The Canadian Height Modernization Initiative

Information for British Columbia Stakeholders / Clients

Introduction

A modern society requires the ability to measure elevations relative to mean sea level easily, accurately, and at the lowest possible cost. Applications range from engineering surveys to monitoring sea level rise; from navigation and mapping to the use of remote sensing for resource management; from mineral exploration to assessment of potential flooding areas; from the construction and precise positioning of dams and pipelines to the interpretation of seismic disturbances. The height reference system is also implicated in many legal documents related to land management and safety such as easement, flood control, and boundary demarcation. All of these applications depend on the universal compatibility of a common coordinate reference system through which geo-referenced information can be interrelated and exploited reliably.

The current system of elevations in Canada, the Canadian Geodetic Vertical Datum of 1928 (CGVD28), was established using a classical spirit levelling technique. It has numerous limitations, such as prohibitively high maintenance costs, limited geographic coverage, difficulty integrating it with the Canadian Spatial Reference System (CSRS), and incompatibility with modern space-based technologies. An opportunity exists to define a new datum based on the latest space-based technologies - one that is compatible with the latest international standards and enables cost-saving implementation of technologies such as GPS.

This information paper describes the problems with the current vertical datum, the Canadian Height Modernization initiative, the proposed steps for the initiative and the work currently underway by the Province of BC (through the Federal-Provincial/Territorial Canadian Council on Geomatics and its Canadian Geodetic Reference System sub-Committee).

The Problem (Background)

The current height reference system is based on the Canadian Geodetic Vertical Datum (CGVD28), adopted in 1935, which was constructed using classical surveying techniques. The datum reference level was defined as mean sea-level determined from data collected at five tide gauges on the east and west coasts. The datum is accessed by users through an extensive network of precisely levelled benchmarks provided by government agencies. Historically, the definition of this height reference system has been separate from the definition of the horizontal reference system, but with the implementation of the Canadian Spatial Reference System, this is changing.

A number of limitations (described below) are associated with the continued use of CGVD28 including the cost of maintenance, coverage in remote areas, compatibility with the Canadian horizontal reference system and the height reference systems in other jurisdictions, accuracy and distortions in the system, and compatibility with modern space-based positioning technology.

Degradation and Maintenance

Maintenance of the benchmarks and related levelling lines required for the current reference system remains labour-intensive and very costly, but the resources available to maintain the networks have been declining. Until 1993, the Geodetic Survey Division (GSD) of Natural Resources Canada carried out an average of 4,000 to 5,000 km of levelling annually. Approximately 65% (~3,000 Km) of the levelling was for maintenance purposes, the other 35% (~1,500km) was related to network expansion. From 1994 to

2000, GSD performed an average of 1,200 km of levelling annually. GSD has performed only minimal levelling since 2001.
In BC, the densification of the vertical networks is concentrated in urban areas where an estimated 2000km of 1st-order and 10,000 km of 2nd- / 3rd-order levelling networks have been established - there are over 25,000 municipal geodetic control monuments within BC that are part of the standardized Municipal Geo-Spatial Reference System (MGSR) layer within the provincial survey control system. The provincial survey control is housed in a database called MASCOT and accessible to all clients and users via the Web. In addition to this, many other agencies within the province may have levelling networks that are have been extended from the Federal / Provincial survey control and which are not part of the MASCOT database (e.g. road/highway surveys, water-related surveys, floodplain surveys, etc.).

The current height reference system is accessible only in areas near existing levelling lines. The network does not extend to the North or unpopulated regions, and its expansion to remote areas is prohibitively expensive and technically challenging.

Assuming the primary vertical network were to be maintained on a 25-year cycle, approximately 5,600 km of levelling would be required annually. Since this level of maintenance is not being performed, the network is deteriorating. The degradation rate of the network across Canada is estimated to be in the range of 15% to 20% of the benchmarks per 20 years. In urban or near-urban areas the degradation rate could reach 35% for the same period.

Accuracy and Distortions

The current height system is a construct of annual survey observations that date back to 1904. Despite great care to minimize potential errors, the network was established piece-meal, with data adjusted locally. This resulted in significant regional distortions in published heights that are, over time, further exacerbated by crustal motion (of the earth's tectonic plates). Comparisons of these heights against the most recent geoid model indicate regional distortions of up to one metre in the primary vertical network. Further, due to the sometimes poor extension of the primary vertical network into project or local areas, the distortions in these areas may be significantly higher (i.e. upto several metres). While the consistency of heights within a localized area (i.e. relative height differences)will likely be sufficiently precise, the application of new technology, such as GPS, is impeded by the inability to obtain 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 such as climate change studies and sea-level rise determination.

There is also a discontinuity in the height system between the datum used in the United States, North American Vertical Datum 1988 (NAVD88), and CGVD28. This has created confusion for cross-border activities (e.g. hydroelectric initiatives/projects related to the Columbia Rover Treaty, floodplains, etc.). However, implementation of NAVD88 in Canada is not considered a viable option that meets today's user requirements.

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. Inconsistencies in the levelling network are expected to increase as maintenance decreases.

Compatibility with the Canadian Spatial Reference System (CSRS)

The Canadian Spatial Reference System (CSRS) provides fundamental reference values for latitude, longitude, height and gravity, including earth's orientation parameters and rotation rate in space, as the foundation for the nation's evolving positioning and navigation activities. The resulting reference frames,

propagated through provincial and municipal reference networks and other government services, serve as standards that ensure the compatibility of Canadian geo-referenced information on earth and in space regardless of their source or date.

The current vertical datum is not well integrated within the CSRS and therefore extra effort is required to translate GPS information into CGVD28 elevations. The horizontal and ellipsoidal height components of CSRS have been realized through the NAD83 initiative, but the CSRS reference system cannot be fully realized without the modernization of the vertical datum.

GPS users require 3D positions referenced to the Canadian Spatial Reference System (CSRS) to ensure compatibility with data from other sources and to meet regulatory requirements. Therefore, the modernization of the vertical component of the CSRS is critical to providing Canadians with a truly three-dimensional integrated datum.

The Canadian Height Modernization Initiative

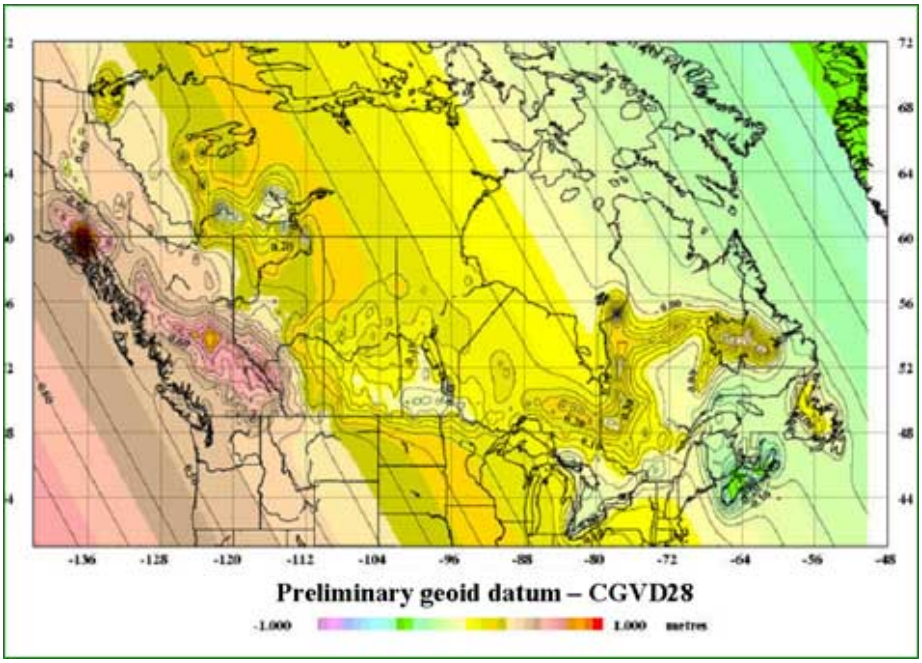
An opportunity exists to define a new datum that resolves the limitations of the current system – one that is compatible with international standards, enables cost-saving implementation of space-based technologies such as GPS, is easily accessible at any point in Canada, and is less sensitive to geodynamic activities and the deterioration of benchmarks. Such a system would be based on an accurate "geoid" model.

Implementation

The adoption of a new vertical datum for Canada could be as early as 2009 (this does not mean that it would be adopted by all provincial users at that time). Publication of a new geoid model is currently planned for 2007 to take advantage of the most recent data from satellite gravity missions. 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 tools to help users make the transition, and to adjust the heights of existing benchmarks to the new geoid-based datum.

The new datum will result in changes in benchmark elevations across Canada. The heights assigned to these points will be of the highest 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. The new primary vertical benchmark 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 (Figure 1). However, due to distortions in the secondary or densifyied vertical networks in each province, there will be larger differences regionally. In B.C. this may amount to a few metres to several metres in remote areas. Assuming that the heights in the Toronto area remain essentially fixed, the new heights would be approximately 5 cm lower in Montreal, 55 cm higher in Vancouver, and 30 cm lower in Halifax. However, the heights differences locally would remain with the same precision of a few cm or better (depending on the quality of the existing local surveys).

Figure 1: Differences in Heights of CGVD28 Compared to a Geoid Datum



Use

The new datum will be accessible directly through space-based positioning tools (e.g. GPS), as well as through monument networks including the federal and provincial Active Control Points (ACP), the Canadian Base Network (CBN), and the provincial High Precision Network (HPN). Both traditional and space-based techniques would coexist throughout a period of transition.

Since the new datum will be defined as a virtual surface (geoid) covering the entire area of Canada, all points will have access to accurate heights, unlike the current datum that is strictly defined at benchmarks only. 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), land or sea.

Transition to Modern Vertical Datum

In order to ease transition to the new system, a number of steps will be taken:

- Support tools will be provided to facilitate adoption among the user communities. Information, tools, and data enabling height determination with respect to the new datum will be disseminated.
- A set of transformation parameters (e.g. grid shift file) and corresponding software tools to support the conversion of existing data sets referenced to CGVD28 will be made available.
- Information on the heights of existing federal and provincial benchmarks using the new datum will be disseminated.
- The existing infrastructure of benchmarks will be incorporated into the new system in order to minimize disruption to stakeholders and maximize access to the new datum. The CGVD28 datum will continue to co-exist with the new datum as long as it will be required. It should be noted, however, that the current network has its limitations and the revision in benchmark heights will not account for, or correct for, poorly established benchmark heights as originally surveyed,

benchmarks that have moved over the years, nor for changes in the Earth's crust (uplift/subsidence) that affect the accuracy of individual bench marks. The gradual deterioration of the existing network of ground benchmarks is expected to correspond to a reduction in its use as space-based positioning tools are increasingly adopted. In the event that damage to the physical network occurs at a rate unacceptable for a successful transition, additional maintenance may be performed.

The following is the timeline to date and projected future timelines for the modernization of the Canadian height reference system:

1993 – The United States adopt the new North American Vertical Datum of 1988.

1994 – Federal government (NRCan's Geodetic Survey Division) announced their intention to move to space-based technology for maintenance and delivery of the CSRS. Physical maintenance of the vertical control network decreased.

1999 - A position paper on the Canadian Vertical Datum was tabled where the concept of a gravity-based datum was introduced.

2006 – Conduct initial Canadian Height Modernization Study with goal of implementation plan. Further studies and outreach is conducted within provincial jurisdictions.

2007 – Anticipated federal publication of a new geoid model for North America.

2008 - Anticipated availability of a new a vertical datum and tools to support the transition.

2009 - Anticipated federal adoption of new vertical datum.

2009 to 2020/30 – Anticipated provincial adoption of the new vertical datum and transition period (10 to 20 years).

International Compatibility

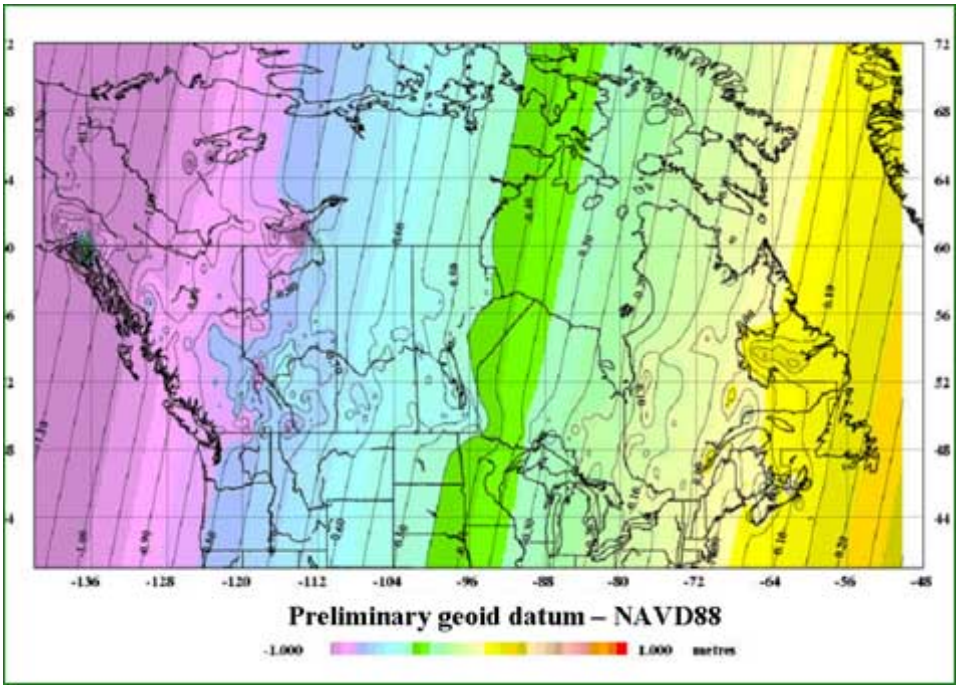
A number of countries have made, or are in the process of making, the transition to a modernized height reference system.

The US National Geodetic Survey (NGS) and Natural Resources Canada (NRCan) cooperated in the development of the North American Vertical Datum (NAVD88). Although the US adopted NAVD88 as its datum in 1993, Canada declined to do so as a result of unexplained discrepancies of about 1.5 m between the east and west coasts (likely due to the accumulation of systematic errors in the original levelling surveys) and the slight improvement overall that such a datum would bring.

Today, a readjustment of the Canadian levelling network in a manner similar to the NAVD88 project would only be a temporary solution, albeit more accurate than CGVD28, and would not solve the problem of its limited coverage and cost of maintenance. Rather, a geoid-based height system has the best potential to harmonize with the United States and other nations in the long-term.

Continued cooperation with U.S. agencies will be necessary to ensure continental and international compatibility. A means to transform measurements between CGVD28, NAVD88, and a new datum will be developed (Figure 2).

Figure 2: Differences in Heights of U.S. NAVD88 Compared to a Geoid Datum



For more information on the **Canadian Height Modernization Program**, please visit:
www.geod.nrcan.gc.ca/hm/index_e.php

What is the Province Seeking?

BMGS is a member of the Canadian Geodetic Reference System Committee (CGRSC) - a Federal - Provincial working committee of the Canadian Council on Geomatics (CCOG). The CGRSC was tasked to plan and coordinate maintenance and improvement of the Geodetic Reference System in Canada. Although the CGRSC is well aware of the technical issues related to the modernization of the vertical reference system, there are a number of practical issues that need to be taken into consideration in the development of an implementation plan. A key concern is that stakeholders be consulted to ensure the envisioned modernization and related transition are conducted in a manner that minimizes negative impacts to business and users, while maximizes benefits to all concerned.

As a result, the CGRSC is preparing a high level implementation plan for a modernized Canadian Height Reference System. Their study is currently well underway and will:

- Consult with a few stakeholders in the federal, provincial and municipal governments, academia, and industry,
- Raise some awareness of the proposed changes,
- Determine user requirements for assistance in making the transition,
- Identify the socio-economic impacts,
- Identify the legal implications,
- Identify risks and impediments and make recommendations for their mitigation,

- Prepare a plan for the implementation of the new system.

The first part of this work has been completed – namely the stakeholder consultation process. This was done via interviews with approximately fifty stakeholders across Canada ranging from industry representatives, to national agencies, to local municipal governments.

Given the limited reach of that overall cross-country consultation, given the need to plan British Columbia's response and work ahead, including the need to prepare clients, stakeholders and users in British Columbia appropriately, over the next few months BMGS is canvassing provincial stakeholders/clients. Some of the questions that we wish to explore are:

1. *What are the applications and activities within your organization that are dependent on height information, and in particular the Canadian Height Reference System?*
2. *What will be the impacts on your organization (and its clients) of benchmark height changes of up to one meter (urban) or more (rural/remote), given that relative local heights will not change significantly?*
3. *What, if any, will be the legal implications on data holdings in your jurisdiction (such as legal licences and encumbrances based on heights of land) of changing the vertical datum?*
4. *What will be the short and long-term impacts on your organization of not maintaining a levelling-based Canadian datum assuming that most federal/provincial benchmarks will not be replaced when they are destroyed?*
5. *What is the accuracy required in the applications and activities undertaken by your organization? Accuracy should be addressed both in absolute and relative terms.*
6. *Within your organization what will be the international cross-border datum difference implications?*
7. *What will be the advantages and disadvantages to your organization (and its clients) of adopting a national geoid model as a vertical datum? In particular, what will be the cost implications and how best might you prepare?*
8. *What might be the requirements within your organization for the transition to the modernized height system in terms of scientific tools, software applications, communications, and training?*
9. *What will be the risks and impediments for the modernization of the height system, and possible approaches to mitigation?*
10. *Are there any other comments you would like to make?*

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