Report to the Canadian Council On Geomatics (CCOG)

on the

Modernization of the Canadian Height Reference System

Prepared by

Canadian Geodetic Reference System Committee (CGRSC)

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INTRODUCTION

This report was prepared in response to a request from the Canadian Council on Geomatics (CCOG) at its fall annual meeting, for additional information concerning the Modernization of the Canadian Geodetic Vertical Datum (Resolution F03-01). This information would help in determining the level of support CCOG would provide for a Canada-wide stakeholder consultation, itself recognized as a prerequisite for building a comprehensive implementation strategy. More specifically, the adopted resolution demanded:

1) That the Canadian Geodetic Reference System Committee (CGRSC) review the state of the current primary vertical network and report to CCOG; and

2) That the CGRSC review and report to the CCOG on the roles and responsibilities, accountabilities with regard to the maintenance of the Vertical Reference Frame and its current access through the Primary Vertical Networks; and

3) That Council receive a report from the CGRSC before the end of 2003 to review a consultation plan (issues, questions and approaches) on the future maintenance of the primary vertical networks, the evolution to the new Vertical Reference Frame and the identification of financial or equivalent resources to carry out the consultation plan, whereby Council will decide next steps.

EXECUTIVE SUMMARY

Precise positioning and a consistent height system are at the base of an immense number of activities. These activities range from mapping, engineering and dredging to environmental studies and natural hazards; from precision agriculture and forestry, to transportation, commerce and navigation; and from mineral exploration and management of natural resources to emergency and disaster preparedness. All depend on the universal compatibility of a common coordinate reference system through which all types of geo-referenced information can be interrelated and exploited reliably. While the height reference system supports numerous technical applications, it is also implicated in many legal documents related to land management and safety such as easement, flood control, boundary demarcation, etc.

Until recently, Geodetic Survey Division (GSD) of Natural Resources Canada (NRCan) has relied on conventional line-of-sight survey measurements to provide the physical framework of vertical reference points. These benchmarks were accessible to users across the country and used as the basis for their own surveys. Conventional levelling methods required crews of surveyors to literally walk from coast to coast along all major road systems taking measurements every 100 metres or so. The height reference system was established in this fashion and consisted of a network of more than 80,000 benchmarks spread over approximately 150,000 km.

In recent years, limitations of the current height reference system (instability, distortion, limited coverage, etc.) combined with high maintenance costs and the opportunities and pressures of new technology, has forced re-thinking the means of providing the national height standard.

Today, new technologies tied to absolute gravimetry, airborne gravimetry, and satellite gravity missions have emerged to enhance gravity information as an alternative for the definition of the height reference surface. More importantly, the Global Positioning System (GPS) technologies have continued to improve in accuracy and ease of use and have gained further acceptance as geo-referencing tools of choice in the geomatics and scientific communities. Now GPS can offer a relatively inexpensive means for users to obtain consistent heights connected to the reference system, and can also provide the means for

geomatics agencies to maintain the reference system at lower cost. Unfortunately, the existing height reference system is not compatible with GPS and requires modernization to fully support and realize the substantial benefits of GPS and related modern technologies for accurate height measurement.

The current plan of realizing a new vertical datum to replace the Canadian Geodetic Vertical Datum of 1928 (CGVD28) does not represent a first attempt for NRCan. In 1976-1977, a GSD study group investigated problems related to the existing vertical reference system (CGVD28) and recommended a redefinition of the vertical datum. The US National Geodetic Survey (NGS) and GSD agreed to cooperate on the realization of a new vertical datum for North America by 1988. This project was known as the North American Vertical Datum of 1988 (NAVD88). During that period, significant efforts were devoted to improving the precise levelling procedures and a large portion of the primary vertical network was reobserved. Although the US NGS adopted NAVD88 as their new vertical datum in the early 90s, GSD did not follow because of unexplained discrepancies in the order of 1.5 m from east to west coasts (likely due to accumulation of systematic errors) and the slight improvement overall that this new datum would bring. Since then, GSD has continued its data analysis and experimental adjustments of the primary levelling network while also continuing development of a gravimetric geoid model as a more advanced potential solution for height modernization.

The recently computed geoid model CGG2000, while not quite achieving the accuracy requirement of a new datum, confirms the potential implementation of a gravity-based system as a seamless vertical datum covering all of the Canadian territory and surrounding oceans. It is also compatible with modern positioning techniques for more effective height determination. Current international efforts to move towards satellite technology and geoid modeling, combined with present and upcoming satellite gravity missions, will contribute greatly to the refinement of the Canadian geoid model and enable its adoption as a new datum. Computation of a new geoid model is currently planned for 2006 at the earliest, in order to take advantage of data from the most recent satellite gravity missions. We can realistically estimate that an additional two years will be required to confirm the adequacy of this geoid model as the basis for the new datum, to finalize the development of the required user tools, and to carry out the readjustment of the vertical networks that would allow adoption of the new datum.

Similar to the long-term and presently ongoing transition from the North American Datum of 1927 (NAD27) to NAD83, it is expected that the transition from CGVD28 to a new a datum will span several years or even decades during which time the two systems will co-exist. Our experience with the transition to NAD83 is exemplified by the fact that several organizations throughout the country are still using NAD27 today, including the city of Toronto where conversion to NAD83 was just initiated this year.

Although GSD and the CGRSC are well aware of the technical issues related to the modernization of the reference system, there are a number of practical issues that need to be taken into consideration in the development of a height modernization implementation plan. A key concern is that sufficient consultations be held to ensure the envisioned modernization and related transition are conducted in a manner that minimizes negative impacts and maximizes benefits. Therefore, a stakeholder consultation is proposed, along with related data analysis and development of recommendations, as a critical input to the height modernization implementation plan.

HEIGHT REFERENCE SYSTEM - TERMINOLOGY

Before getting to the core of this subject, it is important to clarify the terminology and more specifically to highlight the distinction between two components of the Canadian Height (or Vertical) Reference System: the “datum” and the “levelling networks”.

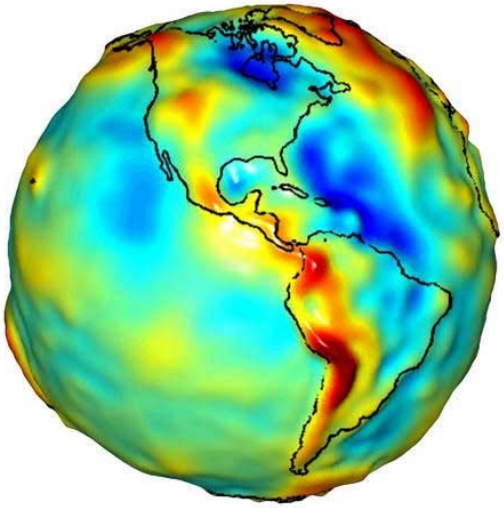
The Canadian Height Reference System is commonly and somewhat misleadingly called the “Canadian Vertical Datum”. Strictly speaking, the **“datum”** refers to the origin (the zero) surface adopted as the basis for the height reference system. For the current CGVD28 reference system, the datum is Mean Sea Level (MSL) as determined from data collected at 5 tide gauges. Two of these gauges are on the Pacific Ocean (Vancouver and Prince Rupert), one on the St Lawrence River (Pointe-au-Père near Rimouski) and two on the Atlantic Ocean (Halifax and Yarmouth). Monumented points at these locations

actually served as the fundamental references for that datum, and the levelling networks originated from those original points.

The **"levelling networks"** (also called the vertical networks), are a series of interconnected monumented points (benchmarks) that originate from the datum fundamental reference points, with heights propagating across the landmass to realize and provide access to the reference system. The levelling networks have a hierarchical structure and are classified according to their expected accuracies based on observational procedures used in their establishment. The **Primary Vertical Network,** established over the last century mainly by GSD[1], serves as the cross-Canada **"framework"**, upon which all other "densification" networks (2nd, 3rd and 4th order) or height determinations are based.

The issue of accurate height determination is somewhat more complicated than for horizontal coordinates (latitude and longitude) especially when related to managing water or water flow, since heights, in this context, are not dependant on geometric displacement with respect to the centre of the earth but on the local gravitational force of the earth. Therefore, the ideal height reference system would be based on a surface of equal gravitational potential (equipotential surface) where water would be at rest. This theoretical level surface, known in geodesy as the **"geoid",** is irregular, as depicted in Figure 1, undulating as a function of the density of the earth's interior and related gravity. For years, it was impractical to determine the geoid with any kind of accuracy and the average or mean sea level, representing the best approximation of the geoid, was adopted universally[2] as the datum (reference) surface for heights. Hence, geodesists and the geomatics community often talk about two types of heights. A "**geodetic (or ellipsoidal) height**" is based solely on a geometric measurement from the centre of the earth to a point on the earth's surface (eg. the type of height obtained from GPS), while an **"orthometric height"** is a height with respect to the geoid or its approximation to "mean sea level". The orthometric height accounts for the gravitational force and is consistent with the direction of water flow (eg. the type of height obtained from levelling, corrected as required for gravity variations).

Figure 1 - Representation of the geoid, based on data from the GRACE satellite gravity mission[3]



[1] In a few instances mainly related to value-added initiatives, provincial survey agencies have contributed financially or in kind to the monumentation and/or survey
[2] Annual report of the Director of the Geodetic Survey of Canada, Department of the Interior, 1935
[3] Prepared by The University of Texas Center for Space Research, as part of a collaborative data analysis effort with the NASA Jet Propulsion Laboratory and the GeoForschungsZentrum Potsdam (http://www.csr.utexas.edu/grace/)

PART I -- STATE OF THE PRIMARY VERTICAL NETWORK

"BE IT RESOLVED that the CGRSC review the state of the current primary vertical network and report to CCOG…"

Description of the Primary Vertical Network

The Primary Vertical Network consists of a series of interconnected levelling lines that originate from the datum fundamental reference points, propagating heights across the landmass with respect to the datum. Hence, the Primary Vertical Network provides access to the reference system.

The physical extent of the primary vertical network in each of the provinces is detailed in Table 2 and illustrated in Figure 2. It includes over 140,000 km of levelling lines and some 80,000 benchmarks that were established over several decades. As depicted in Figure 2, several regions of Canada have difficulty in accessing the network, especially those located far from major roadways and in the North.

For practical and cost efficiency reasons there are a number of variations in benchmark designs and construction techniques employed throughout the network. In general, intermediary benchmarks were established at a spacing of two km along levelling lines to satisfy the requirement of the spirit levelling technique employed. These less costly/more rapidly installed types of markers often have the disadvantage of being more susceptible to movement (frost heave or physical disturbance), especially in areas of significant soil coverage. However, there are many examples of this and many exceptions, since tablets were very easily installed in stable structures and bedrock, where the choice existed. More stable types of markers (eg. "deep benchmark" or bronze tablet anchored to rock or foundations) were installed approximately every ten km and preferably in a protected location such as on government properties, churches, municipal offices etc. to ensure increased permanency and stability of these principal benchmarks of the network.

Although the distribution of benchmarks is quite dense along the levelling lines, the levelling lines themselves are rather sparse. In the southern part of Canada, levelling lines were established at 30 to 100 km spacing in a quasi-grid fashion and denser networks were often established in major cities as an exception, through special agreements with municipal and provincial governments. Further north, levelling lines were established largely along major roads or transportation routes, including winter roads. Guidelines for the establishment of the primary vertical network[4] are summarize in Table 1.

Table 1: Guidelines for establishing levelling lines in Canada

In southern Canada:

Population density:	Spacing between levelling lines
30 or more persons per sq. km	25 km
1 to 29 persons per sq. km	100 km
fewer than 1 person per sq. km	300 km

In northern Canada:

Along major transportation routes or, in their absence;
at line spacing of about 500 km.

[4] Geodetic Survey of Canada, Summary of activities, 1987

Figure 2. Physical extent of the federal Primary Vertical Network

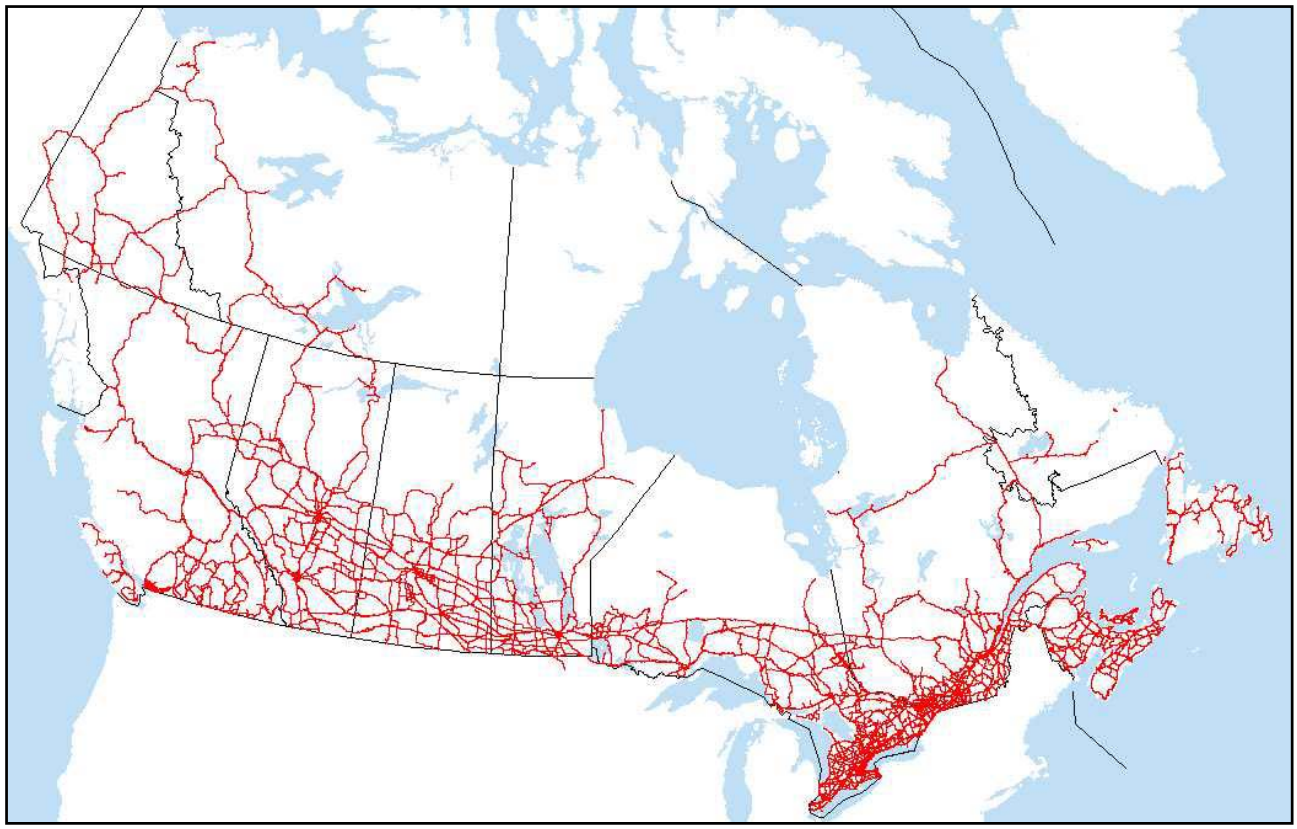


Table 2: Details on the extent of the federal Primary Vertical Network in each provinces and territories.

	Km of 1st order levelling lines	Km of 2nd order levelling lines	Total Km of levelling lines	1st order BMs	2nd order BMs	Total BMs
Yukon	4,918	42	4,960	1,786	0	1,786
British Columbia	17,099	153	17,252	9,732	35	9,767
Northwest Terr.	4,536		4,536	1,876	4	1,880
Alberta	17,513	6,114	23,627	9,840	899	10,739
Saskatchewan	16,140	8,204	24,344	7,552	626	8,178
Manitoba	12,378	753	13,131	5,572	85	5,657
Ontario	27,556	2,954	30,510	14,507	1,128	15,635
New Brunswick	4,078		4,078	3,713	34	3,747
Quebec	21,320	957	22,277	13,945	180	14,125
Nova Scotia	4,591	68	4,659	4,150	60	4,210
Prince Edward Is.	1,008		1,008	1,113	2	1,115
Newfoundland	4,917		4,917	3,616	1	3,617
United States	531		531	144	0	33
Total	136,585	19,245	**155,830**	77,546	3,054	**80,489**

Some provinces and municipalities have extended the federal primary vertical network with other networks of various accuracies. Table 3 below illustrates the extent of complementary levelling that serves as densification of the federal network, based on information from provincial databases.

Table 3: Extension of the federal Primary Vertical Network by provinces (1st order or lower)

Province	Levelling (km)	# Benchmarks [(a)] Provincial / Municipal
British Columbia	19,700	694 / 26,309
Alberta	25,000	27,500
Saskatchewan	800	7,800
Manitoba	5,750	8,000
Ontario		8,500 / 7,000 [(b)]
Quebec	73,000	9,654 / 2,525
NB	0	0
NS		3,200
PEI		
Nfld	0	0

(a) Non federal benchmarks on Provincial databases
(b) City of Toronto

Network Maintenance

From 1972 to 2000 nearly the entire network was re-surveyed with 124,000 km of levelling carried out. Until 1993, GSD carried out an average of 4000 to 5000 km of levelling annually. Approximately 65%[5] (~3000 Km) of the levelling was for maintenance purposes, the other 35% (~1500km) was related to network expansion. From 1994 to 2000 (following federal government Program Review and associated budget reductions), GSD performed an average of 1200 km of levelling annually, with a steady decline over the years. There were essentially no levelling surveys carried out since 2000.

Assuming the vertical network continued to be maintained on a 25-year cycle, approximately 5,600 km of levelling would be required annually. At a rate of $250-300 per km, the O&M cost of re-survey alone would range between $1.4M to $1.7M annually. Furthermore, this cost does not include repair or replacement of damaged benchmarks ($1000-$2500 per benchmark depending on the type), nor the salary costs related to the surveys coordination, mathematical adjustment and related data management. Even a skeletal network of about 30,000 km proposed as the minimum vertical framework for Canada would cost about $400K (O&M) per year to maintain and potentially pre-empt or delay the work essential to establishing a modernized solution.

Physical state of network

Due to the extent of the network and the related time required to carry out a full inspection, it is difficult to assess the exact state of the network at a specific point in time. We can only extrapolate based on statistics currently available in our databases or derived from the most recent inspections of small sections of the network.

Although only 5% of the 80,000 benchmarks on the GSD database show reports of dubious condition (damaged, destroyed, not found, displaced or inaccessible), it is expected that the current state of the vertical network is in much worse shape. Until 1996, as part of the network maintenance program, GSD inspected 3000 to 4000 km annually. These inspections found 11 to 22% of the BMs inspected were unusable or destroyed. Assuming roughly a 20-year inspection cycle was in place, this extrapolates to an estimated rate of degradation of 16% in 20 years. In urban or near-urban settings the rate can be much

[5] The Future of Vertical Control In Canada (Internal study paper published in 1993)

higher. A systematic inspection of some 400 primary benchmarks established 25 years ago in the Greater Vancouver Regional District (GVRD) reported 32% of the benchmarks were either not found, inaccessible or destroyed. Somewhat consistent with these statistics, a student summer project recently carried out by the Ontario MNR, yielded a level of destruction of 22 % based on the inspection of 110 bench marks selected randomly in and around six cities. On the other hand, Alberta provincial agency records show that they have inspected 12% of the federal benchmarks on their database since 1988, with less than 2.5 % reported as destroyed or having an "anomalous" condition. At the other end of the spectrum, the Newfoundland provincial survey agency estimates the destruction rate at about 2.5 % per year (yielding a rate of about 40% over 20 years) based on the destruction rate of their own control monuments in the province (not based on inspection of vertical benchmarks alone).

In summary, we can probably estimate the degradation rate of the network across Canada to be in the range of 15% to 20% per 20 years. In urban or near-urban areas the degradation rate could reach 35% for the same period. In the context of datum modernization, this implies that a significant portion of the existing monumented networks should remain intact and enable a transition period of a few decades. However, additional network maintenance may be necessary in certain areas where damage to the physical network occurs at a rate unacceptable to a successful transition.

Other Limitations of the network

The heights currently published are a construct of annual survey observations that date back to 1904. Despite great care to minimize potential errors, the network was established piece-wise, year after year, and there are significant regional distortions in the current published heights that are further influenced by crustal motion. Comparisons of the heights currently published against more recent scientific re-adjustments of the network and with the most recent geoid model, indicate regional distortions of up to one metre. While the consistency of heights at a local level (relative heights) may still have sub-centimetre precision, the application of new technology such as GPS is impeded by the inability to obtain accurate point heights consistent with the current datum.

As an extension of the latter difficulty, the current published heights are also based on a datum that assumed the Pacific and Atlantic oceans were at the same height. In fact, the water level at Vancouver could be higher than the water level at Halifax by 40 to 70 cm. This discrepancy causes a national-scale tilt in the published heights that has significant impacts on different scientific applications. It also has implications for potential discrepancies in heights along the Canada/US border, where the US Government adopted NAVD88.

Subsidence or uplift of individual benchmarks due to frost or other local instability is another weakness of the network, significantly affecting its accuracy (or equivalently, confidence in that accuracy) at a local level. Occasional reports of such inconsistencies in the levelling network are expected to increase as the time period since the last maintenance increases.

PART II - ROLES, RESPONSIBILITIES AND ACCOUNTABILITIES

"BE IT FURTHER RESOLVED that the CGRSC review and report to the CCOG on the roles and responsibilities, accountabilities with regard to the maintenance of the Vertical Reference Frame and its current access through the Primary Vertical Networks…"

It is generally recognized that the federal government, NRCan in particular, has had the leading responsibility in the development and maintenance of standards related to Geodesy and spatial reference systems. However, adoption and promotion of the standards within each jurisdiction and densification of the networks when required have been a provincial responsibility. Therefore, maintenance and provision of the overall spatial reference system has been a shared responsibility where the provinces and federal government play complementary roles.

The role and responsibility of NRCan (GSD) has changed little since its inception[6] over nine decades. However, the methods GSD uses to fulfill its role have changed significantly especially with the advent of space-based technology. GPS in particular, has caused profound changes in the techniques and methods of geodesy.

Official (legislative) documents describe the role and responsibility of NRCan (GSD) with respect to the maintenance of the Reference System only in broad terms. The most recent "comprehensive" description is found in the mandate of the Surveys and Mapping Branch, approved by Cabinet in 1984 and then reconfirmed by Cabinet in 1987 (Appendix B). This description serves as the basis for the mandate summarized in GSD annual Business Plans since the early 1990s :

- To establish, maintain and enhance as necessary the fundamental framework of reference for spatial positioning for Canada (the Canadian Spatial Reference System -- CSRS);
- To formulate, maintain and promote national standards for geodesy and contribute to the formulation of international standards; and
- To make available the resulting spatial referencing information and databases.

The overall objectives, or raison d'être, of these NRCan activities are best summarized by the following two desired outcomes of the Canadian Geodetic Service, presently the 'home base' for delivery of the Height Reference System under the latest Earth Sciences Sector Science & Technology (ESS S&T) strategy:

- National consistency and global compatibility of georeferenced applications and data enabling their seamless integration and interoperability.
- Availability of authoritative time-varying data related to the Earth in space and the Earth's surface critical to geosciences and space navigation.

The mandate implies two main responsibilities related to reference systems:

1. to carry out the required investigation, monitoring, R&D, etc. to ensure that the datum (the standard) chosen remains adequate for the purpose intended and to make recommendation for corrections, adjustments or change.
2. to provide the infrastructure (the framework), compatible with current positioning techniques, required to provide access to the datum and therefore ensuring heights/positions consistent with that standard.

Traditionally, for both the horizontal and vertical reference systems, this infrastructure consisted of a relatively dense network of monumented points or benchmarks with accurate positions and heights determined with respect to the adopted datum. NRCan was responsible for the provision of what was considered the highest level of the infrastructure across the country (primary or first order networks) as the basis for all other surveys. In many instances the primary networks were extended beyond the nominal plans in order to satisfy local requirements, but normally this was subject to convenience (eg. levelling crew already in the area) and might have included some form of cost-shared or in-kind arrangement. The densification, such as 2nd, 3rd and 4th order networks, required to satisfy end user and specific applications (except for those of the federal government), was the responsibility of provincial and municipal governments.

The extent of the "framework" was linked directly to user needs and these in turn were dictated by the limitations of the available instrumentation. For decades the only survey instruments available required line of site observations. Users would start from a point of known position on the framework and propagate positions to the location of interest. This leap-frog technique would turn short distance observations into long distance transfer of position. It was not only time consuming, but also prone to accumulation of errors. Under these conditions a framework of high-density was required to ensure the usefulness and practicality of the network. However the advent of new and more accurate technologies,

[6] Audit of geodetic Survey Division, Audit and Evaluation Branch, May 1993

such as space-based GPS in particular, has enabled a substantial reduction in the extent of the framework required. In the case of horizontal positioning, the framework of 8000 primary (1st order) control monuments historically provided by NRCan at a nominal spacing of 60 -100 km, has now been replaced by a network of some 200 points consisting of a combination of continuously operating GPS tracking stations (Active Control Points) and high precision monumented points of the Canadian Base Network.

With the adoption of a new height datum compatible with space-based positioning techniques such as GPS, a drastic reduction in reliance on the dense monumented ground network is expected. This reduction would go hand-in-hand with the increasing adoption by the geomatics community of new technologies with their related improvements in accuracy and efficiency.

In this new context, NRCan will continue to be responsible for realizing a relevant and viable datum as a standard by carrying out the required investigation, monitoring, R&D, etc. and making recommendations for required improvements. The principal means of obtaining heights consistent with this datum will be available to GPS users through a file of corrections (geoid model) that will enable direct determination of orthometric heights (ie. heights above "Mean Sea Level"). In fact, any 3D positions referenced to NAD83 (CSRS) could be converted directly into heights referenced to this new datum.

The highest-level monumented framework for heights will then consist of the federal Active Control Points and Canadian Base Network (CBN) points, with NRCan continuing their physical and mathematical maintenance. Provincial High Precision Network (HPN) points will serve as densification to this. NRCan will also continue the mathematical maintenance of the Primary Vertical Network with respect to the new datum possible through the existing links to the CBN and ACPs. This requires an overall readjustment of the network, not only to generate heights with respect to the new datum, but also to remove much of the distortion resulting from the piece-meal approach to construction of the network. It should be noted however that the current network has its limitations and a new adjustment will not account for or correct for monuments that have moved over the years, nor for changes in the Earth's crust (uplift/subsidence) that affect the accuracy of individual benchmarks.

The availability of heights referenced to the new datum for the existing network should greatly facilitate the transition to this new datum. To help ease the potential burden associated with moving information to a new datum and as further incentive, NRCan will also compute and maintain a set of transformation parameters (grid shift file) and corresponding software tools to support the conversion of existing data sets referenced to CGVD28.

GSD also recognizes that during the transition period and beyond, there may be some additional requirements for monumented benchmarks or levelling lines on a local basis. These situations should be evaluated on a case-by-case basis and where justified, could be addressed in a cost-shared/collaborative fashion. In this regard, NRCan will strive to maintain its precise levelling expertise.

Accountability

Accountability [7] is defined as**:** "The obligation to demonstrate and take responsibility for performance in light of agreed expectations. There is a difference between responsibility and accountability - responsibility is the obligation to act whereas accountability is the obligation to answer for an action".

Accountability relates to the commitments made or expectations created in relation to a responsibility and must be a function of the capacity (authority as well as available skills, knowledge and resources) to deliver.

[7] Guide for the Development of Results-based Management and Accountability Frameworks, Treasury Board of Canada (http://www.tbs-sct.gc.ca/eval/pubs/RMAF-CGRR/rmafcgrr01_e.asp#sec1)

For the Height Modernization project and the ongoing maintenance of the CSRS reference system, it is understood that the level of effort devoted to those responsibilities attributed to NRCan, and the time frames for their realization, are dependant upon resource levels available. The complete realization of these activities are also dependant upon factors over which NRCan has little control, such as the availability and accuracy of critical technical data sets generated by other organizations outside the country or as part of global collaborations. The Height Modernization project must recognize this changing environment in delineating responsibilities and related accountabilities.

The development of a detailed Height Modernization Implementation Plan, approved with the required level of resources, is a prerequisite for setting the accountability framework. This plan should define key results and commitments, show links to objectives, specify in detail the work to be done, by whom, and related constraints, and address how progress towards outcomes will be measured and reported.

PART III – CONSULTATION PLAN FOR HEIGHT MODERNIZATION

*"BE IT RESOLVED that the Council receive a report from the CGRSC **before the end of 2003,** to review a consultation plan (issues, questions and approaches) on the future maintenance of the primary vertical networks, the evolution to the new Vertical Reference Frame and the identification of financial or equivalent resources to carry out the consultation plan, whereby Council will decide next steps."*

The CGRSC presented a position paper on the modernization of the Canadian Geodetic Vertical Datum to CCOG in October 2002 that provides information related to the committee's position on the need for height modernization. This document is provided as an appendix to this report.

GSD has consulted with provincial agencies through meetings of the CGRSC, and has committed to providing the necessary technical contributions to enable height modernization. The actual process entails the scientific development of a gravity-based geoid or sea level surface model for Canada. An official height datum would be adopted which corresponds to this model. The heights for all benchmarks of the existing federal primary vertical networks would be recomputed and published with respect to the new datum. It is expected that height values across Canada could change by up to one metre in the transition from CGVD28 to the future datum. This modernization will enable determination of accurate heights via satellite methods (GPS, etc.) regardless of the user's location in Canada.

Although GSD and the CGRSC are well aware of the technical issues related to modernization of the reference system, there are a number of organizational and societal issues that need to be taken into consideration for the development of the Height Modernization Implementation Plan.

A key concern of the CGRSC is that sufficient consultations with stakeholders be held to ensure that the envisioned modernization is conducted in a manner that minimizes any negative impacts of such a transition while maximizing the benefits. The main objective of a consultation would be to obtain information on potential technical and non-technical impacts and needs, as a basis for developing an effective implementation plan. A secondary objective would be to raise community awareness that this change and improvement in capabilities is on the horizon. This awareness issue is required to ensure a smooth transition to and adoption of this new national standard while accelerating the achievement of benefits linked to development of advanced, value-added applications.

The key results expected from such a consultation include:

- Identification of the technical and socio-economic fields of activities potentially affected by height modernization
- Identification of needs in terms of scientific tools, software applications, communications and education required to facilitate both the transition and future usage of the modernized height system.

- Key milestones specifying how height modernization can be introduced into each jurisdiction and field of activities, identifying and taking into consideration the formal and/or legal implications.
- Recommendations for a governance system during implementation and on roles and responsibilities following modernization, taking into consideration capabilities and capacity of both federal and provincial geodetic agencies.
- Estimated costs and benefits of Height Modernization taking into account expected changes in user access for a variety of accuracies, and any requirements for transformation of current data holdings.
- Identification of risks and impediments and recommendations for mitigation.

Consultation Options

OPTION 1 (higher cost($) - low in-house resources requirement)

Due to the scope of this consultation and the limited human resources available within each agency, CGRSC members recognized that the most desirable option would involve consultation carried out through an external consultant. The request for proposal (RFP) would summarize the issues requiring investigation as well as the key results expected, while leaving the consultant with significant freedom to propose approaches for gathering information and developing the methodology and tools required. This approach should promote innovation and ensure that consultation extend well beyond our most traditional client bases.

The tasks envisioned for the consultant include: developing the list of stakeholders/clients for consultation (with CGRSC input), identifying the best mechanisms to obtain the required information (eg. focus groups, surveys, interviews, etc.), developing the specific tools that may be required, carrying out the data gathering, performing analysis of collected data and generating the report and recommendations. This would require close cooperation with the CGRSC throughout the process.

As partners in the delivery of the spatial reference system, CGRSC members agreed to share the cost of this undertaking, assuming that funds could be made available from their respective organizations. NRCan committed to fund approximately half of the study costs. The estimated requirement is $120-150K based on similar consultations undertaken by NRCan and provincial agencies in the past.

OPTION 2 (potentially lower cost ($) – higher in-house resources requirement)

At the October CCOG meeting some members expressed concern about the estimated cost and suggested that some provincial/territorial agencies or departments might prefer an in-kind approach, as possible. Others clearly indicated that their lack of in-house resources precludes this possibility. This type of mixed approach is definitely possible but would require more complex preparation of a more elaborate RFP than that proposed above. The Statement of Work would require a detailed list of consultant tasks specifying any boundaries and coordination with CGRSC member responsibilities. Similarly, each individual province or territory would identify and commit to those tasks for which they could take an active role. The potential reduction in consultant fees would likely relate mostly to reduced travel requirements. For example, CGRSC members or other staff could arrange a one-day seminar in their own region to accomplish the required task, follow-up on a common questionnaire established for the consultant, and/or interview local stakeholders or clients identified on the list. The actual savings by the direct involvement of some CGRSC members and the overall impact on the cost of the contract is difficult to evaluate and may be counterbalanced by the complexities of planning combined with the additional logistics required by the consultant to coordinating and reconcile the different inputs. Assurance of consistency/quality of results would also require close attention at the planning and throughout the process.

OPTION 3 (lower cost($) – high in-house resources requirement)

Another option would involve hiring a consultant to serve strictly as facilitator responsible to oversee and lead the project. Responsibilities would extend to providing assistance for: the development of data gathering tools, the compilation and analysis of results and the development of the final report, complete with recommendations. The bulk of the data gathering (interviews, focus groups or other selected mechanisms) would be carried out by the individual geomatics organizations in each of their areas of jurisdiction. This approach could potentially reduce the cost of the contract to the $40-60K range but implies a significantly greater involvement of in-house resources from every organization.

Recommendation

The CGRSC seeks endorsement to proceed with a stakeholder consultation to obtain technical and non-technical information on potential impacts and needs related to height modernization, to serve as a basis for developing an effective implementation plan for Height Modernization. Option 1 for the consultation is the preferred approach recommended by the CGRSC and the option originally proposed. For all options, NRCan would initiate development of the RFP Statement of Work and CGRSC members from each province would take an active part in its development. CCOG members would be provided with the opportunity to review and comment on the RFP contents prior to initiating the tendering process.

APPENDIX A Height Modernization - Background & Summary of Suggested Responsibilities

The current Height Reference System is based on the CGVD28 datum, adopted in 1935.

- The datum reference level was defined as mean sea-level determined from data collected at five (5) tide gauges on the east and west coasts. An extensive network of precisely levelled benchmarks provides access to the datum.
- The physical network is very expensive to maintain because of the large number of benchmarks (close spacing) and extent of the levelling lines – understandable for a very large landmass.
- The reference system has significant distortions for a variety of reasons and is not consistent with the US reference system.
- The datum is only defined at benchmarks, leaving much of the country without access to the height standard.

Height modernization involves the following:

- A new standard for Canadian heights will be defined, resulting in changes in benchmark elevations across Canada. The heights assigned to these points will be of the highest scientific accuracy achievable when the datum is revised, and will remain at these values for many years (several decades) except for changes due to benchmark motion or geodynamics.
- Publication of a new geoid model is currently planned for 2006, at the earliest, in order to take advantage of the most recent data from the satellite gravity missions. Realistically, an additional two years will be required to confirm the adequacy of this geoid model as the basis for the new datum, to finalize the development of the required user tools and to adjust the levelling network to the new geoid-based datum.
- The new heights will differ from the current published heights by less than one metre at any single point in Canada, but by more than 10 cm at most locations. Assuming that the heights in the Toronto area remain essentially fixed, the new heights would be approximately 5 cm lower in Montreal, 30 cm higher in Vancouver, and 10 cm lower in Halifax.
- The current information channels will disseminate heights in the old and new datum for existing benchmarks.
- NRCan has performed no systematic maintenance of the levelling network since 1996, and none is planned for the future. The gradual deterioration of the networks is expected to correspond with the gradual adoption of space-based positioning tools, a process anticipated to take decades.
- The new datum will be accessible directly through space-based positioning tools (i.e. GPS, etc.), as well as through monumented networks including the ACS, CBN, HPN and the existing primary vertical network. Both traditional and space-based techniques would ideally coexist throughout a period of evolution. All points in Canada, including offshore, will have access to accurate heights with respect to a modernized datum.

NRCan will contribute as follows to Height Modernization:

- Resume scientific research with academic partners, to define and recommend the best gravity-based surface (geoid) to adopt as datum.
- Publish the mathematical model that will enable height determination with respect to the new datum, for space-based technology such as GPS.
- Carry out the required re-adjustments of the existing primary levelling network in order to compute and propagate new heights.
- Provide conversion tools required to ensure that information gathered with respect to the CGVD28 datum can be integrated with data in the newly defined datum.
- Disseminate information on the heights of federal benchmarks in the new datum and identify benchmarks in the database as they become unusable.

- Provide support to the provinces to facilitate transition and adoption of the new standard among their user communities.

Provinces will contribute as follows to Height Modernization:

- Lead client liaison activities in their region.
- Provide continuous feedback to NRCan regarding user needs, user adaptation and potential improvements.
- Establish the datum formally in their constituencies over time.
- Disseminate information, tools and data enabling height determination with respect to the new datum, to clients and stakeholders.
- Provide support to the municipalities and other provincial stakeholders to facilitate transition and adoption of the new standard.

Recent years have witnessed a significant shift towards space-based positioning such as through GPS. These systems are capable of providing orthometric height information when their inherent 3D information is combined with a mathematical model of the vertical datum (geoid). Many national governments are proceeding with similar height modernization initiatives - where satellite positioning is combined with a mathematical model to enable height determination. The existing monumented networks will remain for some time despite a continuous erosion, allowing a period of transition that could last for decades. In the event that damage to the physical network occurs at a rate unacceptable for a successful transition, additional maintenance may be necessary.

APPENDIX B - 1984 MANDATE OF THE SURVEYS AND MAPPING BRANCH

1984 MANDATE OF THE SURVEYS AND MAPPING BRANCH

(As confirmed by Cabinet in 672-RD83 January 11, 1984)

(note the activities more directly related to the Geodetic Survey Division are underlined)

- As the national agency for surveying and mapping the Surveys and Mapping Branch of Energy, Mines and Resources has the responsibilities to:
    - formulate and maintain national standards for surveying and mapping which respond to Canadian needs, reflect changing technology and contribute to the formulation of internationally accepted standards and practices;
    - survey and map Canada and to disseminate, maintain and update national data bases concerning topographic, geodetic, geographic information and legal surveys of Canada Lands including the cartographic application of remote sensing to support the national needs and in particular the national government during times of emergency;
- The present levels of service and their objectives are to:
    - foster and maintain national cartographic and survey standards including the associated research and development;
    - complete the national mapping program in both graphical and digital form before the end of the century and to maintain and upgrade topographic and cartographic digital files;
    - complete the national survey framework by the end of this decade and to enhance it thereafter to satisfy user requirements;
    - refurbish and maintain the national levelling network covering the settled areas in this century and to complete the necessary extension to the North early in the next century;
    - manage and regulate the surveying being carried out on Canada Lands, including the offshore, in conformance with the Canada Lands Surveys Act;
    - carry out the legal obligation for the Government of Canada through Surveys and Mapping Branch to maintain the international boundary with the United States and provide a service for internal boundary demarcation;
    - produce an up to date edition of the National Atlas of Canada every mid-census;
    - produce and maintain aeronautical charts required in support of military and civilian aviation in Canada;
    - develop the cartographic applications of modern technology including remote sensing technology and to effectively and efficiently apply modern technology in response to evolving and anticipated user needs;
    - reproduce and distribute maps, charts and survey products as required by the user including the maintenance of cartographic capability to support the national governments reaction to emergency.

Note: Cabinet reconfirmed the 1984 Mandate in a decision during 1987 (8-0325-87RD(01)).

APPENDIX C - CGRSC Position Paper on the Modernization of the Canadian Geodetic Vertical Datum

CGRSC Position Paper on the Modernization of the Canadian Geodetic Vertical Datum

Canadian Geodetic Reference System Committee
Report to CCOG
October 2002

1.0 Executive Summary:

A modern vertical datum representing mean sea level as the national standard of reference for elevations is an essential infrastructure in a modern economy. The Canadian Geodetic Vertical Datum (CGVD28), the current orthometric height reference in Canada, is a 1928 construct established by classical surveying techniques and has prohibitively high maintenance costs. It is not compatible with modern space-based technologies and inhibits cost-saving utilization of these new technologies. With the situation further exacerbated by the deterioration of the existing infrastructure, a decision regarding the future of the Vertical Datum is urgent.

GPS has become the tool of choice for the positioning component of a number of activities related to Sustainable Development: Environmental studies, forestry and other resource applications, oil and gas exploration and development, land development, and precision agriculture, among others. GPS users want to obtain 3D positions referenced to the Canadian Spatial Reference System (CSRS) to ensure compatibility with data from other sources and to meet regulatory requirements. The current vertical datum has limited Canadian coverage and is not well integrated within the CSRS, resulting in extra effort from contemporary users to obtain CGVD28 heights. An opportunity exists to define a new datum based on the latest scientific results - one that is compatible with international standards and enables cost-saving implementation of space-based technologies such as GPS.

A business plan is required to develop a coordinated approach to the development and implementation of a new datum. The changes being considered have considerable impact on the Canadian economy and a large body of stakeholders. The envisioned changes to the datum cannot be implemented without the leadership of CCOG member agencies and the active support of stakeholders, whose input is necessary to define the new datum.

2.0 Problem Statement and Opportunity:

The Canadian Geodetic Vertical Datum (CGVD28), the foundation for the current orthometric height system in Canada, is a 1928 construct established by classical surveying techniques. The datum is accessed via monuments in the ground for which elevations are provided by government agencies.

A number of problems are associated with the continued use of CGVD28:

- Maintenance of the monumentation and related levelling lines remains labour-intensive and very costly. Other funding priorities have significantly reduced this maintenance effort over the past 10 years, resulting in this urgency for action.
- The monumented network does not extend to the North or unpopulated regions.
- Local datums are being developed in some localities (e.g. Vancouver and Victoria) in order to meet user needs.
- There is significant regional distortion in the datum. Heights are not in agreement with those obtained utilizing GPS and modern Geoid models.

- A revised datum entitled the North American Vertical Datum (NAVD88) has been implemented in the United States, creating confusion for cross-border activities and the false expectation in Canada that change is imminent. Implementation of this datum in Canada is not considered a viable option that meets today's user requirements.

An opportunity exists to define a new datum that resolves these problems and which enables cost-saving utilization of space-based positioning technologies (GPS, etc.).

The future datum will be based completely or largely on the Geoid model for Canada. The Geoid surface is equivalent to the mean global sea level height. This model is determined by analysis of data from traditional surveying as well as gravity measurements taken on the ground, at sea, from the air and from space.

As envisioned, a new datum will be defined as a surface covering the entire area of Canada including oceans. Height values would thus be defined at any point in Canada, unlike the current datum which is strictly defined at monuments only. The existing infrastructure (monuments) will be incorporated into the new system in some manner in order to minimize disruption to industry and maximize access to the new datum. Cooperation with U.S. agencies is necessary to ensure continental and international compatibility. Development of a means to transform measurements between CGVD28, NAVD88 and any new datum is necessary.

By defining the datum as a continuous surface the height can be accessed at any point through satellite-based position determination. Geoid models can be made available in the field to allow instantaneous determination of latitude, longitude, ellipsoidal height and orthometric height within the Canadian Spatial Reference System (CSRS) at any point in Canada, land or sea. The effort to modernize the orthometric realization of the CSRS is critical to providing Canadians with a truly three-dimensional integrated datum.

Canadian scientists are world leaders in Geoid research and there are three recent or ongoing collaborative research efforts directly related to the vertical datum issue within the "Geomatics for Informed Decisions (GEOIDE)" Network of Centres of Excellence (NCE). These projects are:

#10 "Precise Geoid Determination for Geo-referencing and Oceanography" 1999-2002
#13 "Precise Geoid Determination for Geo-referencing and Oceanography" 2002-2003
#36 "Development of a Dynamic Seamless Vertical Reference System for Environmental, Climatic, Geodynamical, Oceanographic, Hydrographic and GIS Applications" 2002-2005

These scientific efforts will take advantage of the latest developments as well as new data available from a number of specialized satellite gravity missions. We believe that the Geoid-based height system has the best potential to harmonize with the United States and other nations in the long-term.

However, several questions arise, including:

- Have all user needs been met in the envisioned elevation system (ie one based on the Geoid and accessed by space-based positioning techniques)?
- How can we maximize the benefits to industry and other users from this change?
- How can we minimize the transition costs for industry and other users?
- Errors in orthometric height determination will be dominated by GPS errors. Some users will require guidance in establishing precise local networks. What are the needs for precise users? How can these be met and what training/information is required from Government?
- Sea surface topography causes the Geoid to vary from observed sea level height. The Vertical Datum could be offset from the Geoid proper to another equipotential surface to minimize the impact of this, if any. Is such an offset necessary?
- Temporal changes in the Geoid are significantly smaller than topographic changes, however change does occur due to geophysical processes. A means of managing these changes as well as scientific improvements and error correction must be available. What should the process be for managing changes to the datum?

Providing answers to these questions of implementation can and should be addressed in parallel with the scientific efforts mentioned above (NCE projects).

3.0 Next Steps:

In May 2002 the CGRSC passed a resolution (see Appendix 1) recommending further action toward modernizing the Canadian Geodetic Vertical Datum. The planned activities leading to the implementation of a new vertical datum are shown in the attached timetable. Stakeholder consultations are a key element to a successful adoption and implementation of a new vertical datum and these must be led by all government agencies involved. The agencies involved must have the capacity to engage in this effort. As stated above, these consultations do not require prior resolution of the scientific issues being addressed by the NCE projects.

4.0 Recommendation

The CGRSC seeks endorsement of the above plan and approval in principle for CCOG financial support through CGRSC member agencies of up to $150,000 to enable activity to begin in preparation of a business plan. NRCan will initiate the Business Plan development and will provide detailed cost information at the Spring 2003 CCOG meeting. CGRSC members will cooperate in steering the Business Plan development. This business plan will entail the following:

- Confirmation of scientific approach envisioned
- Validation of CGRSC Resolution
- Stakeholder consultation
- Scientific and Technical options reviewed and recommendations made
- Cost estimate of implementation and benefits to industry
- Implementation recommendations

The business plan development would be overseen and the plan formally reviewed by the CGRSC before submission to CCOG in 2003 for discussion. Further implementation steps will be detailed in the business plan.

	2001		2002		2003		2004		2005	
Major Project Milestones	Jan - Jun	Jul - Dec	Jan - Jun	Jul - Dec	Jan - Jun	Jul - Dec	Jan - Jun	Jul - Dec	Jan - Jun	Jul - Dec
Geoide Project 10 (start 2000)										
Geoide Project 13										
Geoide Project 36										
CGRSC Resolution			May-02							
CGRSC Presents Recommendation to CCOG				Oct-02						
CGRSC Update to CCOG on Detailed Business Plan Funding Requirements					Spring -03					
Consultant produces Business Plan										
Stakeholder consultation										
Business Plan Review by CGRSC					May-03					
Business Plan Review by CCOG						Oct-03				

Legend:

Accomplished

Underway

Pending

Appendix 1)

CGRSC Resolution Regarding the Modernization of the Canadian Geodetic Vertical Datum

Whereas:

1. A modern vertical datum giving orthometric (mean sea level) height is an essential infrastructure in a healthy economy.
2. The Canadian Geodetic Vertical Datum (CGVD28) is currently a 1928 construct established by classical techniques and is not compatible with modern space-based positioning technology.
3. The current realization through monumented levelling lines is rapidly deteriorating and the cost of refurbishing using classical techniques is prohibitive.
4. The current realization provides user access only to areas near levelling lines and makes expansion to remote areas prohibitively expensive and technically challenging.
5. The current datum does not meet accuracy requirements for scientific applications such as climate change studies, sea-level rise determination, etc.
6. There is a discontinuity in the orthometric (mean sea level) height system between the U.S. 1988 datum and the Canadian 1928 datum.
7. The national direction for the Canadian Spatial Reference System (CSRS) is for an integrated datum incorporating the horizontal component plus ellipsoidal and orthometric (mean sea level) heights aligned to a space-based reference.
8. The horizontal and ellipsoidal height components of CSRS have been realized through the NAD83 initiative.
9. The CSRS reference system cannot be fully realized without the modernization of the vertical datum.
10. The national vertical reconciliation project has become the basis for a modern vertical reference system that rationalizes the geoid, ellipsoidal height system and orthometric height systems.
11. A business plan is required to develop a coordinated approach to the development and implementation of a new vertical datum.

Be it resolved that the CGRSC will:

- Develop a proposal for a national business plan taking into account the technical, non-technical and administrative requirements towards modernizing the Canadian Geodetic Vertical Datum.
- Present such a proposal to CCOG at the meeting in the autumn of 2002, seeking endorsement and funding support for development of the national business plan.

Appendix 2)

DRAFT CCOG Resolution Regarding the Modernization of the Canadian Geodetic Vertical Datum

Whereas CCOG has recognized the significance of standardized geodetic referencing based on the Canadian Spatial Reference System (CSRS);

Be it resolved that Council members **recognize the need** for Modernization of the Canadian Geodetic Vertical Datum, a key component of the CSRS, **will ensure capacity** exists in member agencies for stakeholder consultation and communications, and **approve in principle funding** of up to $150,000 for the development of a business plan to address key questions and provide a detailed implementation plan.