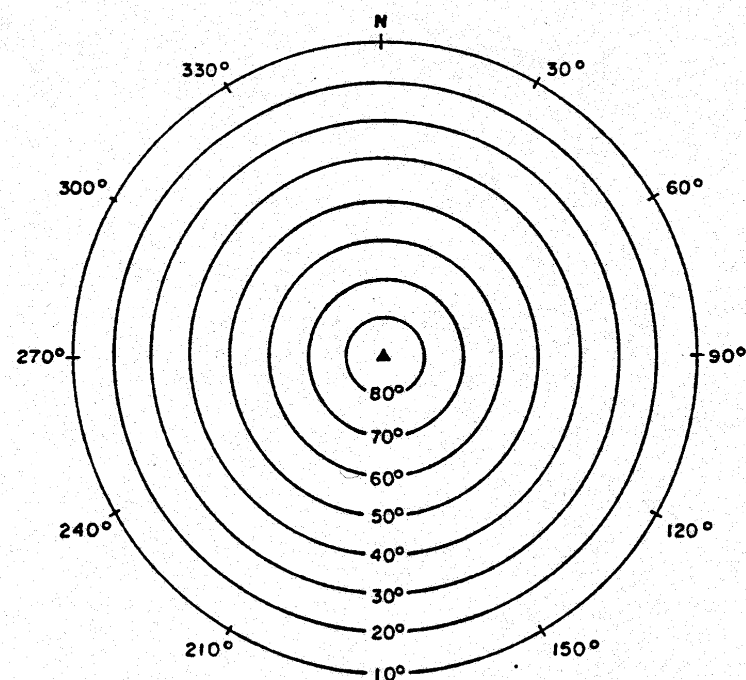
Figure 2
N
E
S
W
Session A
Session B
Monuments
398321
21451
25254
351148
GPS Survey - CBN Integration (Town of Hyder)

APPENDIX B - BLANK SKYPLOT & GPS FIELD LOG FORMS

Sky plot Form

PROJECT NO. ____________

AZIMUTH / INCLINATION ANGLE



STA NO: ____________

DATE: ____________

SKETCH:

GPS FIELD LOG

SITE ______ Page 1 of

PROJECT NAME PROJECT NO.

RECEIVER MODEL ______
RECEIVER NO. ______
ANTENNA NO. / TYPE ______
ANTENNA RADIUS ______
CABLE LENGTH 10m ☐ 30m ☐
SOFTWARE VERSION ______

STA. NAME ______
STA. NUMBER ______
DATE (Y-M-D) ______
OPERATOR ______

DATA COLLECTION

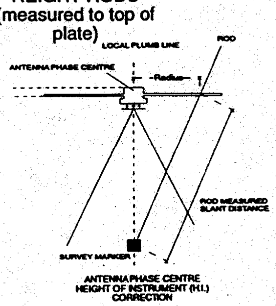
RECORDING INTERVAL ______
START JULIAN DAY/TIME (UT) ______
END JULIAN DAY/TIME (UT) ______

RECEIVER COMPUTED POSITION

LAT. ______
LON. ______
ALT. ______
PDOP. ______

ANTENNA HEIGHT

HEIGHT RODS
(measured to top of plate)



SLANT BEFORE	SLANT AFTER
______ m	______ m
______ m	______ m
______ m	______ m

MEAN SLANT: ______ m

ROD CORRECTION
TO VERTICAL: ______ m

HI: ______ m

DIRECT MEASUREMENT
(measured to top of pillar plate)

BEFORE	AFTER
______ m	______ m
______ m	______ m
______ m	______ m

PLATE THICKNESS:
ASHTECH 0.003 M
DORNE MARGOLIN T 0.000 M

HI MEAN: ______ m

PLATE THICKNESS: ______ m

HI: ______ m

CONSTANT HEIGHT GPS POLE WITH ASHTECH ANTENNA

YES ☐ HI: 2.065 m

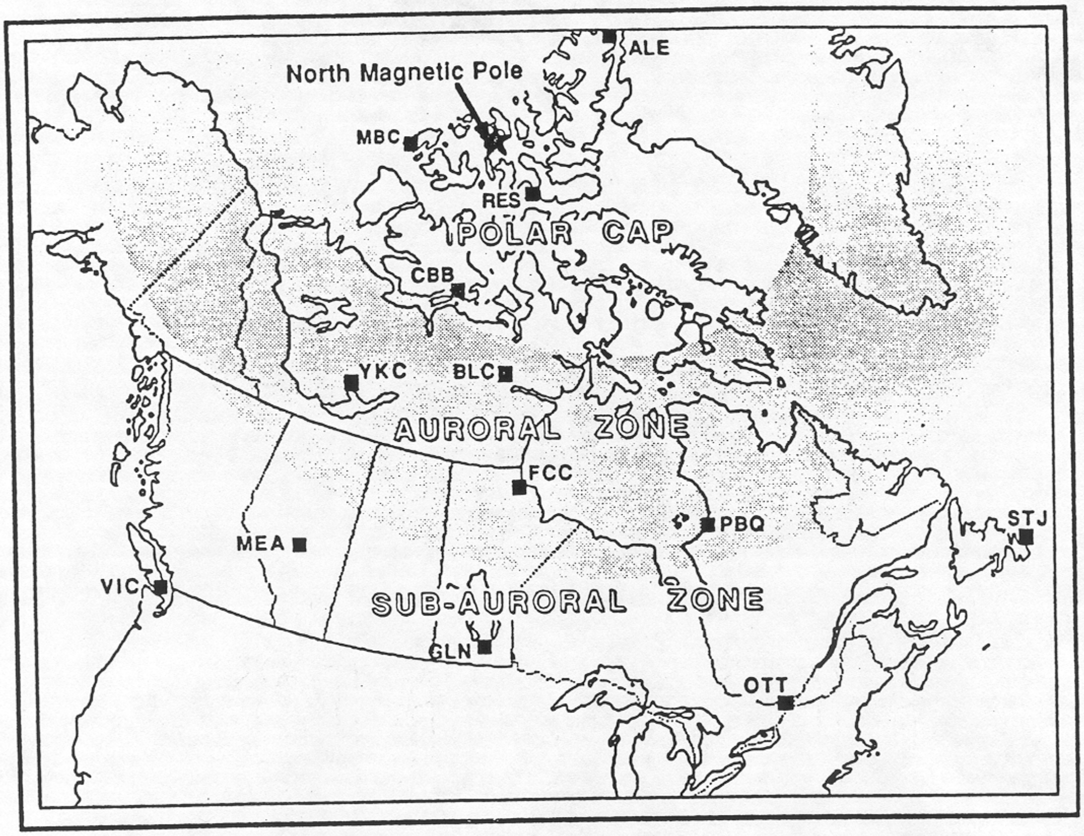
CHECKED BY: ______

GPS Field Log Form

APPENDIX C – GEOMAGNETIC ACTIVITY ZONES IN CANADA

Geological Survey of Canada (NRCan) Web-site: http://www.geolab.nrcan.gc.ca/geomag

Geomagnetic Activity Zones in Canada



Polar Cap	Auroral Zone	Sub-Auroral Zone
ALE Alert RES Resolute Bay MBB Mould Bay	CBB Cambridge Bay BLC Baker Lake YKC Yellowknife FCC Fort Churchill PBQ Poste-de-la Baleine	MEA Meanook GLN Glenlea STJ St.-John's VIC Victoria OTT Ottawa

Canadian Magnetic Observatory Network

APPENDIX D – ASCM CONDITION REPORT

Government of Alberta

ALBERTA SURVEY CONTROL MARKER CONDITION REPORT Side 1

<u>INTRODUCTION</u>

The Surveys Act and pursuant Regulations require that Alberta Land Surveyors shall complete and certify an "Alberta Survey Control Marker Condition Report" form (on reverse side) when dealing with Alberta Survey Control Markers, and forward same to:

ALBERTA SUSTAINABLE RESOURCE DEVELOPMENT
Lands Division
Geodetic Control Unit
15th Floor, Oxbridge Place
9820 - 106 Street
Edmonton, Alberta T5K 2J6

PH: (780) 422-1291 / FAX: (780) 427-1493

<u>EXPLANATORY NOTES ON "MARKER CONDITION" DESIGNATIONS:</u>

1. GOOD - Marker found in good condition.
2. CAP MISSING - Marker cap missing. Please also mark "3" and/or "4" if applicable.
3. PIPE BENT - Marker pipe bent. Please also mark "2" and/or "4" if applicable.
4. OTHER DISTURBANCES - Other disturbances to the marker or site, such as:
   - concrete pillar partly broken.
   - suspected subsidence of site.
   - suspected rebound of site
   - inscription on marker partly or wholly effaced.
   - marker loose, i.e. movable.
   - pipe broken off or protruding abnormally from the ground.
   - does not fit with adjacent reference markers.
5. NOT FOUND - Marker not found, i.e. could not be located from marker type description and marker location description, or determined to be under landfill, asphalt, etc.
6. PHYSICALLY LOST - No evidence of physical marker on 'Exhaustive Search", i.e. determined to be physically lost upon establishment of approximate position by location description and coordinates from surrounding control. In some cases it should be obvious that a marker is destroyed without actual re-establishment by coordinates (i.e. large building on site.

On the basis of this report the Division will update the record to reflect "GOOD", "SEE BELOW" OR "DESTROYED" on the ID card.

<u>NOTES ON DESTROYED MARKERS</u>:

Lands Division, Geodetic Control Unit, will assign the condition of "Destroyed' to any marker which is:
a) in an urban area and certified by an Alberta Land Surveyor on this form as "physically lost" or "cap missing".
b) in a rural area and certified by an Alberta Land Surveyor on this form as "physically lost".

Once a marker is designated destroyed by Geodetic Control Unit it will be struck from the index map and condition on the ID card will reflect "DESTROYED".

Alberta
Freedom To Create. Spirit To Achieve.

ALBERTA SURVEY CONTROL MARKER CONDITION REPORT FORM Side 2

DATE: ________________ TABLET MARKINGS: ________________ ASCM #: ________________
(Y) (M) (D)

MUNICIPALITY OR LEGAL DESCRIPTION:

** **MARKER CONDITION** ** *(Please check appropriate boxes and give details below).*

1. ☐ GOOD
2. ☐ CAP MISSING
3. ☐ PIPE BENT
4. ☐ OTHER DISTURBANCES *(Fill in condition details)*
5. ☐ NOT FOUND *(Fill in condition details)*
6. ☐ PHYSICALLY LOST *(Exhaustive search)* *(Requires explanation in condition details)*

CONDITION DETAILS:

____

MARKER LOCATION UPDATE: All Existing Location & Reference Statements Checked

☐ YES ☐ NO

INFORMATION NO LONGER VALID: ____

____

____

UPDATE INFORMATION: ____

____

____

____

GENERAL: ☐ LANDSCAPED ___ CM. ABOVE GRADE ___ CM. BELOW GRADE

☐ MANHOLE & COVER ____________ # OF GUARD POSTS & RELATIONSHIP (e.g., 30 cm N. of GP)

SIGHT LINES AVAILABLE TO ADJACENT ASC MARKERS:

________________ ________________

________________ ________________

THE ABOVE INFORMATION IS THE RESULTS OF AN:

EXHAUSTIVE INSPECTION AT THE SITE ☐

CURSORY INSPECTION AT THE SITE ☐

CERTIFIED CORRECT

____
ALBERTA LAND SURVEYOR

____
Print Name and Phone Number

** Refer to explanatory notes overleaf

Rev. 2009-11-17

LANDS DIVISION
Geodetic Control Unit

MASCOT SMS-1

APPENDIX E – INPUT DATA FILE FORMATS

1 GHOST FORMAT INPUT FILE

The following information describes the file format for the GHOST input data file required by the Branch for GPS production surveys and GPS validation surveys. An example of a GHOST input data file follows this descriptive information.

1.1 Title Block

Col 2-80 Project name and number

1.2 Adjustment Definition Header Record

This describes the type of adjustment that will be performed using the data. The adjustment definition information is all contained on the second line of the GHOST input data file. All GHOST input data files will use the following format for data submitted to the Branch:

Col 3-4 Ellipsoid number record (*14*)
Col 5-6 Number of iterations record (*3*)
Col 10 Print input data image record (*1*)
Col 73 Test Statistic record (*N*)

1.3 Coordinate Parameter Definition

GHOST code-4 geographic coordinates will be used to define the initial (or input) values for the coordinate parameter definitions. There is one coordinate parameter definition per line.

Col 3 Code to identify the data type record (*4*)
Col 7-14 Station number record (*usually ASCM number*)
Col 40 Latitude indicator record (*N*)
Col 41-42 Latitude degrees record (*00*)
Col 44-45 Latitude minutes record (*00*)
Col 46-54 Latitude seconds record (*00.000000*)
Col 55 Longitude indicator record (*W*)
Col 56-58 Longitude degrees record (*000*)
Col 59-61 Longitude minutes record (*00*)
Col 62-70 Longitude seconds record (*00.000000*)
Col 71-79 Orthometric Height record (*0000.0000*)

Col 2-3 Switch record marking the end of the fixed stations (*10*)
Col 2-3 Switch record marker the end of the coordinate parameter definitions (*40*)

1.4 Session Description Information

As previously discussed within this manual, all processed GPS baselines must be broken into their respective sessions. The following information shows this format.

Col 1	Comment record (*C*)
Col 3-16	Date indicator record (*DATE: 99-02-21*)
Col 3-11	Session indicator record (*SESSION A*)

Note that that comment record is included at the start of each line for the *Date* and for the *Session*. This header information is only required at the start of each group of baselines that comprise one session (i.e., one set of header lines per session).

1.5 Observation Definition

Col 1	Comment record (*C*)
Col 3-7	Position difference observation header record (*91GPS*)
Col 3-4	Position difference observation cartesian coordinate observation record (*92*)
Col 7-14	Station number (*usually ASCM number*)
Col 36-50	From station X-cartesian coordinate value (*always 0.000*)
Col 51-65	From station Y-cartesian coordinate value (*always 0.000*)
Col 66-80	From station Z-cartesian coordinate value (*always 0.000*)
Col 36-50	To station X-cartesian coordinate position difference record with respect to the From station
Col 51-65	To station Y-cartesian coordinate position difference record with respect to the From station
Col 66-80	To station Z-cartesian coordinate position difference record with respect to the From station
Col 3-13	Position difference observation trailer record (*97PDV UPPER*)
Col 1-20	Position difference observation matrix input record
Col 21-40	Position difference observation matrix input record
Col 41-60	Position difference observation matrix input record
Col 61-80	Position difference observation matrix input record

Note that this format is using the upper triangular matrix definition.

Col 99	Record marking the end of the data

The following example shows other extraneous information associated with the adjusted baselines. This "extra" information will vary depending on the baseline processing software manufacturer. When submitting the processed baseline data in GHOST format, the surveyor can either completely remove this information or comment it out. For further information on GHOST format files, please contact the Branch.

```
GHOST PROJECT FILE 96006
 14 3   1                                                                   N
 4    71126                            N49 3917.993080W112 49 8.074440 906.0970
10
 4   359281                            N49 3839.537280W112 4949.597200 818.6311
 4   554501                            N49 3744.745820W112 4927.324570 913.3631
 4    95547                            N49 3917.690450W112 5049.047970 905.3728
 4   437749                            N49 3840.725520W112 4959.385800 821.6924
 4   369983                            N49 39   .731570W112 4948.420640 826.5384
 4   459842                            N49 3854.970850W112 5014.658360 904.6888
40
C    24 solutions
C
C DATE: 99-02-21
C SESSION A
C
CGRP  O126281A.052,obs#:     1 day  52                                   type  07
C  THE FIXED DOUBLE DIFFERENCE   Session: A
 91GPS
 92    71126                               0.000           0.000           0.000
 92   359281                           -1097.135        -459.312        -836.006
 97PDV UPPER                                                              4.00000
   .101569690000E-04   .453694946000E-05  -.821729706000E-05
   .175309690000E-04  -.110527169900E-04
   .376873210000E-04
CGRP  O126501A.052,obs#:     2 day  52                                   type  07
C  THE FIXED DOUBLE DIFFERENCE   Session: A
 91GPS
 92    71126                               0.000           0.000           0.000
 92   554501                           -1209.441       -1878.223       -1860.274
 97PDV UPPER                                                              4.00000
   .100679290000E-04   .441129498000E-05  -.832645968000E-05
   .167199210000E-04  -.102192288000E-04
   .390375040000E-04
CGRP  O126547A.052,obs#:     3 day  52                                   type  07
C  THE FIXED DOUBLE DIFFERENCE   Session: A
 91GPS
 92    71126                               0.000           0.000           0.000
 92    95547                           -1869.439         779.880          -6.606
 97PDV UPPER                                                              4.00000
   .879715600000E-05   .386434208000E-05  -.704454660000E-05
   .146842240000E-04  -.931808280000E-05
   .319790250000E-04
CGRP  O501281A.052,obs#:     4 day  52                                   type  07
C  THE FIXED DOUBLE DIFFERENCE   Session: A
 91GPS
 92   554501                               0.000           0.000           0.000
 92   359281                             112.306        1418.910        1024.268
 97PDV UPPER                                                              4.00000
   .153585610000E-04   .679421354000E-05  -.132774544300E-04
   .259998010000E-04  -.160700084000E-04
   .620786410000E-04
CGRP  O547281A.052,obs#:     5 day  52                                   type  07
C  THE FIXED DOUBLE DIFFERENCE   Session: A
 91GPS
 92    95547                               0.000           0.000           0.000
 92   359281                             772.304       -1239.193        -829.400
 97PDV UPPER                                                              4.00000
   .106732890000E-04   .473969826000E-05  -.896268780000E-05
   .182072890000E-04  -.117060878000E-04
```

GHOST Input File

```
   .407044000000E-04
CGRP  0547501A.052,obs#:     6 day  52                                          type  07
C  THE FIXED DOUBLE DIFFERENCE    Session: A
 91GPS
 92    95547                                     0.000           0.000           0.000
 92    554501                                  659.999       -2658.103       -1853.668
 97PDV UPPER                                                                    4.00000
   .994771600000E-05   .439989308000E-05  -.850485562000E-05
   .168346090000E-04  -.102919652000E-04
   .393254410000E-04
C
C DATE: 99-02-21
C SESSION B
C
CGRP  0501281B.052,obs#:     1 day  52                                          type  07
C  THE FIXED DOUBLE DIFFERENCE    Session: B
 91GPS
 92    554501                                    0.000           0.000           0.000
 92    359281                                  112.305        1418.906        1024.269
 97PDV UPPER                                                                    4.00000
   .162328410000E-04   .109691942400E-04  -.977145312000E-05
   .321715840000E-04  -.249330910400E-04
   .574412410000E-04
CGRP  0842281B.052,obs#:     2 day  52                                          type  07
C  THE FIXED DOUBLE DIFFERENCE    Session: B
 91GPS
 92    459842                                    0.000           0.000           0.000
 92    359281                                  344.010        -478.720        -374.364
 97PDV UPPER                                                                    4.00000
   .884467600000E-05   .617732514000E-05  -.567162618000E-05
   .179691210000E-04  -.144533367900E-04
   .333968410000E-04
CGRP  0842501B.052,obs#:     3 day  52                                          type  07
C  THE FIXED DOUBLE DIFFERENCE    Session: B
 91GPS
 92    459842                                    0.000           0.000           0.000
 92    554501                                  231.706       -1897.626       -1398.633
 97PDV UPPER                                                                    4.00000
   .897601600000E-05   .605431680000E-05  -.538704768000E-05
   .177241000000E-04  -.137204742000E-04
   .315731610000E-04
CGRP  0983281B.052,obs#:     4 day  52                                          type  07
C  THE FIXED DOUBLE DIFFERENCE    Session: B
 91GPS
 92    369983                                    0.000           0.000           0.000
 92    359281                                 -213.407        -446.102        -430.052
 97PDV UPPER                                                                    4.00000
   .112091040000E-04   .765915264000E-05  -.695526912000E-05
   .227147560000E-04  -.182551144800E-04
   .421460640000E-04
CGRP  0983501B.052,obs#:     5 day  52                                          type  07
C  THE FIXED DOUBLE DIFFERENCE    Session: B
 91GPS
 92    369983                                    0.000           0.000           0.000
 92    554501                                 -325.712       -1865.008       -1454.321
 97PDV UPPER                                                                    4.00000
   .113232250000E-04   .763182000000E-05  -.678491680000E-05
   .223256250000E-04  -.172678905000E-04
   .397026010000E-04
CGRP  0983842B.052,obs#:     6 day  52                                          type  07
```

```
C  THE FIXED DOUBLE DIFFERENCE   Session: B
 91GPS
 92   369983                                     0.000            0.000            0.000
 92   459842                                  -557.418           32.618          -55.688
 97PDV UPPER                                                                     4.00000
   .481363600000E-05  .329100000000E-05  -.296699008000E-05
   .976562500000E-05 -.779168750000E-05
   .178590760000E-04
C
C DATE: 99-02-21
C SESSION C
C
CGRP  O126547C.052,obs#:    1 day  52                                         type  07
C  THE FIXED DOUBLE DIFFERENCE   Session: C
 91GPS
 92    71126                                     0.000            0.000            0.000
 92    95547                                 -1869.435          779.885           -6.592
 97PDV UPPER                                                                     4.00000
   .720922500000E-05  .464161320000E-05  -.358372320000E-05
   .169414560000E-04 -.116741284800E-04
   .173972410000E-04
CGRP  O126749C.052,obs#:    2 day  52                                         type  07
C  THE FIXED DOUBLE DIFFERENCE   Session: C
 91GPS
 92    71126                                     0.000            0.000            0.000
 92   437749                                 -1268.063         -359.143         -809.898
 97PDV UPPER                                                                     4.00000
   .136161000000E-04  .917658720000E-05  -.690557670000E-05
   .319451040000E-04 -.217956945600E-04
   .321602410000E-04
CGRP  O126983C.052,obs#:    3 day  52                                         type  07
C  THE FIXED DOUBLE DIFFERENCE   Session: C
 91GPS
 92    71126                                     0.000            0.000            0.000
 92   369983                                  -883.725          -13.219         -405.948
 97PDV UPPER                                                                     4.00000
   .155630250000E-04  .100441278000E-04  -.723946950000E-05
   .367478440000E-04 -.255860652600E-04
   .374176890000E-04
CGRP  O547749C.052,obs#:    4 day  52                                         type  07
C  THE FIXED DOUBLE DIFFERENCE   Session: C
 91GPS
 92    95547                                     0.000            0.000            0.000
 92   437749                                   601.372        -1139.027         -803.307
 97PDV UPPER                                                                     4.00000
   .130754560000E-04  .860781568000E-05  -.645672960000E-05
   .306472960000E-04 -.210057984000E-04
   .311364000000E-04
CGRP  O547983C.052,obs#:    5 day  52                                         type  07
C  THE FIXED DOUBLE DIFFERENCE   Session: C
 91GPS
 92    95547                                     0.000            0.000            0.000
 92   369983                                   985.709         -793.105         -399.356
 97PDV UPPER                                                                     4.00000
   .862009600000E-05  .610588176000E-05  -.414985984000E-05
   .204394410000E-04 -.139784799000E-04
   .195098890000E-04
CGRP  O983749C.052,obs#:    6 day  52                                         type  07
C  THE FIXED DOUBLE DIFFERENCE   Session: C
 91GPS
```

```
 92   369983                                  0.000          0.000          0.000
 92   437749                               -384.337       -345.924       -403.950
 97PDV UPPER                                                              4.00000
   .136604160000E-04   .945362880000E-05  -.665398272000E-05
   .323078560000E-04  -.220649469600E-04
   .316518760000E-04
C
C DATE: 99-02-21
C SESSION D
C
CGRP  0281842D.052,obs#:    1 day  52                                  type  07
C  THE FIXED DOUBLE DIFFERENCE   Session: D
 91GPS
 92   359281                                  0.000          0.000          0.000
 92   459842                               -344.016        478.712        374.367
 97PDV UPPER                                                              4.00000
   .162409000000E-04   .174322083000E-04  -.162706011000E-04
   .393003610000E-04  -.334610382600E-04
   .468266490000E-04
CGRP  0547281D.052,obs#:    2 day  52                                  type  07
C  THE FIXED DOUBLE DIFFERENCE   Session: D
 91GPS
 92    95547                                  0.000          0.000          0.000
 92   359281                                772.301      -1239.201       -829.415
 97PDV UPPER                                                              4.00000
   .145618560000E-04   .155614953600E-04  -.140860771200E-04
   .359640090000E-04  -.299041604400E-04
   .419385760000E-04
CGRP  0547749D.052,obs#:    3 day  52                                  type  07
C  THE FIXED DOUBLE DIFFERENCE   Session: D
 91GPS
 92    95547                                  0.000          0.000          0.000
 92   437749                                601.369      -1139.033       -803.306
 97PDV UPPER                                                              4.00000
   .106929000000E-04   .112658040000E-04  -.980725320000E-05
   .272484000000E-04  -.220338288000E-04
   .308469160000E-04
CGRP  0547842D.052,obs#:    4 day  52                                  type  07
C  THE FIXED DOUBLE DIFFERENCE   Session: D
 91GPS
 92    95547                                  0.000          0.000          0.000
 92   459842                                428.287       -760.488       -455.050
 97PDV UPPER                                                              4.00000
   .111756490000E-04   .119381873000E-04  -.104619185000E-04
   .284089000000E-04  -.230490520000E-04
   .323761000000E-04
CGRP  0749281D.052,obs#:    5 day  52                                  type  07
C  THE FIXED DOUBLE DIFFERENCE   Session: D
 91GPS
 92   437749                                  0.000          0.000          0.000
 92   359281                                170.932       -100.167        -26.110
 97PDV UPPER                                                              4.00000
   .152802810000E-04   .162916174800E-04  -.150316686000E-04
   .375646410000E-04  -.312891579000E-04
   .439569000000E-04
CGRP  0749842D.052,obs#:    6 day  52                                  type  07
C  THE FIXED DOUBLE DIFFERENCE   Session: D
 91GPS
 92   437749                                  0.000          0.000          0.000
 92   459842                               -173.083        378.546        348.256
```

```
97PDV UPPER                                                                    4.00000
  .173472250000E-04   .185041370500E-04  -.162299637500E-04
  .439701610000E-04  -.357052826000E-04
  .501972250000E-04
99
```

2. GEOLAB INPUT FILE (VERSION 2 OR 3)

The following images show a GEOLAB input file (including the constraint equation used for a validation at the Edmonton GPS Validation Network) and an extracted GEOLAB covariance file with position observations. The GEOLAB input file also demonstrates the format for DATE and SESSION identifiers to be used to place the processed GPS baselines into their appropriate sessions.

These files are typical of the data formats that the Branch requires if the GHOST format is not going to be used by the surveyor when submitting data to the Branch. For further information on GEOLAB V2 or V3 formats, please contact GEOsurv Inc at Tel. (613) 820-4545, Fax (613) 820-9972, e-mail geosurv@geosurv.net.

```
 ELEM          1.0000000000000          -0.4790632128716
 ELEM          1.0000000000000
 ELEM            0.00334009575            0.00426014699           0.00276321755
 GRP  0595744A.170,obs#:      3 day 170                                      type 19
*  THE FIXED DOUBLE DIFFERENCE   Session:  65
 3DD
 DXYZ      208595        492744           1898.5085     7700.0220     5685.8405
 CORR CT UPPR
 ELEM          1.0000000000000           0.3225570619106          0.2949055135250
 ELEM          1.0000000000000          -0.4713231623173
 ELEM          1.0000000000000
 ELEM            0.00259444979            0.00340821850           0.00222178269
 GRP  0595959A.170,obs#:      4 day 170                                      type 19
*  THE FIXED DOUBLE DIFFERENCE   Session:  65
 3DD
 DXYZ      208595        265959          -1335.9430      583.0506      -10.6688
 CORR CT UPPR
 ELEM          1.0000000000000           0.3455376327038          0.4277639389038
 ELEM          1.0000000000000          -0.3815688192844
 ELEM          1.0000000000000
 ELEM            0.00251815235            0.00307145179           0.00209636707
 GRP  0744424A.170,obs#:      5 day 170                                      type 07
*  THE FIXED DOUBLE DIFFERENCE   Session: 1706A
 3DD
 DXYZ      492744        320424           5770.7018   -11172.1193    -5783.1310
 CORR CT UPPR
 ELEM          1.0000000000000           0.2200000000000         -0.0400000000000
 ELEM          1.0000000000000          -0.6600000000000
 ELEM          1.0000000000000
 ELEM            0.00764800000            0.01346500000           0.01715600000
 GRP  0744959A.170,obs#:      6 day 170                                      type 19
*  THE FIXED DOUBLE DIFFERENCE   Session:  65
 3DD
 DXYZ      492744        265959          -3234.4449    -7116.9445    -5696.5106
 CORR CT UPPR
 ELEM          1.0000000000000           0.4729103147984         -0.0364026874304
 ELEM          1.0000000000000          -0.7163556218147
 ELEM          1.0000000000000
 ELEM            0.00314379274            0.00374380266           0.00642321724
* DATE: 96/06/18 DAY 170
* SESS: B
*      6 solutions
 GRP  0424595B.170,obs#:      1 day 170                                      type 19
*  THE FIXED DOUBLE DIFFERENCE   Session:  66
 3DD
 DXYZ      320424        208595          -7669.2102     3472.1017       97.3023
 CORR CT UPPR
 ELEM          1.0000000000000           0.5312983989716         -0.4210656881332
 ELEM          1.0000000000000          -0.5719919204712
 ELEM          1.0000000000000
 ELEM            0.00783432648            0.00963883474           0.01432891656
 GRP  0424744B.170,obs#:      2 day 170                                      type 19
*  THE FIXED DOUBLE DIFFERENCE   Session:  66
 3DD
 DXYZ      320424        492744          -5770.7126    11172.1212     5783.1424
 CORR CT UPPR
 ELEM          1.0000000000000           0.5371929407120         -0.4339972436428
 ELEM          1.0000000000000          -0.5782216787338
 ELEM          1.0000000000000
 ELEM            0.00939340703            0.01150000747           0.01657122560
```

```
GRP  0424959B.170,obs#:     3 day 170                                          type 19
*  THE FIXED DOUBLE DIFFERENCE   Session:  66
3DD
DXYZ      320424        265959          -9005.1501     4055.1540        86.6428
CORR CT UPPR
ELEM          1.0000000000000        0.5166373252869        -0.4301734864712
ELEM          1.0000000000000       -0.5736340880394
ELEM          1.0000000000000
ELEM            0.00732250372          0.00993669499           0.01337708067
GRP  0595744B.170,obs#:     4 day 170                                          type 19
*  THE FIXED DOUBLE DIFFERENCE   Session:  66
3DD
DXYZ      208595        492744           1898.4963     7700.0141      5685.8431
CORR CT UPPR
ELEM          1.0000000000000        0.5388576388359        -0.4349216520786
ELEM          1.0000000000000       -0.5762776136398
ELEM          1.0000000000000
ELEM            0.00717713870          0.00872852840           0.01258961949
GRP  0959595B.170,obs#:     5 day 170                                          type 19
*  THE FIXED DOUBLE DIFFERENCE   Session:  66
3DD
DXYZ      265959        208595           1335.9400     -583.0507        10.6587
CORR CT UPPR
ELEM          1.0000000000000        0.5171823501587        -0.4326407611370
ELEM          1.0000000000000       -0.5690062642097
ELEM          1.0000000000000
ELEM            0.00424705073          0.00575624360           0.00777995866
GRP  0959744B.170,obs#:     6 day 170                                          type 19
*  THE FIXED DOUBLE DIFFERENCE   Session:  66
3DD
DXYZ      265959        492744           3234.4370     7116.9644      5696.5014
CORR CT UPPR
ELEM          1.0000000000000        0.5247815847397        -0.4390859901905
ELEM          1.0000000000000       -0.5721761584282
ELEM          1.0000000000000
ELEM            0.00761969294          0.00995917153           0.01345222164
* DATE: 96/06/18 DAY 170
* SESS: C
*      4 solutions
GRP  0454784C.170,obs#:     1 day 170                                          type 19
*  THE FIXED DOUBLE DIFFERENCE   Session:  67
3DD
DXYZ      388454        421784         -28886.6753    58062.0460     30930.7416
CORR CT UPPR
ELEM          1.0000000000000        0.2049916833639        -0.4469536840916
ELEM          1.0000000000000       -0.3719452321529
ELEM          1.0000000000000
ELEM            0.00633771392          0.01082079113           0.01369784679
GRP  0797454C.170,obs#:     2 day 170                                          type 19
*  THE FIXED DOUBLE DIFFERENCE   Session:  67
3DD
DXYZ      107797        388454         139066.9196   -63944.3501     -2356.2220
CORR CT UPPR
ELEM          1.0000000000000        0.1990416049957        -0.4166594147682
ELEM          1.0000000000000       -0.4982609450817
ELEM          1.0000000000000
ELEM            0.00582034420          0.01155396830           0.01298125833
GRP  0797784C.170,obs#:     3 day 170                                          type 19
*  THE FIXED DOUBLE DIFFERENCE   Session:  67
3DD
```

```
 DXYZ     107797        421784         110180.2439    -5882.2987     28574.5098
 CORR CT UPPR
 ELEM          1.0000000000000         0.3640934228897        -0.4609091579914
 ELEM          1.0000000000000        -0.4917256236076
 ELEM          1.0000000000000
 ELEM            0.00666443026           0.00962551963            0.01339510735
 GRP  O959797C.170,obs#:     4 day 170                                     type 19
*  THE FIXED DOUBLE DIFFERENCE   Session:  67
 3DD
 DXYZ     265959        107797         -91263.9375    43296.4051     1977.1639
 CORR CT UPPR
 ELEM          1.0000000000000         0.2614976167679        -0.4661233723164
 ELEM          1.0000000000000        -0.6039307117462
 ELEM          1.0000000000000
 ELEM            0.00503012165           0.00992195588            0.00986302085
* DATE: 96/06/28 DAY 180
* SESS: A
*      6 solutions
 GRP  O424454A.180,obs#:     1 day 180                                     type 19
*  THE FIXED DOUBLE DIFFERENCE   Session:  65
 3DD
 DXYZ     320424        388454          38797.8109   -16592.8141     -292.4076
 CORR CT UPPR
 ELEM          1.0000000000000         0.3442440032959        -0.2676562368870
 ELEM          1.0000000000000        -0.5232685804367
 ELEM          1.0000000000000
 ELEM            0.00273435633           0.00383308367            0.00581837771
 GRP  O424784A.180,obs#:     2 day 180                                     type 19
*  THE FIXED DOUBLE DIFFERENCE   Session:  65
 3DD
 DXYZ     320424        421784           9911.1611    41469.2888     30638.2772
 CORR CT UPPR
 ELEM          1.0000000000000         0.3557403087616        -0.2413806170225
 ELEM          1.0000000000000        -0.5730167031288
 ELEM          1.0000000000000
 ELEM            0.00277935807           0.00406391406            0.00594826508
 GRP  O424797A.180,obs#:     3 day 180                                     type 19
*  THE FIXED DOUBLE DIFFERENCE   Session:  65
 3DD
 DXYZ     320424        107797        -100269.0758    47351.6202     2063.7526
 CORR CT UPPR
 ELEM          1.0000000000000         0.3647312521935        -0.2781051993370
 ELEM          1.0000000000000        -0.5189396739006
 ELEM          1.0000000000000
 ELEM            0.00310901413           0.00428916002            0.00664137397
 GRP  O454797A.180,obs#:     4 day 180                                     type 19
*  THE FIXED DOUBLE DIFFERENCE   Session:  65
 3DD
 DXYZ     388454        107797        -139066.8868    63944.4347     2356.1602
 CORR CT UPPR
 ELEM          1.0000000000000         0.3615843057632        -0.2727413177490
 ELEM          1.0000000000000        -0.5261175036430
 ELEM          1.0000000000000
 ELEM            0.00398084195           0.00553732226            0.00848157145
 GRP  O784454A.180,obs#:     5 day 180                                     type 19
*  THE FIXED DOUBLE DIFFERENCE   Session:  65
 3DD
 DXYZ     421784        388454          28886.6512   -58062.1018    -30930.6867
 CORR CT UPPR
 ELEM          1.0000000000000         0.3061682581902        -0.2222149372101
```

```
ELEM         1.0000000000000         -0.5643911957741
ELEM         1.0000000000000
ELEM           0.00361876329            0.00531006232          0.00786047149
GRP  O784797A.180,obs#:    6 day 180                                 type 19
*  THE FIXED DOUBLE DIFFERENCE   Session:  65
3DD
DXYZ     421784        107797         -110180.2364     5882.3317   -28574.5258
CORR CT UPPR
ELEM         1.0000000000000          0.3560361862183        -0.2435122728348
ELEM         1.0000000000000         -0.5748847723007
ELEM         1.0000000000000
ELEM           0.00296290591            0.00429839967          0.00625188136
* THE END
END
```

GEOLAB Extracted Covariance File

```
*
* Extracted coordinates follow: (extracted on 10:36:32, Mon Aug 23, 1999)
* Source (GeoLab adjustment): Pf96018c
* Variance factor of adjustment = 5.427157
* Variance factor used in computing covariance matrix = 1.000000
* Number of degrees of freedom of adjustment = 54
* Number of stations in adjusted network = 7
* Number of stations extracted = 7
*
 3DC
 PLH  000 320424       N 53 34   7.74586 W113  2  48.29487      735.735 m      0
 PLH  000 388454       N 53 33  53.95050 W112 24  35.78684      687.145 m      0
 PLH  000 208595       N 53 34  14.38421 W113 10  25.59555      705.186 m      0
 PLH  000 492744       N 53 39  27.22746 W113 11  35.54863      640.193 m      0
 PLH  000 421784       N 54  2   9.94000 W113  9  19.16155      637.070 m      0
 PLH  000 107797       N 53 35  57.64701 W114 43  13.62264      793.527 m      0
 PLH  000 265959       N 53 34  14.43990 W113 11  44.79389      690.650 m      0
 COV  LG UPPR
 ELEM     5.70906372089991e-06    8.14614661066719e-07   -2.57350261943893e-06
 ELEM     4.96958183001199e-06    5.83481966548044e-07   -2.64742768438227e-06
 ELEM     2.43221396525738e-06    3.08434080343728e-07    -5.9779332912558e-07
 ELEM     2.05466495650321e-06    3.97163406708207e-07   -2.57096657311461e-07
 ELEM     4.94610942425514e-06    4.69710895453987e-07    -2.5931392059256e-06
 ELEM     4.67956297467959e-06     4.0448656445139e-07   -2.33612887390295e-06
 ELEM     9.99997809714891e-07      2.092752852461e-09   -3.08370512500596e-11
 ELEM     4.13430540463592e-06    1.48904789023115e-06    4.34442454513483e-07
 ELEM     3.65478648512895e-06    1.18894184410723e-06    3.18391890184109e-07
 ELEM     1.88175865865362e-06    4.15024629585342e-07    3.83324950276655e-07
 ELEM     1.67433459263111e-06    2.13871855485173e-07    4.25384317571148e-07
 ELEM     3.62558690026786e-06    1.16025188550353e-06    2.46471714971781e-07
 ELEM     3.52581826168388e-06     1.5561444975667e-06   -2.09270272514606e-09
 ELEM     9.99996617348682e-07    1.54463151158171e-09
 ELEM     8.05395517932108e-06   -2.43843887480012e-06    1.31251853159547e-06
 ELEM     7.15177334294414e-06    -6.1945959071939e-07    3.94043749287639e-07
 ELEM     2.39989818012361e-06   -2.91235185986603e-07    2.05949799755898e-07
 ELEM     1.93059058324373e-06   -2.46782180713336e-06    1.40374640195577e-06
 ELEM     7.06696727264695e-06   -2.72359036380575e-06    1.02351319238151e-06
 ELEM     6.84872669176728e-06    3.40996350124263e-13   -1.54463041090084e-11
 ELEM     9.99998806476344e-09
 ELEM     9.60603262139822e-06    2.28117379818385e-07   -5.50411987162403e-07
 ELEM     2.19942616655465e-06    2.35064848145041e-07   -6.46593081930446e-07
 ELEM     1.86957952792253e-06    2.75674922411043e-07   -2.70988365126114e-07
 ELEM     6.36583222537632e-06    2.00155486900028e-07   -1.72329082437923e-06
 ELEM      6.0833244623759e-06    3.05145096883262e-07   -1.73218261012933e-06
 ELEM     9.99939111735255e-07     1.1034938322352e-08   -5.43905845915203e-11
 ELEM     6.28194641839288e-06    1.28797710589369e-06    1.90863341964171e-07
 ELEM     1.74419968923666e-06     3.2779050683482e-07    3.08687007308545e-07
 ELEM     1.56519565631661e-06    1.81718656750414e-07    3.18675347522121e-07
 ELEM     4.40461893062411e-06    1.10736361516916e-06   -5.31638604037515e-08
 ELEM     4.32085561931981e-06    1.52053904625947e-06   -1.10341292453301e-08
 ELEM      9.9990594519985e-07    8.14547394584495e-09
 ELEM     2.65096517436105e-05    -5.9879475320257e-07    3.44277729433588e-07
 ELEM     2.11908530567792e-06   -3.49231814209442e-07    1.42415486391248e-07
 ELEM     1.68406230749751e-06   -1.88107067077272e-06    1.29285811814152e-06
 ELEM     1.43347325112922e-05   -1.89459751288702e-06    9.41023422278819e-07
 ELEM     1.38706443774717e-05    1.44301023792307e-12   -8.14444437014031e-11
 ELEM     9.99966823051205e-09
 ELEM     4.05814852001927e-06    8.82701429498077e-07   -1.41439706483373e-06
 ELEM     2.55907597304125e-06    6.57066202996865e-07   -2.89473600529715e-07
 ELEM     2.19112909007525e-06    1.94101079689386e-07   -6.26078638348702e-07
 ELEM     2.10955854723388e-06    1.99730869306589e-07   -5.78170890928575e-07
 ELEM     9.99999952279891e-07   -3.08933854203765e-10    3.34929695362354e-15
 ELEM     3.01228385164233e-06    8.04348753358884e-07    6.52096116851178e-07
 ELEM     2.02926632013634e-06    3.27570084093915e-07    1.95134215375773e-07
 ELEM     1.73454744743739e-06     3.1478733922177e-07    1.11930146282234e-07
 ELEM      1.7035368066645e-06    4.12258586465409e-07    3.08933915688187e-10
 ELEM     9.99999926285823e-07   -2.28076066545213e-12
 ELEM     4.38124062483257e-06   -3.64568883074354e-07    2.75341381476263e-07
 ELEM     2.81891784294921e-06   -6.08685998540728e-07    3.69519066504591e-07
 ELEM     2.09505875346037e-06   -6.78932673703364e-07     2.6056494236178e-07
 ELEM     2.02365755438832e-06   -2.34453071963309e-13    2.28009280807354e-10
 ELEM       9.999999739906e-09
 ELEM      4.8307897740153e-06    1.61404457146699e-06   -9.95551330766411e-07
```

APPENDIX F - GPS PRODUCTION & VALIDATION SURVEY CHECKLIST

	Description	SECTION	YES	NO
1	Each new point established occupied at least two separate times.	3.1.B		
2	Each new and existing point connected to at least two other points in the network in each of at least two different observing sessions.	3.1.B		
3	At least three receivers used.	3.1.B		
4	Marker Condition Report prepared and submitted for each ASC marker in the project.	3.3.E		
5	Multipath or Imaging problems avoided.	2.2.E		
6	Optical - mechanical means of centring the antenna checked.	4.1.B		
7	Sketch showing the antenna height measurements and determination included.	4.1.B		
8	Detailed field log showing at the very least the following information. a) Date of observations, (Julian day and YY, MM, DD format). b) Station identification (ASCM number, tablet markings). c) Session identification. d) Serial numbers of receiver, antenna and data logger. e) Identification of diskettes. f) Receiver operator. g) Antenna height (to nearest 1 mm). h) Station diagram illustrating location and deployment of equipment: - Site condition details including Obstruction diagram showing any obstructions above 10 elevation. - Starting and ending time (UTC) of observations. - Satellites observed (including time of changes). - General weather conditions. - Any problems.	4.2.A		
9	Tabulated internal consistency test results which include: a) Repeated baseline comparisons. b) Single baseline residuals.	4.2.D		
10	All discrepancies, closures or comparisons resulting from minimally constrained adjustment do not exceed the minimum geometric standard error value w.r.t. baseline length.	3.2, 5.2 & 5.3.B		

	Description	SECTION	YES	NO
11	All correlation amongst the observations within a session accounted for in the adjustment model (unless waived by the Branch).	5.1		
12	Inter-station baselines derived from observation sessions include continuous and simultaneous observations involving all common stations and all satellites within an observation session.	5.1		
13	Both baseline and network stations adjustments performed.	5.1, 5.2 & 5.3		
14	No systematic effects (especially undetected or wrongly corrected cycle slips) remain.	5.1		
15	External reliability demonstrated through tabulation of coordinate differences at the unconstrained stations in a minimally constrained adjustment performed using scientific values provided by the Branch.	5.1, 5.2 & 5.3.A		
16	Survey description including the following: a) Short description of survey location. b) Aim of the survey. c) Number of markers positioned. d) Summary of project logistics including personal involved and difficulties encountered.	5.3.A		
17	Suitable plot/plan to scale showing existing and new markers.	5.3.A		
18	Any conventional survey field notes.	5.3.A		
19	Number of receivers used per session.	3.1.B & 5.3.A		
20	Receiver, antenna type(s) and serial numbers compare between validation and proposal.	5.3.A		
21	Time, number and duration of sessions per day as compared to the proposal and validation.	5.3.A		
22	Summary of stations occupied per session.	5.3.A		
23	Horizontal/vertical antenna offset determination	5.3.A		
24	Field check procedures.	5.3.A		
25	Logistics Information compared to proposal & validation a) Means of transportation b) Equipment deployment scheme c) Personnel involved and their duties d) Difficulties encountered and how they were overcome	5.3.A		

	Description	SECTION	YES	NO
26	Daily diary detailing all work accomplished.	5.3.A		
27	Computer and Software including version number. a) Processing b) Adjustment c) Any Other Compare to proposal and validation.	5.3.A		
28	Data editing description.	5.3.A		
29	Source and accuracy of ephemeris data.	5.3.A		
30	Parameters adjusted and held fixed.	5.3.A		
31	A description of cycle slip detection and rectification procedure and the list of baselines involved if done manually (only).	5.3.A		
32	Methodology used for scaling of covariance matrix consistently applied (compare to validation).	5.3.B		
33	Data collection time span as compared to validation.	5.3.A		
34	Each observation session includes continuous and simultaneous observations.	5.1		
35	All parameters used for any coordinate transformations presented with worked examples.	5.3.A		
36	Provide a detailed explanation for rejecting any baselines (non-trivial or trivial) from the network solution.	5.1.B		
37	Adjusted 3D coordinates to the nearest millimetre based on an adjustment constrained to values published by the Branch.	5.3.B		
38	Position difference observations used in adjustment.	5.1.B & 5.3.B		
39	Geoidal undulation values as provided by the Branch are used for derivation of orthometric heights	2.3.B & 5.3.B		
40	Minimally constrained network adjustment to values provided by the Branch performed and the following are included: a) Full formal covariance matrix of adjusted parameters (including nuisance parameters). b) Statistical testing of survey results from network results including: - Analysis of variance factors.	5.2		

	Description	SECTION	YES	NO
40	Minimally constrained network adjustment (Cont'd) - semi-major axes of 2-D (horizontal) and 3-D 95% relative confidence regions between all possible pairs of points included and meet the second order accuracy. c) Residuals and residual outliers.	5.2		
41	Original and RINEX format raw data provided on contractor chosen media.	5.3.C		
42	Stations identified by the actual ASCM numbers in all the files, listing, plots and reports (digital and hardcopy).	5.3.C		
43	Data included in the Production Survey returns in compliance with Table 1 (*pg 28*) of this manual.	5.3.C		
44	Data included in the validation survey returns in compliance with Table 3 (*pg 36*) of this manual.	6.2.3.C		
45	**All the results meet Branch requirements.**			

Checked by:

Date:

Revised: March 2000

APPENDIX G REFERENCES

Alberta Environmental Protection (1988). Spatial Reference Design Alternatives Issues, Roles & Strategies. Geodetic Control Section, Director of Surveys Branch, Alberta Enviromental Protection, Edmonton, Alberta.

Beatie, D.S. (1987) and (1998). Program GHOST: User Documentation. Geodetic Survey of Canada, Geodetic Survey Division, Geomatics Canada, Natural Resources Canada, Ottawa, Ontario.

Craymer, Micheal R., N. Beck (1992). Session Versus Baseline GPS Processing; Presented at the 5th International Technical Meeting of the Institute of Navigation, ION GPS-92, Albuquerque, NM, 16-18 September 1992.

Craymer, M.R., A.Tarvyadas, and P. Vanicek (1987). NETAN: A program package for the interactive covariance, strain and strength analyses of networks. Geodetic Survey of Canada Contract Report #88-003, Canada Centre for Surveying, Ottawa, Ontario.

Craymer, M. E., D. Wells, and P. Vanicek (1989). Report on Urban GPS Research Project. Phase III - Evaluation. Volume 3: Specifications and Guidelines. Geodetic Research Services Limited Contract Report for the City of Edmonton, Transportation Dept., Engineering Division, Edmonton, Alberta.

Davis, E. S. W. G. Melbourne, and T. P. Yunck (1990). GPS applications to space-based remote sensing missions: coping with denial of accuracy. Presented at GPS'90: Second International Symposium on Precise Positioning with the Global Positioning System, Ottawa, Ontario, September, pp. 25 to 33.

Doucet, K., H. Janes, D. Delikaraoglou, D. E. Wells, R. B. Langley, and P. Vanicek (1986). Examples of geodetic GPS network design. Presented at the Joint Annual Meeting of the Geological Association of Canada, Mineralogical Association of Canada, and Canadian Geophysical Union, Ottawa, Ontario, May.

Duval, R., and N. Beck (1990). Guidelines and Specifications for GPS Surveys. Draft 1.1. Geodetic Survey Division, Canada Centre for Surveying, Surveys, Mapping and Remote Sensing Sector, Ottawa, Ontario.

Geiger, A. (1990). Influence of phase centre variations on the combination of different antenna types. Presentated at GPS'90: Second International Symposium on Precise Positioning with the Global Positioning System, Ottawa, Ontario, September, pp. 466 to 476.

Geodetic Control Section, Alberta Environmental Protection (1998). Presentation Material: National Seminar Series on the Canadian Spatial Reference System (CSRS) and Canadian Active Control System (CACS); Edmonton Oct 21, 1998 and Calgary Oct 22, 1998. Geodetic Control Section, Alberta Environmental Protection, Edmonton, Alberta.

Gurtner, W., G. Mader, and D. McArthur (1989). "A common exchange format for GPS data." GPS bulletin vol. 2, no. 3. CSTG GPS subcommission, Rockville, MD.

Hatch, R., and E. Avery (1988). A strategic planning tool for GPS surveys. Presented at GPS-88: engineering applications of GPS satellite surveying technology, American Society of Civil Engineers annual meeting, Nashville, TN, May 11-14.

Heroux, P. (1988). Experiences processing GPS data from Canadian auroral zone with DIPOP 2.0. Department of Serving Engineering, University of New Brunswick, Fredericton, N.B.

Janes, H., K. Doucet, B. Roy, D. E. Wells, R. B. Langley, P. Vanicek, and M. R. Craymer (1986). GPSNET: A program for the interactive design of geodetic GPS networks. Geodetic Survey of Canada Contract Report No. 86-003, Surveys and Mapping Branch, Ottawa, Ontario.

Kremer, G. R. Kalafus, P. Loomis and J. Reynolds (1990). The effect of Selective Availability on differential GPS corrections. Navigation, Vol. 37, No. 1, pp. 39-52.

Land Information Division (1992). Standards, Specifications & Guidelines for Alberta Survey Control Chapter 5 (GPS Surveys) 1992-08-28. Geodetic Survey Branch, Land Information Division, Edmonton, Alberta.

Martin, E. H. (1980). GPS user equipment error models. In Global Positioning System: Papers Published in Navigation, Vol. I, The Institute of Navigation, Washington, D. C., pp. 109-118.

McNeff, J. (1990). NAVSTAR Global Positioning System (GPS) Signal Policy. Presented at ION GPS-90: Third International Technical Meeting of the Satellite Division of the Institute of Navigation, Colorado Springs, Colorado, September, 1990, pp. 17 to 21.

Merminod B. (1988). Resolution of the cycle ambiguities. School of Surveying Technical Report, University of New South Wales.

Resource Data Division, AEP/Geodetic Survey Division, NRCan (1997). Edmonton GPS Validation Network March 1997 / Calgary GPS Validation Network March 1997. Resource Data Division, AEP Edmonton, Alberta & Geodetic Survey Division, NRCan Ottawa, Ontatio.

Tolman, B. W., J. R. Clynck, D. S. Coco, and M. P. Leach (1990). The effect of Selective Availability on differential GPS positioning. Presented at ION GPS-90: Third International Technical Meeting of the Satellite Division of the Institute of Navigation, Colorado Springs, Colorado, September, 1990. pp. 579 to 586

Vanicek, P., G. Beutler, A. Kleusberg, R. B. Langley, R. Santerre and D. E. Wells

(1985). DIPOP: Differential Positioning Program package for the Global Positioning System. Department of Surveying Engineering Technical Report 115, University of New Brunswick, Fredericton, N.B.

Vanicek, P. and E. J. Krakiwsky (1986). Geodesy: The concepts. Second Edition. North Holland, Amsterdam.

Wells, D. E., N. Beck, D. Delikaraoglou, A. Kleusberg, E. J. Krakiwsky, G. Lachapelle, Langley, R., Nakiboglu, M. Schwarz, K. P. Tranquilla, and P. Vanicek (1986) Guide to GPS Positioning. Canadian GPS Associates, Fredericton, New Brunswick.

Wells, D. E. and J. Tranquilla (1986). GPS users equipment: Status and trends. Paper presented at Colloquium IV of the Canadian Petroleum Association and the Canadian Hydrographic Association: Land, Sea and Space - Todays Survey Challenge, Banff, Alberta, April 21-25.

Young, L. E., R. E. Neilan and F. R. Bletzacker (1985). GPS satellite multipath: experimental investigation. Proceedings of the First International Symposium on Precise Positioning with the Global Positioning System, Rockville, M.D., April 15-19, pp. 423-432.