Final Report

Stakeholders Consultation for the Development of the Canadian Height Reference System Modernization Implementation Plan

Prepared for:

Natural Resources Canada

Prepared by:

Hickling Arthurs Low

Technology Management, Strategy, and Economics

In association with:

Geoplan Opus

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Executive Summary

A modern society depends on a common coordinate reference system through which geo-spatial information can be interrelated and exploited reliably. For height measurements this requires the ability to measure elevations relative to mean sea level easily, accurately, and at the lowest possible cost. The current reference system for elevations in Canada, the Canadian Geodetic Vertical Datum of 1928 (CGVD28), was established over the past century using classical spirit leveling, a labour intensive and time consuming technique when applied over large areas. It has numerous limitations, such as high maintenance costs, limited geographic coverage, inaccuracies and distortions, and lack of compatibility with NAD83, the geometric component the Canadian Spatial Reference System (CSRS). The Canadian Geodetic Reference System Committee (CGRSC), a working committee of the Federal-Provincial Canadian Council on Geomatics (CCOG) that coordinates the maintenance and improvement of the Geodetic Reference system in Canada, has been tasked to plan the modernization of the Canadian Height Reference System (CHRS). A new geoid based datum has been proposed to eventually replace CGVD28. Some of the modernized system advantages are compatibility with international standards, cost-saving implementation of Global Navigation Satellite System (GNSS) technologies such as Global Positioning System (GPS), accessibility from any location in Canada, and less sensitivity to geodynamic activities and to the deterioration of benchmarks.

Although CGRSC members are well aware of the technical issues related to the modernization of the vertical reference system, a key concern was that stakeholders' requirements be identified and taken into consideration during the implementation of the new system to ensure the transition occurs in a manner that minimizes negative impacts and maximizes benefits.

Stakeholders representing a range of sectors and application areas were consulted on their views about modernizing the CHRS. Overall, there is recognition that the current system is outdated, inaccurate, and at odds with modern approaches. The majority feel that the benefits of height modernization outweigh the disadvantages. The primary concerns expressed relate to costs, legacy data conversion, and the confusion and errors that may result from the height changes. The development of tools to enable the transformation of legacy data and guidance to assist in adopting the new methodologies were seen as the critical steps towards a smooth transition, especially by small geomatics firms and users in other sectors. The majority of those consulted also consider that a minimum number of federal benchmarks would have to be maintained to ensure the utility of the height reference system. The most commonly identified advantage, noted by virtually all interviewees, was that a continuous and homogenous precise datum with reduced distortion across the country would improve their ability to share and integrate data.

While there are numerous applications in which height has legal implications, no significant issues resulting from the transition to a new height system were foreseen as long as documented elevations remain traceable and proper transformations between systems are possible. Although it would be prudent for stakeholders to review and amend the wording in legal documents, as long as it is clear which datum was used at the time an agreement was reached, the appropriate conversions can be made.

Regarding accuracy requirements, most users are interested in relative accuracy within local areas (extending a few tens of kilometres). Only those establishing precise control networks over large areas (such as some watersheds) may be interested in absolute accuracy. Absolute accuracy does become important, however, when combining information from different data sets – a practice that is becoming more common as information in various GIS systems is shared and integrated among users. Centimetre relative accuracy is required in urban areas to monitor and manage municipal infrastructure. For applications such as watershed flow monitoring and natural hazard risk management, this centimetre relative accuracy requirement can extend to regional scales of few hundred kilometres. Along specific corridors that may extend country-wide for infrastructure such as pipelines and transmission lines, decimetre relative accuracies will likely be sufficient.

The view that moving to a geoid based height system makes good economic sense is increasingly shared by other jurisdictions and countries around the world, although New Zealand is the only country that has implemented and fully adopted a geoid-based height reference system to date. The Canadian situation has many parallels with that of New Zealand and their experience provides a guide for Canada. New Zealand encountered no major obstacles in implementing the new system that were not easily resolved. While the United States is considering such a change, they are planning to do so over a longer timeframe given their recent adoption of a new datum following a significant investment to update their traditional leveling network.

An initial strategic plan has been developed that should lead to the adoption of a modernized height reference system by 2010. Computation of the geoid model that would serve as the new datum is currently planned for 2008 to take advantage of the data from an upcoming satellite gravity mission. An additional two years will be required to confirm the adequacy of this geoid model and finalize the development of tools to help users make the transition.

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1. Introduction

1.1 Background

A modern society depends on a common coordinate reference system through which geo-spatial information can be interrelated and exploited reliably. For height measurements this requires the ability to measure elevations relative to mean sea level easily, accurately, and at the lowest possible cost. Applications range from topographic 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, water resources, and boundary demarcation. Vertical datum stakeholders include municipal, provincial, territorial and federal government departments and agencies, geomatics data providers (such as surveyors), and users such as construction companies, water management organizations, academic institutions, and international bodies.

The current system of elevations in Canada, the Canadian Geodetic Vertical Datum of 1928 (CGVD28), was established using a classical spirit leveling technique. It has numerous limitations, such as prohibitively high maintenance costs, limited geographic coverage, difficulty integrating it with the North American Datum of 1983 (NAD83), the geometric component of the Canadian Spatial Reference System (CSRS), and incompatibility with modern space-based technologies.

The Geodetic Survey Division (GSD) of Natural Resources Canada (NRCan), in cooperation with the provinces and territories, is planning the modernization of the Canadian Height Reference System (CHRS) using a new geoid based datum that will eventually replace CGVD28. This new datum will offer numerous advantages over CGVD28, it will: be compatible with international standards, enable cost-saving implementation of new and increasingly popular Global Navigation Satellite System (GNSS) technologies such as Global Positioning System (GPS), be accessible at any point in Canada[1], and be less sensitive to geodynamic activities and the deterioration of benchmarks.

[1] Access to GNSS signals requires a clear view of the sky, which can be a constraint in areas of dense forest or urban canyons.

1.2 Study Objectives

The Canadian Geodetic Reference System Committee (CGRSC) is a Federal-Provincial working committee of the Canadian Council on Geomatics (CCOG) tasked to plan and coordinate maintenance and improvement of the Geodetic Reference system in Canada. Although they are 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 and maximizes benefits.

As a result, they engaged Hickling Arthurs Low (HAL) Corporation to conduct this study for the modernization of the Canadian Height Reference System. The study team has:

- Consulted with stakeholders in the federal, provincial and municipal governments, academia, and industry,
- Raised awareness of the proposed changes,
- Determined user requirements for assistance in making the transition,
- Identified the financial impacts,
- Identified the legal implications,
- Identified risks and impediments and made recommendations for their mitigation, and
- Prepared a plan for the implementation of the new system.

1.3 Study Methodology

Background information was obtained through a literature review. Documents consulted are referenced in Appendix A.

Stakeholder views were gathered through telephone and in-person interviews and a web-based survey between December 2005 and February 2006. In addition, the New Zealand experience was examined through a literature review and interviews with stakeholders there.

In consultation with the Study Steering Committee members, 50 interviewees were selected across sectors (academic; federal, provincial, and municipal governments; user industries; geomatics industry; and international bodies), and application areas (research, agriculture, transportation, oceans, urban development, surveying, emergency preparedness, environment monitoring, water surveys, energy, forestry, insurance, and mining). The organizations consulted are listed in Appendix B.

An interview guide, introducing the study and containing the interview questions, was distributed to interviewees before each interview. It is contained in Appendix B.

A web-based survey was available to people that visited the project webpage. This was not considered a primary data collection tool, and no effort was made to publicize its availability. However, a request from the Canadian Council of Land Surveyors (CCLS) that we consult with their members more widely than we could accommodate through the interviews was met by having the CCLS publicize the web-based survey to their members. In total we received 14 responses to the survey. While the survey was anonymous, based on the 'sector' and 'roles' self-identified by the respondents, we believe 11 returns to be from CCLS members.

For the purpose of analysis in this study, stakeholders have been segmented into seven groups: data providers, data users, provincial and territorial governments, municipal governments, academic, and international, with data users concerned with water management given special attention because of their particular requirements for accuracy over large areas.

1.4 Report Structure

Chapter 2 introduces the traditional (leveling) and modern (space-based) approaches to height reference determination.

Chapter 3 describes the current Canadian height reference system, the users of the system and their requirements, and the status of the system in terms of its degradation and maintenance, accuracy and distortions, and compatibility with the Canadian Spatial Reference System.

Chapter 4 then examines the advantages and disadvantages of modernizing the Canadian height reference system using a geoid-based approach. The impacts of elevation changes and gradual benchmark deterioration are considered, as well as the financial impacts on users of the system and the providers of the system infrastructure.

Chapter 5 considers the legal implications of changing datums and allowing the number of benchmarks to decrease substantially.

Chapter 6 looks at international experience in providing height reference systems in New Zealand, which has recently adopted a geoid-based approach, and the United States, which has chosen to move towards a geoid-based approach over a longer time frame than Canada is considering.

Chapter 7 is a strategic plan for the implementation of modernized height reference system in Canada. It has been structured to exist as a stand-alone document and therefore re-caps material in the previous chapters.

Appendix A contains the references consulted in the document review. Appendix B lists the stakeholders consulted and the interview questions. Appendices C and D summarize the results of the consultations by question and stakeholder, respectively. Appendix E contains the Quebec Civil Code Articles concerning contract interpretation referred to in Chapter 5 - Legal Implications.

2. Introduction to Approaches Used to Establish a Height Reference Frame

2.1 The Traditional Approach

Traditionally, a Height Reference System or Vertical Datum is based on spirit leveling measurements tied to one or more fundamental points, usually at tide gauges. The spirit leveling technique is a well-known approach that has been conducted for more than 200 years. Although an inherently accurate method for determining height differences, spirit leveling is costly and difficult to undertake in remote areas. It involves making differential height measurements between two vertical graduated rods, approximately 100 metres apart, using a tripod mounted telescope whose horizontal line of sight is controlled to better than one second of arc by a spirit level vial or a suspended prism. This process is repeated in a leapfrog fashion to determine elevation differences between established benchmarks that comprise the height reference system.

Maintaining existing and establishing new benchmarks by spirit leveling is a time consuming, weather and terrain dependent, and costly procedure. Moreover, a leveling-based datum (like the Canadian Geodetic Vertical Datum of 1928 – CGVD28) is entrenched with systematic errors, is accessible only at benchmarks, and is typically not compatible with GPS measurements. It is therefore clear that a modern datum should be established in a way that minimizes or eliminates these drawbacks. Possibly the best way to do this is by choosing the geoid as the reference surface for elevations. This approach is described in the next section.

2.2 The Modern Approach

The alternative approach to spirit leveling for the creation of a vertical datum is geoid modeling. If the two approaches were errorless, they would produce the same results. Geoid modeling is defined in relation to an ellipsoid (e.g. GRS80), that approximates the overall shape of the earth, and the geoid, that corrects for local variations in the Earth's gravity field (Figure 1).

The geoid is an equipotential surface, i.e. a level surface where gravity (plumb line) is perpendicular at all points on the surface and water stays at rest. The geoid, by definition, corresponds to the surface that best approximates mean sea level. The geoid surface is determined by analysis of gravity measurements taken on the ground, at sea, from the air and from space. Orthometric elevations are then heights above the geoid (Figure 2).

Figure 1: Geoid Model for North America

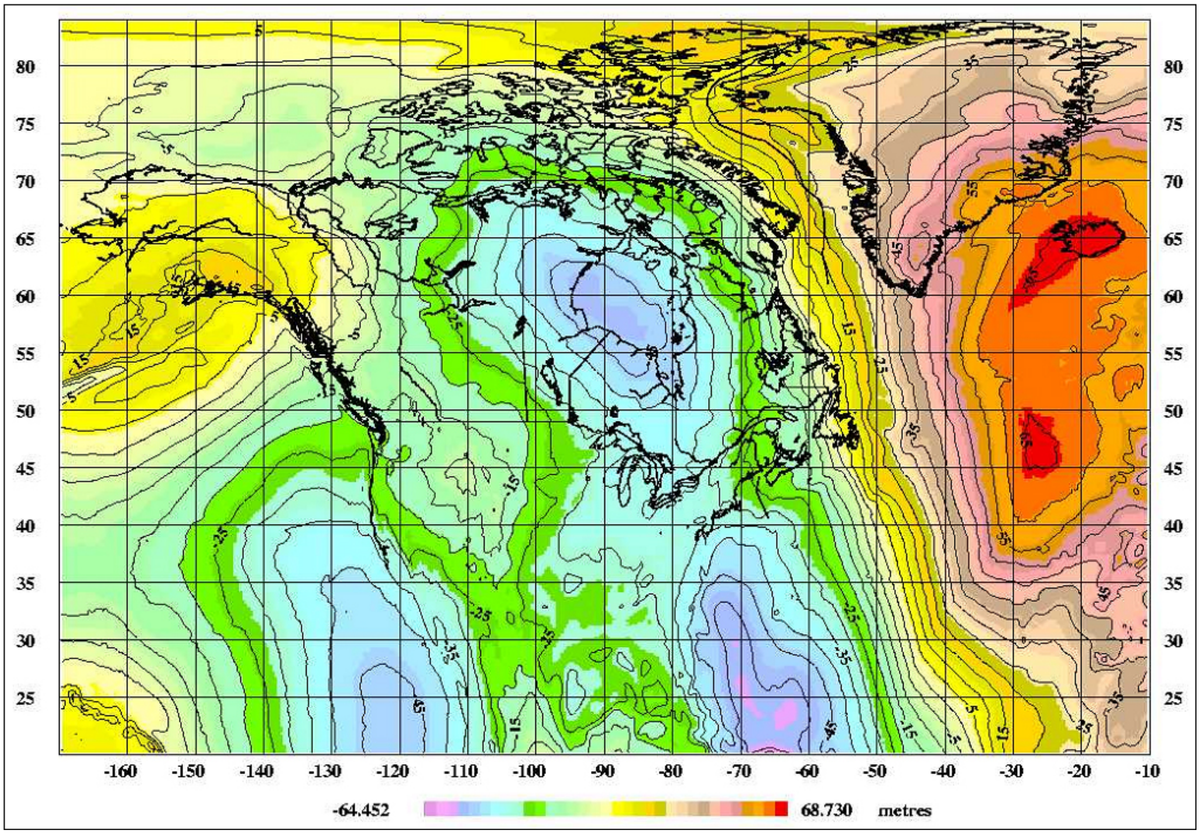
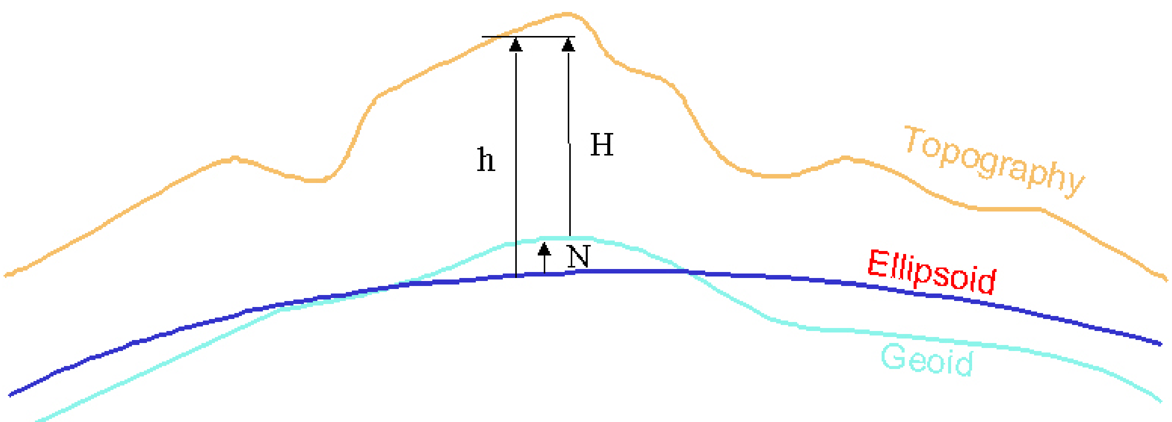


Figure 2: Orthometric Height vs Geoid Height vs Ellipsoidal Height

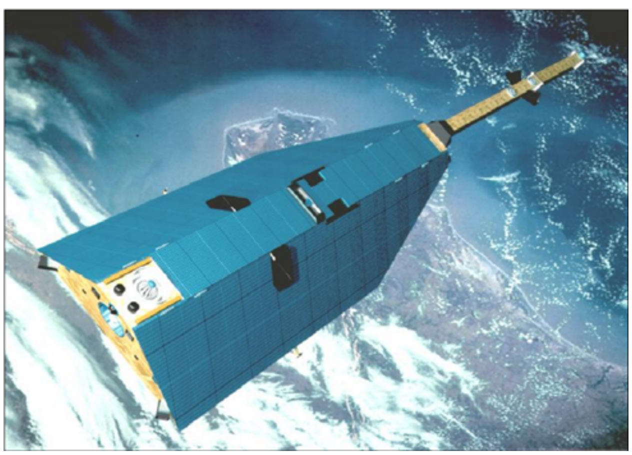


$$H = h^{GPS} - N^{Geoid}$$

A geoid-based datum has a number of advantages over a spirit-leveling approach. It is a continuous surface defined everywhere on land and at sea, and, in principle, it does not need benchmarks for its realization. Also, it is very easy to relate GPS elevations h (measured with respect to a reference ellipsoid), to orthometric heights H simply by knowing the ellipsoid-geoid separation, called geoid undulation or geoid height N. This relationship for a single point is $H = h - N$, and differentially between two points is $\Delta H = \Delta h - \Delta N$. One can thus convert easily between heights measured by GPS at any point (and not only on benchmarks) and elevations above mean sea level by simply knowing the geoid height.

The expression $H = h - N$ implies that in order to replace spirit leveling by GPS and the geoid we need to be able to estimate h and N with accuracies compatible to those of H from leveling. Currently, h from GPS can be obtained at the cm level (and even mm level with long observation campaigns), however the estimation of N cannot reach this level of accuracy. Geoid undulations are estimated from a combination of satellite and terrestrial gravity data, plus digital elevation and crust density models. The satellite data provide the long wavelengths of N and they are responsible for its limited absolute accuracy, which is currently at the level of a few decimeters globally. Of course, if one works differentially, these long wavelength errors mostly cancel out and thus the ΔN accuracy is quite good, typically of the order of 1 ppm (part per million) or better of the inter-station distance between the two stations. Nevertheless, the fact remains that the single point N accuracy is nowhere near the level of the h accuracy.

Figure 3: CHAMP



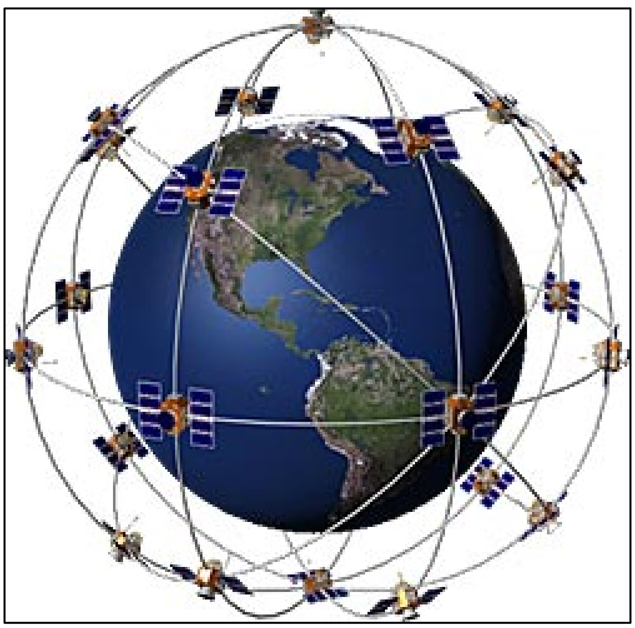
This situation has already improved and will improve further in the near future as a result of the CHAMP, GRACE and GOCE dedicated gravity satellite missions. CHAMP (CHAllenging Minisatellite Payload) is a German satellite mission for geoscientific and atmospheric research and applications, launched in July 2000 (Figure 3). It is generating highly precise gravity and magnetic field measurements. The geoid will become available with nearly cm-accuracy up to a spatial resolution (half-wavelength) of about 650 km. GRACE (Gravity Recovery And Climate Experiment) is a joint project between the National Aeronautics and Space Administration (NASA) and the Deutsches Zentrum für Luft- und Raumfahrt (DLR), launched in March 2002. Its primary objective is to provide global high-resolution models of the Earth's gravity field with unprecedented accuracy for a period of up to five years. The geoid will have sub-cm accuracy at a spatial resolution as small as 400 km and a temporal resolution of one month. ESA’s gravity mission GOCE (Gravity Field and Steady-State Ocean Circulation Explorer) will be launched in 2007. It is dedicated to measuring the Earth’s gravity field and modeling the geoid with extremely high accuracy and spatial resolution, namely 1-2 cm accuracy at spatial resolution of 100 km or better.

With the new geopotential models of increased accuracy at long wavelengths provided by CHAMP and GRACE, and the expected considerable improvement in accuracy of medium and short wavelengths by GOCE, the computation of a cm-level geoid will become realizable in the near future. Thus, the geoid becomes indeed a very attractive alternative to the traditional vertical datum in Canada. Since any mass redistribution, such as those induced by tectonics and postglacial rebound, affect the Earth's gravity potential and thus the geoid, the temporal variations of the geoid must be carefully estimated so that a geoid-based vertical datum can be periodically updated. To achieve this, the general long-term temporal variations of the geoid and orthometric heights need to be quantified based on the data provided by terrestrial and space-based techniques such as GRACE. Any future geoid-based vertical datum for Canada must therefore be also accompanied by a model for its temporal variations.

2.3 Space Based Positioning

Space-based Global Navigation Satellite Systems (GNSS), such as the United States' Global Position System (GPS), Russia's GLONASS, and the proposed European Galileo system, are based on networks of satellites that send out radio signals (Figure 4) to portable receivers. They provide accurate positions at any time, in any weather, any place in the world. They continue to improve in accuracy and ease of use, and have gained acceptance as the geo-referencing tools of choice in the geomatics and scientific communities. They are capable of providing orthometric height information when their inherent 3D information is combined with the geoid information.

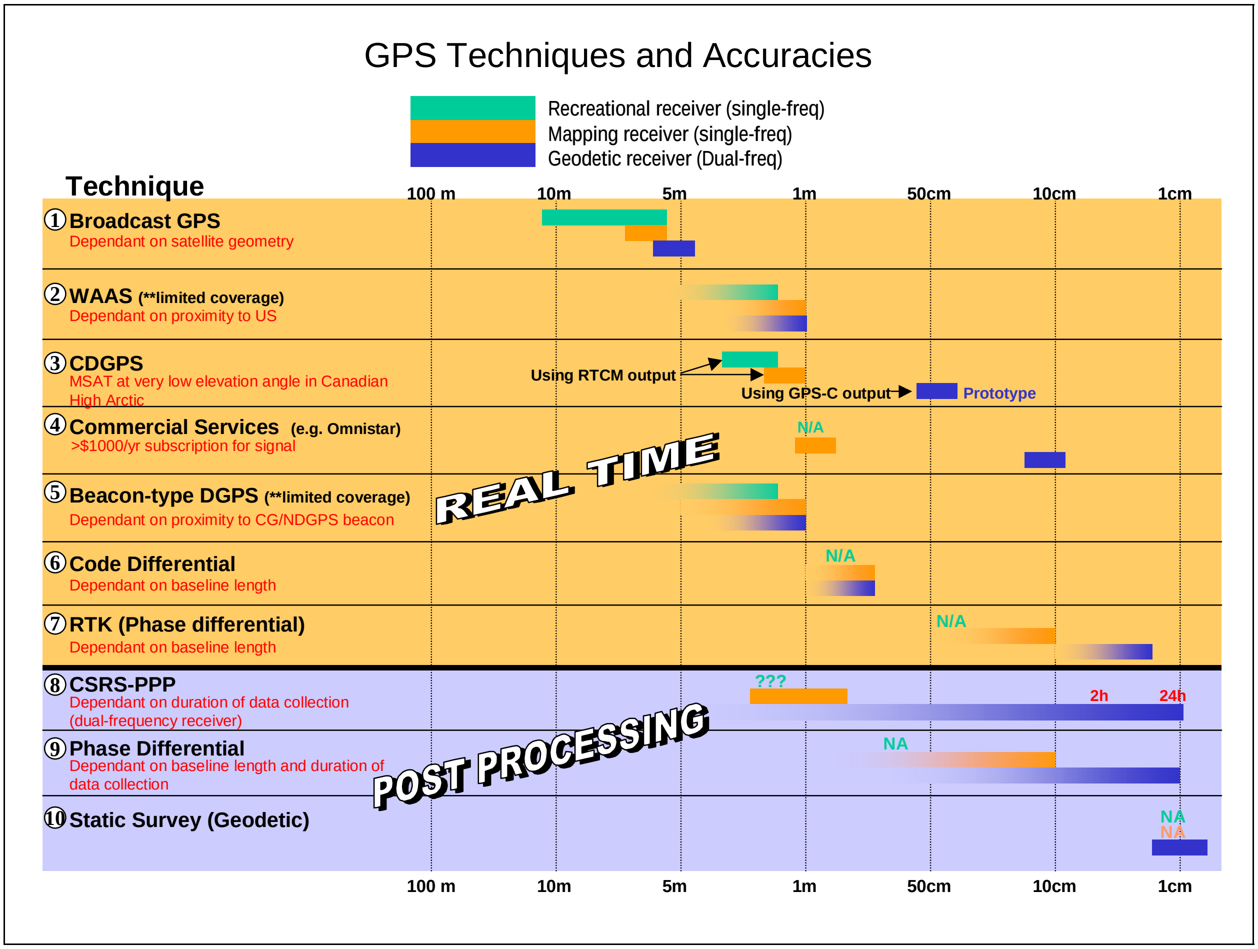
Figure 4: GPS Constellation



Systems such as GPS provide both a relatively inexpensive means for users to obtain consistent heights connected to the 3D reference system, and the means for geomatics agencies to maintain the 3D reference system at lower cost.

There is a wide range of space based positioning techniques and equipment available for many different applications and accuracy requirements as illustrated in Figure 5. Users must be aware of their particular needs and requirements in order to take full advantage of the technology.

Figure 5: GPS Applications and Accuracy Requirements

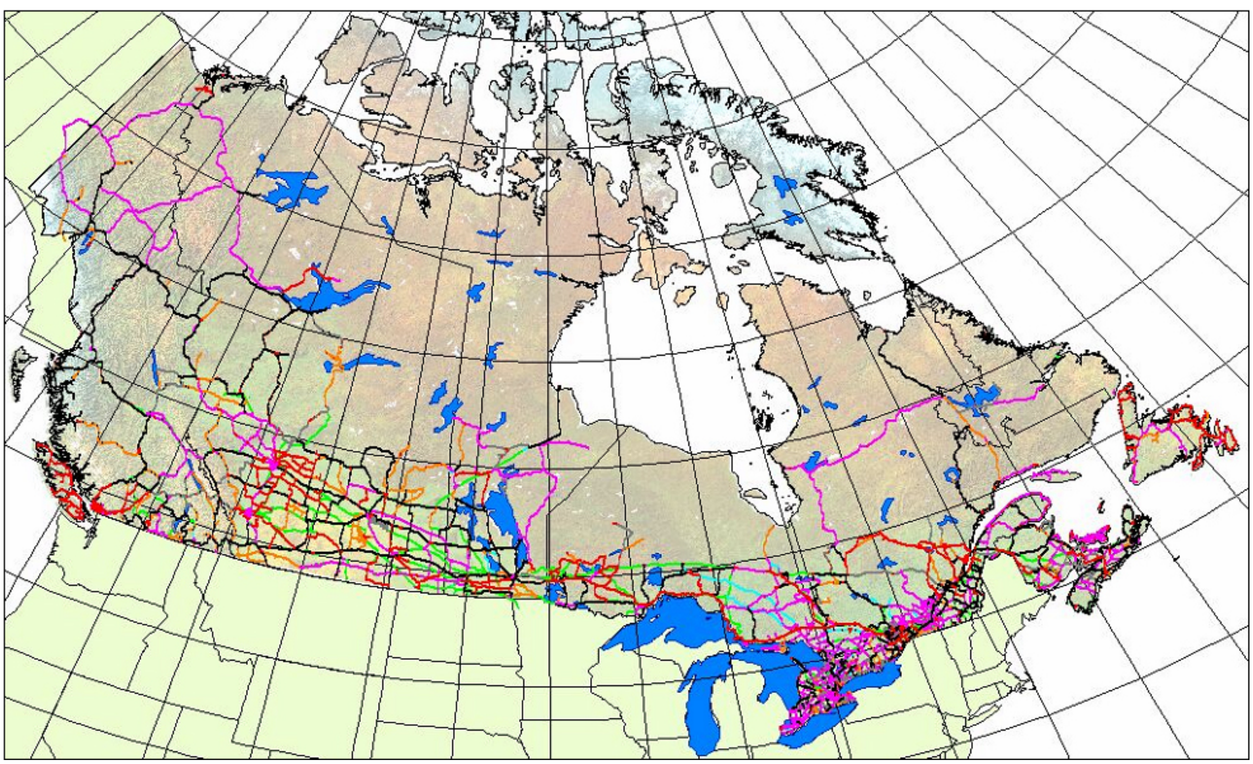


3. The Canadian Height Reference System

3.1 The Current System

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. Over the last 100 years, crews of surveyors literally walked from coast to coast along all major road systems creating a network of more than 80,000 benchmarks spread over approximately 150,000 km of leveling lines, mostly in southern Canada (Figure 6).

Figure 6: Canadian Primary Leveling Network



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.

Natural Resources Canada is responsible for the provision of the highest level of the network of benchmarks across the country (first order network) as the basis for all other surveys. In many instances, this primary network has been extended in order to satisfy local requirements through 2nd, 3rd and 4th order networks created by provincial and municipal governments. Over time, these many sub-networks have resulted in many 'realizations' of the datum that can be converted between each other, but which may not have the same values.

The extent of these networks is linked directly to the limitations of traditional survey instruments that require line of site observations. GPS-based approaches will require a substantially less dense network of benchmarks for the same functionality.

3.2 System Uses and Requirements

Interviewees and survey respondents reported a broad range of applications and activities dependent on height information, although they are not always clear as to which subsystem (federal, provincial, regional, municipal, or special purpose) they are using.

Municipal infrastructure, such as streets, water, sewer, drainage, public utilities, etc., is very dependent on height information, and municipal governments frequently provide a local reference system that is tied to the provincial system. Users of these municipal systems are typically concerned with local relative heights, and are not concerned with the relationship to the national system.

Outside of municipal infrastructure, major applications for vertical data include: transportation and utilities infrastructure such as roads, bridges, dams, hydro transmission towers, and pipelines; watershed management and disaster management; natural resource production such as forestry, mining, oil and gas; and mapping. Most users will access whichever vertical system is most convenient and they are concerned primarily with local relative heights. Watershed management is the application most likely to require the absolute accuracy over large areas that the national system provides.

Height is used in watershed management primarily to determine water flow for various purposes. For example, the Water Survey of Canada, within Environment Canada, operates and monitors approximately 2,800 hydrometric stations across the country, 10% of which are referenced to the Canadian Height Reference System (CHRS), and Ducks Unlimited maintains and monitors water control structures at some 12,000 locations in the prairies, 30% of which are referenced to the CHRS, and the remainder often linked to other systems. Watershed management users include modellers who interpolate time series data to monitor flow, for example in the St. Lawrence Seaway or the Red River basin, or to establish and monitor flood plains and regions at risk. Currently there are some 280 inhabited areas at risk of flooding in Canada.

Internationally, the most important applications involve watershed management. For example, in the Great Lakes area an independent common datum, the International Great Lakes Datum (IGLD), is overseen by a Canada-US committee (the International Joint Commission) and used by a number of federal, provincial and state government agencies, private organizations,(e.g., hydro-electric power producers and the shipping and construction industries), and the public for water resources management and planning purposes.

Outside of the Great Lakes, there is no common vertical system between Canada and the United States. U.S. agencies receive frequent requests (both from the U.S. and Canada) on how to convert between their respective systems to facilitate scientific, commercial and other applications across the border, and have, therefore, a high interest in any developments in the Canadian system.

Beyond the U.S., there are also international activities regarding standards for geodesy. These have become more prominent with the increasing use of GPS and the need to integrate international datasets for global monitoring. For example, it is crucial that height information be consistent between countries for use in global gravity field (geopotential) models.

Universities use the height reference system for research and teaching in areas that include sea level changes, vertical crustal motion, precise surveying, navigation, mapping, oceanography, and engineering applications.

Most users are concerned with relative accuracy with respect to local control networks. Only those establishing precise control networks over large areas (such as some watersheds) may be concerned with absolute accuracy to ensure high relative accuracy over large distances. For example, the desire of the Water Survey is to eventually have all benchmarks referenced to the CHRS, however even in this case, since the primary purpose is to monitor water flow, relative local water height changes are of greatest interest. Where high relative accuracy is required over large areas, techniques such as LiDAR and interferometric synthetic aperture radar (InSAR) can be used in place of leveling approaches.

Absolute accuracy does become important, however, when combining information from different data sets – a practice that is becoming more common as information in various GIS systems is shared and integrated among users. For example, users integrating Water Survey data have reported incidences where water 'flowed up hill' when referenced to the CHRS.

Relative accuracy requirements vary by stakeholder and by application type, ranging from mm to sub-metre level for all interviewees, with most operating at the centimetre level.[2] Table 1 provides some examples by application.

[2] The methodology and terminology regarding accuracy are different between GPS and leveling derived measurements. With a leveling approach, relative accuracy is more or less constant, but absolute accuracy decreases, as a vertical height system is extended. With GPS, relative and absolute accuracy are much the same, since height readings are not propagated from one benchmark to the next. In general, the relative accuracy obtained by leveling is currently better than that obtained by GPS, but the absolute accuracy from GPS tends to be better than that from leveling.

Table 1: Application Relative Accuracy Requirements

Example Applications	Cited Relative Accuracies	Operating Ranges
Bridges and Dams	Millimetres	100s of metres
Research	Millimetres	10s to 100s of Kilometres
Construction	Centimetres	100s of metres to Kilometres
Legal Surveys	Centimetres	100s of metres
Municipal	Centimetres	10s of Kilometres
Water Management	Centimetres	10s to 100s of Kilometres
Oil and Gas	Decimetres	10s of Kilometres
Ports	Decimetres	Kilometres
Mapping	Metres	10s to 100s of Kilometres

3.3 The System Status

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

3.3.1 Degradation and Maintenance

Maintenance of the benchmarks and related leveling lines required for the current reference system remains labour-intensive and very costly, but the resources available to maintain the network 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 leveling annually. Approximately 65% (~3,000 km) of the leveling was for maintenance purposes; the other 35% (~1,500 km) was related to network expansion. From 1994 to 2000, GSD performed an average of 1,200 km of leveling annually. GSD has performed only minimal leveling since 2001.

Figure 7: Benchmark Degradation

The current height reference system is accessible only in areas near existing leveling 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 vertical network were to be maintained on a 25-year cycle, approximately 5,600 km of leveling 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 (Figure 7). In urban or near-urban areas the degradation rate could reach 35% for the same period.

3.3.2 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. Comparisons of these heights against the most recent geoid model indicate regional distortions of up to one metre. While the consistency of heights at a local level (relative heights) probably still has sub-centimetre precision, 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 assumes the Pacific and Atlantic oceans are 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. 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 leveling network are expected to increase as maintenance decreases.

3.3.3 Compatibility with the Canadian Spatial Reference System

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.

4. Modernization Advantages and Disadvantages

4.1 Overview

GNSS is transforming not just how height is measured, but making its measurement accessible to more people. As geospatial data becomes more common and electronically available, there will be a greater desire to share and integrate it – making dataset compatibility significantly more important and valuable. Datasets will only be compatible if they are referenced to a common coordinate system. There is, however, confusion over the different datums and height measures (orthometric, geoid, ellipsoid).

The truth is that there are currently a multitude of datums being used in both the vertical and horizontal dimensions. Many of these have been changed over time without serious implications. As long as there is a means to convert between the various datums, in most cases they can probably continue to be used.

The majority of stakeholders consulted feel that the benefits from modernizing the Canadian Height Reference System outweigh the disadvantages. There is a realization that the current system is outdated, inaccurate, and at odds with modern space-based positioning approaches. In fact, few other spatial reference systems have lasted as long as CGVD28. This realization is shared by many other jurisdictions, and countries around the world are moving towards a geoid model approach.

Support for the change tends to be strongest among those who have the best knowledge of vertical positioning. Where there is concern, it often comes from a lack of understanding of vertical datums and misunderstandings about what is being proposed or what it implies.

The primary exception to support for modernization is municipal governments, which are concerned with costs, legacy data conversion, and the confusion that may result from the change to a geoid model. All stakeholders shared concerns about confusion and errors.

Some provincial, municipal, and watershed stakeholders stated that the cost impact would be significant if their databases with a height component needed to be modified – however, it is not clear whether this would in fact be necessary (see 'Height Change Impacts' below). They also mentioned the cost of acquiring GPS technology and training, and the difficulty of acquiring GPS signals in urban centres.

Stakeholders that have modern GIS databases were less concerned about legacy data conversion – they felt that if they were provided with the appropriate transformation they would be able to update their database at minimal expense.

The most commonly identified advantage, noted by virtually all interviewees, was the use of a homogenous, precise datum with reduced distortion and continuity across the country that would improve their ability to share and integrate data.

Some stakeholders would also see reduced costs of establishing vertical heights on remote job sites where benchmarks are not available or the terrain makes leveling difficult. Many stakeholders are already intense users of GPS and would be pleased to have a datum that better supported that approach.

There are two fundamental issues arising from the proposed change in the Canadian Height Reference System:

1. There will be changes in the elevations of CGVD28 benchmarks of up to 1 metre.
2. Over time, the federally maintained benchmarks will degrade.

The following two sections examine the anticipated impacts of these two issues. Section 4.4 then examines the financial impacts that are expected.

4.2 Elevation Change Impacts

Views on the impact of elevation changes must be taken in the context that, among some stakeholders, there is a perception that height is absolute and that the current reference system is accurate. This perception is wrong, but in the past, for most users of the vertical reference system, there was little evidence to dissuade them. However, the use of space-based reference systems is changing that. First, changes in the height of benchmarks, and even in sea level, will become evident using GPS – no longer can a terrestrially based datum be considered static. Second, errors in the current reference system will be immediately evident using GPS. As GPS becomes more common and more accurate, these problems will be magnified.

Stakeholders frequently noted the concern that the height changes could result in misunderstandings and errors. In fact, the feeling was that the likelihood of error due to confusing values from different datums would be greater with small changes in height. The suggestion was made that new elevations should be somehow indicated differently so as to clarify the reference datum to which they refer.

There is a concern among some stakeholders, particularly municipal, that their legacy databases will need to be converted to the new datum – at considerable cost. However, it is not clear that this will really be the case. Currently, many municipalities have their own networks that are tied to the CHRS, but exist independently. A change in the CHRS would not necessitate a change in the municipal network – just a change in the conversion necessary when moving from one to the other. In such cases, there would be no need to change the municipal datum or the legacy data.

Survey companies felt that absolute changes of up to one metre would have little impact on their clients as long as relative heights are maintained and the differences between the old and new datums are documented and publicized.

In the minority of cases where heights for watershed monitoring are tied to the CHRS, some flow models may have to be recalibrated.

Universities consider that there will be no major impact, and only a minor impact for users requiring very precise leveling information. They note that such effects can be minimized or eliminated by providing users with appropriate transformation models between the old and new vertical datums.

Geomatics data providers and users also consider that there will be little impact from absolute height changes with the exception of applications dealing with risk or disaster management (such as flooding). As with the municipalities, they point to the potential for increased error when two or more datum values exist. They believe that height change impacts can be reduced by providing transformation models between old and new datums, and the publication of historical values along with new values.

International stakeholders considered that there would be little negative impact and it could be mitigated with sufficient information. There may even be positive impacts for cross border compatibility as the U.S. moves to a geoid-based datum.

4.3 Benchmark Degradation Impacts

There are two ways of interpreting the impact of benchmark degradation: the impacts of a general degradation of all benchmarks, and the impacts specific to those benchmarks maintained by the federal government. Because most stakeholders do not necessarily know which benchmarks they use (federal, provincial, or municipal, for example), most think of this issue in terms of a general degradation of all benchmarks. In the context of this study, it is only the reduction in the number of federal benchmarks that is being proposed – other networks may still be maintained by other agencies, and in fact more municipal governments are establishing their own networks. However, all agencies will probably be looking to decrease the number of their benchmarks in the future as well.

Municipal and provincial stakeholders expressed the greatest concern that federal benchmarks would be abandoned. This is especially true in urban environments where benchmarks are vital, as GPS often does not operate well in urban canyons. The majority consider that a minimum number of federal benchmarks would have to be maintained over time to ensure the utility of existing height data.

Provincial and municipal governments say they have already felt the impact of the lack of maintenance of benchmarks. These levels of government, as well as some watershed stakeholders, feel that the longer-term impact of a decrease in the number of federal benchmarks would be a greater reliance on their own networks, at a greater cost to their organizations.

The larger surveying companies do not feel they will be impacted by a reduction in permanent benchmarks. They are already intense users of GPS techniques and tend to maintain their own Active Control System Networks based on the HPN reference system. However, they consider that there is a need to maintain some reference benchmarks tied to the old system for continuity to legacy data. It was noted that smaller firms would be more impacted by benchmark degradation, needing to upgrade equipment and skills.

Researchers reported that there would be minimal impact given they have the equipment to create their own static benchmarks. Current methodologies are not dependent on the CHRS benchmarks.

International stakeholders noted that leveling efforts have decreased in the U.S. as well. Their main concern is that for areas of joint interest (e.g. the Great Lakes), decisions regarding the shift to a GPS-based methodology should not be undertaken unilaterally.

Universities noted that impacts of not maintaining a leveling based datum would be insignificant to them as they have the capacity to adapt to the new system.

4.4 Financial Impacts

Each stakeholder group will see different impacts from the modernization of the height reference system. From a financial point of view, stakeholders fall into two major groups: users of height information and providers of the height reference infrastructure (primarily federal, provincial, and municipal governments). Each of these groups will potentially see both costs and savings.

Whether users of height information obtain the information themselves, or out-source to providers of height information (i.e. survey companies) is not relevant to this analysis because the costs and savings of information providers will, given a competitive market, be passed on to their clients.

4.4.1 Impact on Users

Costs

Users will potentially incur three types of costs: 1. Training costs required to implement the new approach to height determination, 2. Capital costs for new equipment and private infrastructure, and 3. Data processing costs to convert legacy data to the new datum. Each of these will be considered in turn.

In any field, on-going training is an expected requirement in a changing world. Based on our consultations with stakeholders, most have already made the transition to the use of GPS and they already have the capability to implement a geoid-based approach to height measurement. Therefore, to a great extent the training costs are sunk costs, i.e. they have already been incurred. This is particularly true for the larger organizations. Also, it can be expected that younger workers will be trained in the new techniques as a matter of course during the transition period.

On-going upgrading of equipment is also an expected requirement, and in tandem with training, users and providers of height information have been renewing their equipment and these are now sunk costs. However, more investment will be required. At the moment, GPS-based survey equipment is more expensive than leveling equipment, although this may change as its use becomes more common.

Legacy data will only need to be converted to the new datum under three conditions:

- The change is significant enough to impact the user. In the majority of locations, the change is a few centimeters or less, which is less than the accuracy with which most users measure elevation.
- The user will be directly impacted by the change. Many municipalities have their own height reference system. While it may be tied to other reference systems and ultimately CGVD28, there is no particular reason that the municipal system or the legacy data needs to change.
- Legacy data must be consistent with new data. In many situations, legacy data may be able to stay in its original format, while new data is collected based on the new datum with appropriate indications to differentiate the two.

In those cases where the conversion of legacy data is required or desired, the effort required will depend on the condition of the database. Data stored in a modern GIS will be relatively easy to transform. Data stored in paper records will require substantially more effort.

Savings

For users of height information, cost savings will accrue in situations where obtaining height measurements using GPS is less expensive than using leveling, such as when a benchmark is not convenient and where there is not a clear line of sight along leveling lines. This will certainly be true in remote areas or rugged terrain and may be true in other situations. Therefore, the impact on a stakeholder will depend on their location and whether other height reference systems (such as provincial or special purpose) are available.

However, it should be remembered that, where it is more cost effective, leveling will continue to be an available approach. The only change that may be required is that a local benchmark be established, if one is not already conveniently located, using GPS and the geoid-based approach.

To the extent that height modernization contributes to the use of a common and consistent height datum, users may also obtain savings due to the ease of combining data from disparate datasets.

Costs Versus Savings

Will the savings exceed the costs for users of height information and by how much? The answer is not straightforward and will differ for each particular user. Factors to consider:

- The costs of training and equipment replacement are ongoing regardless of height modernization, although the marginal costs due to height modernization may be higher in the short-run.
- The cost of legacy data conversion will depend on the necessity of conversion and the current format of the data.
- The savings are very idiosyncratic, depending on the environment of interest to the user – for example, savings will be greater in remote locations with rugged terrain.
- The timing of the costs and savings differ and therefore the time-value of money must be taken into consideration. As is typical with investments such as this, the costs occur sooner and are more certain; the savings occur well into the future and are less certain.
- All of the costs are essentially one-time, whereas the savings continue to accrue into the future.

Overall, however, most users will have the flexibility to participate in the new approach to the extent that maximizes their savings/cost ratio. If they believe it to be to their advantage, users can continue to obtain height data through leveling referenced to CGVD28. Therefore, it can be expected that in the majority of cases, savings will exceed the costs for users of height information.

The experience of Canadian petroleum producers with NAD83 is illustrative of the considerations and costs involved in changing datums. NAD83 was formally adopted by the federal government in 1990. However, the oil industry resisted the change and the Canadian Association of Petroleum Producers (CAPP) did not recommend that its members convert from NAD27 to NAD83 until 2005. Even then, it was understood that some organizations might still decide to delay conversion further still; an organization could decide to store all their data in NAD27 and use 'gatekeepers' to ensure that all data received or distributed by a company has the correct datum. Of course, over time the effort to do this would increase as the rest of the world converted.

In considering this matter, CAPP performed a cost benefit analysis. It found that the cost of conversion for a large organization could be around \$1.5 million, while the cost for a small organization could be very little. They also found that the benefits to industry in the form of cost savings and risk reduction should result in a pay-back of these costs in 1.5 to 5 years, depending on the changes needed to convert. CAPP emphasizes the need to explicitly define the reference datum of any data interchanged with other organizations.

The procedures and systems that the petroleum industry puts in place for the conversion from NAD27 to NAD83 should significantly reduce the cost and effort of the future conversion of height information. Therefore the benefit- cost ratio should be greater and the difficulties fewer. Other industries that have already converted their horizontal data should also experience similar economies with their future conversion of height data.

4.4.2 Impact on Infrastructure Provision

Costs

Providers of height reference infrastructure will potentially incur four types of costs: 1. Establishing and maintaining the geoid, 2. Providing the tools and communications material to facilitate acceptance and implementation of height modernization by users, 3. Creating and maintaining a reduced set of benchmarks consisting of the current Active Control Stations, Canadian Base Network, and High Precision Network, plus additional stations in areas where there is more uncertainty in the geoid model (e.g., Labrador, Manicouagan, South West Yukon, etc.), and 4. Calculating and disseminating the revised heights of all existing benchmarks.

The federal government will bear components of all of these costs. The provincial governments will not be responsible for the cost of establishing and maintaining the geoid.

Savings

The use of a geoid-based approach to height measurement will enable a substantial reduction in the number of benchmarks required in Canada. The savings to providers of height reference infrastructure will be because the legacy network of benchmarks will no longer need to be maintained. In truth, the federal and provincial networks are no longer being maintained in any case. However, the state of the networks will eventually become such that, without modernization of the system, the system is unusable and the cost to repair it exorbitant.

As discussed in Section 3.3.1, assuming the existing vertical network was to be maintained on a 25-year cycle, approximately 5,600 km of leveling would be required annually. At a cost of $250-300 per km, the maintenance cost alone would be $1.4 to $1.7 million per year. This cost does not include repair or replacement of damaged benchmarks ($1,000 to $2,500 per benchmark), nor the costs related to surveys coordination and data management. Even a skeletal network of about 30,000 km proposed as the minimum vertical framework for Canada would cost about $400,000 per year to maintain and potentially pre-empt or delay the work needed to establish a modernized solution.

While GPS can theoretically be used in isolation to determine height, current practice prefers having a benchmark available for calibration, so it is clear that a network of some high precision benchmarks is required. However, freed from the constraints of leveling lines, these benchmarks could possibly be placed in more useful locations and maintained at far less cost.

Costs Versus Savings

While there will be up-front costs from height modernization for infrastructure providers, the long-term costs of maintenance of the benchmark network is such that there is clearly a very positive savings/cost ratio. As will be discussed in Section 6.1.2, New Zealand estimated the cost of upgrading and maintaining their leveling-based system over ten years to be NZ$21,200,000, compared to NZ$900,000 for a geoid-based approach – a benefit-cost ratio of 23.5.

5. Legal Implications

5.1 Overview

While there are numerous applications in which height has legal implications – examples include flood zone and high water mark delineation, reservoir water level regulation, building height regulation, and airspace surveys – most stakeholders felt that there would be minimal legal repercussions to changing the vertical datum. They feel a change in the height datum should not lead to any significant legal issues as long as an official transformation exists between the old and new systems. It may be prudent for stakeholders to review and amend the wording in legal documents, but as long as it is clear which datum was used at the time of the drafting of an agreement, the appropriate conversions can be made.

While legal implications should not be an issue for professionals, they may be confusing for the layperson. The greatest legal risk is that an inadvertent error in confusing the two systems results in a liability situation. Table 2 summarizes the responses of those consulted on legal matters arising from the height modernization initiative. The majority of those consulted, including representatives from all sectors except municipal governments, indicated that there were no legal implications. Of the 48 who provided a response, one quarter indicated that legislation, regulations or contractual obligations would have to be reviewed, and the remainder emphasized the possibility of legal issues arising without effective communications initiatives targeted to the users of height information. Some respondents either did not answer the question, or did not have a view.

Table 2: Views on mitigating legal risks involved in height modernization.

Sector	None	Require Review of Legislation and Contracts	Require Effective Communications to Mitigate Risk	No Answer	Unknown	Total
Federal	2		1			3
Provincial	6	4	1	1		12
Municipal		2	1			3
Industry	10	5	5	1	1	22
Not-for-profit	3	1		1		5
Academic	3			1		4
International	4				1	5
Total	28	12	8	4	2	54

5.2 Issues

Based on the consultations and document review, four legal aspects of the proposed height modernization initiative were identified:

- Legal issues that could arise from legislation, regulations or contracts that make reference to absolute heights and or a height reference system,
- Legal issues that could arise from Natural Resources Canada no longer maintaining benchmarks,
- Legal issues that could arise from changing the height reference system without sufficient communications, and
- Legal issues that could arise from the re-opening of agreements.

These are examined in the following sections.

5.2.1 Legislative, Regulatory and Contract Matters

The activity areas where legal matters could arise as a result of the modernization of the height system, and the nature of the legal issues in those areas, were identified as follows:

- *Water level management:* Provincial and municipal directives can require water levels to be controlled between certain minimum and or maximum heights, for example to control spring run-off. These directives may take the form of water control licenses, and organizations, such as water control boards, can be held liable for damages if the thresholds are not adhered to;
- *Water access:* Provincial and municipal directives can require water levels to be managed between certain minimum and or maximum heights by heavy users of water. These directives may take the form of water access licenses, and organizations, such as hydro companies, can be held liable for damages if the thresholds are not adhered to;
- *Flood zone definition:* Provincial and municipal authorities may define flood zones for such purposes as delimiting property available for urban development, or identifying territory to be affected by a new water control structure. These flood zones are defined by height information on flood zone maps. Organizations that define these zones can be held liable if a flood extends beyond the zone;
- *Topographic data and mapping*: Private and public organizations may create topographic maps used for characterizing flood zones based on flood zone definitions, or for determining the height of airport runways. The producers of these maps may be held liable for incorrect representations of height, for example when a house is constructed in a flood zone;
- *Construction:* Federal, provincial and municipal authorities can provide directives specifying height information for construction purposes. Building permit information may specify

heights in multiple level condominiums, or agreements may specify how high a structure may be built, for example to prevent the obstruction of navigation aids on the Saint Lawrence Seaway.

In general, the concern is that there may be legal repercussions for contractual or other obligations referencing a height value. For example, the top of a building structure currently measured at 18 metres above mean sea level and that is not permitted to exceed that height, could exceed that height as a result of the datum change.

Under both civil and common law, however, the principle that would apply, referred to by some as a cardinal rule[3], is that the intention of the parties at the time a contract is entered into (or legislation is passed) must prevail. The intention must be considered in light of the purpose of the contract or legislation. In all of the activity areas above, the purpose of contracts and legislation is to specify a physical location for conducting activity relative to that physical location. Accordingly, because the physical location has not moved as a result of modernizing the height system, and because both the intentions of the legislatures and the contracting parties and the purposes of the documents have not changed, there should be no strictly legal matters that would arise due to the modernization of the height system. Appendix E identifies the civil code articles from which this principle is drawn; the same principle is reportedly drawn from case law under the common law system.

5.2.2 Benchmark Maintenance

While it has a mandate to maintain, continuously improve, and facilitate efficient access to what is now known as the Canadian Spatial Reference System (CSRS), the view of those consulted in this study is that there is no legal obligation of Natural Resources Canada to continue to provide the current number of physical benchmarks as long as there are other means to access the system. A geoid-based approach can provide such access with far fewer benchmarks.

We were told of a similar situation involving the Water Survey of Canada that had provided water height monitoring services, including the creation of benchmarks, at no charge through the Dominion Water Works Company. Since mid-way through the last century, however, this function has been carried out through a variety of alternative approaches involving one or more of federal, provincial, municipal and private sector organizations. We were not made aware of any legal issues that arose as a result of the reduction of the service by the Water Survey.

5.2.3 Importance of Communications

All consulted through this study emphasized the importance of undertaking an effective communications campaign to promote awareness of the modernized system.

[3] See “Bijuralism in Supreme Court Of Canada: Judgments since the enactment of the Civil Code Of Quebec”, Louise Lavallée, Legislative Services Branch, Department of Justice Canada.

5.2.4 Opening of Legal Agreements

Some concern was expressed about cases where parties would rather that height not be used as a reason to re-open existing agreements where other contentious issues exist that would be painful and expensive to consider.

For example, there were two instances where those consulted identified legal agreements that were of a highly sensitive nature and that, while modernizing the height reference system would not change the intent of the parties to the agreement, it might open controversies. For example, it was reported that several organizations are taking action against a dam operator based in part on evidence from a water flow model used to estimate the downstream effects of an action of a dam operator. The model would have to be changed if the absolute height values entered into it are changed, which could cause one party or the other to question the validity of the model itself, which to this point has not occurred. Similarly, one organization has been given long term water access licenses reported to make reference to absolute heights, while such agreements do not need to be reopened based on the legal interpretation above, some may attempt to reopen them on that basis.

5.3 Review of Legislation and Other Documents

Over the course of the study legislation and other documents were provided that make reference to the height reference system, including absolute heights, i.e. with respect to mean sea level. The findings from a review of these documents are summarized in Table 3.

Table 3: Legal documents brought to the attention of study team, and their treatment

Document	Selected Text	Legal Issue	Treatment
New Brunswick			
Provincial Legislation	CHAPTER A-7.01 - "geodetic elevation" means an established elevation based on (i) the Canadian Geodetic Datum, authorized by Privy Council Order 630, dated March 11, 1935, and appearing in an official publication of the Geodetic Survey of Canada, and (ii) a bench mark derived from the Canadian Geodetic Datum and approved by the Director of Surveys.	References Canadian Geodetic Datum.	An amendment will be necessary when the federal government formally adopts the new datum.
Provincial Legislation	CHAPTER M-14.1 Mining Act PART VIII - BOUNDARY SURVEYS, FRACTION - Surveys and Surveyors Section 91 All angles in a boundary survey under this Act shall be designated by co-ordinates provided for under section 2 of the Surveys Act and the geodetic elevations of those angles shall be based on the Canadian Geodetic Datum authorized by Privy Council Order 630, dated March 11, 1935, and derived from a bench mark approved by the Director of Surveys.	References Canadian Geodetic Datum.	An amendment will be necessary when the federal government formally adopts the new datum.

Nova Scotia			
Land Surveyors Act (Nova Scotia) - Regulations	Elevations used in the determination of a property boundary shall be based on the Canadian Geodetic Datum.	References Canadian Geodetic Datum.	No change required.
Alberta			
Surveying Related Acts	No documents directly refer to the height reference system. In all cases they refer to Alberta Survey Control.		No change required.
Quebec, City of Montreal			
Reglement d'urbanisme	References to "official heights" from the Geodetic Survey of Canada and to Mean Sea Level.		No change in intent or purpose, so no change required.
Direction de la gestion du domaine hydrique de l'État	References to flood risk zone definitions, land rights to forestry companies, and water level maintenance through dams by municipalities and energy companies.		No change in intent or purpose, so no change required.
British Columbia[4]			
Geothermal Resources Act - Geothermal Drilling and Production Regulation	Test hole information requirements: Not more than 3 months after the date of rig release of the drilling rig from a test hole, the operator shall submit a report to the division containing the following information: … (c) the ground elevation of the test holes drilled in metres above sea level;		No change in intent or purpose, so no change required.
Land Title Act	Part 9 — Air Space Titles: "geodetic elevation" means an elevation derived from a source approved by the Surveyor General.	GPS equipment must be approved as source of height data	The Surveyor General of BC has approved GPS equipment for this purpose for certain applications
Land Survey Act	Power to make rules for surveys (1) For the purposes of this Act and the following enactments, the corporation may make rules for surveys: … (c) make rules requiring a land surveyor to report damage to or destruction of a control monument to the Surveyor General;	It is planned that monuments would deteriorate and not be maintained.	Rules or regulations requiring reporting of damage to federal monuments, if any, would have to be repealed given these will no longer be maintained
Manitoba			
Flood Agreement	A.S.L. means above sea level, as established by the Geodetic Survey of Canada in accordance	References an absolute height.	No change in intent or

4 This jurisdiction classified documents according to the importance of reviewing them, only those marked "high importance" are included here.

(example)	with Revision No. 1 dated May, 1970, quad 56096. “To the extent it is possible to do so and is within the control and authority of Hydro, control the flow of water on the regulated waterways so as to ensure that the Static Inundation Level […] does not exceed elevation 169.47m (556.0 ft) A.S.L.; and Use all practical means, including adjustment of flows through control structures, to prevent any inundation of [lands] lying between a Static Inundation Level 169.47m (556.0 ft) A.S.L. and the Setback Lines.		purpose, so no change is required. However, the elevations mentioned will need to be transformed into the new datum.

6. International Experience

New Zealand has already implemented a geoid-based height reference system and their experience is examined in some detail in the following section. The United States is considering such a change, but over a longer timeframe. Their status is examined in Section 6.2.

6.1 New Zealand

Prior to 1998, the official geodetic datum for New Zealand was the New Zealand Geodetic Datum 1949 (NZGD49). This is a two-dimensional datum defining horizontal position only. Where heights were assigned to benchmarks they were in terms of a local determination of Mean Sea Level (MSL). In 1998, NZGD49 was replaced by the New Zealand Geodetic Datum 2000 (NZGD2000). NZGD2000 is a three dimensional datum where the horizontal and vertical components are observed at the same time, unlike NZGD49. The vertical component or NZGD2000 is, however, in terms of the Geodetic Reference System 1980 ellipsoid (GRS80). Heights are therefore ellipsoidal and not related to the local determination of MSL. To make the NZGD2000 ellipsoidal heights useful, a method of deriving orthometric heights from these heights is required.

Complicating the issue is the fact that New Zealand does not have a national height datum. Instead it has thirteen different tide gauges located around the country. These tide gauges represent thirteen different datums, as a number of factors, such as harbour and river outflow, sea level rise and plate tectonics, mean that the different determinations of MSL do not lie on the same equipotential surface.

Precise leveling networks are connected to these gauges. The networks consist of approximately 9500km of first and second order leveling (approximately 10800 1st order marks and 2300 2nd order marks). The networks are not particularly well linked. No attempt has ever been made to carry out an adjustment of all of the precise leveling data (Hannah, 2001).

To address the matter, the Vertical Datum Project was established by Land Information New Zealand (LINZ). The program was designed to develop and implement a geoid model specifically designed for New Zealand that is capable of enabling quality orthometric heights to be derived from ellipsoidal heights and to establish an authoritative national vertical datum.

The Land Information New Zealand (LINZ) Geodetic Strategic Business Plan specifies three goals specifically related to heights datums. These goals are:

- Goal 2. To provide a cost effective system that can generate orthometric heights of points in terms of a nationally accepted system to an acceptable and defined accuracy.
- Goal 4. To support (in the short term) multiple vertical datums and authoritative transformations of heights to an acceptable and defined accuracy.
- Goal 7. To develop a height system to a defined accuracy that enables the generation of orthometric heights from ellipsoidal heights.

From the above it can be seen that Goal 2 relates to a national height datum and Goal 7 relates to the creation of a New Zealand specific geoid model.

A project plan was prepared in 2001, OSG Technical Report 16, to develop a National Vertical Reference System and geoid model. The decision was made to create the new vertical datum using the ellipsoidal heights from NZGD2000 as the authoritative heights. The new datum will be known as The New Zealand Vertical datum 2005 (NZVD05). The geoid model will be known as NZGeoid05.

Note that a decision was made by LINZ to calculate offsets from the geoid to each of the thirteen MSL determinations. This decision was made in preference to attempting to compute one MSL datum for the country, correcting for the variations between the various MSL datum, which may well have resulted in only minor changes to published benchmark levels and resulting in user annoyance rather than any practical benefit. The chosen course of action means that existing MSL datum can continue to be used as they are. There is no intention to create a national orthometric height datum.

6.1.1 Legal Implications

LINZ is required by legislation to provide a geodetic network to support the cadastral systems. The Cadastral Survey Act 2002 section 7 states that the functions of the Surveyor General, and therefore LINZ, include, amongst other things, maintaining a national geodetic system and a national survey control system. Previously, the Survey Act 1986 specifically required the Surveyor General to administer, coordinate, maintain and extend, amongst other things, precise leveling measurements. This act has subsequently been revoked, however the process of developing a project for the creation of a geoid model and a national height datum commenced under this Act.

As mentioned above, the official geodetic datum of New Zealand is now (NZGD2000). This is a geocentric datum and uses ellipsoidal heights on GRS80. As the geodetic control in terms of NZGD2000 is extended and the density of marks increased, more cadastral surveys are being undertaken in terms of NZGD2000. However many cadastral surveys also require heights in terms of MSL. Where available these surveys are generally in terms of one of the precise leveling datums. Where a precise datum is not available, heights are in terms of a lesser standard determination of MSL (e.g. by vertical angle). In order to relate the various height datums used to the official datum, a geoid model is required.

An implication of the implementation of NZVD05 is the contradiction in the Surveyor-General's Rules for Cadastral Survey 2002/2 as introduced by subsequent rulings. SG Ruling 2004/1 specified that NZGD2000 is the preferred datum for cadastral surveys. Since NZGD2000 is 3 dimensional and NZVD05 is part of this datum, then it is implied that NZVD05 is the preferred vertical datum. A subsequent ruling (SG Ruling 2005/3) does not include NZGD2000 as a "preferred height datum"; this means that height datums other than MSL cannot be used for cadastral surveys and is contrary to the previous ruling. A review of the Surveyor-General's Rules may be required to remedy this situation.

6.1.2 Cost

Precise leveling was undertaken over a period of approximately forty years (ending in the 1980's). Since then, no additional leveling and little maintenance has been done on the networks. The network has been deteriorating over the years as marks are being destroyed, damaged and their reliability compromised. LINZ estimates that approximately 10% of the original benchmarks have been destroyed, damaged or otherwise considered unreliable. This figure accounts only for those marks that have been reported; there will be additional marks that have been damaged or destroyed and not reported as such.

In proposing the new project, LINZ undertook a cost benefit analysis of two options to maintain the vertical reference system for New Zealand. The first option is to continue to maintain the existing system by conventional means, i.e. precise leveling. The LINZ study considered costs to re-level and upgrade the network over a 10-year period. LINZ estimated the cost to be NZ$1,400,000 per year. Over the 10 years the cost was estimated to be in excess of NZ$14 million. In addition to this cost there was an annual maintenance cost of approximately NZ$720,000.

The second option was to develop a national geoid model of sufficient accuracy to convert ellipsoidal heights to orthometric. This cost was estimated to be NZ$750,000 over a four year period with annual maintenance costs expected to be in the order of NZ$50,000. Over 10 years the cost was estimated to be NZ$900,000. This cost included the establishment of a National Vertical Datum.

The second option was the preferred option and is currently being implemented.

6.1.3 Benefits

Obviously there is a significant financial benefit to choosing the second option.

The primary benefit arising from the implementation of NZVD05 is the availability of a geoid model that will enable ellipsoidal heights to be converted to orthometric with a greatly improved accuracy. Previously, the EGM96 geoid was used with accuracies in the order of 1 – 2m. Offsets from the geoid to each of the thirteen MSL datums have been calculated so that orthometric heights in terms of the local MSL determination can be derived. This will enable the use of satellite based technology such as GPS to be used to determine and transfer orthometric heights. The use of the geoid model combined with the calculated offsets will allow the height relationship between adjacent (or otherwise) MSL datum to be determined if required.

A limitation of the existing precise leveling network is the relatively poor spatial coverage of marks across the country. This is a factor of the time consuming nature of precise leveling, even taking into account the use of modern digital levels, and the rugged terrain that is a feature of this country. The implementation of NZGD2000, primarily by GPS, and the continuing geodetic observation programme undertaken by LINZ has meant that there is now an extensive and increasing number of marks available with good ellipsoidal heights. These marks are not located just on the main highways, as in general are the precise level benchmarks, but right across the country. They are also placed in locations of relatively easy access. Use of NZVD05, NZGeoid05 and GPS will enable improved orthometric heights to be determined remote from the existing precise leveling routes.

Apart from cost, the time required to undertake a precise leveling program, e.g. the 10 years indicated in section 3, is a major factor in deciding against this option. Due to the extended timeframe the effects of physical phenomenon means the quality the network will be degraded before it is completed. Precise leveling will still not provide a unified vertical datum for New Zealand. On the other hand the use of GPS will allow the geodetic network to be extended much more rapidly and into areas that previously had poor quality height information. The improved coverage of the network, in particular the accurate vertical component, should see the NZVD05 used for more and more applications where precise orthometric heights are not required.

6.1.4 Funding

In the past, the geodetic network (NZGD49) has been seen as a two dimensional datum designed primarily to support New Zealand's cadastral system. Funding for the maintenance and extension of the geodetic network is generated by a levy on all property transactions and cadastral surveys. As noted earlier, NZGD49 has been replaced by NZGD2000. The funding for the development and implementation of NZGD2000, for the purposes of supporting the cadastral system, is from same source as for the maintenance of NZGD49 i.e. levies on land transactions.

As NZGD2000 is a three dimensional datum, it therefore has a vertical component. While this datum was developed to support the cadastre, funding from user levies was not an issue. When the purpose of the datum was extended to encompass a national vertical datum and the development of a geoid model the question of the source of funding became an issue.

An attitude prevailed whereby the funds derived from levies should not be spent on a project that did not directly benefit the original purpose of the levy, i.e. a vertical component having minimal benefit for cadastral users. With unit and strata titles, and height restrictions being applied to subdivision consents and titles, this attitude is no longer completely valid. What has also become obvious is that the geodetic datum, both NZGD49 and latterly NZGD2000, is now used by a much wider range of users than just the cadastral community. With the rapidly expanding growth of the GIS industry, the need to meet international standards for air and maritime navigation and the increasing use of GPS by survey and non-survey users, coordinate systems play a far more significant part in information systems than previously. Of particular interest is the need by more and more users for authoritative heights over a greater spatial extent. Obtaining orthometric heights remote from the precise leveling runs is expensive and time consuming. An increasing demand was being made by the public at large to be able to obtain accurate orthometric heights from GPS observations. To do this a suitable geoid model is necessary.

Noting the foregoing, LINZ management and the government were approached with a proposal showing that the new datum has uses exceeding the requirements of the cadastral system. Funding in addition to the standard geodetic budget was sought and obtained from the government, recognizing the greater public good resulting from the development of the new datum, and in particular the vertical component.

6.1.5 Obstacles

No major obstacles were encountered in building the geoid model. Potentially, funding was an issue, however, as indicated in the previous section, additional funds were obtained from Government once the extent of the varied use made of the geodetic datum was made known. However there were a number of issues that had to be addressed and resolved.

One of the more significant was while the building of a geoid model is reasonably straightforward; LINZ considered that there was no one in New Zealand who had the skills to undertake the work. While the work could have been contracted out, possibly to an overseas agency, it would mean that LINZ would not have the skills and knowledge to carry out ongoing maintenance without resorting to external or overseas contractors. The issue was resolved by sending a suitably qualified LINZ staff member to the Western Australian Centre for Geodesy at Curtin University of Technology in Perth, Australia. This person did PhD studies at the university using the New Zealand geoid model as the basis for a thesis.

The other technical issues encountered relate to the availability of suitable data across the country. There is a relatively poor spread of GPS and leveling heights across the country due to the nature of the terrain. As a result, gravity observations were used to build the geoid model. There is sufficiently accurate gravity and terrain data in New Zealand to enable the gravimetric method of geoid building to be used. There were some issues with formatting of the various files that made up the data sets; however, these issues were resolved without too much trouble.

6.1.6 Risks

At the time of creating the Vertical Datum Project LINZ identified a number of technical and project risks associated with not completing the work. The risks and mitigating comments noted below are quoted directly from the LINZ Vertical Datum Project charter.

"This project carries a medium to high degree of risk if not undertaken. The following technical risks are identified:

- Very expensive maintenance work on the existing vertical network was deferred on the basis that this project, undertaken after completion of the NZGD2000 network, would provide a much cheaper alternative. (Mitigation – expensive maintenance work will need to be undertaken if this project does not proceed, taking funds away from Datum 2000 development).

- New Zealand risks not following international best practice. Even developing countries in Africa, Asia, Central and South America, are well down the path of producing precise geoid models. New Zealand is the only developed country to not have a precise, GPS compatible, national geoid model. (Mitigation – undertake project otherwise we will lose credibility if the project is not undertaken).

- In 1997, in the Geodetic Management System User Requirements project, Airways Corporation identified the need for geoid model for them to be able to meet international airport approach safety obligations consistent with GPS technology that will increasingly be used in aviation. The long lead times (3 – 4 years) for the geoid model mean that this work must start immediately. (Mitigation – undertake project otherwise a major stakeholder will not be satisfied by the geodetic system).

- NTHA advise that Port Authority needs for precise local geoid models will increase in the next few years. Again, this means that the geoid model project must start immediately. (Mitigation – undertake project otherwise a major stakeholder will not be satisfied by the geodetic system).

- A top international expert from the UK is currently available at Curtin University to provide supervision, and software to the project. If advantage of this is not taken this year, it cannot be assumed that a person of his calibre will be available in our region, at no cost, in the future. (Mitigation – undertake project now to take advantage of this opportunity which will lead to reduced costs).

- In his report on the International Association of Geodesy (IAG) Scientific Assembly in September 2001, Don Grant identified the possibility that some of New Zealand's innovative ideas for a cost effective national vertical reference system could be translated to global systems standards. Support for New Zealand's proposals came from key people including the President of IAG. The risk is that otherwise, global systems could be unnecessarily costly for New Zealand to comply with. The key IAG meeting for putting forward these ideas is in 2003 (by which time New Zealand need to show progress and by which time this project should be finished if New Zealand is to have any credibility). (Mitigation – undertake project now to maintain credibility and take advantage of this opportunity which will lead to reduced costs).

- The geoid model and associated vertical transformations will be developed in terms of existing gravitational data with appropriate infill. The final model will be one that is incrementally refined as new data becomes available. This incremental development allows an appropriate risk management approach to the data collection program. The project will not set out to deliver a model that meets the needs of all industry and researchers to the "nth degree". It will meet the needs of most users. For high accuracy or specialized users, it will provide them with a consistent framework or infrastructure that they can connect to and build on (at their expense), or contribute to. (Mitigation – the staged nature of this project will enable an accurate geoid to be built up over a number of years taking advantage of new datasets, as they become available. The approach to carrying out this project essentially in-house, rather than contracting out all work, will minimize costs and see LINZ develop a capability for future maintenance of a National Vertical Datum)".

6.1.7 Implications for Canada

The Canadian situation has many parallels with that of New Zealand. Canada, like New Zealand, has relied on multiple tide gauges as the foundation for the leveling networks, but which suffer from the fact that these different determinations of MSL do not lie on the same equipotential surface. As a result, there are distortions in the benchmark systems of both countries. Also, New Zealand and Canada share challenging topography and remote areas into which it is difficult to extend leveling networks.

New Zealand has led Canada in the decision to address these challenges by moving to a geoid-based approach to measuring vertical height. As in Canada, this move was motivated by both the operational and cost advantages. Operational advantages include the ability to work in areas not covered by the leveling network and improved compatibility with the increasing use of GPS for positioning. Cost advantages include decreases in maintenance of the benchmark network.

New Zealand had adequate gravity information to enable the calculation of an accurate geoid. Canada is waiting for the results from the GOCE satellite mission to enable the calculation of a new geoid with increased accuracy – these results are expected in 2007. Canada will also require additional field work to verify the model.

The New Zealand experience should provide some comfort to Canada as it sets out on its own transition. New Zealand encountered no major obstacles in implementing the new system that were not easily resolved.

6.2 United States

In the United States, the National Geodetic Survey (NGS) defines and maintains the National Spatial Reference System (NSRS), including the nation's vertical datum. Currently, the official vertical datum in the US is the North American Vertical Datum of 1988 (NAVD 88). The primary method of accessing this datum has been through hundreds of thousands of permanent benchmarks. Although the United States do not have firm plans for a geoid-based vertical datum yet, they have, since 1996, supplemented spirit leveling by orthometric heights derived by combining ellipsoid heights from GPS with a hybrid model of the geoid, built specifically to transform from ellipsoid heights to NAVD 88 heights. When controlled by the dense network of accurate NAVD 88 benchmarks, the geoid/GPS method of height determination has been proven to be accurate to 2 cm. Realizing that orthometric heights can change as much as centimeters per year, and because flooding is a primary concern due to hurricanes, tsunamis and other major storms, the United States is seeking a rigorous and cost-effective method to determine elevations. Re-leveling has been ruled out because of the high costs associated with it. Instead, NGS is beginning a program to slowly move from the benchmark realization of the vertical datum to a geoid/GPS realization.

Overall, it seems that the United States plans are similar in approach and scope to those of Canada. Their timeline for establishing a geoid-based vertical datum is a bit more extended though (10 years). Nevertheless, NGS is already funding several research efforts focused on improving geoid determination techniques as well as data collection. In addition, the National Geospatial-Intelligence Agency (NGA) is already funding the development of the next Earth Gravitational Model (EGM) to degree and order 2160[5] (spatial resolution of 10 km) using improved data sets based on high quality SRTM[6] information, altimetry derived gravity anomalies in the oceans, and numerous sources of terrestrial (land, marine, and airborne) gravity data. In parallel, they have been pursuing the acquisition of control data sets (GPS/leveling implied geoid undulations, deflections of the vertical, etc.) that will be used for the evaluation of the quality of various test EGMs. It is expected that this upcoming high-resolution EGM will provide a highly accurate global geoid, which could be used as the basis for the vertical datum not only in the United States but globally, as well.

6.2.1 Implications for Canada

The US National Geodetic Survey and Natural Resources Canada 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) and the slight improvement overall that such a datum would bring.

Today, a readjustment of the Canadian leveling 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.

Stakeholders consulted in our interviews noted that there is currently a significant difference between Canada's CGVD28 datum and the NAVD88 used in the U.S and that therefore the cross-border implications of a datum change in Canada will be minimal.

With respect to the Great Lakes datum, it is expected that IGLD 1985 may have to be replaced with an entirely new datum to correct for changes in elevation due to crustal movement since 1985. Discussions have begun on moving to a geoid-based datum. Such a datum would have to cover at least the Great Lakes basin in both Canada and the U.S. Adopting a Canadian-only national vertical datum would not likely be acceptable unless it was part of a North-American datum adopted in both countries.

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5 This is the maximum degree of the spherical harmonic expansion series that is often used to represent the gravity potential (and geoid). It basically indicates a maximum geoid resolution (half wavelength) of about 10 km.

6 Shuttle Radar Topography Mission

Cooperation with U.S. agencies should continue to ensure continental and international compatibility of future datums and a means to transform measurements among CGVD28, NAVD88, and a new datum should be developed. Ideally, when the U.S. does move to a geoid-based datum, the two geoids will be identical, or at least meet seamlessly along the border.

7. Proposed Strategic Plan

The following proposed strategic plan for the modernization of the Canadian Height Reference System is based on the results of the stakeholder consultations conducted for this study. Members of the Study Steering Committee reviewed and contributed to the strategic plan at a two-day workshop.

7.1 Vision, Mission, and Objectives

7.1.1 Vision

The Canadian Height Reference System[7] will use a geoid-based datum that allows vertical height to be easily and accurately measured at any location in order to meet the current and future needs of stakeholders for compatibility with GNSS[8] technology and international standards.

7.1.2 Mission

The federal government, in cooperation with the provinces and territories, will provide the models, tools, and information necessary to facilitate the transition to a geoid-based datum for the Canadian Height Reference System.

7.1.3 Objectives

During the transition from CGVD28 to a geoid-based datum, the federal government, in cooperation with the provinces and territories, will accomplish the following:

Geoid Development and Maintenance – A geoid will be defined and verified that is capable of allowing orthometric height to be determined to centimetre accuracy. The definition of the geoid will be adjusted as necessary to account for geophysical movement. Monitoring, research, and development will continue to support future improvements.

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7 A height reference system enables the accurate measurement of the vertical position of features in the physical world and ensures that diverse spatial datasets can be properly correlated and compared within a consistent framework.

8 Global Navigation Satellite System. The US Global Positioning System (GPS) is the most famous of these systems, but the Russian GLONASS also exists, and the European Galileo system is under construction.

Stakeholder Interaction – The process and implications for modernization of the height reference system will be communicated to stakeholders. Stakeholders will be consulted regarding their views and concerns, which will be used to guide the modernization plans and process. Stakeholders will be provided with guidance in developing procedures and verifying calculations.

Tools Development – Conversion tools (software and databases) will be made available to allow legacy data to be converted to the new datum and to enable conversions among different datums.

Education – Educational resources (tools, information, guidance, assistance) will be made available to providers and users of height information to assist them in adopting the new methodologies and data.

Infrastructure Development and Maintenance – A system of benchmarks will be maintained consisting of, at a minimum, Active Control Points (ACP), the Canadian Base Network (CBN), and the High Precision Networks (HPN). Additional benchmarks will be required for the verification and maintenance of the geoid, especially in areas where there is greater uncertainty in the geoid model (e.g. Labrador, Manicouagan, South West Yukon, etc.).

Data Dissemination – Information on the heights of existing benchmarks in the new datum will be disseminated.

7.2 Rationale for Modernization

The current Canadian Height Reference System (CHRS) is based on the Canadian Geodetic Vertical Datum of 1928 (CGVD28), adopted in 1935. The datum reference level was defined as mean sea-level determined from data collected at five tide gauges on the east and west coasts. An extensive network of precisely levelled benchmarks provides access to the datum. Although it has successfully served stakeholders for over 70 years, it now suffers from some significant limitations:

- The physical network is very expensive to maintain because of the large number and extent of benchmarks upon which it depends. As a result, neither the federal nor provincial governments have been maintaining benchmarks, and do not plan to in the future.
- The datum is only defined at benchmarks, leaving much of the country without access to the height standard.
- The reference system has significant inherent distortions that are further exacerbated by geodynamic movement.
- The system is not directly compatible with GPS-based measurements and therefore will not be in accord with future international standards.

An opportunity now exists to define a new vertical 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 will be based on a geoid model.

7.3 Proposed Approach

Recent years have witnessed a significant shift towards the use of GPS by the geomatics community because it is more accurate and efficient. GPS allows direct determination of latitude, longitude, ellipsoidal height and, with a geoid model, orthometric height (i.e. height above 'Mean Sea Level') on land or at sea. Since the geoid is a 'virtual' surface 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. In this way, any 3D positions referenced to NAD83 (Canadian Spatial Reference System) will be able to be converted directly into orthometric heights referenced to the new datum.

The new datum will also be accessible through monumented networks, including the federal Active Control Points (ACP) and Canadian Base Network (CBN) points, the provincial High Precision Networks (HPN), and the existing primary vertical network. Both traditional and space-based techniques will coexist throughout a period of transition that could last for decades, however the adoption of the geoid approach to height measurement will allow a drastic reduction in the number of benchmarks required over time.

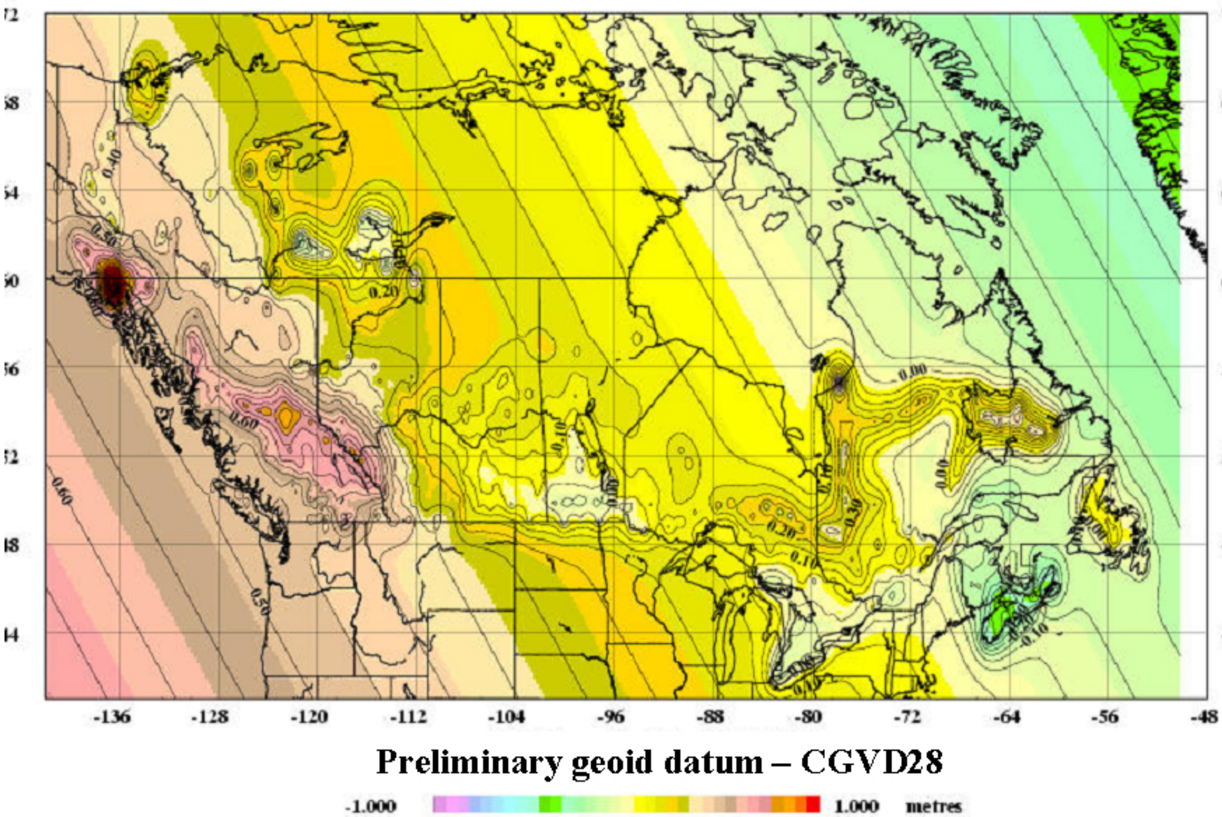
The definition of the new datum will correct benchmark elevations across Canada. The new heights will differ from the current published heights by less than one metre at any single point in Canada, but by more than 10 cm at most locations. Using mean water level at the Rimouski tide gauge as the datum, the change in heights of representative sites across Canada are given in Table 4 (see also Figure 8).

Table 4: Change in heights of the New Datum in Relation to CGVD28 (preliminary)

Location	Change in Height (cm)	Location	Change in Height (cm)
Halifax	-35	Regina	0
Montreal	-10	Edmonton	25
Toronto	-5	Banff	75
Winnipeg	-5	Vancouver	50

The definition of the geoid will be of the highest scientific accuracy achievable when the datum is revised, and its definition will be consistent for many years (several decades) except for changes due to geodynamics.

Figure 8: Differences in Heights of CGVD28 Compared to a Geoid Datum



7.4 *Support of the Stakeholder Community*

Overall, the height reference stakeholder community is supportive of the proposed changes. The provincial governments also support the height modernization initiative and encourage the federal government to exercise the necessary national leadership to make it happen. Height data providers and users in the private sector and the academic and research communities are also supportive.

However, the municipalities are more reluctant. While they understand the reasons for abandoning the current datum, they are concerned that the changes in height values will impact the maintenance of their legacy data – they fear that conversion will be costly, disruptive, and could cause confusion. They want more information before they make the decision to adopt the new datum.

An important activity for the implementation of a modern height reference system will be to involve the municipalities in the process in order to minimize any negative impacts and to maximize the benefits that they can achieve.

7.5 Responsibilities

7.5.1 Federal Government

In 1909, the Geodetic Survey of Canada was created by an order-in-council and given a mandate to determine the positions (and elevations) of points throughout the country with the highest attainable accuracy. In 1984, and again in 1987, the mandate of the Surveys and Mapping Branch was confirmed by Cabinet to include the responsibility to[9]:

> "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, and
>
> survey and map Canada and to disseminate, maintain and update national data bases concerning topographic, geodetic, geographic information …"

With an objective to:

> "refurbish and maintain the national leveling network covering the settled areas in this century and to complete the necessary extension to the North early in the next century."

The modernization of the CHRS is being proposed to meet the objective of maintaining and extending the national standard for height measurement in a manner that responds to Canadian needs, is cost effective, meets internationally accepted standards and practices, and reflects changing technology.

The federal government, through the Geodetic Survey Division of Natural Resources Canada, will contribute to height modernization in the following ways:

- Continue scientific research with academic partners to define and recommend the most appropriate gravity-based surface (geoid) to adopt as datum and conduct additional fieldwork to verify and maintain this model.
- Provide and maintain the Canadian Base Network and the Active Control Points.
- Publish the mathematical model that will enable height determination with respect to the new datum using space-based technology such as GPS.
- Carry out the required transformation of the existing primary leveling network in order to compute and propagate new heights.
- Provide conversion tools and guidelines required to ensure that information gathered with respect to the CGVD28 datum can be integrated with data in the newly defined datum.

[9] www.geod.nrcan.gc.ca/hm/app2_e.php

- Disseminate information on the heights of federal benchmarks in the new datum.
- Help the provinces to facilitate transition and adoption of the new standard among their user communities by providing information and tools for communications.
- Work with the GPS receiver and GIS software industries to ensure that the standards, procedures and documentation are in place to assist users in using the new height reference system.
- Adopt the datum formally when appropriate.
- Monitor progress of the implementation of the new Canadian Height Reference System and make changes to the process as needed.

7.5.2 Provincial and Territorial Geomatics Departments

Each of the provincial and territorial governments has a department or agency that is responsible for matters pertaining to the region's spatial reference system – the coordination of its establishment, maintenance, and integration into the national system. In the past, provinces and territories have differed in the degree to which they have actively participated in the provision of vertical reference system benchmarks, but today no provinces or territories continue to maintain or extend the system of physical benchmarks.

The provinces and territories will contribute to height modernization in the following ways:

- Provide and maintain the High Precision Networks.
- Lead client liaison activities in their region, including communications, consultations, and guidance.
- Carry out the required transformation of the existing provincial leveling network in order to compute and propagate new heights.
- Provide continuous feedback to federal government regarding user needs, user adaptation and potential improvements.
- Consider adopting 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.
- Help the municipalities and other provincial stakeholders to facilitate transition and adoption of the new standard.

7.5.3 Providers and Users of Height Information

The responsibilities of the providers and users of height information vary considerably, but all share an interest in an accurate, accessible, and cost effective height reference system. As for all organizations, providers and users of height information have a responsibility to invest in the education and tools necessary to adapt to, and take advantage of, the opportunities offered by technological improvements such as the modernization of the height reference system.

Providers and users of height information will contribute to height modernization in the following ways:

- Become informed of the proposed changes and consider the implications for their operations.

- Invest in the education and technology required to implement the new approach within their operations.

Educational institutions will provide educational material that incorporates the geoid-based approach to height determination.

7.6 Advantages and Disadvantages

Modernization of the Canadian height reference system has both advantages and disadvantages.

Advantages include:

- Significantly lower cost for maintenance of the height reference system.

- Lower costs for determining heights, especially in remote or rugged terrain.

- Accessibility to the datum at any point on land or sea, without the need for access to benchmarks.

- Compatibility with modern spaced-based approaches to height measurement using, for example, GPS.

- Better compatibility across disparate datasets, making it easier to share and integrate data.

- Improvement in accuracy.

- Future compatibility with international standards for height measurement.

Disadvantages include:

- Cost of training and equipment acquisition necessary to implement a geoid-based approach to height measurement.

- Cost of the creation and maintenance of an accurate geoid, and the cost of communicating the changes to stakeholders.
- Possible need to convert legacy databases to the new datum.
- Possible confusion between the old and new datums, resulting in confusion and errors.
- Possible need to update legal documents and legislation.

Of course, the advantages and disadvantages will not impact all stakeholders equally, and so the decision whether or not to implement the new datum will be specific to each organization.

7.7 Impediments, Risks, and Mitigating Actions

Table 5 summarizes the impediments, risks, and mitigating actions suggested during the stakeholder consultations.

Table 5: Impediments, Risks, and Mitigating Actions

Impediments and Risks	Mitigating Actions
Dependence on Satellite Technology ▪ Problems with the GPS system could result in the unavailability of position data.	▪ Maintain at least some major existing benchmarks and ensure compatibility with other Global Navigation Satellite Systems (GNSS) in addition to GPS.
Misunderstandings and Errors ▪ The small changes between the old and new datums could result in errors and confusion.	▪ Create a designation for the new datum system that will differentiate it from the previous datum. ▪ Ensure that data users are fully informed of the changes and their implications. ▪ Provide a national network of benchmarks where all three heights (ellipsoid, geoid, and orthometric) are available.
Maintenance of the New Datum ▪ Stakeholders are concerned that the datum will change too often. ▪ The earth is dynamic and the geoid will change.	▪ 'Get it right the first time' and minimize changes necessary to the geoid in the future. ▪ Develop geophysical models of the various processes that impact elevation in all regions of North America.
Resistance to change ▪ Stakeholders may be wary of uncertainty and reluctant to change.	▪ Provide communications and educational material that reduces uncertainty and demonstrates the advantages of the new approach.
Transformation of Legacy Data ▪ Some stakeholders are concerned about the cost and difficulties of transforming legacy data to the new datum.	▪ Provide methodologies and tools for data translation. ▪ Publishing old and new height values for federal and provincial benchmarks.

	▪ Support the continued use of the old datum.
Cost of Implementation ▪ The transition period will require information, tools, and data dissemination.	▪ Provide the provinces and territories with help to facilitate the transition in their jurisdictions.
Implementation Management ▪ Stakeholders may not support the datum change unless they feel that they have had the opportunity to guide its implementation.	▪ Implementation should be steered by a joint council of federal and provincial agencies (such as CCOG) and other stakeholders, such as municipalities, surveyors, and water resource professionals, should be involved.

7.8 Implementation Plan

7.8.1 Activities

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

Governance

A Working Committee, reporting to CCOG[10], will be established that is responsible for implementation of height modernization. The committee will exist until the federal government formally adopts the new geoid datum; a period estimated to be four years. With the approval of CCOG, membership on the Working Committee will consist of the current Steering Committee for this strategic plan (consisting of representatives from the federal government and the provinces) and representatives of other stakeholder communities, including water management, the municipalities, the survey industry, and the height community in the United States. The Working Committee and CCOG will need to work closely with the Deputy Ministers of Natural Resources Canada and the relevant provincial and territorial ministries concerning the transition and formal adoption of the new height datum by the federal government and possibly some provincial governments. The Working Committee should work closely with U.S. government agencies to ensure that they are kept apprised of Canadian progress and to seek ways to develop reference systems in the two countries that are compatible.

Geoid Development and Maintenance

An accurate geoid model for Canada will be developed and maintained. The geoid datum will remain stable for an extended period of time (decades)[11], but corrections will be made available to account for changes due to geodynamics. The development and maintenance of the geoid will be done according to international standards and in consultation with other international geodetic organizations, particularly the United States.

[10] The Canadian Council on Geomatics (CCOG) is a federal-provincial-territorial group dedicated to building geomatics partnerships, and sharing information and data. CCOG meets twice a year and develops common areas of interest regarding geomatics policy within Canadian federal, provincial and territorial agencies.

[11] Users of the height reference system have expressed that desire that the geoid be re-defined as infrequently as possible to avoid disruptions in its use.

The geoid model CGG2000[12] is based on the results from GRACE[13] and CHAMP[14] satellite missions and provides accuracies of 5-15 cm. While this does not provide the accuracy of 1-2 cm desired for the new datum, CGG2000 has confirmed the feasibility of the approach.

Achieving the desired accuracy in a new geoid model will require a successful GOCE[15] satellite mission. The plans outlined here are predicated on the success of this mission. If the mission is not successful, the Working Committee should re-evaluate the appropriate course forward.

Verification and maintenance of the geoid model will require an ongoing program of observations by the Geodetic Survey Division to determine when adjustments and corrections are appropriate.

Stakeholder Interaction

Continuing interaction with stakeholders is vital. Such interaction was consistently and persistently reported as being absolutely critical prior to and throughout the transition period, if credibility and confidence in the system are to be preserved. Interaction will be of three types – communications, consultation, and guidance.

Communications

Communications with stakeholders, users and clients will cover the rationale for the change, the implementation and transition plan, timetables, tools, and educational materials.

Communications media might include a website, newsletters, pamphlets, email, publications, and advertisements.

Communications messages should include:

- The need for change – degradation and maintenance, accuracy and distortions, CSRS compatibility.
- The geoid-based approach and the use of GPS for height measurement – theory, procedures, techniques, standards, tools.
- Advantages and disadvantages of the new approach – height measurement savings, accessibility, accuracy, compatibility with GPS and international standards, consistency across data sets, new equipment, training, legacy data conversion, legal issues, confusion and errors.

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12 The Canadian Gravimetric Geoid model (CGG2000)

13 The Gravity Recovery and Climate Experiment (GRACE) is the second mission under the NASA Earth System Science Pathfinder (ESSP) Program. Launching in March of 2002, the GRACE mission will accurately map variations in the Earth's gravity field over its 5-year lifetime.

14 The Challenging Mini-Satellite Payload (CHAMP) is a satellite mission of GeoForschungsZentrum Potsdam (GFZ), Germany's National Research Centre for Geosciences. One of its missions is to measure global long- to medium-wavelength recovery of the static and time variable earth gravity field from orbit perturbation analyses.

15 The Gravity Field and Steady-State Ocean Circulation Explorer (GOCE) is dedicated to measuring the Earth's gravity field and modelling the geoid with extremely high accuracy and spatial resolution. It is the first Earth Explorer Core mission to be developed as part of ESA's Living Planet Programme and is scheduled for launch in 2007.

- Implementation plan – activities, roles, timetable.
- Options for adoption – data conversion or archival.
- Resources – tools, information, guidance, assistance, education.
- Stakeholder feedback on height modernization issues.

Communications and outreach events could include presentations, seminars and workshops across Canada, with materials geared to particular stakeholder groups. To the extent possible, communication events will take advantage of opportunities such as conferences and meetings of user groups.

GeoConnections[16] is a federal organization with excellent recognition among stakeholders and extensive experience in outreach to the geomatics community. They are well positioned to assist in communications activities for height modernization.

Consultation

The process of consultation with stakeholders has begun, but must continue through the implementation period. However, consultation must be extended to more stakeholders, through tools such as surveys and workshops, with the objective of better understanding user needs for information and assistance. In particular, the needs and concerns of the municipalities must be addressed.

Guidance

Data providers and users may require guidance from time to time in methods for using the new height system and in verifying that heights they have measured are accurate. This may be accomplished by the creation of a 'help-line' that could be consulted by telephone, email, and on-line concerning matters related to leveling and data conversion.

The GPS receiver and GIS software industries are often the first source of information for data users and therefore should be assisted in developing publications, manuals, and procedures that take full advantage of the new height reference system.

Tools Development

Clear guidelines, transformation parameters, and tools will be provided for the conversion of legacy data to the new datum.

Conversion software tools similar to the National Transformation (NTv2) will be provided to support the conversion of existing data sets referenced to CGVD28. The tools will be suitable for Windows operating systems and the source code will be available so that users can compile the software on other operating systems (e.g. Macintosh, LINUX, UNIX). The conversion tools will also be made available online.

[16] GeoConnections is a national partnership program to evolve and expand the Canadian Geospatial Data Infrastructure (CGDI). The CGDI provides Canadians with on-demand access to geographic information (e.g. maps, satellite images) and related services and applications in support of sound decision making. See www.geoconnections.org

Software tools will also be created to determine the relative precision of points calculated with reference to the new geoid model.

The Working Committee will work with the producers of GIS software and GPS receivers to incorporate capabilities and file standards in these products that are compatible with the new height reference system.

Education

The standard geomatics educational institutions, including the universities, community colleges, and CEGEPS, will conduct the bulk of the education concerning the details of how to use the new geoid-based approach to height determination. They will be supported in these activities by procedures, guidelines, online tutorials developed by the federal and provincial governments.

Infrastructure Development and Maintenance

The core infrastructure will consist of the Active Control Stations, Canadian Base Network, and the provincial High-Precision Networks. All of these benchmarks will provide 3D coordinates to the ellipsoid and the geoid.

There are also organizations that have, or plan to install, their own stations. Standards for installing, operating, and accessing such stations will be defined.

In order to be able to control and validate the accuracy of a geoid-based vertical datum in Canada, it is recommended that Geodetic Survey Division installs additional GPS-on-benchmark stations for their own use in areas of high geoid slopes and in areas where there is currently very little vertical control and thus the discrepancies between gravimetric and GPS/leveling geoid undulations are high, such as in the Rockies and northern Canada. The spacing of these new stations should be determined based on (i) the slopes of the finally adopted national geoid model for the new vertical datum, and (ii) the sought absolute and relative accuracies for elevations in the new datum.

Manufacturers of GPS receivers will be encouraged and assisted in providing the new geoid model in their equipment. Similarly, GIS developers will be encouraged and assisted in ensuring their software is compatible with the new datum.

Data Dissemination

Transformations to the new height datum for federal and provincial benchmarks will be disseminated through channels such as the Internet. The provinces will assist municipalities in adapting their networks to the new height datum as appropriate. A conversion tool will assist users in transforming their legacy data (see Tools Development above).

Formal Adoption

When the new geoid is available and the other measures for implementation are in place, the federal government will formally adopt the new datum through an Order-in-Council, as was done for the adoption of CGVD28 and NAD83. Such adoption will not preclude the continued use of

CGVD28 by those users that wish to, and the two standards will co-exist for as long as necessary. The process for the development of the Order-in-Council will be coordinated with the Minister of Natural Resources and the Orders in Council Division of the Privy Council Office.

Formal adoption by the provinces will be at their discretion. In many cases, this will not be necessary.

Monitoring

Progress on the development and implementation of the new height reference system will be monitored through the development and application of a Results-based Management and Accountability Framework (RMAF). Work on this has already been initiated.

7.8.2 Schedule

The adoption of a new vertical datum for Canada could be as early as 2010. Publication of a new geoid model is currently planned for 2008 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.

Figure 6 provides the timeline for the modernization of the Canadian height reference system.

Figure 6: Timeline

	2006	2007	2008	2009	2010	…	2030
Geoid development	■	■	■				
Geoid maintenance				■	■	…	■
Stakeholder communications	■	■	■	■	■		
New datum adoption					■		
Tools development			■	■			
Education			■	■	■	…	■
Support			■	■	■		
Infrastructure development			■	■			
Infrastructure maintenance					■	…	■
Data dissemination					■		
Transition period					■	■ …	■

Milestones Achieved

1994 - GSD announced the 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.

2001 - The Canadian Gravimetric Geoid 2000 (CGG2000) was released that confirmed the potential for gravity-based heights.

Milestones Proposed

2008 - Anticipated publication of a new geoid model for Canada.

2009 - Anticipated availability of a new a vertical datum and tools to assist the transition.

2010 - Anticipated adoption of new vertical datum.

2010 to 2030 - Transition period.

A. References

The following reference material has been identified and reviewed.

A.1 Canada

A.1.1 Reports

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Véronneau, Marc (2005) “A Gravimetric Geoid Model as a Vertical Datum in Canada” (CIG paper).

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A.2 New Zealand

A.1.3 Reports

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A.4 International

A.1.5 Reports

Makinen, Jaakko (2004) "Some remarks and proposals on the re-definition of the EVRS and EVRF"; Finnish Geodetic Institute, Massala, Finland.

B. Consultations

List of Organizations Consulted

Organization	Sector	Application
University of Calgary	Academic	Research
University of New Brunswick	Academic	Research
Laval University	Academic	Research
Prairie Farm Rehabilitation Administration	Federal	Agriculture
NAVCANADA	Federal	Transportation
Transport Canada	Federal	Transportation
Saint John Port Authority	Federal	Transportation
EC-NWRI	Federal	Water
National Hydrographic Network	Federal	Water
Water Survey of Canada	Federal	Water
Bedford Institute of Oceanography	Federal	Research
NRCan - Pacific Geosciences Centre	Federal	Research
Canadian Association of Geophysical Contractors	Geomatics Industry	Geomatics
LiDAR Services International	Geomatics Industry	Geomatics
Novatel	Geomatics Industry	Geomatics
Nautical Data International	Geomatics Industry	Geomatics
Alberta Geomatics Group	Geomatics Industry	Geomatics
Canadian Council of Land Surveyors	Geomatics Industry	Surveying
J.D. Barnes	Geomatics Industry	Surveying
Yukon Engineering Services	Geomatics Industry	Surveying
McElhanney Consulting Services Ltd.	Geomatics Industry	Surveying
Universität Hannover	International	Research
International Boundary Commission	International	Geomatics
National Geospatial Intelligence Agency	International	Geomatics
National Geodetic Survey	International	Geomatics
Land Information New Zealand	International	Geomatics
International Joint Commission	International	Water
City of Toronto Survey & Mapping Services	Municipal	Urban
City of Vancouver Engineering Services	Municipal	Urban
Ville de Montréal	Municipal	Urban
Emergency Measures Organization Nova Scotia	Provincial	Emergency
Développement durable,de l'Environnement et des Parcs	Provincial	Environment
Manitoba Water Stewardship	Provincial	Water
Ministry of Transportation Ontario	Provincial	Transportation
BC Base Mapping and Geomatics Services	Provincial	Geomatics
NL Government Services and Lands	Provincial	Geomatics
Geographic Information Ontario	Provincial	Geomatics
Information Services Corporation of Saskatchewan	Provincial	Geomatics
Northwest Territories	Provincial	Geomatics
EPCOR	User Industry	Urban

Aliant Telecom Inc.	User Industry	Communications
Talisman Energy Inc. and	User Industry	Energy
Canadian Association of Petroleum Producers	User Industry	Energy
Canadian Energy Pipeline Association	User Industry	Energy
Hydro-Québec	User Industry	Energy
Manitoba Hydro	User Industry	Energy
Ducks Unlimited	User Industry	Environment
F.E.R.I.C.	User Industry	Forestry
Insurance Bureau of Canada	User Industry	Insurance
INCO Ltd.	User Industry	Mining

Canadian Spatial Reference System
Canadian Height Modernization
Interview Guide

INTRODUCTION

The Canadian Geodetic Vertical Datum of 1928 (CGVD28) does not represent today's required national accuracy. Furthermore, the maintenance and expansion of the vertical network by leveling is too costly, time consuming and laborious. A readjustment of the leveling network, 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. The only viable alternative for the realization of a long-term vertical datum for Canada is a geoid model. It will define the datum in relation to an ellipsoid, making it compatible with space-based technologies for positioning (e.g., GPS and satellite radar altimetry). It will allow easy access to heights above mean sea level all across the Canadian territory. The current first-order leveling will be readjusted by constraining it to ellipsoidal heights and geoid heights at selected CBN stations across Canada. The new datum will bring changes of heights ranging from 0 to 1 m across Canada. However, the heights differences locally will remain with the same precision of a few cm or better. CGVD28 will continue to co-exist with the new datum as long as it will be required, but it will eventually disappear mainly due to the destruction of benchmarks over time.

The adoption of a new vertical datum for Canada could be as early as 2009.

An implementation plan is currently being developed that will:

- Identify the socio-economic impacts
- Identify the legal implications
- Identify the risks and impediments, and provide recommendations for their mitigation
- Develop a communications and transition strategy

THE PROCESS

Hickling Arthurs Low (HAL) Corporation has been engaged by Natural Resources Canada to prepare a strategic plan for the implementation and maintenance of a new modernized Canadian Height Reference System (CHRS).

The purpose of this consultation process is to obtain input from a representative cross-section of stakeholders who may be impacted by the transition to a modernized CHRS.

WE ARE ASKING FOR YOUR INPUT. YOUR VIEWS ARE IMPORTANT IN THE DEVELOPMENT OF AN IMPLEMENTATION PLAN.

Please prepare your responses to the following Questions. You will be contacted by telephone for an interview on ________ at ________.

THE QUESTIONS

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 is the accuracy and precision required in the applications and activities undertaken by your organization? Accuracy and precision should be addressed both in absolute and relative terms.

3. What are the short and long-term impacts on your organization of not maintaining a leveling-based Canadian datum assuming that most benchmarks will not be replaced when they are destroyed?

4. What are the advantages and disadvantages to your organization of adopting a national gravimetric geoid model as a vertical datum? In particular, what are the cost implications?

5. What are the impacts on users of benchmark height changes of up to one meter?

6. What, if any, are 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?

7. Within your organization what are the international cross-border datum difference implications, especially with respect to the US HGS and International Joint Commission long-term planning regarding NAVD88 and IGLD85 respectively?

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 education?

9. What are 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?

THANK YOU FOR YOUR INPUT

C. Consultation Findings by Question

Results are reported here following the structure of the interview guide. For the purpose of summarizing the findings, stakeholders have been segmented into seven groups: data providers, data users, provincial and territorial governments, municipal governments, academic, and international, with data users concerned with water management given special attention because of their particular requirements for accuracy over large areas.

C.1 Applications and Activities

> *What are the applications and activities within your organization that are dependent on height information, and in particular the Canadian Height Reference System?*

Interviewees and survey respondents reported a broad range of applications and activities dependent on height information, although what part of the CHRS is used is less clear since a multitude of height reference sub-systems exist (provincial, regional, municipal, and special purpose) and users are not always aware of which they are using.

Within each province, a ministry or department has the mandate to create, administer and maintain their provincial geo-spatial reference system. Natural Resources Canada (NRCan) has the same responsibilities for the Territories. The provincial systems are tied to the national system maintained by NRCan.

Since municipal infrastructure, such as streets, water, sewer, drainage, public utilities, etc., is very dependent on height information, municipal governments frequently provide a local reference system that is tied to the provincial system. Users of these municipal systems are typically concerned with local relative heights, and are not concerned with the relationship to the national system.

Outside of municipal infrastructure, major applications for vertical data include: transportation and utilities infrastructure such as roads, bridges, dams, hydro transmission towers, and pipelines; watershed management and disaster management; natural resource production such as forestry, mining, oil and gas; and mapping. Most of these will use whichever vertical system is most convenient and they are concerned primarily with local relative heights. Watershed management is the most likely to require the absolute accuracy over large areas that the national system provides.

Height is used in watershed management primarily to determine water flow for various purposes. For example, the Water Survey of Canada, within Environment Canada, operates and monitors approximately 2,800 hydrometric stations across the country, 10% of which are referenced to the Canadian Height Reference System, and Ducks Unlimited maintains and monitors water control structures at some 12,000 locations in the prairies, 30% of which are referenced to the CHRS, and the remainder often linked to other systems. Users include modellers who interpolate time series data to monitor flow, for example in the St. Lawrence Seaway or the Red River basin, or to establish and monitor flood plains and regions at risk. Currently there are some 280 inhabited areas at risk of flooding in Canada.

Studies often examine glacier height and flow in the same way as water, and height differences between points up to 50 km apart can be of interest.

Universities use the CHRS for research and teaching in areas that include sea level changes, vertical crustal motion, precise surveying, navigation, mapping, oceanography, and engineering applications.

Internationally, the most important applications involve watershed management. For example, in the Great Lakes area an independent common datum, the International Great Lakes Datum (IGLD), is overseen by a Canada-US committee (the International Joint Commission) and used by a number of federal, provincial and state government agencies, private organizations,(e.g., hydro-electric power producers and the shipping and construction industries), and the public for water resources management and planning purposes.

Outside of the Great Lakes, there is no common vertical system between Canada and the United States. U.S. agencies receive frequent requests (both from the U.S. and Canada) on how to convert between their respective systems to facilitate scientific, commercial and other applications across the border, and have, therefore, a high interest in any developments in the Canadian system.

Beyond the U.S., there are also international activities regarding standards for geodesy. These have become more prominent with the increasing use of GPS and the need to integrate international datasets for global monitoring. For example, it is crucial that height information be consistent between countries for use in global gravity field (geopotential) models.

C.2 Accuracy Requirements

> *What is the accuracy required in the applications and activities undertaken by your organization? Accuracy should be addressed both in absolute and relative terms.*

The methodology and terminology regarding accuracy are different between GPS and leveling derived measurements. With a leveling approach, relative accuracy is more or less constant, but absolute accuracy decreases, as a vertical height system is extended. With GPS, relative and absolute accuracy are much the same, since height readings are not propagated from one benchmark to the next. In general, the relative accuracy obtained by leveling is currently better than that obtained by GPS, but the absolute accuracy from GPS tends to be better than that from leveling.

Most users are concerned with relative accuracy with respect to local control networks. Only those establishing precise control networks over large areas (such as some watersheds) may be concerned with absolute accuracy to ensure high relative accuracy over large distances. For example, the desire of the Water Survey is to eventually have all benchmarks referenced to the CHRS, however even in this case, since the primary purpose is to monitor water flow, relative local water height changes are of greatest interest. Where high relative accuracy is required over large areas, techniques such as LiDAR and interferometric synthetic aperture radar (InSAR) can be used in place of leveling approaches.

Absolute accuracy does become important, however, when combining information from different data sets – a practice that is becoming more common as information in various GIS systems is shared and integrated among users. For example, users integrating Water Survey data have reported incidences where water ‘flowed up hill’ when referenced to the CHRS.

A select group of researchers studying geophysical deformation require 1 mm absolute accuracy, but they use a global reference frame and not the CHRS.

Relative accuracy requirements vary by stakeholder and by application type, ranging from mm to sub-metre level for all interviewees, with most operating at the centimetre level. The following table provides some examples by application.

Application Accuracy Requirements

Example Applications	Cited Relative Accuracies
Bridges and Dams	Millimetre
Research	Millimetre
Construction	Centimetre
Legal Surveys	Centimetre
Municipal	Centimetre
Water Management	Centimetre
Oil and Gas	Decimetre
Ports	Decimetre
Mapping	Metre

C.3 Leveling-Based Datum Maintenance Impacts

What will be the short and long-term impacts on your organization of not maintaining a leveling-based Canadian datum assuming that most benchmarks will not be replaced when they are destroyed?

There are two ways of interpreting this question: the impacts of a general degradation of all benchmarks, and the impacts specific to those benchmarks maintained by the federal government. Because most respondents do not necessarily know which benchmarks they use (federal, provincial, or municipal, for example), most respondents answered this question in terms of a general degradation of all benchmarks. In the context of this study, it is only the reduction in the number of NRCan benchmarks that is being proposed – other networks may still be maintained by other agencies, and in fact more municipal governments are establishing their own networks. However, all agencies will probably be looking to decrease the number of their benchmarks in the future as well.

Municipal and provincial stakeholders expressed the greatest concern that federal benchmarks would be abandoned. This is especially true in urban environments where benchmarks are vital, as GPS often does not operate well in urban canyons. The majority consider that a minimum number of federal benchmarks would have to be maintained over time to ensure the utility of existing height data.

Provincial and municipal governments say they have already felt the impact of the lack of maintenance of benchmarks. These levels of government, as well as some watershed stakeholders, feel that the longer-term impact of a decrease in the number of federal benchmarks would be a greater reliance on their own networks, at a greater cost to their organizations.

The larger surveying companies do not feel they will be impacted by a reduction in permanent benchmarks. They are already intense users of GPS techniques and tend to maintain their own Active Control System Networks based on the HPN reference system. However, they consider that there is a need to maintain some reference benchmarks tied to the old system for continuity to legacy data. It was noted that smaller firms would be more impacted by benchmark degradation, needing to upgrade equipment and skills.

Researchers reported that there would minimal impact given they have the equipment to create their own static benchmarks. Current methodologies are not dependent on the CHRS benchmarks.

International stakeholders noted that leveling efforts have decreased in the US as well. Their main concern is that for areas of joint interest (e.g. the Great Lakes), decisions regarding the shift to a GPS-based methodology should not be undertaken unilaterally.

Universities noted that impacts of not maintaining a leveling based datum would be insignificant to them as they have the capacity to adapt to the new system.

C.4 Advantages and Disadvantages

> *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?*

The majority of organizations interviewed felt that the advantages of the geoid model outweigh the disadvantages, with the exception of municipal governments, which are concerned with costs, conversion, and the confusion that may result from the change to a geoid model. Concern about confusion and errors was shared by all stakeholders.

Some provincial, municipal, and watershed stakeholders stated that the cost impact would be significant if their databases with a height component needed to be modified – however, it is not clear whether this would in fact be necessary (see 'Height Change Impacts' below). They also mentioned the cost of acquiring GPS technology and training, and the difficulty of acquiring GPS signals in urban centres.

Stakeholders that have modern GIS databases were less concerned about data conversion – they felt that if they were provided with the appropriate transformation they would be able to update their database at minimal expense.

The most commonly identified advantage, noted by virtually all interviewees, was the use of a homogenous, precise datum with reduced distortion and continuity across the country which would improve their ability to share and integrate data.

Some stakeholders would also see reduced costs of establishing vertical heights on remote job sites where benchmarks are not available or the terrain makes leveling difficult. Many stakeholders are already intense users of GPS and would be pleased to have a datum that better supported that approach.

C.5 Height Change Impacts

What will be the impacts on your organization (and its clients) of benchmark height changes of up to one meter, given that relative local heights will not change significantly?

Stakeholders frequently noted the concern that the height changes could result in misunderstandings and errors. In fact, the feeling was that the likelihood of error due to confusing values from different datums would be greater with small changes in height. The suggestion was made that new elevations should be somehow indicated differently so as to clarify the reference datum to which they refer.

There is a concern among some stakeholders, particularly municipal, that their legacy databases will need to be converted to the new datum – at considerable cost. However, it is not clear that this will really be the case. Currently, many municipalities have their own networks that are tied to the CHRS, but exist independently. A change in the CHRS would not necessitate a change in the municipal network – just a change in the conversion necessary when moving from one to the other. In such cases, there would be no need to change the municipal datum or the legacy data.

Survey companies felt that absolute changes of up to one metre would have little impact on their clients as long as relative heights are maintained and the differences between the old and new datums are documented and publicized.

In the minority of cases where heights for watershed monitoring are tied to the CHRS, some flow models may have to be recalibrated.

Universities consider that there will be no major impact, and only a minor impact for users requiring very precise leveling information. They note that such effects can be minimized or eliminated by providing users with appropriate transformation models between the old and new vertical datums.

Geomatics data providers and users also consider that there will be little impact from absolute height changes with the exception of applications dealing with risk or disaster management (such as flooding). As with the municipalities, they point to the potential for increased error when two or more datum values exist. They believe that height change impacts can be reduced by providing transformation models between old and new datums, and the publication of historical values along with new values.

International stakeholders considered that there would be little negative impact and it could be mitigated with sufficient information. There may even be positive impacts for cross border compatibility as the U.S. moves to a geoid-based datum.

C.6 Legal Implications

> *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?*

While there are numerous applications in which height has legal implications – examples include flood zone and high water mark delineation, reservoir water level regulation, building height regulation, and airspace surveys – most stakeholders felt that there would be minimal legal repercussions to changing the vertical datum.

A change in the height datum should not lead to any significant legal issues as long as an official transformation exists between the old and new systems. It may be prudent to review and amend the wording in legal documents, but as long as it is clear which datum was used at the time of the drafting of an agreement, the appropriate conversions can be made. Some concern was expressed about cases where parties would rather that height not be used as a reason to re-open existing agreements where other contentious issues exist that would be painful and expensive to consider.

While legal implications should not be an issue for professionals, they may be confusing for the layperson. The greatest legal risk is that an inadvertent error in confusing the two systems results in a liability situation.

C.7 Cross-Border Implications

Within your organization what will be the international cross-border datum difference implications, especially with respect to the US NGS and International Joint Commission long-term planning regarding NAVD88 and IGLD85 respectively?

International stakeholders noted that there is already a significant difference between Canada's CGVD28 datum and the NAVD88 used in the U.S., and that the U.S. thus has a strong interest in defining a common geoid model (and thereby vertical datum). It is expected that IGLD 1985 may have to be replaced with an entirely new Great Lakes datum to correct for changes in elevation due to crustal movement since 1985. The need for an IGLD will continue regardless of the Canadian height modernization.

Municipal and provincial governments consider that the cross-border implications will be minimal since the two countries currently use different datums. When necessary, joint committees resolve these issues, usually using the vertical datum from one country. Universities also consider this to be of minimal impact provided that databases are maintained. Water and hydropower stakeholders consider the implications minimal provided that there is clear communication and documentation of the datums being used.

C.8 Transition Requirements

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?

Communications was consistently and persistently reported as being absolutely critical prior to and throughout the transition period, if credibility and confidence in the system are to be preserved. Suggested activities include:

- Creating a communications strategy to inform stakeholders, users and clients. This should include the rationale for the change, an implementation and transition plan, timetables, tools, and presentation materials.

- Providing communications and outreach events such as educational seminars, workshops and training opportunities across Canada on the new vertical datum, with materials geared to particular stakeholder groups.

- Providing clear guidelines, transformation parameters, and tools for the conversion of legacy data to the new datum. Conversion tools similar to the National Transformation (NTv2) should be provided on various computer platforms (LINUX, UNIX, CAD, PL/SQL for applications in Oracle Spatial database).

- Ensuring that sufficient active control stations are in place, including consultations with those organizations that have, or plan to install, their own stations. Standards for installing, operating, and accessing the stations must also be defined.
- Publishing old and new height values for federal and provincial benchmarks.

Provincial stakeholders stated that they are concerned about the difficulty in convincing their stakeholders, clients and users to convert to a new datum and will require support, including educational and promotional material, to persuade these groups. They noted in particular the possible cost impact for municipalities, water, and hydropower stakeholders to transform benchmarks to the new datum, to change flow calculations and operating guidelines for structures, and to change models.

Provincial stakeholders felt that additional funding would be required to facilitate the transition – specifically, for additional leveling to fix existing historical problems and for strategic stations, as well as to meet increased equipment, maintenance and training costs, and increased liability due to the complexities of the modernized system.

The provinces felt it important that the transition project be steered by a joint council of federal and provincial agencies (such as CCOG) and that other stakeholders, such as municipalities, surveyors, and water resource professionals, be involved.

Federal water stakeholders noted that the National Administrators Table (NAT), an F/P/T board, approves all national standards for water stakeholders. For example, approval by NAT may be required for water survey technicians to use GPS.

The Water Survey pointed out that their Common Support Process would have to be followed to ensure that anticipated user reactions could be responded to in accordance with the organization's service quality management system. They noted that that major education and communication initiatives have been found to be instrumental in ensuring changes have been accepted in the past.

An ongoing issue is how often to change the definition of the geoid. The preference of the majority of stakeholders is to 'get it right the first time' and to minimize changes necessary in the future. The majority of stakeholders prefer consistency to accuracy.

C.9 Risks and Impediments

> *What will be the risks and impediments for the modernization of the height system, and possible approaches to mitigation?*

The responses from many interviewees imply a close relationship between the transition requirements and risks/impediments. Without the steps and tools noted above, there is significant risk that confidence in, and support for, the new vertical datum will be compromised.

Geomatics data providers consider that there are risks in adopting a vertical datum should there be problems with the satellite technology and the data were to become unavailable. They suggested that mitigation strategies include maintaining at least some major existing benchmarks, and ensuring compatibility with other Global Navigation Satellite Systems (GNSS) in addition to GPS.

Universities noted that there is a risk that new heights may be less accurate if the new datum is not properly implemented. There is a risk that inexperienced users will not understand the implications and accuracies of local frames versus the national datum. Communications is critical to mitigate this risk. Allowing degradation of most current control points means that relative accuracy will become unreliable. Risk mitigation in this instance requires that a geoid-based vertical datum be controlled by a national network of benchmarks where all three heights (ellipsoidal, geoidal, and orthometric) are available.

International stakeholders felt that there is a risk that there will be errors in modeling. The mitigation strategy is to make significant progress on geophysical models of various processes that impact elevation in all regions of North America.

The risk of errors and confusion resulting from small changes between the old and new datums has already been discussed.

Previous experience with the transition from IGLD1955 to IGLD1985 indicates that any resistance to change or suspicions related to changes in known height values, such as water level regulation limits and chart datums, need to be address though communication and education efforts. The use of different, non-uniform methodologies and software would impede the transition from the old to the new datum.

C.10 Additional Comments

Are there any other comments you would like to make?

At the federal level, the Water Survey noted that they are currently undergoing a review of their leveling equipment requirements, and thus the timing of the modernization is good. They consider that greater collaboration and joint investment would be beneficial to both parties.

International stakeholders noted that U.S. plans are similar in approach and scope to those in Canada, but with a longer timeline – they expect it will take more than 10 years to create a sufficiently reliable geoid-based model. Canada must make sure that the gravity and elevation data are accurate enough to model the country well.

Provincial governments consider the height modernization initiative long overdue and encourage the federal government to exercise the necessary national leadership to make it happen.

The municipalities point out that the modernization of the Canadian Height Reference System will have a major impact on them. They want more information before the decision to adopt the new datum can be made – they have their own vertical networks to maintain. They fear conversion will be very costly, disruptive, and could cause significant confusion. While they understand the reasons for abandoning the current datum, they see ‘substantial downside and not much upside’ for them in adopting the new datum.

The geomatics data providers are supportive of the change.

University stakeholders are also supportive. They noted that accuracy of the today’s geoid/quasi-geoid models (based on GRACE and eventually GOCE) is sufficient to justify the change. However, reliable accuracy estimates should be available to users. They consider that Canada should learn from the European experience where numerous height systems and datums are causing multiple problems. They suggest that Canada and the U.S. cooperate on a common datum.

D. Findings by Stakeholder

The following sections present the same information contained in the previous appendix, but this time by stakeholder, rather than interview question.

D.1 Data Providers

Geomatics data providers consider that there will be little impact from absolute height changes, with the exception of applications dealing with risk or disaster management (such as flooding). As with the municipalities (see below), they point to the potential for increased error when two or more datum values exist. They believe that height change impacts can be reduced by providing transformation models between old and new datums, and the publication of historical values along with new values.

In particular, Survey companies felt that absolute changes of up to one metre would have little impact on their clients as long as relative heights are maintained and the differences between the old and new datums are documented and publicized.

The larger surveying companies also do not feel they will be impacted by a reduction in permanent benchmarks. They are already intense users of GPS techniques and tend to maintain their own Active Control System Networks based on the HPN reference system. However, they consider that there is a need to maintain some reference benchmarks tied to the old system for continuity to legacy data. It was noted that smaller firms would be more impacted by benchmark degradation, needing to upgrade equipment and skills.

Geomatics data providers consider that there are risks in adopting a vertical datum should there be problems with the satellite technology and the data were to become unavailable. They suggested that mitigation strategies include maintaining at least some major existing benchmarks, and ensuring compatibility with other Global Navigation Satellite Systems (GNSS) in addition to GPS.

Overall, geomatics data providers are supportive of the proposed height modernization.

D.2 Data Users

In addition to municipal infrastructure (considered below), major uses for vertical data include: transportation and utilities infrastructure such as roads, bridges, dams, hydro transmission towers, and pipelines; watershed management and disaster management; natural resource production such as forestry, mining, oil and gas; and mapping. Most of these will use whichever vertical system is most convenient and they are concerned primarily with local relative heights. Watershed management is the most likely to require the absolute accuracy over large areas that the national system provides.

The most commonly identified advantage of height modernization, noted by virtually all data users, was the use of a homogenous, precise datum with reduced distortion and continuity across the country that would improve their ability to share and integrate data.

Some data users would also see reduced costs of establishing vertical heights on remote job sites where benchmarks are not available or the terrain makes leveling difficult. Many are already intense users of GPS and would be pleased to have a datum that better supported that approach.

Data users that have modern GIS databases were the least concerned about the cost of data conversion – they felt that if they were provided with the appropriate transformation they would be able to update their database at minimal expense.

D.3 Provincial and Territorial Governments

Within each province, a ministry or department has the mandate to create, administer and maintain their provincial geo-spatial reference system. Natural Resources Canada (NRCan) has the same responsibilities for the Territories. The provincial systems are tied to the national system maintained by NRCan.

Provincial stakeholders expressed concern that federal benchmarks would be abandoned. The majority consider that a minimum number of federal benchmarks would have to be maintained over time to ensure the utility of existing height data.

Provincial governments say they have already felt the impact of the lack of maintenance of benchmarks. Provinces have increased their own leveling work by over 50%. They feel that the longer-term impact of a decrease in the number of federal benchmarks would be a greater reliance on their own networks, at a greater cost to their organizations.

Provincial stakeholders stated that they are concerned about the difficulty in convincing their stakeholders, clients and users to convert to a new datum and will require support, including educational and promotional material, to persuade these groups. They noted in particular the possible cost impact for municipalities, water, and hydropower stakeholders to transform benchmarks to the new datum, to change flow calculations and operating guidelines for structures, and to change models.

Provincial stakeholders felt that additional funding would be required to facilitate the transition – specifically, for additional leveling to fix existing historical problems and for strategic stations, as well as to meet increased equipment, maintenance and training costs, and increased liability due to the complexities of the modernized system.

The provinces felt it important that the transition project be steered by a joint council of federal and provincial agencies (such as CCOG) and that other stakeholders, such as municipalities, surveyors, and water resource professionals, be involved.

Provincial governments consider the height modernization initiative long overdue and encourage the federal government to exercise the necessary national leadership to make it happen.

D.4 Municipal Governments

Since municipal infrastructure, such as streets, water, sewer, drainage, public utilities, etc., is very dependent on height information, municipal governments frequently provide a local reference system that is tied to the provincial system. Users of these municipal systems are typically concerned with local relative heights, and are not concerned with the relationship to the national system.

Municipal stakeholders expressed the greatest concern that federal benchmarks would be abandoned. This is especially a concern in urban environments where benchmarks are vital, as GPS often does not operate well in urban canyons. The majority consider that a minimum number of federal benchmarks would have to be maintained over time to ensure the utility of existing height data.

Municipal governments say they have already felt the impact of the lack of maintenance of benchmarks, and as a result many municipalities have established their own leveling-based network.

There is a concern among municipal stakeholders that their legacy databases will need to be converted to the new datum – at considerable cost. However, it is not clear that this will really be the case. Currently, many municipalities have their own networks that are tied to the CHRS, but exist independently. A change in the CHRS would not necessitate a change in the municipal network – just a change in the conversion necessary when moving from one to the other. In such cases, there would be no need to change the municipal datum or the legacy data.

Municipal governments do not necessarily feel that the advantages of the geoid model outweigh the disadvantages, and are concerned with costs, conversion, and the confusion that may result from the change to a geoid model. Concern about confusion and errors was shared by all stakeholders.

The municipalities point out that the modernization of the Canadian Height Reference System will have a major impact on them. They want more information before the decision to adopt the new datum can be made – they have their own vertical networks to maintain. They fear conversion will be very costly, disruptive, and could cause significant confusion. While they understand the reasons for abandoning the current datum, they see ‘substantial downside and not much upside’ for them in adopting the new datum.

D.5 Academic and Research

Universities use the CHRS for research and teaching in areas that include sea level changes, vertical crustal motion, precise surveying, navigation, mapping, oceanography, and engineering applications.

Universities noted that impacts of not maintaining a leveling based datum would be insignificant to them as they have the capacity to adapt to the new system. Researchers reported that there would minimal impact given they have the equipment to create their own static benchmarks and their current methodologies are not dependent on the CHRS benchmarks.

Universities noted that there is a risk that new heights may be less accurate if the new datum is not properly implemented. There is a risk that inexperienced users will not understand the implications and accuracies of local frames versus the national datum. Communications is critical to mitigate this risk. Allowing degradation of most current control points means that relative accuracy will become unreliable. Risk mitigation in this instance requires that a geoid-based vertical datum be controlled by a national network of benchmarks where all three heights (ellipsoidal, geoidal, and orthometric) are available.

University stakeholders are supportive of the height modernization. They noted that accuracy of the today's geoid/quasi-geoid models (based on GRACE and eventually GOCE) is sufficient to justify the change. However, reliable accuracy estimates should be available to users. They consider that Canada should learn from the European experience where numerous height systems and datums are causing multiple problems. They suggest that Canada and the U.S. cooperate on a common datum.

D.6 International

Internationally, the most important applications involve watershed management. For example, in the Great Lakes area an independent common datum, the International Great Lakes Datum (IGLD), is overseen by a Canada-US committee (the International Joint Commission) and used by a number of federal, provincial and state government agencies, private organizations,(e.g., hydro-electric power producers and the shipping and construction industries), and the public for water resources management and planning purposes. It is expected that IGLD 1985 may have to be replaced with an entirely new Great Lakes datum to correct for changes in elevation due to crustal movement since 1985. The need for an IGLD will continue regardless of the Canadian height modernization.

Outside of the Great Lakes, there is no common vertical system between Canada and the United States. U.S. agencies receive frequent requests (both from the U.S. and Canada) on how to convert between their respective systems to facilitate scientific, commercial and other applications across the border, and have, therefore, a high interest in any developments in the Canadian system. U.S. plans are similar in approach and scope to those in Canada, but with a longer timeline – they expect it will take more than 10 years to create a sufficiently reliable geoid-based model. Canada must make sure that the gravity and elevation data are accurate enough to model the country well.

Beyond the U.S., there are also international activities regarding standards for geodesy. These have become more prominent with the increasing use of GPS and the need to integrate international datasets for global monitoring. For example, it is crucial that height information be consistent between countries for use in global gravity field (geopotential) models.

D.7 Water Management

Height is used in watershed management primarily to determine water flow for various purposes. For example, the Water Survey of Canada, within Environment Canada, operates and monitors approximately 2,800 hydrometric stations across the country, 10% of which are referenced to the Canadian Height Reference System, and Ducks Unlimited maintains and monitors water control structures at some 12,000 locations in the prairies, 30% of which are referenced to the CHRS, and the remainder often linked to other systems. Users include modellers who interpolate time series data to monitor flow, for example in the St. Lawrence Seaway or the Red River basin, or to establish and monitor flood plains and regions at risk. Currently there are some 280 inhabited areas at risk of flooding in Canada.

Studies often examine glacier height and flow in the same way as water, and height differences between points up to 50 km apart can be of interest.

Implementation of height modernization may have the following implications for water management stakeholders:

- In the minority of cases where heights for watershed monitoring are tied to the CHRS, some flow models may have to be recalibrated.
- Federal water stakeholders noted that the National Administrators Table (NAT), an F/P/T board, approves all national standards for water stakeholders. For example, approval by NAT may be required for water survey technicians to use GPS.
- The Water Survey pointed out that their Common Support Process would have to be followed to ensure that anticipated user reactions could be responded to in accordance with the organization's service quality management system. They noted that that major education and communication initiatives have been found to be instrumental in ensuring changes have been accepted in the past.

E. Civil Code Articles

The articles listed below are from the Civil Code Of Québec, updated to 1 March 2006[17]. These articles were reported to apply to contract interpretation.

BOOK FIVE

OBLIGATIONS

TITLE ONE

OBLIGATIONS IN GENERAL

CHAPTER I

GENERAL PROVISIONS

1371. It is of the essence of an obligation that there be persons between whom it exists, a prestation which forms its object, and, in the case of an obligation arising out of a juridical act, a cause which justifies its existence.

1991, c. 64, a. 1371.

1372. An obligation arises from a contract or from any act or fact to which the effects of an obligation are attached by law.

An obligation may be pure and simple or subject to modalities.

1991, c. 64, a. 1372.

1373. The object of an obligation is the prestation that the debtor is bound to render to the creditor and which consists in doing or not doing something.

The debtor is bound to render a prestation that is possible and determinate or determinable and that is neither forbidden by law nor contrary to public order.

1991, c. 64, a. 1373.

[17] See www2.publicationsduquebec.gouv.qc.ca

1374. The prestation may relate to any property, even future property, provided that the property is determinate as to kind and determinable as to quantity.

1991, c. 64, a. 1374.

1375. The parties shall conduct themselves in good faith both at the time the obligation is created and at the time it is performed or extinguished.

1991, c. 64, a. 1375.

1376. The rules set forth in this Book apply to the State and its bodies, and to all other legal persons established in the public interest, subject to any other rules of law which may be applicable to them.

1991, c. 64, a. 1376.

CHAPTER II

CONTRACTS

DIVISION I

GENERAL PROVISION

1377. The general rules set out in this chapter apply to all contracts, regardless of their nature.

Special rules for certain contracts which complement or depart from these general rules are established under Title Two of this Book.

1991, c. 64, a. 1377.

DIVISION II

NATURE AND CERTAIN CLASSES OF CONTRACTS

1378. A contract is an agreement of wills by which one or several persons obligate themselves to one or several other persons to perform a prestation.

Contracts may be divided into contracts of adhesion and contracts by mutual agreement, synallagmatic and unilateral contracts, onerous and gratuitous contracts, commutative and aleatory contracts, and contracts of instantaneous performance or of successive performance; they may also be consumer contracts.

1991, c. 64, a. 1378.

DIVISION III

FORMATION OF CONTRACTS

§ 1. — *Conditions of formation of contracts*

I. — *General provision*

1385. A contract is formed by the sole exchange of consents between persons having capacity to contract, unless, in addition, the law requires a particular form to be respected as a necessary condition of its formation, or unless the parties require the contract to take the form of a solemn agreement.

It is also of the essence of a contract that it have a cause and an object.

1991, c. 64, a. 1385.