Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

GUIDELINES AND SPECIFICATIONS FOR GPS SURVEYS

DRAFT 2.0

MAY 1991

GEODETIC SURVEY DIVISION
CANADA CENTRE FOR SURVEYING
SURVEYS, MAPPING AND REMOTE SENSING SECTOR

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FOREWORD

Geodetic Survey Division has been involved with Global Positioning System (GPS) surveys since 1983 and the information presented in this document is based largely on the experience gained during those years. Various publications related to GPS and specifications from other agencies have also been consulted in the production of this document.

An early draft, version 1.1 (March 1990), of this document has been distributed to GPS users outside of the Division for comments in the past year. In this revised version, many of the comments or suggestions received have been taken into consideration. We want to thank all those that have contributed and invite them and others, who will use this document to continue providing us with comments to ensure this document evolves as the GPS technology continues to progress.

Finally we want to thank the many people at Geodetic Survey Division who were consulted or contributed to this document by their comments and suggestions.

Robert Duval
Norman Beck

Positional Control Section
Geodetic Survey Division
Canada Centre for Surveying

May 1991

1. INTRODUCTION

These guidelines and specifications are intended for surveys using the Global Positioning System (GPS) for the Geodetic Survey Division of the Department of Energy, Mines and Resources to ensure the efficient execution of survey operations within acceptable standards, both internally or under contract. Other organizations are welcome to use this document and to modify it according to their specific needs.

Because GPS equipment, observing techniques, applications and software are still evolving rapidly, and what is valid today may change tomorrow, it is almost impossible to establish rigid specifications for GPS surveys at this time without deterring the use of future developments. Current work on the so-called semi-kinematic or stop-and-go applications, the completion of the full satellite constellation and the implementation of selective availability and anti-spoofing will affect the future capabilities of GPS.

In order to take advantage of the accumulated experience of GPS users and innovations in GPS positioning techniques, the concept of an acceptance test or validation survey is advocated to evaluate the mechanics (receiver type, observing procedures, processing techniques and software, etc.) proposed for a particular survey project, instead of a description of specific procedures to be followed. This acceptance test is carried out as a complete survey on a known network to confirm that the proposed procedures are capable of producing results at the accuracy level desired. Once the equipment, procedures and software are validated, they are adopted in their entirety for the conduct of the production survey for which they were proposed.

However, some aspects of a survey project, especially those judged necessary to ensure adequate redundancy and reliability, are specified in this document. The various aspects introduced fall into three categories of requirements. In this document the words shall or must indicates a mandatory requirement, should indicates a recommendation and may is a suggestion. Those aspects that are considered mandatory for the conduct of a GPS survey are summarized in Section 4 of the document. Specifications related to the reports and returns required for GPS survey projects are detailed in Section 5. Throughout this document, "project authority" refers to the Geodetic Survey Division for surveys carried out under contract and refers to field surveys management group for project carried out internally.

Because the application of GPS relative positioning techniques is relatively new and still evolving, these guidelines should not be construed as inflexible rules but as a framework which allow for innovation and change in the use of GPS technology as it evolves. It must be remembered that GPS is just another tool for establishing survey control, and as with other control survey methods, the principle of ensuring adequate redundancy and reliable positioning information are of the utmost importance regardless of the accuracy required.

This document is designed as an appendix to the upcoming revision of SPECIFICATIONS AND RECOMMENDATIONS FOR CONTROL SURVEYS currently in preparation at the Geodetic Survey Division. The latter should be referred to for accuracy standards and the classification of surveys.

2. GUIDELINES

2.1 EQUIPMENT SELECTION

2.1.1 Receiver and Antenna

Because the accuracy for geodetic work is only achievable from relative positioning, a minimum of two receivers must be used on any survey project. However, because of the advantages in using a larger number of receivers -- increased production rate, multiple connection to adjacent stations, repeated baselines and stronger geometric design -- use of at least 4 receivers is recommended for economy and efficiency.

Multi-channel code correlating receivers, tracking the phase of the carrier frequencies, are the most widespread surveying GPS receivers on the market at the present time. However, receivers using other observables, such as codeless squared beat carrier, code phase or other techniques that are in existence or may be developed, would also be acceptable if results obtained from a validation survey proved to be acceptable for the accuracy required.

Receivers of different models or manufacturers may be used on the same project. However, compatibility and observation simultaneity must be verified during the validation survey.

Each antenna type has its own phase center definition which may vary with direction to the satellites. Ideally, an antenna type with the smallest sensitivity to multipath and the smallest phase center variation should be selected. Although the use of the same type of antenna for all receivers on the project is recommended to minimize phase centre biases, use of different antenna types is allowed but must be tested during the validation survey.

2.1.2 Single Versus Dual Frequency Receivers

For both dual and single frequency receivers, ionospheric disturbance can cause loss of lock and what appears to be noisy data (actually uncorrected ionospheric biases). The "noise" can be at the cycle level or greater, making it impossible to distinguish between ionospheric variations and cycle slips [Héroux 1988]. With dual frequency receivers the major effect of the ionosphere can potentially be corrected for.

The behavior of the ionosphere is a function of many interrelated variables including the solar cycle, time of year, time of day, geographical location and geomagnetic activity.

The Geophysics Division of the Geological Survey Sector at EMR monitors geomagnetic activities across the country and has determined three zones in Canada according to the average level of activity (see appendix B). In the sub-auroral zone (Canadian southern latitudes), the magnetic flux is usually small and steady, leading to a generally homogeneous and predictable ionosphere. In the auroral and polar zones (latitudes of ≈55° and higher), the magnetic flux is large and irregular leading to a generally disturbed ionosphere. The zones boundaries are not absolute and vary with seasons, solar cycles, sunspot activities, etc. It should also be kept in mind that at all Canadian latitudes there is potential for sudden disturbances in the earth's magnetic field (magnetic storms) causing large disturbances in the ionosphere.

In the auroral zone or higher latitudes, because of the unpredictability and irregularity of the ionosphere, dual frequency receivers are recommended for all surveys to ensure reliability of the data and are a mandatory requirement when second order accuracy (57 p.p.m., 3-D 95% confidence level) or better is sought.

In the sub-auroral zone (Canadian southern areas), where the ionosphere is more homogeneous, the ionospheric effect is distance dependant. Use of dual frequency receivers is also recommended for all surveys, but is mandatory when first order accuracy (23 p.p.m., 3-D 95% confidence level) or better is sought and baseline lengths consistently exceed 15 km.

When using single frequency receivers, additional precautions should be taken such as an increased number of repeated baselines, longer tracking sessions and additional connections between stations, to ensure that no systematic biases due to uncorrected ionospheric delay will affect the results at the accuracy level required for the project.

The Geophysics Division provides a forecast service to the public on the level of geomagnetic activity in the form of a long term forecast updated every 3 weeks, applicable for a 28 day period (1 solar cycle) and short term predictions for a period of 72 hours updated daily. GPS users are encouraged to consult these forecasts before and during their campaigns.

2.2 RECONNAISSANCE

2.2.1 Site Selection

Once the general locations have been selected for the new stations, or particular existing control stations have been identified (Section 2.3.1), field reconnaissance must be performed to select the specific sites, or to ensure that the stations, if already established, are suitable for GPS observations. Whenever possible, the use of existing markers instead of establishing new ones is highly recommended to avoid marker proliferation and to improve existing network.

GPS observations require direct line of sight to the broadcasting satellites. Since the signal transmitted could be absorbed, reflected or refracted by objects near the antenna or between the antenna and the signal source, it is desirable that, at normal antenna height, the sky be unobstructed from 15° above the horizon. However, this is not a critical requirement in the northern directions (azimuths between 315°- 45°) for Canadian mid-latitudes since the satellite sky distribution will always have a blank area in that direction where no satellite will ever be present. A polar plot (azimuth vs zenith angle) of the satellite sky distribution for the latitude of the project is a very useful tool at the time of the reconnaissance to precisely identify this blank area where obstructions will not affect the satellite visibility.

Radar or microwave transmitting stations, radio repeaters and high voltage power lines may be sources of interference and their proximity should be avoided.

Multipath is the relative phase offset or time delay between directly and indirectly received radio signals. It is caused by reflections of the signal by nearby metallic objects or other reflective surfaces. In order to minimize this problem, the area within at least 50 metres of the marker should be free of artificial structures, particularly metal walls or fences, or natural reflective surfaces. An extended tracking period can sometimes reduce the effect of multipath through averaging and should be considered whenever the proximity of reflective surfaces cannot be avoided such as in urban area.

Station accessibility should also be considered when selecting a new site. Ideally the marker should be accessible within 30 metres of the means of transportation (either by air or by road). For semi-kinematic or stop-and-go applications, the importance of this is obvious.

The terrain at the site selected should be such that stability and reasonable permanency for the marker is assured. The site should be on firm and stable ground, and not on soil susceptible to erosion, landslide or subsidence.

Where azimuth markers are required for follow-up surveys, GPS can be used for their positioning. For specific guidelines on the selection of these sites, the guidelines for selection of azimuth marker locations found in FIELD MANUAL FOR FIRST-ORDER HORIZONTAL CONTROL SURVEYS (1974) should be followed.

2.2.2 Station Marking

GPS provides a three-dimensional position. This characteristic should be reflected in the type of monument selected to mark the station. Because of the economics of establishing a new position by GPS versus the cost of constructing a sophisticated concrete structure to support the marker, standard concrete monuments (either cylindrical or pyramidal in shape) are no longer considered necessary except for specific projects. With this in mind, Table 1 indicates by order of preference the type of markers that should be used. A detailed description of these markers is presented in appendix C. This list is not exhaustive and therefore, the project authority may authorize alternate markers.

2.3 SURVEY NETWORK DESIGN

2.3.1 Control

Control stations are used to ensure proper integration of the new survey within an existing framework. At least three control stations known three-dimensionally or an equivalent combination of horizontal and vertical control stations must be included in any GPS survey project.

For a local or regional network covering an area of up to 80 km x 80 km, the known control stations should be equilaterally distributed on the periphery of the network to be established.

If the survey covers a larger area, additional control stations are desirable and should be distributed regularly on the periphery and within the network. Ideally the total number of control stations and their distribution should be determined from a pre-analysis to ensure a reliable integration of the network within the national framework. However, wherever practical, existing control stations within the project area should be included to improve their accuracy, to help resolve weakness and ensure homogeneity in the framework.

MARKER TYPE	COMMENTS
1) tablet or bolt marker in bedrock, or large existing concrete structure	acceptable for any accuracy of survey
2) NRC type deep bench mark consisting of a steel pipe driven to refusal and protected by an outer galvanized steel pipe. The datum point is attached at the top of the inner pipe and the annular space between the pipes is filled with heavy oil. A covered well filled with crushed stone provides additional horizontal stability and protection Note: Marker of this type, installed prior to 1988, requires the addition of a horizontal stabilizer cap to prevent wobbling of the inner pipe.	acceptable for any accuracy of survey
3) 3-D marker consisting of a datum point attached to steel rod sections (1.6 cm in diameter) driven to refusal. A covered well filled with tamped crushed stone provides additional horizontal stability and protection.	acceptable for any accuracy of survey
4) Helix pipe marker consisting of a brass cap attached to a 2.4 metre long section of square tubing with a steel helix spiral welded about 15 cm from the bottom end. A covered well filled with crushed stone provides additional horizontal stability and protection.	acceptable for any accuracy of survey
5) post marker consisting of a reinforcing steel rod with identification cap	Acceptable for surveys of accuracies of 57 ppm or better if used in permafrost or in weathered or soft rock (shale); and acceptable in any kind of soil for surveys of lower accuracies

Table 1
Recommended markers for GPS surveys.

2.3.2 Station Interconnection and Multiple Occupations

A minimum number of direct connections (simultaneous observations) is necessary, to all stations to be positioned, in order to ensure sufficient redundancy and strength in the network adjustment. Each station must be directly connected to at least two others in the network. This is essential for achieving reliable relative accuracies and proper integration of the GPS solution with the existing control.

Because it is generally easier to resolve the integer phase ambiguity over short baselines and because it provides a stronger network, simultaneous occupations of adjacent stations must be favoured as opposed to observation of longer baselines.

Direct connections should also be made between control stations. This will provide an additional check on scale and orientation of the network and may also help resolve weakness in the existing control.

It is recognized that multiple occupations of a station (occupation for two or more independent sessions) provide the optimum reliability check on the position, permitting checks for blunders (e.g. centering error, incorrect antenna height, marker misidentification), as well as providing strength and redundancy for the network adjustment. However, for most projects, multiple occupations of all the sites may not be cost-effective and alternate procedures (see antenna setup section 2.4.1) must be in place to control the possibility of blunders. While multiple occupations are highly recommended for all surveys, it is a mandatory procedure when the three dimensional relative accuracy requirement is 5 ppm or better (95% confidence level).

For each observing session, at least one baseline must be common to another session such that, in the final network, a common baseline is observed from session to session. Lengths of these repeated baselines must be representative of the adjacent baseline lengths encountered in the project. If operating with only two receivers, every baseline needs to be repeated. The observation of repeated baselines not only ensures a certain percentage of multiple occupations, but also provides a better connectivity between sessions, and allows for monitoring of variations in scale and orientation between observing sessions, due to changes in atmospheric conditions or orbital errors.

A detailed plan, at a suitable scale, showing existing control and new stations which depicts for each session the stations that will be occupied simultaneously must be submitted for approval to the project authority before field observations begin.

2.4 FIELD OBSERVATIONS

2.4.1 Antenna Setup

Antenna setup (including marker identification, centering and measurement of antenna phase centre above the station mark) can be a major source of blunders in GPS field operations. Specific field procedures can minimize setup errors. This is particularly important since errors at this stage will easily go undetected unless comparison of vector components of repeated baselines can be performed.

A pictorial representation of the marker, such as a sketch with all inscriptions, a photograph or pencil rubbing, should be taken to confirm that the right marker has been occupied.

For all surveys, tribrachs allowing for levelling of the antenna together with an optical or mechanical device permitting accurate centering over the mark must be used. The centering device must be checked before and after the survey as well as every week for the duration of the survey .

For the highest accuracy surveys, such as crustal deformation, a tribrach with a striding level and a rotating plummet assembly should be used. With this type of apparatus it can be determined immediately if the level needs adjustment or if the plummet has been knocked out of collimation.

The height of the antenna's phase centre above the station marker must be measured and recorded to the nearest millimetre before and after each observing session. Use of both metric and English systems is encouraged as a check. All measurements taken to derive the total height of the antenna phase centre above the marker must be recorded in the field log and the procedure should be described by a sketch in order to allow verification of the computation.

If the receiver is to remain at the same station for two or more observing sessions, the antenna must be re-positioned between each session, and the antenna height remeasured and recorded at the beginning and end of each session. This will ensure the independence of each observing session.

2.4.2 Length of Observation Session

The optimal length of the observation session (simultaneous data collection) is dependent upon several factors: the accuracy requirement, the satellite geometry, the ionospheric activity level, the type of receivers, the length of the baselines measured, the geographic location, the potential for multipathing at the sites, the data reduction method and the software used. Experience combined with a pre-analysis of these factors for the area of the survey are probably the best way to determine the length of session required. The length of session selected must be proven adequate under the conditions expected for the production survey during the validation survey. The main criteria is to ensure that sufficient quality data ~~is~~ are collected to adequately resolve carrier phase ambiguities.

It should be noted that the multipath effect is a function of the geometry of the satellite configuration observed. Since the geometry of the constellation is changing over time, a longer observation period may tend to average out somewhat the effect of multipath.

2.4.3 Measurement Rate

The choice of the measurement rate (data recording rate) is governed by the GPS technique used in the survey. The general rule is that the higher the measurement rate, the easier it is to detect and correct for cycle slips. On the other hand, a higher rate will generate cumbersome data files. In general, for static positioning, a recording rate of one observation every 15 seconds has been found adequate. For kinematic positioning a higher data rate may be required. For any technique, the recording rate must be proven adequate during the validation survey.

2.4.4 Surface Meteorological Observations

The requirement for surface meteorological observations is a function of the accuracy requirement, lengths of the baselines, height differences between stations, and purpose of the survey.

In general, for small and medium scale network, meteorological observations are not required. For these cases, small errors in the meteorological observations, due to instrument calibrations, topography effects or local micro-climate effects can introduce larger biases in the topospheric model than if a standard atmosphere (characterized by one set of surface meteorological data) is used with a model such as Saastamoinen or Hopfield [Beutler & al., 1988].

For surveys where accuracies in the order of 0.1 ppm or better are sought, for large scale surveys where baseline lengths would consistently be larger than 100 km or for surveys where there are large height differences between stations the surface meteorological observations may be required. For the later case, when large height differences (several 100 metres) exist between stations, surface observations must be introduced in a model such as explained in [Beutler & al., 1989] where the surface meteorological observations are used to derive height dependent profile of the atmosphere in the layer between the lowest and highest stations surveyed. The final atmospheric delay is computed as the sum of delay below the highest station (based on the surface met profile) and delay above the highest station using a standard atmosphere with models such as Sastamoinen or Hopfield.

When required, observations of meteorological conditions consisting of dry bulb temperature, wet bulb temperature or humidity, and atmospheric pressure should be recorded at the beginning and at the end of the observation session, whenever a sudden change in the conditions occurs, and at least every hour if the session lasts longer than one hour. Ideally the temperature and the humidity will be measured at a height of 3 metres or more above the ground level in order to avoid some of the surface heating effect. Temperatures should be recorded to the nearest 0.1 °C and humidity to the nearest 2%. The atmospheric pressure should be measured at the height of the antenna and recorded to the nearest 0.3 millibar. The meteorological instruments must be compared against a standard prior to the survey project and brought together and compared at least once per week during the project and corrective measure taken if differences are greater than the required precision.

A more sophisticated approach than modelling the atmospheric delay from surface meteorological observations for precise or large scale survey is to model the delay at each station as a stochastic process, estimating values at each epoch, subject to a constraint (permissible rate of change of the tropospheric conditions) implied by the stochastic model. The stochastic estimation yields geodetic results which are comparable or better than those obtained by strategies using instrumentation such as water vapor radiometers (WVR) [Tralli and Lichten, 1990].

2.4.5 Field Notes

In order to ease the task of processing the data, a detailed field log , either digital or on paper must be maintained. Standard forms, similar to appendix D are adequate. The minimum information that must be included is:

-Date of observations (year, month, day and Julian day number)
-Session identification
-Station identification (name and number as provided by the project authority)
-Receiver model
-Serial numbers of receiver, antenna and data logger
-Height of antenna phase center above the marker (to 1 mm) and all measurements taken to derive that height (a sketch depicting the procedure is also recommended)
-Antenna offset from marker, if any (distance and azimuth)
-Starting and ending time (UTC) of observations
-General weather condition and changes, if any during the session
-Detailed meteorological observations, if required
-All equipment or tracking problems or unusual behavior.

An obstruction diagram, showing any obstructions at elevations
greater than 15° as seen from the antenna location, may also be added to the field log.

2.5 DATA PROCESSING

2.5.1 Software

The software used for processing the data must produce relative positions or coordinate differences for stations observed simultaneously and associated rigorous variance-covariance statistics which can be used as input to a three-dimensional network adjustment program.

Although having a minimum impact on the coordinate accuracy of the results, rigorous handling of the correlations among the GPS observables has a definite impact on the associated statistical information in the network adjustment and when integrating this network with or into a larger framework. Thus, all mathematical and physical correlations should ideally be accounted for and modelled correctly.

However, at the present time, software that can handle the physical correlation are almost nonexistent. Therefore, until models are developed that properly account for the physical correlations, the processing software should at least be able to account for the mathematical correlations between satellite observations and stations. Preferably, the processing software should be capable of producing network (session) solution that integrates all observations and stations in order to account for the mathematical correlations. If baseline processing software is used, all baseline combinations must be included in the network adjustment, and consideration must be given to the overestimation of the degrees of freedom.

The software used for the adjustment should provide observation residuals (or equivalent) which should be examined to ensure that no systematic effects remain. It must also be capable of producing the full formal covariance matrix of all the estimated coordinates.

Software and processing procedures must be successfully tested by processing data sets collected on the validation network before being adopted for a production survey.

2.5.2 Ephemerides

Satellite ephemerides used to compute satellite positions are either predicted and included in the broadcast GPS message or post-computed and available from different sources.

The broadcast ephemerides are predicted by the GPS Master Control Segment. These predictions are orbit extrapolations based on a reference orbit computed from five global monitoring sites.

The Naval Surface Warfare Center (NSWC) in cooperation with the U.S. Defense Mapping Agency (DMA) generates what is known as the "precise ephemerides". These post-computed ephemerides are based on data from 10 global tracking sites. These orbits are also referred to as "fitted" orbits because they fit the entire data set and no extrapolation is required. The U.S. National Geodetic Survey (USNGS) also generates post-computed ephemerides based on data collected at the CIGNET (Cooperative International GPS Network) tracking stations.

Extrapolated (broadcast) ephemerides naturally have larger errors than precise ephemerides because they are subject to the effect of unmodelled perturbations. They are, however, adequate for most survey applications. Studies have shown that the broadcast ephemerides (not affected by Selective Availability) compare with NSWC/DMA precise ephemerides at the three to eight meter level depending whether the satellites were operating with Cesium or Rubidium clock [Remondi and Hofmann-Wellenhof, 1989]. This would influence relative positioning at the 0.2 to 0.5 parts per million range.

However, with the intentional degradation of the accuracy of broadcast ephemerides during period of Selective Availability, uncertainties in the orbital information of 100 metres or worse could be expected and precise or post-computed ephemerides may be required to achieve accuracies of a few parts per million. Time delay from a couple weeks to several months can be expected in getting precise ephemerides from outside sources.

To obtain precise baselines at the 0.1 ppm accuracy level or better, the precise ephemerides may not be accurate enough. Another option is to use data collected at fiducial stations (continuous tracking stations peripheral to the project) which are processed with the project's GPS observations. In this method, the fiducial stations are held fixed and the satellite orbital coordinates are adjusted while simultaneously solving for the station coordinate differences. With the introduction of selective availability and the possible intentional degradation of the orbital information, this might become a viable or even a preferred alternative to waiting for post-computed ephemerides.

2.5.3 Data Processing and Analysis

In order to quickly identify any problems with the data and to take the appropriate corrective action, the data should be processed as soon as possible after the observing session. All processing stages and unusual events, inconsistencies or errors encountered must be logged. The following procedures provide information regarding the consistency and reliability of the data. They should be carried out as frequently as possible and preferably daily.

The differences in repeated baseline measurements must be computed to check for blunders and to obtain initial estimates of the internal consistency of the GPS network. The differences should not exceed the accuracy requirement with respect to length of the baseline.

Wherever available, previously established baselines (between two control points for example) should be compared with the GPS network solution baseline. Discrepancies larger than those specified by the accuracy requirement for the survey should be investigated.

As the survey project progresses, new session solutions must be included in a minimally constrained adjustment (i.e. holding only one point fixed in all three coordinates) to monitor internal consistency of the network. Analysis of the normalized residuals (residuals multiplied by the square root of their weights) will help detect problem baselines and may indicate where some reobservations might be needed.

Upon completion of the project, a final network solution must be performed using the minimally constrained adjustment. NAD 83 coordinates or other known geocentric coordinates provided by the project authority must be used for the fixed station. The minimally constrained adjustment allows examination of the GPS results without the influence of the existing control.

Because existing GPS data processing software generally provides overly-optimistic covariance matrices, it is acceptable when justified to scale the formal covariance matrix provided by such software prior to the final adjustment. A scaling factor or algorithm may already be built into the GPS software package used. In any case, if the covariance is scaled, the project authority must be informed of the scaling technique, the scaling must be applied to the entire covariance matrix so as not to affect the correlation, and the scaling technique must have been used for the validation survey.

2.6 REPORT AND RETURNS

The final report shall provide all the information necessary to evaluate the satisfactory completion of the project objectives. One of the intents is also to provide sufficient information in the returns to enable reprocessing of the raw data, if required. A summary of returns and report items are identified in Section 5.

3. GPS "SURVEY SYSTEM" VALIDATION SURVEY

The concept behind the validation survey is to evaluate the entire GPS "survey system" that is intended or proposed for use on a production survey, and to determine with confidence whether or not it produces reliable results that meet the accuracy requirement.

"Survey system" is defined here as the system used from the data collection stage to the final coordinates produced from a three-dimensional minimally constrained adjustment. This includes the equipment and all procedures used for data collection as well as equipment, software and procedures used for data processing and output of the final results.

The validation survey is carried out in a manner similar to a production survey. The main difference is that most stations have known coordinates which are used for evaluation of the test results by the project authority. The geometric design of the production network, and the logistics required to execute it are not verified during the validation survey but are addressed specifically in Section 4.

Once a GPS "survey system" has been successfully tested during a validation survey, it must be adopted in its entirety for the execution of the production survey for which it was proposed.

3.1 VALIDATION NETWORK

The validation network and specific stations to be positioned must be selected by the project authority. The validation network should have been established using methods which are expected to yield results superior to those expected for the production survey.

The network shall consist of a minimum of six stations that are as much as possible representative of the physical conditions expected on the production survey. This is particularly true for the geographical location (eg. latitude of the survey will determine to a great extent the degree of ionospheric activity) and for the interstation spacing and height differences.

Although not the only option, the GPS Basenets currently being established across the country by the Geodetic Survey Division in collaboration with provincial survey agencies, meet all requirements necessary to carry out most validation surveys. These consist of six or more stations monumented by forced-centering pillars with interstation distances of approximately 2, 10, 40 and 50 kilometres at most locations and with additional distances of 100 and 150 kilometres at other strategic locations. As well, most basenets include an EDM calibration baseline which provides a selection of shorter lengths if required.

The requirement for such test networks throughout the country was identified in 1986. Early in 1987 Geodetic Survey published the PRELIMINARY RECOMMENDATIONS FOR ESTABLISHMENT OF GPS CALIBRATION BASENETS which have been followed for the design and implementation of the existing basenets.

3.2 EXECUTION OF THE VALIDATION SURVEY

For the validation survey, the guidelines provided in the previous section should be taken into consideration without limiting the use of innovative procedures. However, in order to satisfy the objectives of the validation survey, the observing scheme must accommodate some conditions (such as station multiple occupations, repeated baselines and sufficient redundancy) that will allow a thorough evaluation of the data.

In order to correlate as much as possible the results obtained from the validation survey with those expected from the production survey, the test should be carried out at approximately the same time of day (because of the high correlation with the ionospheric behavior) and with the same satellite configuration to what is planned for the production survey.

The results of the validation survey must be submitted according to the specifications described in Section 5. Sufficient information must be provided to permit the evaluation of both the internal and external accuracy of the results.

Since the statistical information provided by the GPS processing software is generally overly optimistic, it is acceptable, when justified, to scale the formal covariance matrices prior to the final adjustment. A scaling factor or algorithm may already be built into the GPS software package used. In any case, if the covariance matrix is scaled, the scaling technique must be applied to the entire covariance matrix and becomes part of the procedures being validated. Therefore, the same scaling technique must be used in the production survey.

3.3 EVALUATION OF RESULTS

A GPS "survey system" shall be considered acceptable for a particular production survey if the results from the validation survey meet the following conditions:

Internal accuracy:

The consistency checks described in Section 2.5.3 are completed with no unexplained discrepancies.

The 3-D 95% relative confidence regions of the final network solution determined from the network covariance matrix meet the accuracy requirement of the production survey.

External accuracy:

The final adjusted coordinates for any stations observed during the validation are statistically equivalent to the known values at the 95% confidence level.

A Helmert transformation of the final coordinates of the validation survey to the known coordinates, using up to seven parameters (3 rotations, 3 translations and scale), may be performed to detect network wide systematic distortions caused by unmodelled biases in the GPS data. This analysis would help identify the problems, if results from the validation survey are not statistically equivalent to the known values.

Once a "survey system" has been validated, it must be adopted in its entirety for the execution of the production survey. If the equipment, procedures or software are modified in any way, the project authority must be informed, and if requested, the validation survey or portion of it repeated, depending on what has been modified. A change in the processing software only would not require the re-observation of the network although new computation and results analysis would be required.

4. SPECIFICATIONS FOR THE CONDUCT OF GPS SURVEYS

This section summarizes the mandatory requirements in the conduct of GPS surveys for the Geodetic Survey Division. Further information on recommended procedures is included in Section 2 of this document.

The entire GPS "survey system" that is intended or proposed for use on a production survey must be evaluated during a validation survey to determine with confidence whether or not it produces reliable results that meet the accuracy requirement. Once a "survey system" has been validated, it must be adopted in its entirety for the execution of the production survey. If the equipment, procedures or software are modified in any way, the project authority must be informed and if requested the validation survey or portion of it repeated depending on what has been modified.

4.1 EQUIPMENT SELECTION

Receivers of different models or manufacturers may be used on the same project. However, compatibility and observation simultaneity must be verified during the validation survey.

Although the use of the same type of antenna for all receivers on a project is recommended to minimize phase centre biases, use of different antenna types is allowed but must be tested during the validation survey.

In the auroral zone or higher latitudes, because of the unpredictability and irregularity of the ionosphere, dual frequency receivers are recommended for all surveys to ensure reliability of the data and are a mandatory requirement when second order accuracy (57 p.p.m., 3-D 95% confidence level) or better is sought .

In the sub-auroral zone (Canadian southern areas), the ionosphere being more homogeneous, the effect of the ionosphere has a high correlation with station spacing. Use of dual frequency receivers is also recommended for all surveys, but is mandatory when first order accuracy (23 p.p.m., 3-D 95% confidence level) or better is sought and baseline lengths consistently exceed 15 km.

4.2 SURVEY NETWORK DESIGN

At least three control stations known three-dimensionally or an equivalent combination of horizontal and vertical control stations must be included in any GPS survey project.

Each station must be directly connected to at least two others in the network.

Because it is generally easier to resolve the integer phase ambiguity over shorter baselines and because it provides a stronger network, simultaneous occupations of adjacent stations must be favoured as opposed to observation of longer baselines.

Multiple occupations (occupation for two or more independent sessions) are mandatory when the 3-D accuracy requirement is of 5 ppm or better (95% confidence level).

For each observing session, at least one baseline must be common to another session such that, in the final network, a common baseline is observed from session to session. Lengths of these repeated baselines must be representative of the adjacent baseline lengths encountered in the project.

A detailed plan at a suitable scale showing existing control and new station which depicts for each session the proposed observation scheme (station observed simultaneously, repeated baselines, etc.) must be submitted to the project authority before field observations begin.

A field reconnaissance must be performed to select the specific sites or to ensure that the stations, if already established, are suitable for GPS observations.

4.3 FIELD OBSERVATIONS

For all surveys, tribrachs allowing for levelling of the antenna together with an optical or mechanical device permitting accurate centering over the mark must be used. The centering device must be checked before and after the survey as well as every week for the duration of the survey .

The height of the antenna's phase centre above the station marker must be measured and recorded to the nearest millimetre before and after each observing session. All measurements taken to derive the total height of the antenna phase centre above the marker must be recorded in the field log.

If a receiver is to remain at the same station for two or more observing sessions, the antenna must be re-positioned between each session, and the antenna height remeasured and recorded at the beginning and end of each session.

The length of the observing session (simultaneous data collection) must be proven adequate under the conditions expected for the production survey during the validation survey.

The measurement rate (data recording rate) must be proven adequate during the validation survey.

A detailed field log, either digital or on paper must be maintained. The minimum information that must be included is:

-Date of observations (year, month, day and Julian day number)
-Session identification
-Station identification (name and number as provided by the project authority)
-Receiver model
-Serial numbers of receiver, antenna and data logger
-Height of antenna phase center above the marker (to 1 mm) and all measurements taken to derive that height (a sketch depicting the procedure is recommended)
-Antenna offset from marker, if any (distance and azimuth)
-Starting and ending time (UTC) of observations
-General weather condition and changes, if any during the session
-Detailed meteorological observations, if required
-All equipment or tracking problems or unusual behavior.

4.4 DATA PROCESSING

The software used for processing the data must produce relative positions or coordinate differences for stations observed simultaneously and associated rigorous variance-covariance statistics which can be used as input to a three-dimensional network adjustment program.

Preferably, the processing software should be capable of producing network (session) solution that integrates all observations and stations in order to account for the mathematical correlations. If baseline processing software is used, all baseline combinations must be included in the network adjustment, and consideration must be given to the overestimation of the degrees of freedom.

The software used for the network adjustment should provide observation residuals (or equivalent) which may be examined to ensure that no systematic effects remain. It must also produce the full formal covariance matrix of all the estimated coordinates.

Software and processing procedures must be successfully tested by processing data sets collected on the validation network before being adopted for a production survey.

All processing stages and unusual events, inconsistencies or errors encountered must be logged.

The differences in repeated baseline measurements must be computed to check for blunders and to obtain initial estimates of the internal consistency of the GPS network. The differences should not exceed the accuracy requirement with respect to length of the baseline.

As the survey project progresses, new session solutions must be included in a minimally constrained adjustment (i.e. holding only one point fixed in all three coordinates) to monitor internal consistency of the network. Analysis of the normalized residuals (residuals multiplied by the square root of their weights) will help detect problem baselines and may indicate where some reobservation might be needed.

Upon completion of the project, a final network solution must be performed using a minimally constrained adjustment. NAD83 coordinates or other known geocentric coordinates provided by the project authority must be used for the fixed station.

Because existing GPS data processing software generally provides overly-optimistic covariance matrices, it is acceptable when justified to scale the formal covariance matrix provided by such software prior to the final adjustment. A scaling factor or algorithm may already be built into the GPS software package used. In any case, if the covariance is scaled, the project authority must be informed of the scaling technique, the scaling must be applied to the entire covariance matrix so as not to affect the correlation, and the scaling must have been used for the validation survey.

5. SPECIFICATIONS FOR GPS SURVEY REPORTING AND RETURNS

The final report of a GPS survey project shall provide all the information necessary to evaluate the satisfactory completion of the project objectives. One of the intents is also to provide sufficient information in the returns to enable reprocessing of the raw data, if required. The summary of returns and report items identified below represents the minimum returns required for a project. Depending on the instrumentation or methodology used, additional information may be required.

5.1 PROJECT DESCRIPTION

A short description of the objectives of the project, location of the survey and number of stations positioned must be presented.

A plot shall detail all stations included in the survey. The plot shall be to scale and shall depict the stations observed simultaneously for each session.

5.2 SURVEY PROCEDURES

The returns submitted must be accompanied by a clear description of the survey procedures used in the field. The information provided should include but is not limited to the following:

(i) A summary of the equipment used, including serial numbers, and a brief descriptions of characteristics and principle of operation;

(ii) Information related to specific procedures used in the field such as oscillator warm up time period, time synchronization procedure (if applicable), antenna height-determination procedure and data recording rate;

(iii) A summary indicating for each session, the station occupied, their respective start and end time of data collection and the satellites simultaneously observed;

(iv) A description of procedures used for eccentric ties and explanation of the need for an eccentric station if applicable;

(v) Logistics information including: means of transportation, equipment deployment scheme, personnel involved and their duties, and difficulties encountered and how they were overcome.

5.3 RAW DATA AND FIELD NOTES

All original observational data collected in the field must be provided to the project authority. These include:

(i) All measurement data (raw data) collected during the campaign on the original media, clearly labelled and described. If data are stored in internal memory, the first portable digital media to which they are transferred is considered "original" for the purpose of this requirement. Data should also be provided in RINEX (Receiver INdependent EXchange) format.

(ii) The original field logs as described in section 4.3, in a paper or digital form;

(iii) Any conventional survey field notes from eccentric ties that were necessary for the completion of the project;

(iv) Any updated station descriptions.

5.4 PROCESSING PROCEDURES

A detailed description of the procedures used for processing and verifying the data in the field or at the office must be presented. The information provided must include but is not limited to:

(i) Computer and software (version number and date) used in the data processing and adjustment;

(ii) A detailed description of how trivial baselines, between baseline mathematical correlations and scaling of the covariance matrix are handled;

(iii) Information and explanations about data editing performed including percentage of data rejected for each station and criteria for rejection;

(iv) Description of the ionospheric and tropospheric models used;

(v) A description of the cycle slip detection and rectification procedure;

(vi) A summary of resolution strategies for phase ambiguities and the results.

5.5 SURVEY RESULTS

The results must be presented in the format and on the media specified by the project authority and shall include:

(i) The coordinate difference observations with associated covariance matrices for each individual session in the format specified by the project authority (GSD is currently requiring GHOST or GEOLAB format);

(ii) The adjusted three-dimensional coordinates from the minimally constrained network adjustment along with the full, formal covariance matrices of the adjusted parameters (including nuisance parameters);

(iii) The statistical testing of the results from the network adjustment including analysis of variance factors, semi-major axes of three-dimensional 95% relative confidence regions between all possible pairs of stations (which must respect the accuracy requirement of the project), residuals and residuals outliers;

(iv) The results of any consistency check or data verifications such as agreement between repeated baselines, agreement with previously established baselines, comparison of single baseline solutions versus network solution.

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APPENDIX A

GPS INFORMATION SOURCES

GEOMAGNETIC ACTIVITY PREDICTION

The Geophysics Division of the Department of Energy, Mines and Resources provides a forecast service to the public on the level of geomagnetic activity. A long term forecast updated every 3 weeks, applicable to a 28 day period (1 solar cycle) is mailed on a regular basis to those requesting it and short term predictions for a period of 72 hours updated daily is available in a detailed form via computer link or summarized on a voice recorded message. GPS users are encouraged to consult these forecasts before and during their campaigns.

The voice recorded forecast (72 hours) is available at (613) 992-1299

To be included in the mailing of the long term forecast or to access the detailed short term forecast contact the Chief Geomagnetic Forecaster at (613) 837-3527 or in writing:

Geomagnetic Forecasting Service
Geophysics Division
1 Observatory Crescent
Ottawa,Ontario
K1A 0Y9

HEALTH AND SATELLITE STATUS

GPS Information Centre

The Global Positioning System Information Centre (GPSIC) provides civil users of the NAVSTAR GPS with system status and other information. The GPSIC is operated by the U.S. Coast Guard. It receives GPS status messages from the U.S. Air Force, which has operational control of the system, and gives the information wide dissemination. Although the information is only updated during the GPSIC's working hours, advisory services are accessible 24 hours a day, seven days a week.

The information available consist of current constellation status (satellites healthy/unhealthy), recent outages, future scheduled outages, and current orbital description data (almanac data) suitable for making GPS coverage and satellite visibility predictions.

A brief summary of the constellation status is available on voice recording at (703) 866-3826. A more detailed information is availablethrough a computer bulletin board. Anyone can use this bulletin board at no charge. registration is done on-line on the first session. The bulletin board may be accessed at either:

(703) 866-3890 for modem connections at 300, 1200 or 2400 bps; or

(703) 866-3894 for modem connections at 1200, 2400, 4800 and 9600 bps.

Comms parameters are: asynchronous comms, 8 data bits, 1 start bit and 1 stop bit, no parity, full duplex connection and XOn / XOf. Both the Bell and CCITT comms protocols are supported.

For additional information on the Centre or the bulletin board write to the Commanding officer, U.S. Coast Guard, Omega Navigation System Centre, 7323 Telegraph Road, Alexandria,VA 22310-3998, U.S.A. or call (703) 866-3806.

Naval Observatory GPS Bulletin Board

Operated by the U.S. Air Force Naval Observatory.in Washington, D.C.. Offers clock data and general GPS information, including constellation status, electronic mail, downloadable files and user advisories.

The bulletin board can be accessed at either (202) 653-0155 or (202) 653-0068. the comms parameters are: no parity, 8 data bits and 1 stop bit. The password "CESIUM133" must be used to access the system and continue with on-line registration.

Further information or assistance is available at (202) 653-1525 or at (202) 653-1034.

Holloman GPS BBS

Operated by the U.S. Air Force at Holloman Air Force Base, New Mexico. Offers GPS information including constellation status, almanac data, electronic mail, downloadable files, and user advisories.

The bulletin board can be accessed at (505) 679-1525. The system uses "smart' modem and will automatically adjust for protocols. For further information or assistance contact (505) 679-2151.

POST COMPUTED EPHEMERIDES

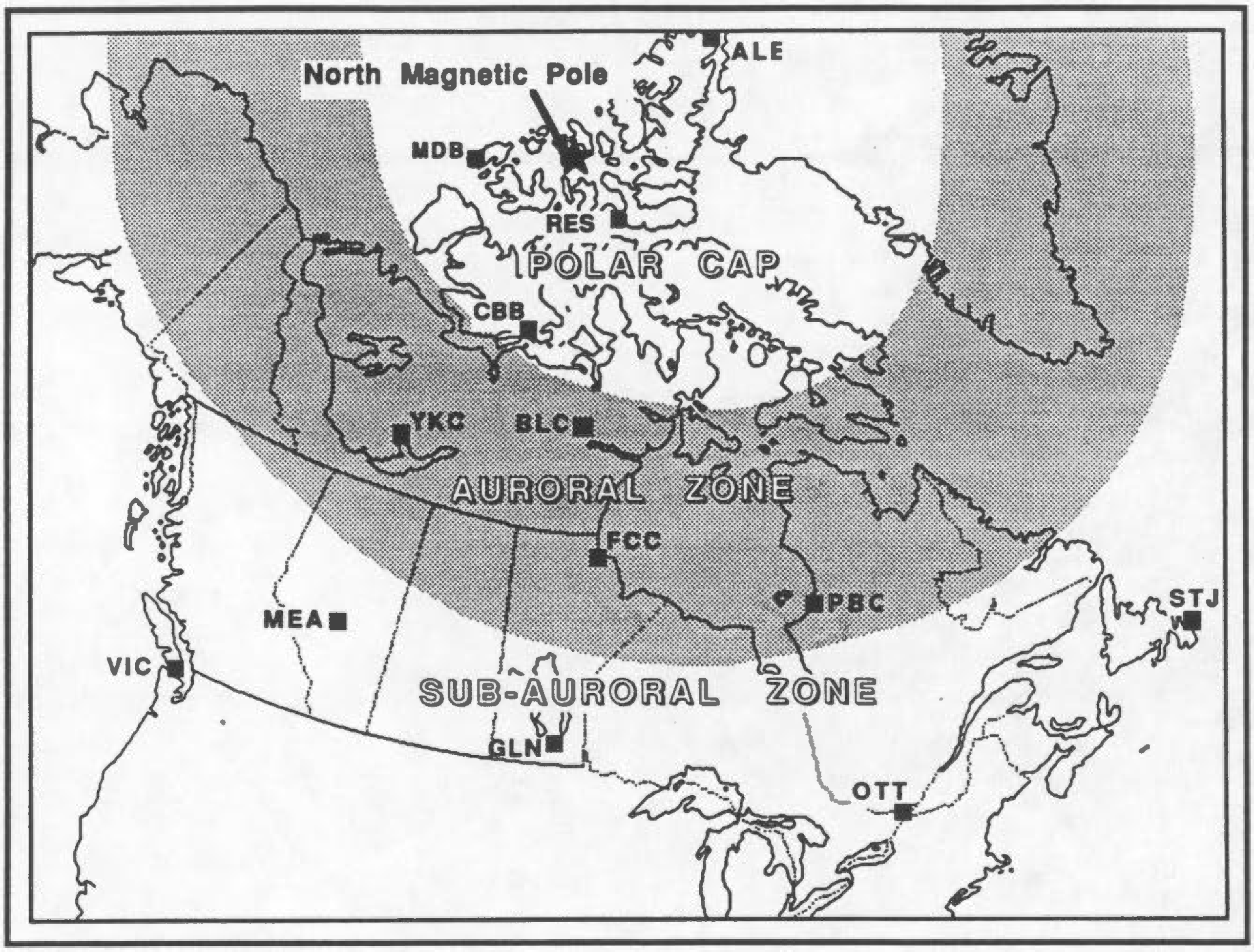
Precise orbital positions and velocities based on computations of tracking data collected from stations of the Cooperative International GPS Tracking Network (CIGNET) are available from the U.S. National Geodetic Survey. Satellite orbital data are scheduled to be available two weeks after the tracking data are collected. Each data set provides one week's ephemeris information at 15 minute intervals, distributed on diskette. For description of formats, fee schedule or to order data, contact:

National Geodetic Information Centre, N/CG174
U.S. National Geodetic Survey, NOS, NOAA
Rockville, MD 20852 USA
(301) 443-8631

The Geodetic Survey Division of the Canada Centre for Surveying does not provide a post computed ephemerides service at the present time but plans to provide this service in the future and to establish a dial-up data base to meet eventual user needs. For further information contact :

Canada Centre for Surveying
Geodetic Survey Division
Information Services
615 Booth Street
Ottawa, Ontario K1A 0E9
(613) 995-4443

APPENDIX B
Geomagnetic Activity Zones in Canada



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

Canadian Magnetic Observatory Network

APPENDIX C

Survey markers

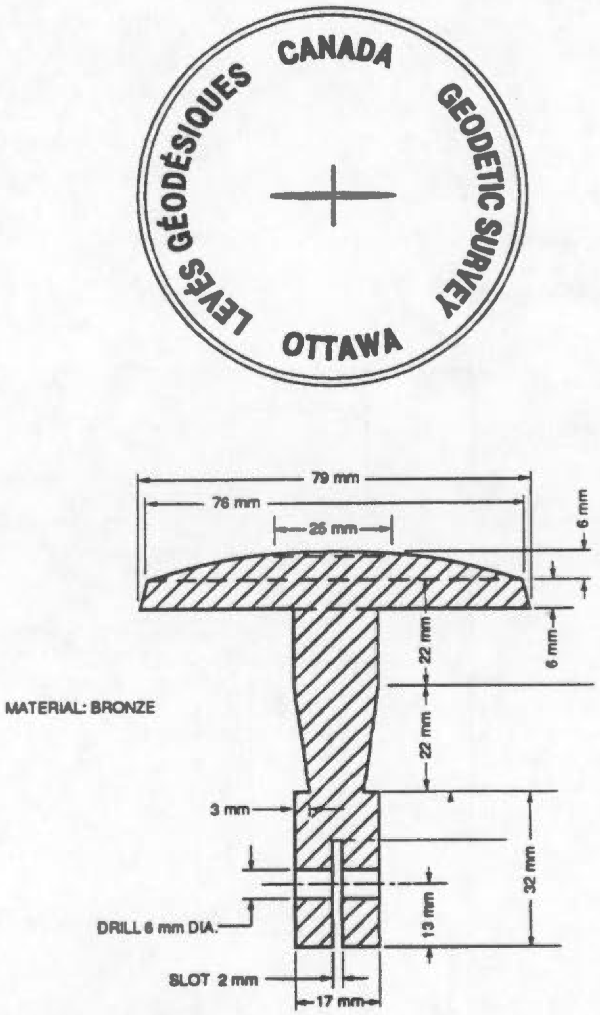
C.1 Tablet and bolt marker

C.2 NRC type bench mark

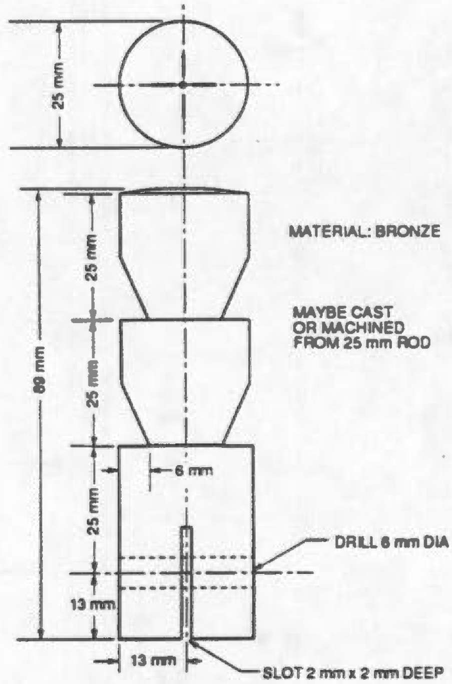
C.3 3-D marker

C.4 Helix pipe marker

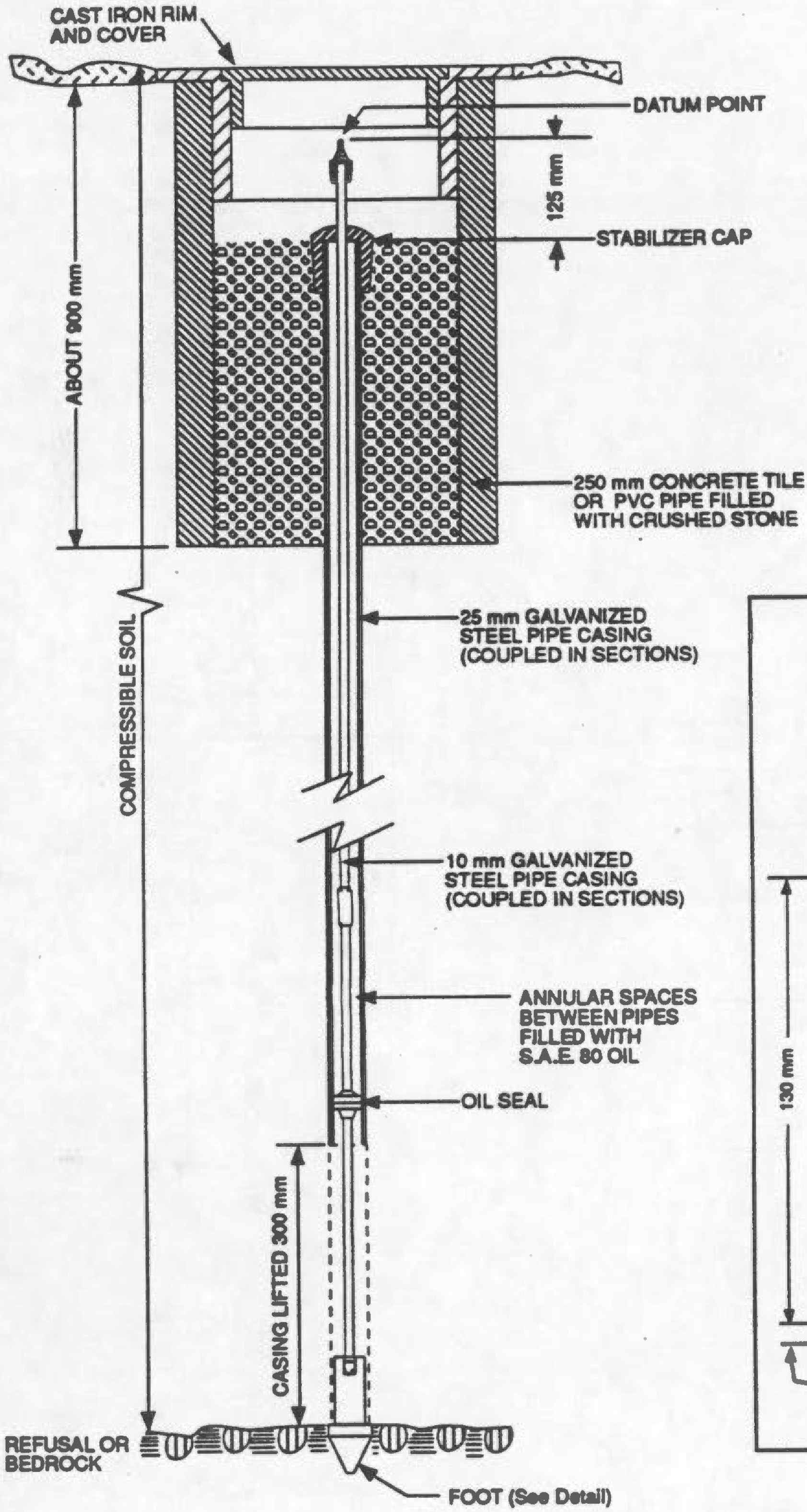
C.5 Post marker

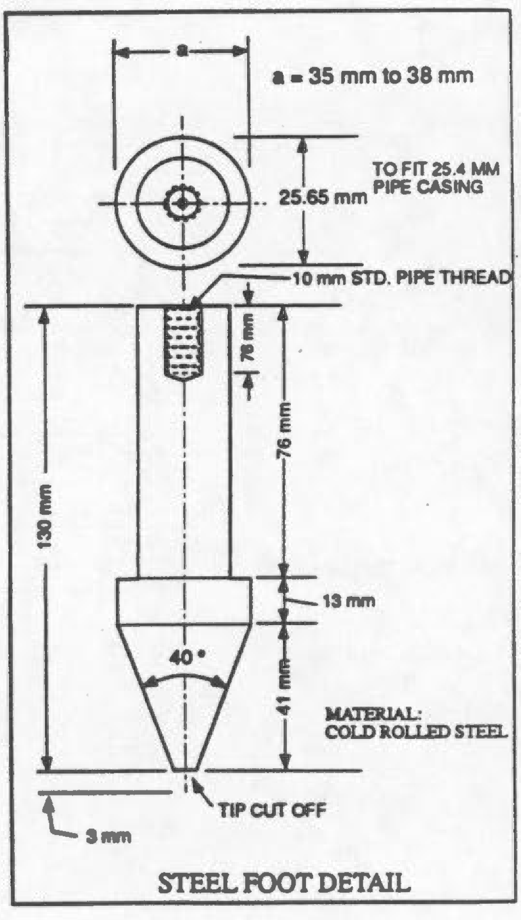


Tablet Marker

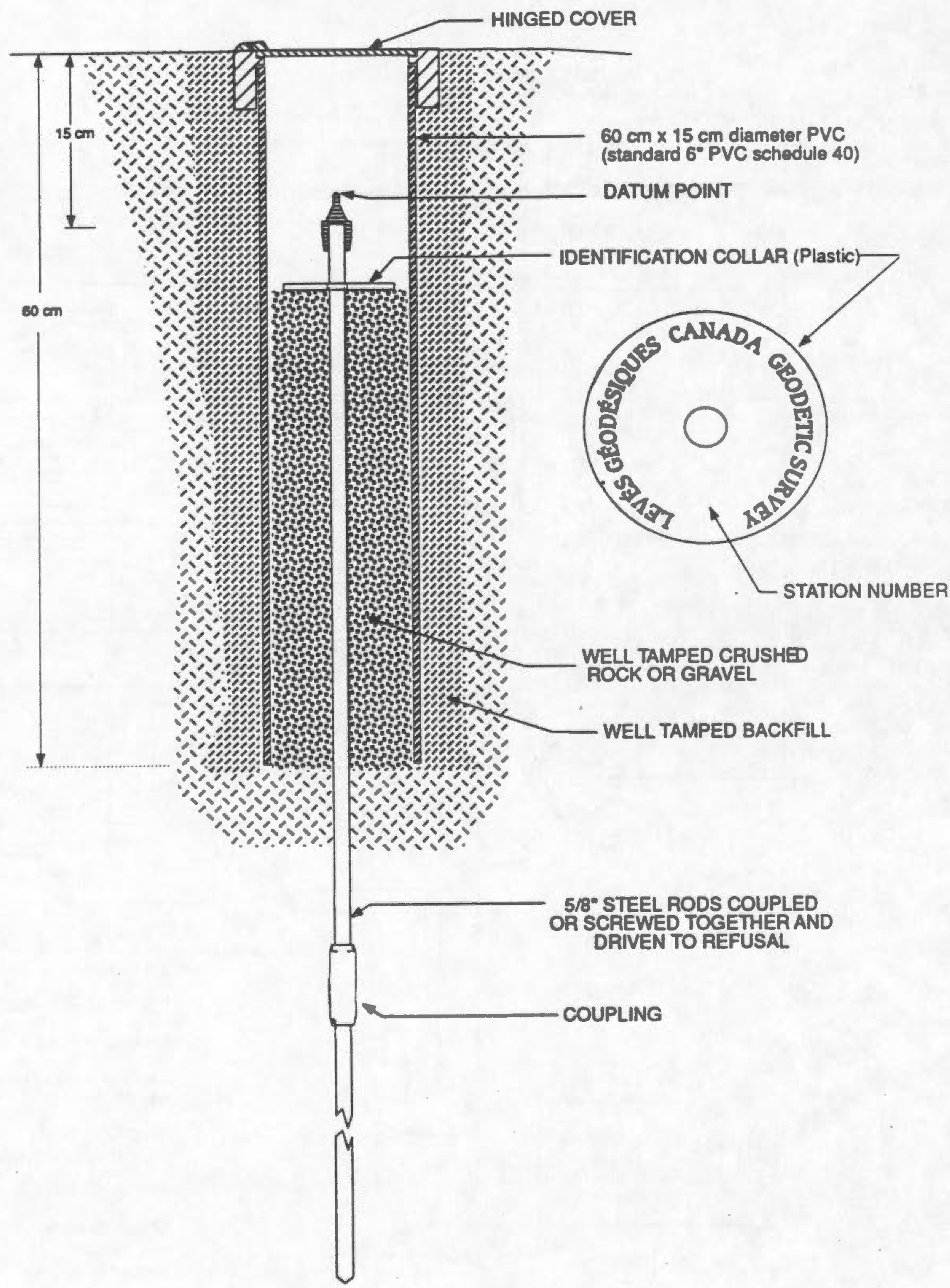


Bolt Marker

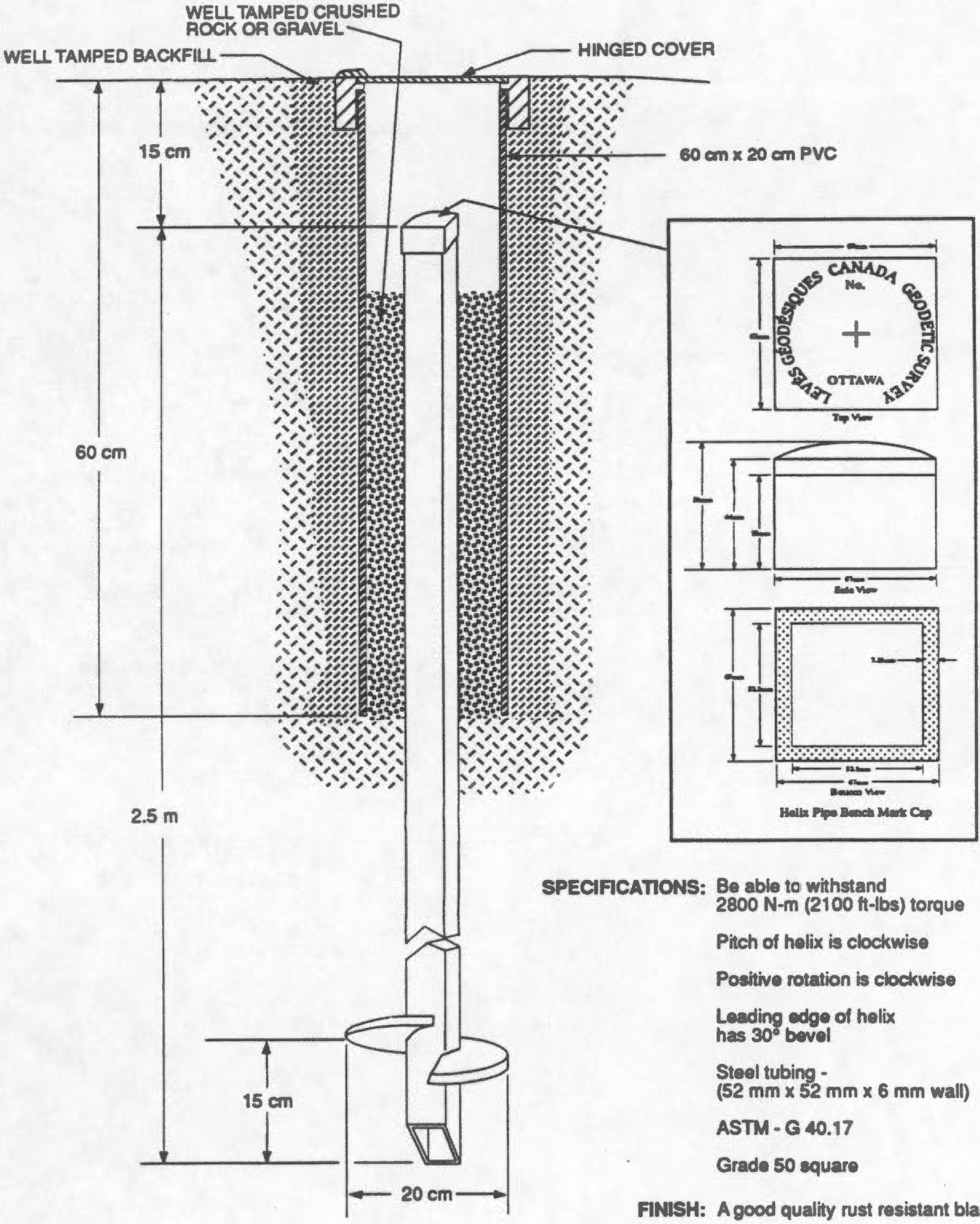




NRC Type Deep Bench Mark



3-D Marker 1990



SPECIFICATIONS: Be able to withstand 2800 N-m (2100 ft-lbs) torque

Pitch of helix is clockwise

Positive rotation is clockwise

Leading edge of helix has 30° bevel

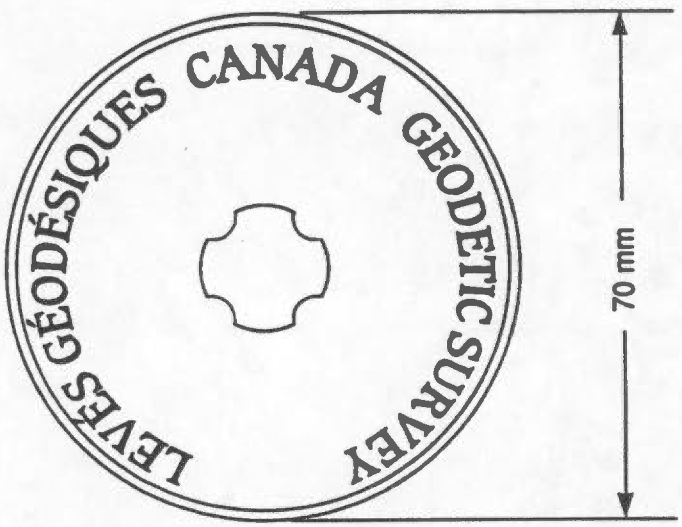
Steel tubing - (52 mm x 52 mm x 6 mm wall)

ASTM - G 40.17

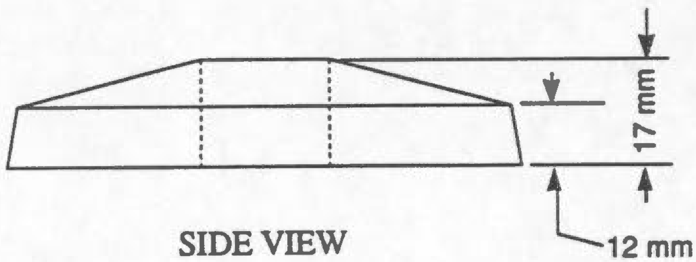
Grade 50 square

FINISH: A good quality rust resistant black paint.

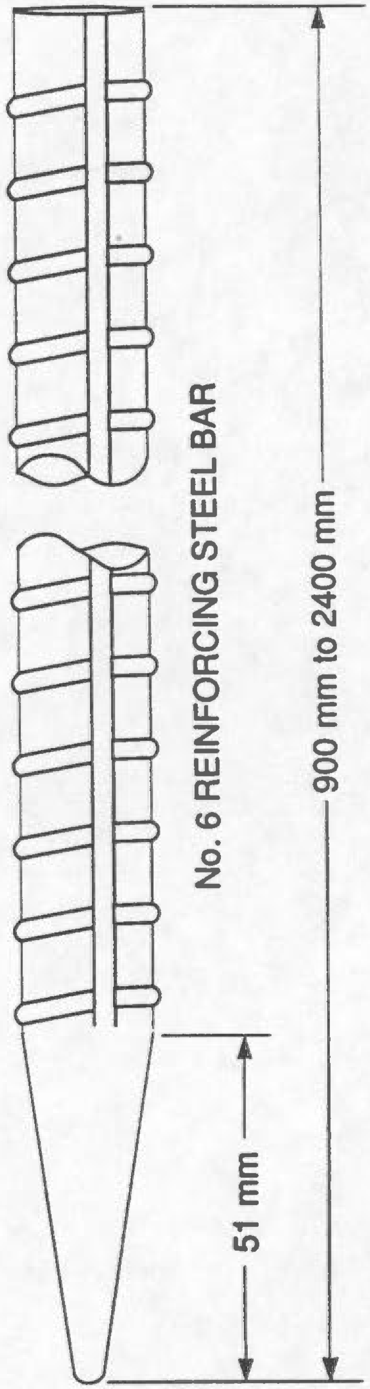
Helix Pipe Marker



TOP VIEW



SIDE VIEW



Cast Aluminum Cap.

Use with unthreaded No. 6 reinforcing steel bar.
Peen top of bar to retain cap.

Top of bar must be centre punched after installation.

Post Marker

APPENDIX D

Sample GPS field log forms

GPS FIELD LOG

RECEIVER MODEL	TI- 4100	STA NAME	BH LOOKOUT
RECEIVER NO.	30082	STA NUMBER	79H1099
ANTENNA NO.	4035	DATE	1989-07-17
RECORDER TYPE/NO.	CASSETTE / 85122036	OPERATOR	W. BROOKES
SOFTWARE VERSION	GESAR 1.5	RECEIVER "ON" DAY/TIME	198 / 17:57

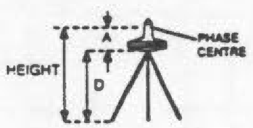
POSITION

INITIAL	LAT	N 48.° 18278
	LONG	W 123.° 64944
	HEIGHT	67 m
COMPUTED	LAT	N 48.° 3160969
	LONG	236.° 3491258
	HEIGHT	−57.0827108 m

DATA COLLECTION

RECORDING INTERVAL	15 SEC
OFFSET	N/A
START DAY/TIME	198/ 19:37
END DAY/TIME	199/ 00:16
CASS/DISK/FILE (1)	1 OF 1

COMPUTING ANTENNA HEIGHT



HEIGHT = marker to antenna phase centre
A = antenna base to phase centre
D = marker to antenna base

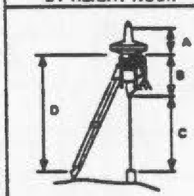
HEIGHT = A + D

A - PHASE CENTRE TO ANTENNA BASE

TI A = 0.240 m
WM A = 0.110 m
NORSTAR A = 0.141 m

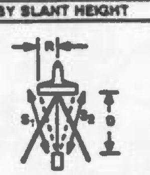
D - ANTENNA BASE TO MARKER

BY HEIGHT HOOK



D = B + C
B = 0.250 m
C = tape reading (read at line on height hook)

BY SLANT HEIGHT



By formula:

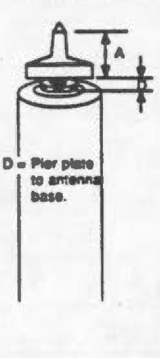
$$D = \sqrt{\left(\frac{S_1 + S_2}{2}\right)^2 - R^2}$$

TI R = 0.034 m
NORSTAR R = 0.104 m

By table:

apply correction for $\left(\frac{S_1 + S_2}{2}\right)$ from conversion table

ON CONCRETE PIER



ANTENNA HEIGHT MEASUREMENT

- [ ] BY HEIGHT HOOK
- [x] BY SLANT HEIGHT
- [ ] CONCRETE PILLAR
- [ ] WILD MINI TRIPOD
- [ ] OTHER ________

	START	END
(S_1)	1.414 m	1.414 m.
(S_2)	1.414	1.414
(m_s)	1.414 ✓	1.414 ✓
( )	−0.002 ✓	−0.002 ✓
D:	1.412 ✓	1.412 ✓
+A:	0.240	+0.240
HEIGHT:	1.652 ✓ m	1.652 ✓ m

MEAN HEIGHT: 1.652 ✓ m

Verified by:

MET SENSOR NO: UNIT 1
STA NAME: BH LOOKOUT
BAROMETER NO: 0550
STA NUMBER: 79H1099
OPERATOR: W. BROOKES
DATE: 1989-07-17

OBSTRUCTION OR POSSIBLE INTERFERENCE SOURCES: 3 trees whose tops approach 20° elevation at azimuths of 108°, 135° and 156° magnetic

GENERAL WEATHER CONDITIONS: SUNNY / LIGHT NW'LY WINDS

Time	19:41	20:11	20:41	21:12	21:42	22:12	22:42	23:16	23:47	00:20
Dry temp (°C)	16.8	18.3	20.1	14.9	14.4	15.0	16.0	15.5	13.9	15.4
Wet temp (°C)	~~78.2~~ N/A	—	—	—	—	—	—	—	—	—
Rh (%)	78.2	74.0	72.7	85.8	86.7	84.3	77.5	79.5	91.2	84.0
Alt rdg (ft)	N/A	—	—	—	—	—	—	—	—	—
Correction	N/A	—	—	—	—	—	—	—	—	—
-1000	N/A	—	—	—	—	—	—	—	—	—
Pressure (mb)	1011.5	1011.6	1011.7	1011.6	1011.4	1011.4	1011.4	1011.5	1011.7	1011.5

Verified by: ______________

DAY	TIME	COMMENTS	SV'S TRACKED						
198	17:57	Power on "Standby"							
	19:07	To "Operate"							
	19:29	[RUN]							
	19:37	Recording	6	0	0	0			
	19:48	Scenario start	6	9	11	0			
	19:49	All 3 SV's tracking O.K.	6	9	11	0			
	20:16	Scenario change							
	20:17	SV 13 acquired O.K.	6	9	11	13			
	20:58	[SOLUTION] LT: 48°.3157549	6	9	11	13			
		LN: 236°.3491015 → 123°.6508985							
		HT: 107.1738192 m							
	21:46	Scenario change - SV 6 dropped	-	9	11	13			
	21:47	SV 3 acquired O.K.	3	9	11	13			
	22:27	[Solution] - values noted on Page 1	3	9	11	13			
		Starting to cloud over							

OPERATOR W. BROOKES STA NAME BH LOOKOUT

DATE 1989-07-17 STA NUMBER 73H1099

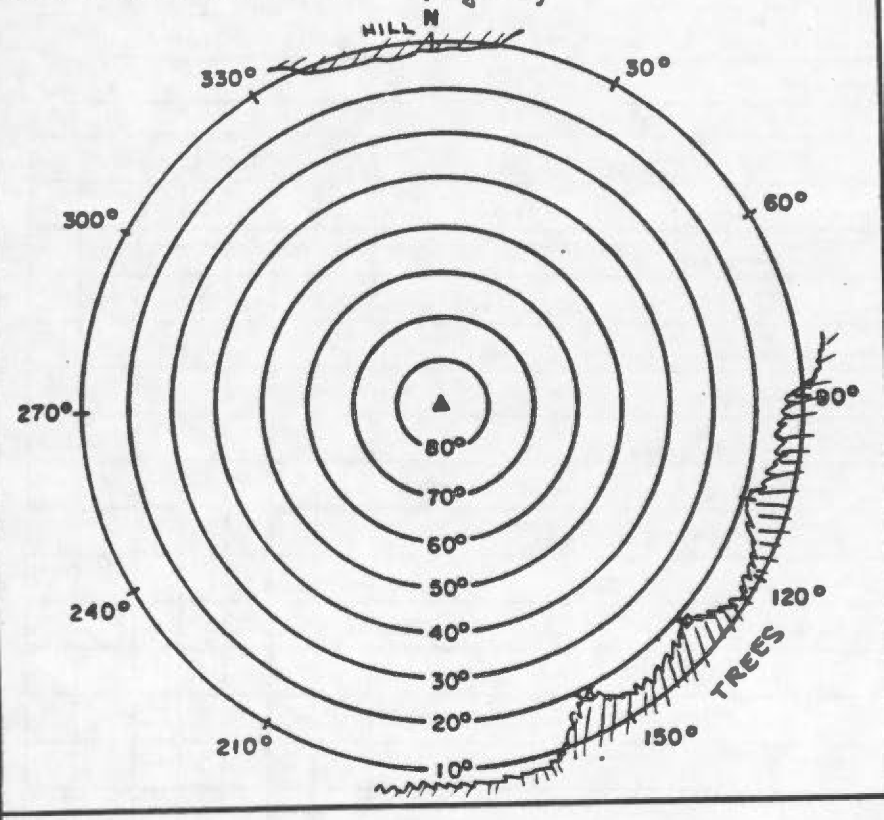
DAY	TIME	COMMENTS	SV'S TRACKED						
198	22:46	Scenario change - SV11 dropped	3	9	-	13			
	22:47	SV 12 acquired	3	9	12	13			
	23:01	Scenario change - SV 9 dropped from tracker	3	0	12	13			
	23:15	Winds increasing from NW / almost							
		complete overcast							
199	00:09	[SOLUTION] LT: 48°3160229							
		LN: 236°3491913 → 123.6508087							
		HT: -39.4300510 m							
	00:16	END — Tape 76 % Full							
		Int. Battery 23 V							

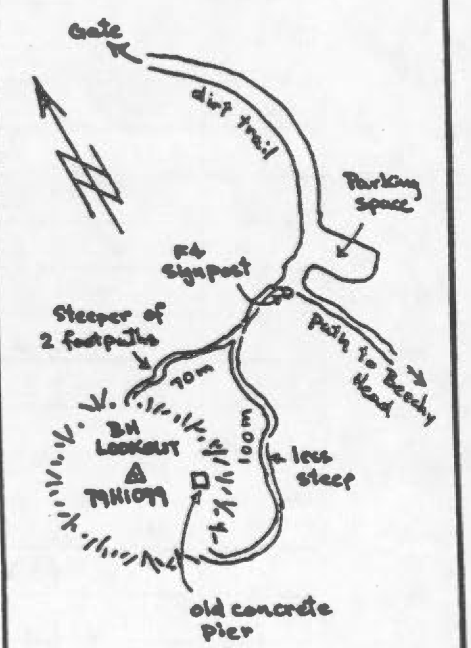
BH LOOKOUT

STA NO: 79H1099

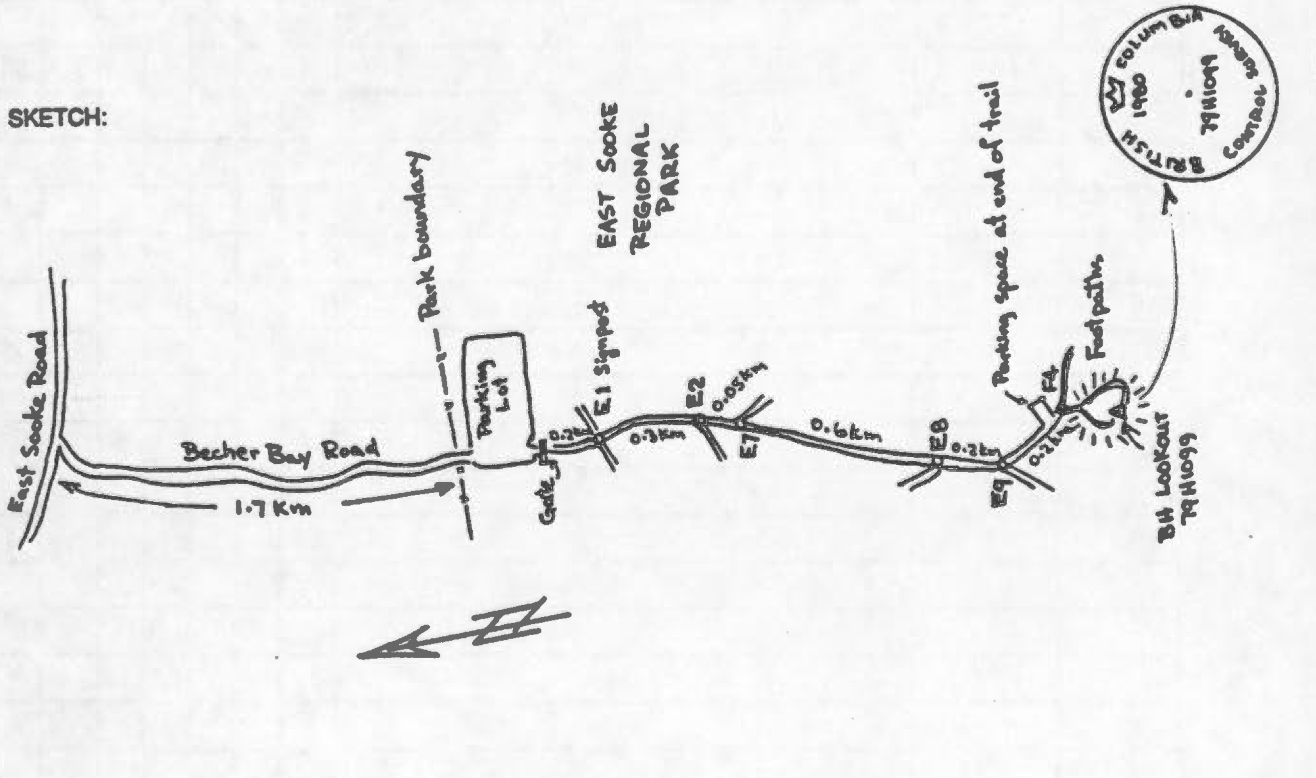
DATE: 1989-07-17

AZIMUTH / INCLINATION ANGLE





SKETCH:



WRB - 89-07-17

GPS FIELD LOG

RECEIVER MODEL ______	STA NAME ______
RECEIVER NO. ______	STA NUMBER ______
ANTENNA NO. ______	DATE ______
RECORDER TYPE/NO. ______	OPERATOR ______
SOFTWARE VERSION ______	RECEIVER "ON" DAY/TIME ______

POSITION

INITIAL	LAT	______
	LONG	______
	HEIGHT	______
COMPUTED	LAT	______
	LONG	______
	HEIGHT	______

DATA COLLECTION

RECORDING INTERVAL ______

OFFSET ______

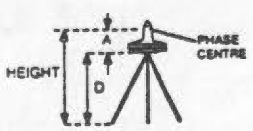
START DAY/TIME ______

END DAY/TIME ______

CASS./DISK/FILE (   ) ______

______

COMPUTING ANTENNA HEIGHT



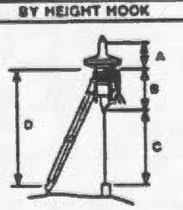
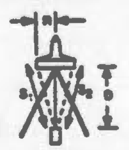
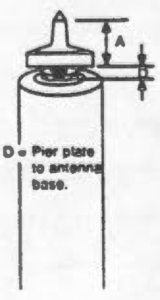
HEIGHT = marker to antenna phase centre
A = antenna base to phase centre
D = marker to antenna base

HEIGHT = A + D

A - PHASE CENTRE TO ANTENNA BASE

TI A = 0.240 m
WM A = 0.110 m
NORSTAR A = 0.141 m

D - ANTENNA BASE TO MARKER

BY HEIGHT HOOK	BY SLANT HEIGHT	ON CONCRETE PIER
 D = B + C B = 0.250 m C = tape reading (read at line on height hook)	 **By formula:** $D = \sqrt{\left(\frac{S_1 + S_2}{2}\right)^2 - R^2}$ TI R = 0.084 m NORSTAR R = 0.104 m **By table:** apply correction for $\left(\frac{S_1 + S_2}{2}\right)$ from conversion table	 D = Pier plate to antenna base.

ANTENNA HEIGHT MEASUREMENT

☐ BY HEIGHT HOOK

☐ BY SLANT HEIGHT

☐ CONCRETE PILLAR

☐ WILD MINI TRIPOD

☐ OTHER ______

	START	END
( )	______ m	______ m.
( )	______	______
( )	______	______
( )	______	______
D:	______	______
+A:	______	______
HEIGHT:	______ m	______ m

MEAN HEIGHT: ______ m

Verified by: ______

MET SENSOR NO ____________________ STA NAME ____________________

BAROMETER NO ____________________ STA NUMBER ____________________

OPERATOR ____________________ DATE ____________________

OBSTRUCTION OR POSSIBLE INTERFERENCE SOURCES: ____________________

____

GENERAL WEATHER CONDITIONS: ____________________

Time										
Alt rdg (ft)										
Correction										
-1000										
Pressure (mb)										
Dry temp (°C)										
Wet temp (°C)										
Rh (%)										

Verified by: ____________________

DAY	TIME	COMMENTS	SV'S TRACKED						

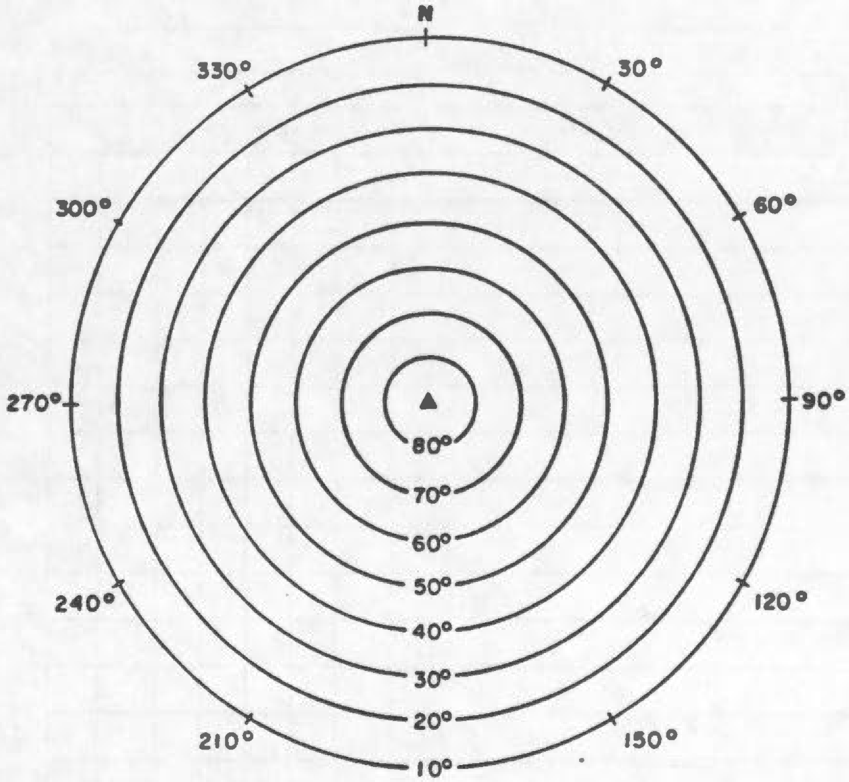
[D15/GPS Field Log-2]

OPERATOR ______________________ STA NAME ______________________

DATE ______________________ STA NUMBER ______________________

DAY	TIME	COMMENTS	SV'S TRACKED						

AZIMUTH / INCLINATION ANGLE



STA NO: ____________________

DATE: ____________________

SKETCH: