GUIDELINES FOR MANAGING
A GPS BASED CONTROL SYSTEM
IN THE MARITIME PROVINCES

Version 1.0

prepared for
Maritime GPS Implementation Committee

prepared by
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in association with
Gillis Survey Systems Inc.

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TERMINOLOGY USED IN THIS REPORT

CSRS = Canadian Spatial Reference System. The concept of the CSRS was developed by the Canadian federal government. The CSRS provides a hierarchy of control points, which can be accessed by various means and at various levels of accuracy in order to support a wide range of positioning applications.

CBN = Canadian Base Network. The Canadian Base Network is a highly accurate GPS based network now being established by the Canadian federal government. Within the Maritime region, twelve stations were positioned by the federal government as part of the 1994 CBN campaign.

Maritime High Precision Network = The regional high precision GPS network established in 1994 by New Brunswick, Nova Scotia, and Prince Edward Island. The Maritime High Precision Network consists of a total of forty-four points established as part of the 1994 CBN campaign. Twelve of these points are the CBN points described above; during the same campaign, thirty-two additional high precision points were established by Maritime provincial agencies.

NBHPN = New Brunswick High Precision Network. The NBHPN includes the New Brunswick portion of the Maritime High Precision Network (as established in 1994), and the densification of that network within New Brunswick.

NSHPN = Nova Scotia High Precision Network. The NSHPN includes the Nova Scotia portion of the Maritime High Precision Network (as established in 1994), and the densification of that network within Nova Scotia.

PEIHPN = Prince Edward Island High Precision Network. The PEIHPN includes the Prince Edward Island portion of the Maritime High Precision Network (as established in 1994), and the densification of that network within Prince Edward Island.

provincial = Within these guidelines, the term provincial refers to any of the three Maritime provinces and does not, in general, refer to provinces outside of the region.

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1.0 INTRODUCTION

The provinces of New Brunswick, Nova Scotia, and Prince Edward Island are currently moving from a conventional survey control system to a more accurate control system based upon Global Positioning System (GPS) technology.

These guidelines have been developed to assist in the management of the new survey control system. Within these guidelines, the following subjects have been addressed: the geodetic datum to be utilized in supporting the control system, accuracy standards, GPS observation procedures, GPS data processing and adjustments, data storage, and the use of validation networks.

The term 'guidelines', rather than 'specifications', has been used in order to convey the sense that this document is subject to change over time, and in fact is expected to change. 'Guidelines' was preferred over 'specifications' because it implies a more flexible approach to the management of the control system.

Additionally, a version number has been assigned to this document. GPS observation and processing techniques continue to evolve, and the provincial agencies using these guidelines may periodically find the need to review and update this document. It is recommended that a two year cycle may be appropriate for such a review and, if required, an updated version should be prepared at that time.

1.1 Basis for the New Control System

The requirement for a sparse, but highly precise, GPS based control network in the Maritime Provinces was outlined in a task force report in 1993 (Hamilton and Doig, 1993).

This high precision GPS network is now being implemented throughout the region. In order to fully support GPS activities and a modern positioning infrastructure, the Maritime Provinces are also in the process of adopting a new geodetic datum which will be fully compatible with GPS.

The basis for the new high precision GPS network in the Maritimes is the Canadian Base Network (CBN). The Canadian Base Network is a highly accurate GPS based network now being established by the Canadian federal government in cooperation with a number of the provinces. The CBN is designed to complement the Canadian Active Control System (CACS) (Duval et al., 1996), and comprises one of the layers of the Canadian Spatial Reference System (CSRS) which will be discussed in more detail in a later section. When completed, the CBN will have a nominal station spacing of 200 kilometres in Canada's southern latitudes.

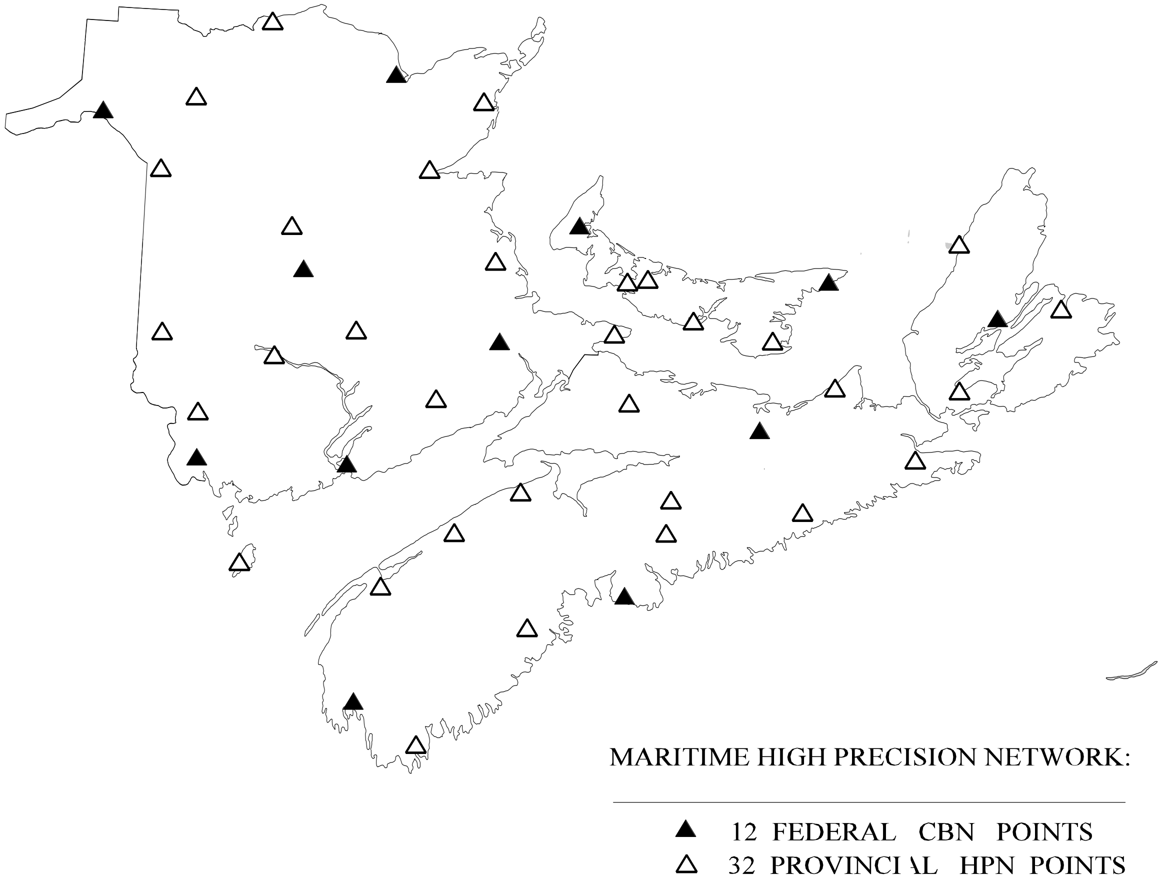
In 1994, the Maritime Provinces cooperated in a joint GPS campaign with the federal government to establish the Maritime portion of the CBN . During the 1994 CBN campaign, twelve CBN stations were established across the region by the Geodetic Survey Division of Natural Resources Canada. During the same campaign, the Maritime Provinces established an additional thirty-two stations with the objective of producing a regional high precision GPS network which would be completely integrated and consistent with the Canadian Base Network.

These forty-four points form what will be referred to in these guidelines as the Maritime High Precision Network (Maritime HPN). The breakdown of the forty-four points by province is as follows:

Maritime High Precision Network

	Federal CBN points	**Provincial HPN points**
New Brunswick	**6**	**14**
Nova Scotia	**4**	**14**
Prince Edward Island	**2**	**4**

A map showing the approximate locations of these points has been included as Figure 1.



MARITIME HIGH PRECISION NETWORK
OCTOBER 1994

Figure 1

The procedures and specifications used in establishing the Maritime High Precision Network are not specifically included as part of these guidelines, but have been included as a matter of record as Appendix "A".

Each of the three provinces has already begun the process of densification within its own jurisdiction.

1.2 Networks Within the Individual Provinces

The Maritime High Precision Network refers to the original network of forty-four points established in 1994: it includes both the federally established CBN points and the provincially established points. As mentioned, each of the three Maritime provinces has gone, or is going through, the exercise of densification of the Maritime High Precision Network. When that exercise is completed, each of the provinces will have a new provincial high precision GPS network at an average station spacing of approximately twenty to forty kilometres.

Each province will be assigning a provincial name to its high precision GPS network as follows: the New Brunswick High Precision Network (NBHPN), the Nova Scotia High Precision Network (NSHPN), and the Prince Edward Island High Precision Network (PEIHPN). These networks comprise points included in the original 1994 Maritime High Precision Network, and any additional densification points added to that network by the three provinces within their own jurisdictions.

These networks are being established cooperatively by the three Maritime provinces, and consistent observation, processing, and adjustment procedures will be used to produce the coordinates for each provincial network.

2.0 DATUM

Coordinates for the GPS based survey control network in the Maritimes will be based upon the North American Datum of 1983 (NAD83), as realized through the Canadian Spatial Reference System in 1995 (CSRS95). This realization of the datum will be referred to as NAD83(CSRS95).

2.1 Current Datum

The NAD83(CSRS95) datum will replace the current geodetic datum in the Maritimes, which is the Average Terrestrial System of 1977 (ATS77).

ATS77 was based on a geocentric ellipsoid; the size, shape, and orientation of that ellipsoid were based on the best estimates available at the time it was selected. However, these estimates continued to be improved and when the new NAD83 datum was officially defined several years later, it utilized a new ellipsoid which reflected those improvements.

2.2 NAD83

The NAD83 datum is based upon the Geodetic Reference System of 1980 (GRS80) ellipsoid. For an outline of some of the parameters that define NAD83, the reader is referred to Appendix "B".

The first major realization of NAD83 in North America was via a massive re-adjustment project. In Canada, this realization is often referred to as NAD83 (1986). Although the NAD83 re-adjustment effort removed most of the existing distortions in the old networks, there were still limitations to the accuracies that were achievable in such an effort. Most of the observations making up the older networks were conventional terrestrial observations, with accuracies that did not approach current GPS accuracies. Also, network configurations continued to be weaker in some areas than others. Thus, there can still often be difficulty in fitting GPS observations into older networks.

The federal governments of both Canada and the United States have recognized this problem, and have begun the implementation of highly accurate GPS networks to better support modern positioning techniques. In Canada, the Geodetic Survey Division has undertaken to establish a high precision GPS network, i.e., the CBN, in cooperation with the provincial agencies.

With the implementation of the CBN, within the context of the CSRS, there will be a new and highly accurate realization of NAD83 within Canada. The new realization of NAD83, based on the CSRS, is a 'top-down' realization, and coordinates produced within this new realization are the most accurate NAD83 coordinates presently available. NAD83, as realized through the CSRS, is fully compatible with GPS positioning techniques.

The distinction between the two realizations is important. It is possible for NAD83(CSRS95) coordinates and NAD83(1986) coordinates for the same control point to differ by several decimetres, or even more on occasion.

2.3 NAD83: Relationship to WGS84 and ITRF

The ellipsoid and coordinate reference frame of NAD83 were defined in such a way as to make them almost identical to the ellipsoid and coordinate reference frame utilized in the World Geodetic System of 1984 (WGS84), the reference system in which the Global Positioning System operates.

A comparison of the ellipsoid parameters used for WGS84 and NAD83 can be found in Appendix “B”. An examination of these parameters will confirm that, for most intents and purposes, both the ellipsoids and the coordinate reference systems of NAD83 and WGS84, as originally defined, could be considered equivalent.

Although the coordinates for the Defense Mapping Agency's (DMA's) GPS tracking stations were determined in the WGS84 system, the original computations to determine these positions relied heavily upon Doppler satellite techniques. As techniques such as Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), and GPS continued to mature, the estimates for a true geocentric system have continued to improve, and cooperative efforts have been organized to continually monitor and improve the parameters defining such a global system.

One system currently supported by such efforts is the International Terrestrial Reference Frame (ITRF) which was established in 1988 by the International Earth Rotation Service (IERS). The ITRF is dynamic, with new solutions for the reference frame being computed annually; the ITRF has been adopted by the International Union of Geodesy and Geophysics (IUGG) for geodetic and geodynamic applications (Boucher and Altamimi, 1992). The coordinates of the stations defining the framework were originally derived from space geodesy techniques including VLBI, SLR, and Lunar Laser Ranging (LLR), and, in 1994, the establishment of the International GPS Service for Geodynamics (IGS) introduced a large number of new GPS tracking stations into the system for computing ITRF solutions.

In 1994, there was an upgrade of WGS84 through modification of its GM (gravitational constant) value (Malys and Slater, 1994) which brought the defining parameters of WGS84 more in line with the ITRF. Defense Mapping Agency (DMA) tracking station coordinates were also upgraded to improve the WGS84 coordinate reference frame. The refined WGS84 reference frame is designated as WGS84 (G730) and is considered to be coincident with ITRF92 at a level approaching 10 centimetres (Malys and Slater, 1994). WGS84 (G730) was implemented in the DMA's GPS orbit processing in January of 1994.

Because of this revision, the coordinate reference system of WGS84 is now very close to that of the current ITRF and is no longer entirely equivalent to that of NAD83. However, the relationships between the ITRF, WGS84, and NAD83 reference frames have been well established (Abusali et al., 1995; Kouba and Popelar, 1994; Blackie, 1994), so it is possible to move back and forth between the systems by applying appropriate transformation parameters and methodologies. It is important to note that these transformations do **not** account for distortions which may occur in the existing NAD83 networks.

2.4 The Canadian Spatial Reference System (CSRS)

The Canadian Spatial Reference System (CSRS) is a system for providing consistent and accurate spatial positions throughout Canada. The CSRS provides a hierarchy of control points, which can be accessed by various means and at various levels of accuracy in order to support a wide range of positioning applications.

The concept of the CSRS was introduced by the Geodetic Survey Division of Natural Resources Canada (Crossley et al.,1994; Geodetic Survey Division, 1996; Geodetic Survey Division, 1995) in response to the need for a system compatible with modern positioning techniques.

The CSRS can be viewed as a hierarchy of control points: the top layer comprises the Very Long Baseline Interferometry (VLBI) sites across Canada, the second layer comprises the Canadian Active Control System, and the third layer comprises the CBN. From a provincial perspective, it is these top three layers which are of concern. These layers form what is now being termed the national CSRS network - the 'Fundamental Level' of the CSRS.

2.4.1 The National CSRS Network: the Fundamental Level of the CSRS

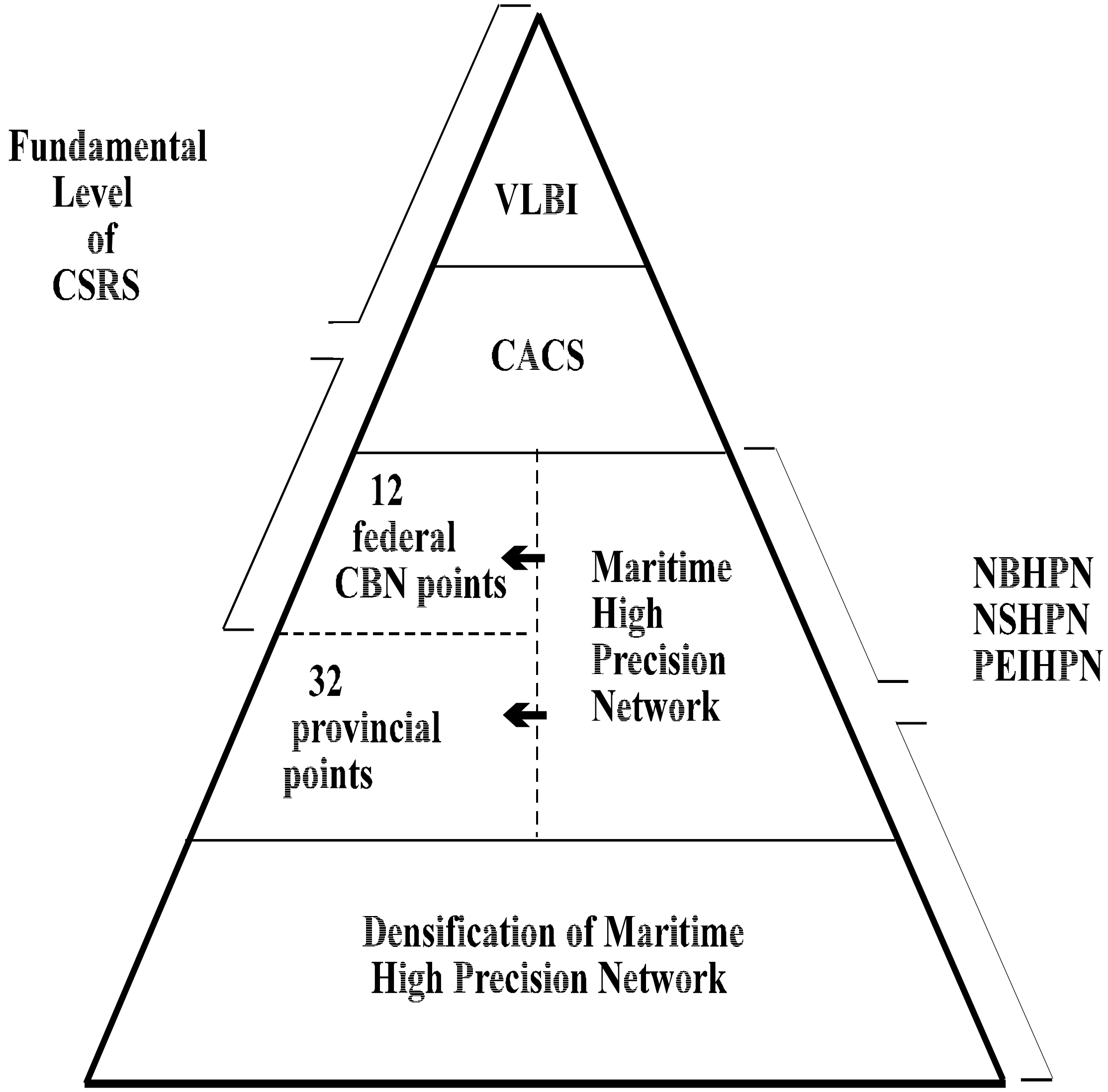
There are currently five VLBI sites across Canada and these comprise the main fiducial points for the CSRS (Duval et al., 1996).

The second layer of the CSRS comprises the stations of the Canadian Active Control System (CACS), where GPS data is collected on a continuous basis. In 1996, CACS consisted of ten stations (Duval et al., 1996). Some CACS stations are co-located with VLBI stations, thus linking the top two layers of the system together. The five VLBI stations, as well as a subset of the ten CACS stations, have been positioned in the ITRF, thus they provide the link between the CSRS and a global framework.

The third layer of the hierarchy is the CBN, an array of GPS monuments established in cooperation with the provinces. These stations are linked directly to the upper levels of the CSRS by utilizing simultaneous GPS observations at the CACS and CBN sites, and establishing the positions of the CBN with respect to the positions of the CACS stations.

The hierarchy of the CSRS has been represented as a pyramid figure by the Geodetic Survey Division (Duval et al., 1996). Following this example, but viewing the system from a Maritime provincial perspective, the CSRS can be visualized as shown in Figure 2.

All control points established within the CSRS will have published values referenced to the NAD83 datum. Coordinates for points in the 'Fundamental Level' are presently the most precise NAD83 coordinates available, and it is upon the Fundamental Level of the CSRS that the new Maritime control system is based. It is important to recognize that, for a given control point, NAD83 coordinates derived from the Fundamental Level of the CSRS may differ from earlier adjusted NAD83 coordinates by several decimetres. It is for this reason that the Maritime Provinces have added the qualifier 'CSRS95' in referring to the Maritime realization of NAD83.



**HIERARCHY OF THE
CANADIAN SPATIAL REFERENCE SYSTEM
FROM A PROVINCIAL PERSPECTIVE**

(Based on figure in Duval et al., 1996)

Figure 2

3.0 ACCURACY STANDARDS

Accuracy standards are used to identify the level of accuracy of surveyed points. Generally, once established, standards remain stable, even though the specifications or guidelines used to achieve those standards may change.

In the case of GPS based survey control in the Maritimes, an entirely new network is being established. New accuracy standards are being adopted by the Maritime Provinces for the following reasons:

1) The accuracies of the new network significantly exceed existing standards; the older standards were not intended to accommodate the accuracies associated with GPS.

2) The new accuracy standards will emphasize a measure of network accuracy in addition to the more traditional relative accuracy.

3) The new accuracy standards can accommodate both horizontal and vertical geodetic quantities.

The accuracy standards for the provincial high precision GPS networks in the Maritimes will closely follow those accuracy standards recently developed by the federal government. The federal document, Accuracy Standards for Positioning, Version 1.0, is nearing completion (Geodetic Survey Division, 1996) and should be available in the near future from the Geodetic Survey Division of Natural Resources Canada. The reader is referred to that document for a more complete discussion of the concepts introduced in these guidelines.

One of the concepts which is utilized within the federal accuracy standards, and which will also be utilized within the provincial accuracy standards, is that of self-labelling accuracy classes based on error ellipses. The emphasis on self-labelling accuracy classes will represent somewhat of a change in expressing the accuracy of positions established for geodetic control. Typically, these accuracies had been expressed in terms of parts per million (ppm) in the case of GPS work, or in terms of 'order' for conventional survey work.

The federal document on Accuracy Standards for Positioning deals with horizontal and vertical accuracies as separate entities, even though a position may be determined in all three dimensions. This is a reasonable way of approaching the problem, since the standards can then accommodate methodologies other than GPS. The standards for the Maritime Provinces will utilize the same approach.

3.1 Measures of Accuracy

Within the federal accuracy standards, two distinct measures of accuracy will be defined. The Maritime accuracy standards will utilize the same definitions for expressing the accuracy of coordinates and other associated values. These measures are described in the Accuracy Standards for Positioning, Version 1.0 (Geodetic Survey Division, 1996):

- ***Network Accuracy*** is the accuracy of a geodetic quantity for a point at the 95% confidence level with respect to the defined reference system. It is an expression of relative accuracy of the position of a point with respect to the Canadian Active Control System and Canadian Base Network points. This is achieved by assuming that for most practical purposes the points in the CACS and CBN are an error-free realization of the defined reference system. Their accuracies are one to two orders of magnitude better than the coordinates for points in most other satellite and conventional surveys. Network accuracy can be computed for any positioning project that is connected to the CSRS.

- ***Local Accuracy*** is the generalized accuracy of a geodetic quantity for a point with respect to other directly connected points at the 95% confidence level. It is computed using an approximate average of the line accuracies between the point in question and other points directly connected to it.

Two of the statistics which may be used in expressing the horizontal accuracy of a point are the confidence ellipse and the confidence circle. Both of these statistics will be utilized in the accuracy standards proposed by the federal government.

A statistic commonly used in expressing the vertical accuracy of a point, and which will be utilized in the accuracy standards proposed by the federal government is the confidence interval. In the case of GPS work, the interval can be produced by projecting the three dimensional confidence ellipsoid onto the vertical plane. This projection is an ellipse from which the interval can be derived.

Both the network and the local accuracy of a point can be represented using confidence ellipses. The network accuracy for a CSRS point, i.e., the accuracy with respect to the defined reference system, can be expressed as a point confidence ellipse. The line accuracy for a point can be expressed as the relative confidence ellipse for that point with respect to another directly connected point. Local accuracy can be expressed by a confidence ellipse which represents the average of the line accuracies computed for a point.

From the provincial perspective, the forty-four points of the Maritime High Precision Network, as established in 1994, comprise the realization of the defined reference system within the Maritime region. For practical purposes the coordinates of these points will be considered errorless, however a measure of the network accuracy of the points with respect to the Fundamental Level of the CSRS will be included as part of the information about a point's position. Local accuracies can also be derived for each of these forty-four points.

It is intended to build databases in support of the NBHPN, NSHPN, and PEIHPN which will contain, among other things, positional information and the associated measures of accuracy as described above.

3.2 Applicability to Geodetic Quantities

The accuracy standards proposed may be applied to the following geodetic quantities:

1. Horizontal coordinates (latitude and longitude);

2. Vertical heights and geoid information, including:
   a) orthometric heights;
   b) ellipsoidal heights;
   c) geoid heights (i.e., geoid-ellipsoid separations).

For the present version of this document, only horizontal positions and ellipsoidal heights as generated through GPS surveys will be considered. Future updates to the 'Guidelines' may be expanded to address all the components listed above.

For a discussion on the determination of orthometric heights using GPS the reader is referred to the GPS Positioning Guide produced by the Geodetic Survey Division (Geodetic Survey Division, 1994), and Milbert (1992).

3.3 Horizontal Accuracies

As mentioned, two of the statistics which may be used in expressing the horizontal accuracy of a point are the confidence ellipse and the confidence circle. In the accuracy standards proposed by the federal government, both the 95% confidence ellipse and the 95 % confidence circle will be utilized. Although the regions bounded by a confidence circle and a confidence ellipse are of different shapes, in both cases there is a 95% probability that the true position of the point lies somewhere within the defined confidence region.

The 95% confidence ellipse is described by the following parameters:

$$a, b, z$$

where:

a = the length of the semi-major axis;
b = the length of the semi-minor axis;
z = the azimuth of the semi-major axis.

The 95% confidence circle can be computed from the *a* and *b* parameters of the confidence ellipse.

Details on both the confidence ellipse and the confidence circle can be found in the federal document 'Accuracy Standards for Positioning, Version 1.0'.

It is recommended that both confidence circle and confidence ellipse values be maintained in the NBHPN, NSHPN, and PEIHPN databases.

3.4 Vertical Accuracies of Ellipsoidal Heights

The statistic used to express the accuracy of the ellipsoidal height of a point will be the 95% confidence interval, which can be represented graphically by a vertical straight line. In the case of GPS work, the interval can be produced by projecting the three dimensional confidence ellipsoid onto the vertical plane, and deriving the interval from the resultant ellipse.

Details on the confidence interval can be found in the document 'Accuracy Standards for Positioning, Version 1.0' (Geodetic Survey, 1996).

3.5 Classification Standards

For points in the Maritime high precision networks, it will be required that the network and local accuracies be computed and placed in the NBHPN, NSHPN, and PEIHPN databases. In addition, the network and local accuracies should be classified according to the federal 'Accuracy Standards for Positioning, Version 1.0'.

The concept of 'classification' differs from earlier concepts of 'orders' of surveying, since the order of a survey was primarily a function of the procedures and equipment used. Generally, all of the points within one survey would be assigned the same order. Classification based on an analysis of the variance-covariance information for a survey is independent of methodology and equipment, however, and thus is equally appropriate for any type of survey.

The proposed classes are referred to as 'self-labelling'. The classes apply all of the geodetic quantities indicated in **Section 3.2**, but for the present , this document will cover only horizontal and ellipsoidal height components.

In the case of horizontal accuracies, the semi-major axis of the 95% confidence ellipse will be used to classify the point. In the case of ellipsoidal height, a value equal to one half of the 95% confidence interval is used to class the point. The same approach would eventually be used for orthometric heights and for geoid heights.

In the present federal draft on accuracy standards there are fourteen classes, ranging from 1 centimetre to 200 metres. For the Maritimes it is proposed to use seven classes, ranging from 5 millimetres to 5 decimetres. Should the provinces later wish to introduce the classification scheme widely (i.e., using it for all existing control, and for spatial referencing in general), it would be necessary to expand the classification scheme. For the present, however, the Maritime classification standards will be as found in Table 1 below.

TABLE 1: SELF-LABELLING ACCURACY CLASSES AND THEIR DEFINING CLASS RANGES AT THE 95% CONFIDENCE LEVEL
(based on table presented in Geodetic Survey Division 1996)

CLASSIFICATION STANDARDS	
Accuracy Class	**Class Range**
5 millimetre	Less than 0.005 metre
1 centimetre	0.005 - 0.010 metre
2 centimetre	0.010 - 0.020 metre
5 centimetre	0.020 - 0.050 metre
1 decimetre	0.050 - 0.100 metre
2 decimetre	0.100 - 0.200 metre
5 decimetre	0.200 - 0.500 metre

3.6 Accuracies for Densification Points in the NBHPN, NSHPN and PEIHPN

The confidence ellipses used to classify a point shall be derived from a least squares adjustment procedure used to estimate the final coordinates of that point.

4.0 OBSERVATION PROCEDURES

This section will be divided into two sub-sections. The first sub-section describes the observation procedures which should be utilized in the densification of the NBHPN, the NSHPN, and the PEIHPN.

The second sub-section describes the observation procedures which should be utilized in positioning of discrete points in such a way as to make them consistent with the rest of the network.

4.1 Densification of the Maritime High Precision Network

Relative GPS positioning using static techniques was used to establish the forty-four points in the Maritime High Precision Network in 1994. For further densification of the high precision networks within the three Maritime provinces, the GPS methodologies considered will generally include only relative positioning using static techniques.

This section will cover site selection, control points, GPS equipment, and general field procedures for NBHPN, NSHPN, and PEIHPN densification projects. All of these densification projects may be considered densification of the Maritime High Precision Network.

4.1.1 Site Selection

The site selection criteria for densification points for the NBHPN, NSHPN, and PEIHPN were developed prior to the 1995 densification effort, and are re-iterated in this section.
The major concerns in selecting suitable points for densification are the following:

1. Technical suitability for GPS;
2. Long term stability of the point;
3. Reasonable ease of accessibility to the point;
4. Appropriate spacing of points and use of existing sites.

The criteria for site selection describe the 'ideal' GPS station. Although no specifications can completely guarantee the quality of data from a station, a thorough examination of the proposed sites can eliminate obvious sources of GPS signal blockage or interference.

There will be cases where no suitable existing monumentation will be available. In these cases, a new monument should be set.

SPACING AND USE OF EXISTING SITES

Spacing	Spacing of the densification stations will vary somewhat from province to province, but in general will be from twenty to forty kilometres. Spacing will vary according to geography, road networks, and population centres. If possible, stations should be located near communities.
Existing sites	Existing ATS77 stations are to be chosen whenever possible. The occupation of these existing stations with GPS will produce the required information for the development of transformation parameters between the old control system and the new GPS based system. Note that control established by agencies such as the Geodetic Survey of Canada and the Canadian Hydrographic Service is also acceptable, if it has been tied into the existing ATS77 framework.

STABILITY AND LONGEVITY

Monumentation types	A mixture of monumentation will be used for the densification effort. In order of preference, monumentation will consist of forced centering concrete pillars, rock plugs, and provincial standard poured concrete monuments. Other stable monument types, such as federal bench marks, may also be considered.

Pillars from provincial GPS validation networks should also be included as densification points. (The points in these networks will serve a double function. In their capacity as validation network points, the interpier baseline vectors as computed prior to any integration will be the product of interest. In their capacity as densification points of the NBHPN and NSHPN, the adjusted coordinates coming out of the integration process will be the product of interest.)

Any EDM calibration baselines in the area should be examined for GPS suitability. Before using a baseline pillar, the baseline history should be reviewed to check pillar stability.

After pillars, rock plugs in solid rock should be the preferred choice for monumentation. Avoid plugs set in fractured or shale type rock.

Should a suitable rock plug not be available, standard poured monuments will be used.

Stability/
Longevity

In all cases, choose sites for long term stability. Do not, for example, choose points in marshy areas. Avoid monuments close to the edge of road banks, or in areas subject to erosion.

If any clearing of trees or brush is required around existing sites, permission will have to be obtained from the landowners or controlling agencies. Some sites may require periodic clearing.

Avoid areas where development activities seem imminent. Such activities may disturb or destroy the monument, or in the case of building or other structure construction, cause blockage of the GPS signals.

It is recommended that, once a site is established, it should be posted with a sign describing it as a provincial GPS station, and referring inquiries about it to the provincial agency in charge. (Signs posted at a sight should be at a height lower than a typical GPS antenna setup.)

EASE OF ACCESSIBILITY

Ease of use

Stations should be accessible to users. It is expected that this should be the case with most existing ATS77 sites.

Sites where the user can move their vehicle completely off the travelled roadway are desirable.

Avoid points where tripod setup may be difficult.

TECHNICAL SUITABILITY

Obstructions

Ample sky visibility is critical for GPS operations. Therefore, at all densification sites, there should be no obstructions over a 15 degree elevation above the horizon. (The forty-four sites of the Maritime High Precision Network were designed for visibility at 10 degrees above the horizon. The provinces should strive to maintain these sites at that level.)

If there are obstructions, the effect of those obstructions on satellite visibility and PDOP should be examined via one of the common mission planning software packages which are available. Personnel evaluating the site must then make a decision on whether the impact of the obstructions on the observations is acceptable. It should be noted that, at Maritime latitudes, there is a section of the northern sky which is not covered by the orbiting GPS satellites. This 'blank spot' in the northern sky does allow the acceptance of some obstructions in that direction. (Before accepting a site with **any** obstruction, evaluate the obstruction for multipath and/or attenuation effects!)

Signal interference and multipath

As much as possible, densification sites should be free from multipath and electromagnetic interference. To this end:

Avoid locating near high voltage transmission lines. Points should be located at least 100 metres away from these types of lines.

Avoid locating directly underneath any type of power lines. Points should be located across the roads from power lines, if possible, such that the power lines are cleared at 15 degrees. If they cannot be cleared at 15 degrees, clearance at 20 or 25 degrees is probably acceptable with approval from the project officer.

Avoid stations with direct line of sight to a microwave tower. These signals are directional in nature, and possibly intermittent, so it is not always possible to tell if they are going to interfere with GPS signal reception or not. If a site is very close to a microwave tower, it may have to be tested ahead of time for signal interference.

Avoid locating near possible reflective surfaces such as large bodies of water, chain link fences, metal buildings or other metallic structures, asphalt parking lots, large signs, or parked vehicles, as these are all potential sources of multipath. (Moving vehicles may also be a source of multipath if they are close to the station).

Use points at an elevation higher than neighbouring roadways if possible. Being at the same elevation or lower could lead to reflection of signal from the roadway surface, and interference from passing traffic.

Some airport navigational aids can be problematic for high accuracy GPS applications. Therefore points in close proximity to these aids (within 1 or 2 kilometres) may have to be tested ahead of time for possible interference.

Along the coastline, sites which are near radio transmitters or other navigational beacons should be tested ahead of time for possible interference.

If there are areas where provincial control is non-existent, or simply not suitable for GPS, a new point should be set.

Once the selected points are more or less finalized, an obstruction diagram for the selected stations should be prepared. An updated description and station sketch will also be required, including a 'drive to' description.

4.1.2 Control Points for A Densification Project

For the densification efforts, the Maritime High Precision Network points established in 1994 will be used as control. A minimum of four of these points surrounding the project area should be used. In the case of a large project area, all Maritime High Precision Network points within the project area must be tied into, and all Maritime High Precision Network points at the bounds of the project area must be tied into.

Stability check on existing Maritime High Precision Network points

An effort should be made to verify the stability of any existing Maritime High Precision Network points which are to be used in a densification project. Therefore, one part of the survey project should be to observe a series of direct ties between existing Maritime High Precision Network points. If possible, a simultaneous observation session on all of the Maritime High Precision Network points throughout and/or surrounding the project area would be desirable. If numbers of receivers or logistics do not allow for a separate stability check, then sufficient direct ties between these points must be made during the course of normal observations in order to achieve the same result. That is, sufficient ties must be made, so that a sub-network of only Maritime High Precision Network points can be derived from the observations.

If significant movement of a point can be detected, the provincial agencies may wish to consider reestablishing the position of the suspect point with respect to the CBN and CACS.

4.1.3 Observation Sessions

In planning observation sessions for densification of the Maritime High Precision Network, there are a number of procedures which should be adhered to. Experience has shown that these procedures should include those listed below.

1) Simultaneous observation sessions of five and one half hours should be used in positioning points for densification.

2) An observation interval of 15 seconds is recommended. Depending on equipment being used, this may be varied to 10 or 20 seconds.

3) Each station should be occupied for a minimum of two observation sessions. Observation sessions should be scheduled for different times of the day to allow for varying satellite geometry and changing atmospheric conditions.

4) Receivers/operators should be switched at each station, so that no station is occupied only by one receiver/operator. In the case where this condition is impossible to achieve, the reasons should be noted in the observation notes. As well, if the same receiver/antenna setup must remain at a station for two consecutive sessions, the antenna setup must be dismantled and set up again, and the H.I. remeasured.

5) Adjacent stations within the network should have direct ties (i.e., occupied within the same observation session).

6) Each new station shall have direct ties (i.e., occupied within the same observation session) to at least two existing Maritime High Precision Network points.

7) At least one common baseline must be included between sessions.

4.1.4 GPS Equipment

Geodetic quality dual frequency P-code receivers should be used; under conditions of anti-spoofing, receivers must still be capable of collecting L1 and L2 code observations and full wavelength carrier phase observations on both L1 and L2. All L1 and L2 observations must be collected and recorded. Receivers should be capable of tracking a minimum of eight satellites simultaneously.

Any GPS equipment to be used must be approved by the project officer. The project officer shall use any of the following means for determining whether GPS receiver/antenna equipment will satisfy project requirements:

1) Validation of the equipment on a provincial GPS validation network, under situations and baseline lengths which will adequately simulate the survey work proposed to be done; or,

2) Prior use of the equipment in the same type of survey, within the province, and with proven acceptable results; or,

3) At the project officer's discretion, acceptance of equipment may be made after consultation with other government agencies using that equipment for the same applications.

For control surveys, the same receiver/antenna model **must** be used at all stations. This is to avoid any biases between receiver/antenna types, which could adversely affect the results.

All GPS equipment used in a survey should be itemized in the station log notes for an observation session. This includes:

- the receiver model and serial number;
- firmware version;
- the antenna model and serial number;
- the L1 and L2 phase centre offsets of the antenna;
- the antenna radius, including ground plate if used;
- any other details which may affect later data processing and analysis.

4.1.5 General Field Procedures

The following is not a comprehensive field manual. All field personnel should be instructed in appropriate field procedures by the project officer in charge of the survey campaign.

Centering of Antenna Over Survey Mark

Most GPS densification stations will be ground marks requiring a tripod setup. Precise centering of the antenna over the mark is critical. Therefore it is required that the optical plummets of all tribrachs be properly adjusted prior to conducting any GPS field operations. Tribrachs should be checked, and adjusted if necessary, not only prior to a project, but every few days during the execution of a project. They should also be checked and adjusted if they are dropped or jarred in any way during the project.

Checking the centering with a plumb bob is recommended whenever possible.

Levelling of Antenna and Orienting Towards North

Levelling of the antenna is essential both when using a tripod, and on forced centering pillars. Some tribrach adaptors have built in striding levels for accurate levelling of the tribrach. Should these types of adaptors not be available, it is recommended that the operator use a standard target with striding level to perform levelling of the tribrach. Once the tribrach has been levelled, the target can be carefully removed and the adaptor and antenna placed on the tribrach. It is important not to disturb the tribrach when doing this.

All antennae in an observation session should be oriented in the same direction, in order that biases in the location of the antenna phase centre cancel out across stations. (Refer to the requirement in **Section 4.1.4 (GPS equipment)** for all receiver/antenna models to be the same for a survey campaign.) The convention for orienting the antennae shall be to magnetic north, determined either from a compass which is incorporated into the antenna, or determined using a pocket compass and a reference mark on the antenna. (In the case of surveys over large areas (national or global), true north should be used. However, in the case of more local surveys, where the magnetic declination doesn't vary beyond the accuracy with which one could reasonably point, orienting all antennae to magnetic north will suffice.) Pay particular attention in not having the compass too close to a pillar, as any re-bar in the pillar, unless it is non-magnetic, may cause erroneous readings.

Measurement of Height of Antenna

Antenna heights should be recorded to the nearest millimetre.

The height of the antenna should be measured by using the height rods or height hooks provided by the receiver manufacturer. The height of the antenna should be measured once at the beginning of the session and once at the end of the session.

To measure the H.I. using the height rods, the rod should carefully be placed at the centre of the mark being measured to, and read at the antenna ground plate as instructed by the manufacturer. This measurement is referred to as a slant height. In determining the height of the antenna, three separate slant heights should be measured from the mark to the antenna ground plate, at points 120 degrees apart (the same three points should be used for the beginning measurement and the end measurement). All three measurements should be recorded in the field notes, and it is recommended that the observer take note of the location on the ground plate of the three measurements. The beginning and end measurements should be taken at the same locations.

The observer must record the known offset from the antenna ground plate to the L1 phase centre of the antenna, and the offset between the L1 and L2 phase centres. This information is usually available from the antenna manufacturer. In addition, the project officer responsible for processing the data should verify the L1 and L2 offsets, if possible, by contacting one of several independent agencies who maintain antenna information, for instance, the International GPS Service for Geodynamics (IGS).

For data processing, true vertical height from the mark to the L1 phase centre should be used. The conversion from slant height to true vertical height can take place in the field by providing observers with appropriate conversion tables for the antenna they are using, or during the data processing stage. Which method is used depends on the receiver/antenna being used, and the software being used.

To measure the H.I. using a height hook, simply extend the tape from the hook down to the mark, being careful not to extend the tape too much. The reading is carefully noted at the appropriate reference mark on the height hook. Some manufacturers provide tapes with both metric and imperial measurements on them. If this is the case, both the metric and imperial measurement should be recorded; the two measurements will serve as a check on each other.

As with slant heights, the observer must record the known offset from the height hook reference point to the L1 phase centre of the antenna, and the offset between the L1 and L2 phase centres. These will have to be applied to the measurement above to get the true H.I.

The methodology for measuring H.I. should be noted, and record made of the measurements and offsets used to compute the final H.I. The final H.I. shall be the vertical H.I. from the mark to the L1 phase centre of the antenna. In the RINEX 2 file, the H.I. recorded shall be final vertical H.I. from the mark to the L1 phase centre of the antenna. A comment should also be inserted in the RINEX header to indicate that the H.I. has been to the L1 phase centre.

Note that this represents a departure from the present RINEX format, which assumes that the H.I. is with respect to an antenna reference point (ARP), normally the bottom of the antenna housing.

Meteorological Observations

At the present time, research on how to best use actual collected meteorological data is still ongoing. To date, most GPS data reduction procedures do not make use of actual met data.

It is therefore not necessary for the observers to record detailed meteorological observations at regular intervals during the data collection process. However, as with most surveying work, the operator should note general weather conditions, including dry temperature, in his or her notes. Dry temperature should be recorded at the start and end of a session and at least once hourly during the session. Over long observation sessions, the observer should record any significant changes which occur in the weather, particularly if any electrical storms are observed in the area.

Temperatures, relative humidity values, and barometric pressures should also be obtained from weather offices in the region of the survey. These may be useful in developing regional atmospheric models during data processing, and should be stored with the station log notes for future reference in processing the data.

Geomagnetic Activity

Geomagnetic activity forecasts and reports are available from several sources. In planning a GPS survey, the project officer should make himself/herself aware of forecasted geomagnetic activity for the survey time period. Details of any significant geomagnetic activity should be filed with the survey processing returns.

Sources of information on geomagnetic activity include the Canadian Space Geodesy Forum (CANSPACE) on the Internet, and the Geophysics Division of Natural Resources Canada.

Other Procedures

Other procedures which should be adhered to in performing field operations include the following:

- do not use cellular phones or radio transmitters within 50 metres of the receiver/antenna setup;
- do not park the survey vehicle within 50 metres of the antenna setup, unless it is out of line of sight of the antenna;
- avoid unnecessary movement around the antenna once tracking has begun.

4.2 <u>Positioning of Discrete Points</u>

Once the NBHPN, NSHPN and PEIHPN densification efforts have been completed, there may occasionally be situations where the positioning of discrete points will be required, that is, points which are established separately from the densification effort. Such cases may include:

1) Replacement of a destroyed point in the NBHPN, NSHPN, or PEIHPN.

2) Positioning a point for inclusion in the NBHPN, NSHPN, or PEIHPN at a user's request, for the following reasons:

    a) User wishes to establish a point at their normal place of operations which will be frequently or continuously used for their own GPS operations.

    b) User wishes to set up an active control point for commercial GPS operations.

The guidelines developed for the positioning of discrete points are restricted to the technical aspects of tying in such points, and do not address policy issues.

4.2.1 Site Selection and Monumentation Criteria

Sites shall meet the criteria as described for the selection of NBHPN, NSHPN, and PEIHPN densification points. Each province shall assign a new point a provincial number upon accepting it into the NBHPN, NSHPN, or PEIHPN.

Monuments shall be, in order of preference:

1) concrete pillars constructed to specifications approved by the provincial agency responsible for the high precision network;

2) a rock plug in solid bedrock; or,

3) a poured concrete monument with tablet, constructed to specifications meeting or exceeding the specifications used in constructing provincial standard poured monuments.

Installation of these monuments shall be in stable ground settings or in bedrock.

Should the agency or individual requesting the point wish to use monumentation other than these three types, the onus is on the agency or individual to prove the stability of the intended monument prior to the point being accepted into the NBHPN, NSHPN, or PEIHPN.

4.2.2 Methodology for Positioning Discrete Points

In the positioning of discrete points, the following guidelines shall apply:

1) The new point shall be positioned with respect to at least three adjacent points which are existing NBHPN, NSHPN, or PEIHPN points (i.e., there shall be **directly measured** baselines from the new point to at least three other points). If possible, these control points should be distributed **around** the new point; it is not desirable, for instance, to tie in to three control points grouped together to one side of the new point.

2) Each point involved in the survey shall be occupied for a minimum of two occupations.

3) Each point involved in the survey shall have a minimum of three baselines measured into it (from three different stations).

4) In order to confirm the stability of the existing NBHPN, NSHPN, or PEIHPN points, direct ties shall be made between all pairs of existing stations (e.g., in tying a new point into three existing control stations, there shall be direct ties between all three control stations).

5) Minimum observation times and observation intervals shall be as described for the NBHPN, NSHPN, and PEIHPN densification efforts. Observation sessions should be scheduled for different times of the day to allow for varying satellite geometry and changing atmospheric conditions.

6) Equipment to be used shall be as described for the NBHPN, NSHPN, and PEIHPN densification efforts.

7) Subsequent occupations of a station shall be independent of each other. This independence will be achieved by swapping equipment and operators from station to station between sessions. In the case where this condition is impossible to achieve, the reasons should be noted in the observation notes. As well, if the same receiver/antenna setup must remain at a station for two consecutive sessions, the antenna setup must be dismantled and set up again, and the H.I. remeasured.

8) Meteorological information recorded shall be as described for the NBHPN, NSHPN, and PEIHPN densification efforts.

9) Other general procedures will be as for the NBHPN, NSHPN, and PEIHPN densification efforts.

5.0 GPS DATA PROCESSING AND ADJUSTMENTS

Data processing can be broken down into four phases:

1. Quality control of the data immediately after its collection.
2. Reduction of the data into a series of coordinate differences.
3. Minimum constraint adjustment.
4. Fixed or constrained adjustment.

At all stages of the data processing, the data processor should keep brief, but clear, notes on the computations and data organization.

5.1 Data Processing Notes

The data processor for the project should prepare a brief precis of the data processing. This is best done on a session by session basis. The information to be included in the session processing summary should include, but not be limited to:

- the project name and number;
- the processor's name and the processing date(s);
- details about the software and version used in the processing;
- the date, day of year, and session identifier for the observations;
- the length of the session (i.e., start and end times);
- a list of all stations included in the session and in the processing (if a station is dropped from the processing, the reasons for doing so should be noted);
- the receiver and antenna models used at each station;
- baseline configuration used in the data processing (a sketch is useful);
- approximate lengths (in km) of configured baselines;

- coordinates (including the datum) and source of coordinates for the fixed station;
- the type of solutions run (and the order in which they were run);
- significant quality indicators from each solution (see **Section 5.3.5**)
- any comments on unusual circumstances or procedures.

When citing start and end times, or other events in the observation sessions, the data processor should use GPS time.

5.2 Quality Control of Data

Normal quality control procedures should include an examination of the field data as soon as possible after data collection. Although every effort should be made to process the GPS data as soon as possible following the data collection, this is not always possible; therefore, the purpose of such an examination is to verify that 'processable' data has been collected and downloaded.

As a minimum, the data processor must be satisfied that the correct observations have been collected (L1 and L2 code and phase data) over the correct period of time and at the correct data observation interval. The data processor should also review all field notes for completeness and correctness. This review should confirm that the observer was at the correct station, that the observer entered the H.I. correctly, and that nothing out of the ordinary took place during the observation session.

Additionally, it is desirable that the data processor examine the single station data for excessive numbers of slips or other indications of poor data quality which may impact negatively on the quality of results. Several software programs exist which can quickly scan the single station data and provide this information.

5.3 GPS Data Reduction

The Bernese GPS Software is presently the software to be used for GPS data processing in support of the NBHPN, NSHPN, and PEIHPN. As with most GPS processing software, the Bernese GPS Software utilizes a 'double differencing' approach to reduce the collected GPS observations to a series of coordinate differences and associated error information.

Within the Bernese GPS Software, the option exists to process the data in a baseline by baseline mode, in a session mode, or even in a multi-session mode. Session processing is the preferred manner of GPS data reduction for NBHPN, NSHPN and PEIHPN densification projects.

5.3.1 Ephemerides and Datum Issues

Precise ephemerides are to be used in all final processing for the high precision control networks.

The datum in which final coordinates are to be produced is the NAD83(CSRS95) datum.

In light of these two requirements, there are several issues which should be addressed.
The ephemerides broadcast by the GPS satellites are presently in the WGS84(G730) system, and, as previously discussed, this upgrade to the WGS84 system makes the coordinate reference system of WGS84 very close to that of the ITRF. Computations of precise ephemerides are also generally with respect to the ITRF. Although the NAD83 coordinate reference system is close to that of WGS84 and the ITRF, they are not completely coincident, and this has implications for precise positioning with GPS.

In practical terms, the differences in absolute coordinates between the ITRF system and the NAD83 system would be somewhere in the vicinity of one to two metres. By utilizing NAD83(CSRS95) coordinates for fixed control points, and at the same time utilizing ITRF based precise ephemerides, very small scale and rotation effects can be introduced into a network.

This situation can be dealt with in one of three ways:

1) Transform the precise ephemerides to the NAD83 datum.

2) Use ITRF values for the fixed control; perform all data reductions and adjustment in the ITRF system; and transform final coordinate results back to NAD83.

3) Assess and absorb the slight loss of accuracy which is introduced by mixing the two systems.

For most typical surveying applications, the third option is probably the most practical. In fact, it is fair to say that the loss of accuracy is probably far below that which would be detectable for most GPS work. However, for maintenance of a high precision GPS network, such as that being established in the Maritimes, one of the first two options is preferable.

It is presently the policy of the Geodetic Survey Division to support the NAD83 datum, and to supply coordinates for all CSRS points in NAD83 (Geodetic Survey Division, 1995). It is expected that NAD83 support will include the transformation of precise ephemerides to the NAD83 datum and, at time of writing, the Geodetic Survey Division are investigating this option. When NAD83 ephemerides become available, the best and easiest option for the Maritime Provinces will be to utilize those ephemerides in GPS data processing. Thus option (1) is the recommended course of action.

Option (2) is currently the option used by the Geodetic Survey Division in its GPS data processing and adjustments. This option should be considered until such time as precise ephemerides become available in the NAD83 system.

5.3.2 Starting Coordinates for GPS Data Reduction

In all cases, starting coordinates for densification shall be the best NAD83(CSRS95) coordinates available at an already established control station (see previous section on NAD83 versus ITRF coordinates). The general procedure in GPS data processing is to hold one station fixed, and propagate the coordinates of that station through the processing sessions.

In all densification efforts, ties will be made to the forty-four points of the Maritime High Precision Network; these points should be used as fixed stations for GPS data reduction. In choosing a starting point, the data processor may want to consider differences in accuracy at various stations, although it is expected that all forty-four points will have very well determined coordinates.

5.3.3 Ambiguity Resolution

The resolution of carrier phase ambiguities is very important for high accuracy work. The Bernese software offers very powerful ambiguity resolution strategies, and these should be utilized by the data processor in order to correctly resolve as many ambiguities as possible.

5.3.4 Other Information for Processing

Other information which will aid in the processing of GPS data may include NANUs (Notice Advisories to Navstar Users) which are available from several sources, information on geomagnetic/ionospheric activity, and meteorological information from weather offices in the area of the survey. This information should be gathered during the field operations or as soon as possible afterwards.

5.3.5 Examination of Results From the GPS Data Reduction

Prior to entering the adjustment stage of data processing, the data reduction results should be examined for each session. A summary of the significant indicators of quality should be prepared. These may include, but are not limited to:

- the RMS of each solution;
- the number or percentage of ambiguities resolved in the session;

- number of cycle slips detected and repaired;
- number of observations rejected, preferably expressed as a percentage of the total available observations;

The sigma value for each baseline component should be noted, but need only be recorded if it is unusually large for the type of solution.

5.4 Comparison of Repeated Baselines

After processing each session, a comparison of any repeated baselines should be made. Repeated baselines are baselines which have had **independent** determinations, i.e., have been observed in different observation sessions (or in different survey campaigns). These comparisons are based on the results of the session processing, prior to the network adjustment.

This will give an indication of the precision of the GPS measurements. Both the length component (delta s) and the three dimensional components (delta x, delta y, and delta z) should be examined. It is necessary to compare all three dimensions, as a consideration of only baseline lengths will give no indication of changes in orientation.

5.5 Minimum Constraint Least Squares Adjustment

A minimum constraint least squares adjustment should be performed to test the internal consistency of the GPS survey. It is required to perform this step prior to attempting to integrate the results of the survey into any existing control.

For the minimum constraint adjustment, only one point is held fixed. In the case of CBN densification projects, the point which is fixed should normally be one of the original CBN points established in 1994. It is important that the reference system of the fixed coordinates and the reference system in which the computations take place be the same.

Upon completion of the minimum constraint adjustment, the data processor will examine the output for indications of poor quality baselines. The processor should isolate any questionable baselines and decide whether re-processing of the session containing the baseline is in order. Occasionally it may be required to drop a station from a session. The session should then be re-processed without the questionable station, and the new session results introduced into the adjustment. Dropping a station from a session should only be considered when there is ample remaining redundancy to reliably determine its position. If this is not the case, re-observations may be required at that station.

5.6 Constrained Adjustment

A constrained adjustment will be used integrate new points into the Maritime High Precision Network. Final coordinates and associated accuracy information will be produced during this procedure. As with the minimum constraint adjustment, the data processor should ensure that the coordinates for the constrained station(s) are in the same reference system in which the computations will be performed.

5.7 Data Returns for a Project

Data returns shall consist of the following:

1) A project report, covering both the field operations and the data processing and analysis operations.

   The report should detail equipment and procedures used, personnel involved, observation times (start and end), and occupation charts indicating location of receivers for each observation session.

2) All observer notes and station log forms.

3) A sketch or sketches showing all baselines observed. Any baselines observed but not included in the adjustment should be indicated. Reasons for not including, these baselines in the adjustment should be provided.

4) Adjustment input and output files in digital ASCII format. A hardcopy listing of the final adjustment should also be included. This listing should include the adjusted coordinates and the relative error ellipses for the network.

5) A table of comparisons of repeated baselines (prior to adjustment) within the project.

6) A listing of all data files collected (raw and RINEX), referenced to the day, session, and station for which they were generated. In organizing the data files, grouping should be by session.

7) Digital observation files as follows:
   - 2 copies of the raw data (receiver format)
   - 1 copy of RINEX 2 formatted data

   These should be stored as discussed in **Section 6 (DATA STORAGE)**.

8) A record of the software which was used in all aspects of data handling (downloading, RINEX conversion, data reduction, adjustments, etc.). The record should include the software program name, version, and source.

6.0 DATA STORAGE

The amount of data and information collected and generated during the course of a GPS project can be quite great. This data can be grouped into the field data, the files and notes generated during processing, and the final outputs.

6.1 Field Data

The field data includes the following:

- digital GPS observation files;
- field notes (station log forms, obstruction diagrams, etc.);
- index maps;
- report on field operations, if available.

The field data may also include station descriptions and sketches if these were not available ahead of time, or if updates to existing descriptions and sketches were required.

Original field notes should be retained as per the provincial agency's policy on surveying field books and notes, as should the index map and report on field operations.

GPS data collected during the establishment of the NBHPN, NSHPN, and PEIHPN should be organized in an easily accessible manner and retained by the provinces. The files which should be retained include but are not limited to the following: GPS raw data files (receiver format); RINEX formatted files, and files containing precise ephemerides.

The reasons for retaining this data are:

1) the data comprises the original survey observations;

2) to aid in the resolution of any errors found in the network in the future;

3) to cover the possibility of re-processing the data at some point in the future, whether for research purposes, or to achieve improved accuracies.

Two copies of the raw data files should be retained, one on-site and one off-site. Optical disk storage should be used for at least one of those copies. Data which is stored on magnetic media should be retained in an appropriate environment for that media to prevent it from becoming unreadable.

It is recommended that the on-site copy be retained as per the agency's regular archiving processes. The life expectancy of the storage medium, particularly in the case of magnetic media, should be considered, and a process put in place to periodically copy the data to a new medium.

Once data processing has been completed, one copy of the RINEX files should be retained. Since the RINEX file can be regenerated from the raw data, it is not necessary to keep two copies of the file. It is recommended that the RINEX files be archived on optical disk.

Files of precise ephemerides which were used in the GPS data reduction should also be retained. One copy of the precise ephemerides file is sufficient, since it is also retained at the original source agency from which it was obtained.

Information about the stored data files will be kept in the NBHPN, NSHPN, or PEIHPN database. This information will include details about file names and contents, storage location, and access information. If possible, the program used in converting the raw data files to RINEX should be stored with the data files, along with details on options and settings used when the RINEX files were generated.

6.2 Files and Notes Generated During Processing

Once **final** results for a project have been obtained, the files generated during processing can be sorted through and many of them eliminated. The data processor must have kept, and must include as part of the final results, a reasonable precis of his/her procedure in arriving at the final results. Results are not considered final until both the GPS data reduction and all adjustment procedures have been completed with satisfactory results.

In general the only outputs that need to be retained for an observation session are the processor's notes, the final output listings from the GPS data reduction program (it is recommended to retain the final output listing from each solution until the processor is satisfied that the results are satisfactory), files affecting input options (e.g., earth orientation parameters, antenna offset values, etc.), the coordinates or coordinate differences obtained, and the associated variance-covariance information. Since most of the interim files and listings produced in the course of processing can be reproduced, there is little use in retaining them.

For the adjustment procedure, the input and output listings should be retained.

6.3 Final Outputs

The final outputs from a GPS project are generally the coordinate values for all points established during the project, and one or more measures of coordinate accuracy. These are to be stored in the NBHPN, NSHPN, or PEIHPN database.

7.0 USE OF VALIDATION NETWORKS

GPS validation networks have a number of uses which include:

1) Allowing provincial survey control agencies to validate new equipment or procedures.

2) Allowing contractors to prove their systems (equipment, procedures, data processing techniques), to satisfy their own needs or to satisfy specific contract requirements.

3) Allowing vendors to demonstrate the capabilities of their systems.

The use of validation networks is presently endorsed and promoted by the Geodetic Survey Division of Natural Resources Canada. However, at the federal level these networks are referred to as GPS basenets. The Maritime Provinces favour the term 'validation network' in order to distinguish these networks from the Canadian Base Network.

Several Canadian provinces have established networks within their jurisdictions. Within the Maritimes, two such networks will exist, one centered around the EDM baseline at Mactaquac near Fredericton, New Brunswick, and one centered around the EDM baseline near the Halifax airport in Nova Scotia.

7.1 Dual Function of Validation Networks in the Maritime Provinces

In addition to serving the functions above, the points in the regional validation networks will serve the dual role of CBN densification points. It is important to differentiate between these two roles.

In their capacity as densification points, the validation network points will be included in the regular densification adjustment procedures. Coordinate values and associated accuracies based on those adjustments will be computed, stored in the NBHPN, NSHPN, or PEIHPN database, and issued as published control values.

In their capacity as points in a validation network, the non-integrated values of the network will be utilized. That is, the coordinate and coordinate difference values will be based on a minimum constraint adjustment of **only** the validation network. These values will be retained by the provincial agencies assuming responsibility for the network, and will be issued to users on request.

7.2 Checks Against Known Control

To test an observation procedure on a validation network, the procedure should be carried out twice, under differing satellite geometry and, if possible, different atmospheric conditions.

In evaluating the results of a survey conducted on a validation network, the validation network is accepted as ground truth. This assumes, of course, that a minimum of two measurements have been made on the network, and that a comparison of the two epochs indicates a stable network.

The internal accuracy of the validation survey is generally assessed through an analysis of a minimum constraint adjustment holding one station fixed to its known coordinates. For the two validation networks in the Maritime Provinces, these will be the NAD83(CSRS95) coordinates. The external accuracy of a validation survey is generally assessed by comparing the results obtained in a survey with the 'ground truth' provided by the validation network.

Several non-rigorous steps may be used to evaluate a survey conducted on a validation network:

1) An examination of the achieved accuracies should be made to ensure that expected accuracies are met;

2) Direct comparison of coordinates. The simplest comparisons are to be made by utilizing Cartesian coordinates instead of ellipsoidal coordinates;

3) Transformation of the two sets of coordinates (e.g., via Helmert transformation);

4) Acceptance testing of the coordinates, which should be done using ellipsoidal coordinates so that the horizontal and vertical components can be separated out.

It is suggested that the acceptance test can be the same as that proposed in the federal Accuracy Standards for Positioning, Version 1.0 (Geodetic Survey, 1996) for checking the validity of surveys which utilize already established CSRS points. The acceptance test is appropriate, for instance, as a non-rigorous test of compatibility between coordinates produced from a minimum constraint adjustment produced in a validation exercise, and the known coordinate control values for the network. The method is described below, for horizontal coordinates and for ellipsoidal heights.

At each point, the shift in horizontal coordinates is tested against a 95% position tolerance. The 95% position tolerance should be derived using the 95% confidence circle, and computed as follows:

$$T_{95} = (n_{fix}^2 + n_p^2 + r_p^2)^{1/2}$$

where:

T_{95} = the position tolerance at 95%

n_{fix} = the published network accuracy of the fixed point, expressed as the radius of the 95% confidence circle

n_p = the published network accuracy of the free point, expressed as the radius of the 95% confidence circle

r_p = the radius of the computed 95% confidence circle for the free point relative to the fixed point, based on the minimum constraint adjustment.

It is expected that shifts in apparent position should not exceed this tolerance.

For ellipsoidal heights, at each point, the shift in ellipsoid height is tested against a 95% height tolerance. The 95% height tolerance should be derived using the 95% confidence interval, and computed as follows:

$$T_{95} = (n_{fix}^2 + n_p^2 + i_p^2)^{½}$$

where:

T_{95} = the height tolerance at 95%

n_{fix} = the published network accuracy of the fixed point, equal to one half of the 95% confidence interval

n_p = the published network accuracy of the free point, equal to one half of the 95% confidence interval

i_p = one half of the computed 95% confidence interval for the free point relative to the fixed point, based on the minimum constraint adjustment.

It is expected that shifts in apparent position should not exceed this tolerance.

A fairly in-depth discussion on the use of validation networks can be found in Craymer et al. (1990). There are also software packages which are specifically designed to aid in this type of analysis, and which offer a more rigorous approach to the analysis than the acceptance procedure outlined above. One example of such a package is NETVAL, a program written by Geodetic Research Services Limited (Geodetic Research Services Limited, 1990). The choice of rigorous versus non-rigorous testing for validation surveys will depend on the application for which the survey is intended.

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APPENDIX A

Procedures and Specifications Used in the Establishment of the Maritime High Precision Network

APPENDIX A

PROCEDURES AND SPECIFICATIONS USED IN THE ESTABLISHMENT OF THE MARITIME HIGH PRECISION NETWORK

The establishment of the Canadian Base Network (CBN) in the Maritimes was a joint federal-provincial project. The CBN is a sparse (nominally at a two hundred kilometre spacing in the southern latitudes of Canada) high precision GPS based network now being established across Canada in order to support the accuracies achievable with modern positioning techniques. This effort is being undertaken by the Geodetic Survey Division of Natural Resources Canada as one means of delivering the Canadian Spatial Reference System.

The provinces of New Brunswick, Nova Scotia, and Prince Edward Island entered into a joint project with the federal government to establish the Maritime portion of the CBN in conjunction with the establishment of a regional high precision GPS network: the Maritime High Precision Network. In October of 1994, twelve federal CBN stations and an additional thirty-two provincial stations were established across the Maritimes.

The Maritime High Precision Network includes both the federal and provincial stations.

A.1 Background

The Maritime High Precision Network, which includes the Maritime portion of the Canadian Base Network, is a network of forty-four points established cooperatively by the Geodetic Survey Division of Natural Resources Canada and the provinces of New Brunswick, Nova Scotia, and Prince Edward Island. These points were established with respect to the Canadian Active Control System (CACS). Data from three Canadian Active Control Points and one Continuously Operating Reference Station in the United States was utilized in the data processing.

The federal government established twelve CBN points throughout the region; the three Maritime provinces established an additional thirty-two points. The breakdown of points by province was as follows:

Maritime High Precision Network

	Federal CBN points	Provincial points
New Brunswick	**6**	**14**
Nova Scotia	**4**	**14**
Prince Edward Island	**2**	**4**

Average station spacing throughout the Maritimes was approximately 70 kilometres.

A.2 Accuracies for the CBN

Federal and provincial accuracy objectives for the CBN differed.

The objective of the Maritime Provinces was to establish a regional high precision network with an average relative (line) accuracy of 1 ppm for the network. This objective was actually exceeded, as the average 3-D ppm values, based on the 3-D error ellipses (at 95%) of 475 lines, from the minimum constraint adjustments was .252 ppm.

A.3 Equipment and Procedures

This section describes the GPS data collection procedures utilized in the establishment of the Maritime High Precision Network. Both federal and provincial collection standards for this campaign were extremely stringent, and designed to provide the utmost accuracy. With the exception of the type of receivers used and the length of observation sessions, the federal and provincial field procedures were almost identical.

GPS Equipment

Anti-spoofing (A/S) was active on the GPS satellites during this campaign. For the federal stations, the federal government used two types of receivers: Turbo Rogue dual frequency P code receivers with cross-correlation of P1 and P2, and ASHTECH Z-12 dual frequency P code receivers with P-W tracking. These receivers are capable of tracking full wavelength L2 observations even under A/S conditions.

Originally, the federal government intended to use Turbo Rogues on all CBN points, and to use the Z-12's for occupation of 'integration' stations, i.e, stations in the old first order framework. (These stations were to be observed in order to determine coordinate differences between the old framework points and the CBN. The integration stations did not form part of the CBN or the Maritime High Precision Network.) However, the Turbo-Rogues were found to be somewhat unreliable under typical field conditions, so the more rugged Z-12's were used on a number of the federal CBN points. Turbo-Rogue antennae were used at all federal CBN stations, even those utilizing the Z-12 receivers. Six receivers were used by the federal government for the CBN stations.

The three Maritime provinces used ASHTECH Z-12 dual frequency P code receivers with P-W tracking, and ASHTECH antennae with ground plates. Nine receivers were utilized by the Maritime Provinces. Therefore, a total of fifteen receivers could be tracking simultaneously during a single observation session. (This number does not include receivers on integration stations, or receivers being used by other agencies and individuals to tie into the high precision network as the campaign proceeded).

Observation Scenarios

Observation session lengths for the federal stations were twenty-four hours. With a few minor exceptions, each federal station was occupied for a minimum of three observation sessions.

Observation session lengths for the provincial stations were eight hours. Each station was occupied for a minimum of three observation sessions. An observation interval of fifteen seconds was used. Two eight hour provincial sessions were generally scheduled within one federal observation session.

Planning of the federal and provincial occupation schedules was done jointly. This ensured that provincial and federal crews worked in the same areas of the region in an observation pattern that attempted to maximize ties between federal and provincial stations, as well as federal-to-federal and provincial-to-provincial ties. The resulting data set could then be processed in such a way as to ensure a network which was completely consistent and homogenous.

From October 3, 1994 to October 13, 1994, fifteen provincial observation sessions took place.

Meteorological Observations

Meteorological observations were logged manually once per hour at provincial stations. Equipment to collect these observations was provided by the federal government. Battery operated psychrometers were used to record wet and dry temperatures to a tenth of a Celsius degree; hand held digital barometers were used to record air pressure in millibars and tenths of millibars.

Meteorological observations were logged automatically at the federal stations by automated environmental sensors.

Meteorological observations were, however, not utilized in the GPS data reduction.

Data Handling

Provincial observers performed their own downloading of GPS data and conversion of data files to RINEX 2 format. Data was moved back to the Nova Scotia Geomatics Centre (NSGC) as soon as possible for data validation. Observers retained one copy of the data and their original field notes until they were deposited in person with the NSGC.

All data was verified using the software programs GIMP and QC, backed up on several different sources, organized, and shipped to Ottawa for processing by the Geodetic Survey Division.

Data Processing and Adjustment

Data processing and adjustments on the collected GPS data were conducted by the Geodetic Survey Division.

APPENDIX B

Datum Parameters

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DATUM PARAMETERS

This Appendix contains some basic parameters defining the ellipsoids and coordinate reference systems of the North American Datum of 1983 (NAD83) and the World Geodetic System of 1983 (WGS84). For more detailed information on these geodetic datums, the reader is referred to publications such as Torge (1980), Schwarz (1989), the Defense Mapping Agency (1987), and others.

B.1 WGS84

The reference ellipsoid for WGS84, the WGS84 ellipsoid, is almost identical to the GRS80 ellipsoid used for NAD83. The geometric parameters for the WGS84 ellipsoid are as follows (Schwarz, 1989):

$a = 6\,378\,137$ m.
$b = 6\,356\,752.3142$ m.
$1/f = 298.257\,223\,563$

where: a = semi-major axis
b = semi-minor axis
f = flattening

For details on all of the parameters defining WGS84, the reader is referred to the Defense Mapping Agency (1987).

The difference between the GRS80 ellipsoid and the WGS84 ellipsoid arise from a difference in the method of obtaining the derived parameters (b and f above, in the case of the geometric parameters). Although these differences are insignificant for most practical purposes, it was decided to give the two ellipsoids different names.

The WGS84 ellipsoid orientation is such that its origin and axes are coincident with those of the Bureau Internationale de l'Heure Terrestrial System of 1984 (BTS-84). The BTS-84 system was realized by applying a shift in Z of 4.5 metres, a rotation around the Z-axis of -0.814 arc seconds, and a scale correction of -0.6 parts per million to the Doppler derived coordinates of the U.S. military's Naval Surface Warfare.

B.2 NAD83 parameters

The NAD83 datum is based upon the Geodetic Reference System of 1980 (GRS80) ellipsoid. That ellipsoid has the following geometric parameters (Schwarz, 1989):

a = 6 378 137 m.
b = 6 356 752.3141 m.
1/f = 298.257222101

where: a = semi-major axis
b = semi-minor axis
f = flattening

For the NAD83 datum, the GRS80 ellipsoid was defined as having its orientation coincident with that of BTS-84. The BTS-84 system was realized by applying a shift in Z of 4.5 metres, a rotation around the Z-axis of -0.814 arc seconds, and a scale correction of -0.6 parts per million to the Doppler derived coordinates of the U.S. military's Naval Surface Warfare Center 9Z-2 (Schwarz, 1989).

Thus the ellipsoid and coordinate reference systems of the WGS84 and NAD83 systems were defined, for most intents and purposes, almost identically.

B.3 NAD83: relationship to WGS84 and WGS84(G730)

The coordinate system of NAD83 was defined in such a way as to make it almost identical to that of WGS84, the reference system in which the Global Positioning System operates. As part of recent maintenance and upgrade operations to WGS84 (Malys and Slater, 1994), however, the WGS84 reference frame has been refined through an updating of coordinate values at a number of Defense Mapping Agency (DMA) tracking stations. These refinements have resulted in an operational WGS84 reference frame which is coincident with the ITRF92 at a level approaching 10 cm. (Malys and Slater, 1994).

This revision changes the coordinate reference system of WGS84 slightly from its original definition, and moves it closer to the ITRF coordinate reference system. The refined WGS84 reference frame is designated as WGS84 (G730).