BCACS-Providing Geo-Spatial Reference Through GPS Network

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SUMMARY

The 21st century has started out with a very positive outlook for the GPS community and its applications around the world. There has been great progress; from the elimination of selective availability in 2000 to a combination of modernizing of GPS signals, by implementing L2C and L5, through planned launches of new GPS satellites and a new GNSS from coming out of Europe called Galileo. It is an important for all nations to develop and update their current geo-spatial referencing infrastructure in order to be compatible with these changes and support and utilize them to develop their nation as a whole. This can be achieved by implementing a network of continuously operating reference systems (CORS) across a country to provide reliable, accurate and compatible GPS data. In the Province of British Columbia in Canada, that CORS system is called the British Columbia Active Control System (BCACS). The BCACS is operated by Base Mapping and Geomatic Services (BMGS) and a few municipal agencies. The BCACS is extensively used through out the urban and rural areas of the province; users range from municipal bodies and industries to land surveyors, all requiring access to accurate and reliable geospatial data. The network is and ever improving and expanding entity that provide quality geospatial services to the industries that drive and shape the provinces economy as a whole. This paper discusses the elements of a successful GPS network and how to utilize it in order to satisfy users and to further improve services to keep up to date with the ever-changing technologies.

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1. INTRODUCTION

The Province of British Columbia provides unique challenges to surveyors and engineers requiring precise positioning. Its geography is extremely rugged, vast and varied. The majority of British Columbians live in the southwest corner of the province in the Lower Mainland and on southernVancouver Island. The rest of the province is dotted with scattered population centers. Much of the province is remote and inaccessible, often with few amenities both technological and otherwise. In the past, surveys were painstakingly carried out within the province using traditional survey equipment consisting of transits and chains, or levels which were initially used to divide land for forestry, mining and homesteading.

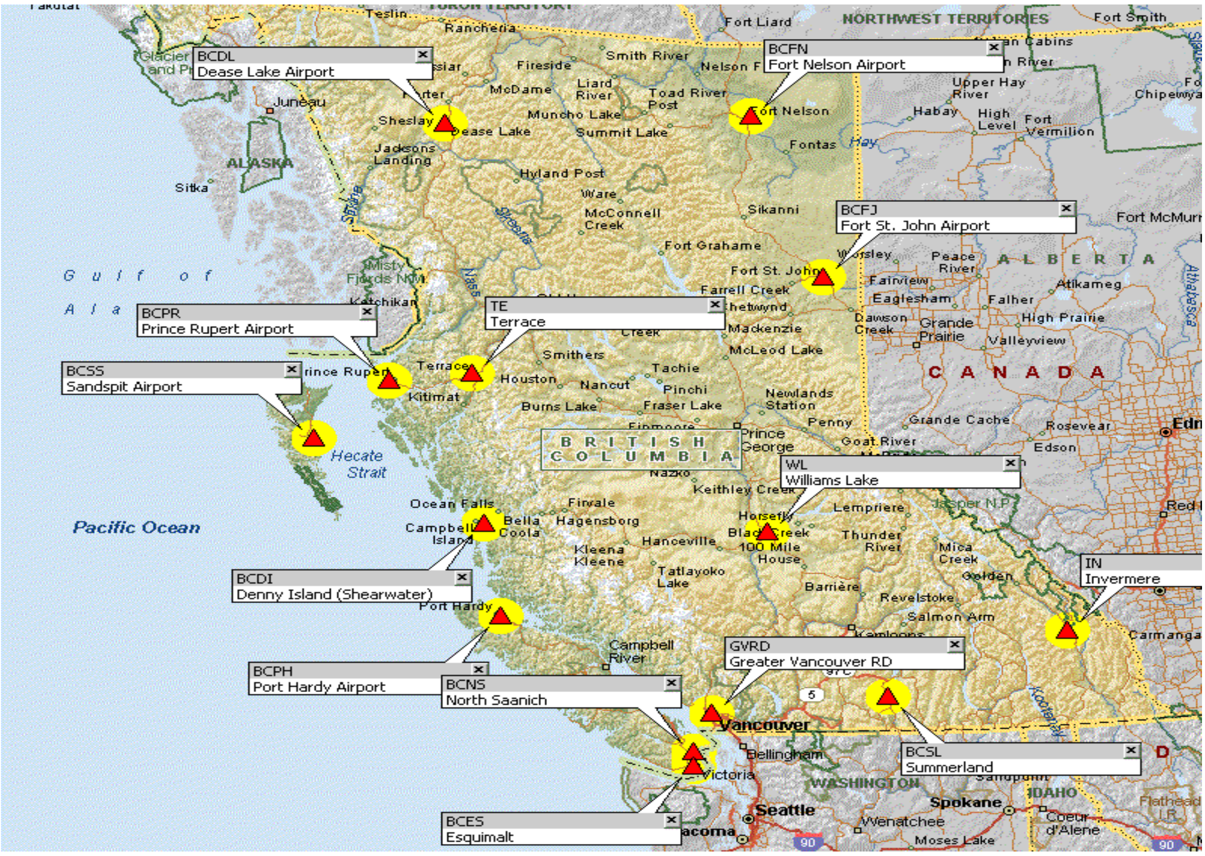
In the past, national and regional control networks were originally developed by surveyors who literally walked across the country to establish a physically monumented system that formed the framework of the NAD27 datum. These monumented systems were vital in developing the country's urban and rural communities, dealing in land ownership issues and determining where the Crown lands were. The monumented system was, and still is, maintained and looked after by Provincial and Federal governmental branches who keep databases and records of the control markers, their accurate coordinates, and other attributes. There have been significant technological advancements since the establishment NAD27 as a national datum. The use of Very Long Baseline Interferometry, electronic theodolites and GPS satellites exposed the weakness and unreliability of the established NAD27 network. New surveys that were established with existing control were constantly showing irregularities in the survey data. Finally, efforts were made to upgrade and modernize to the present NAD83 datum, which provides consistency across the nation for the modern surveyor.

After the implementation of NAD83 as the new nation wide datum, it has become impractical and inefficient to continue using monuments as the sole entity for GSR in the Province of British Columbia. With GPS becoming a prevalent civilian technology in the early to mid 90's, using a continuously operating GPS reference system was the next natural step for the province to provide reliable method for the ever growing professional GPS users. In British Columbia, a network of CORS or ACPs was set up across the province to form the BCACS.

2. BCACS HISTORY AND DESCRIPTION

Ever since the acceptance of GPS technology as a viable survey tool the older methods of traversing from monuments to points of interest has been overshadowed, especially in situations where the full functionality GPS can utilized i.e. under favourable GPS conditions. The physically monumented system has gone from being the primary reference to the coordinate datum to being a backup system that is used in conjunction with, or as a support to a GPS survey. The disadvantages of using monuments arise from replacement and maintenance costs and the extra man hours spent on the field during a survey. The majority of the control monuments in the Province of BC are concentrated in urban areas, along highways or on mountaintops, often requiring helicopter access. Anyone wishing to carry out a survey out in rural areas or in the “bush” will need to traverse from the closest monument; this maybe extremely impractical and expensive. A GPS receiver can accomplish the same task more accurately and much more economically. Differential GPS can be used to achieve very accurate results, and if a CORS/ACS facility is nearby all you need is a single receiver to carry out the survey.

The BCACS is a network of 20 continuously operating Active Control Points (ACPs) installed at strategic locations across the Province of British Columbia in Canada. The BCACS is comprised of a combination of municipal and BMGS (Base Mapping and Geomatic Services) owned GPS receivers of diverse vintage, manufacturers and models. The network is managed by BMGS; base data for post mission services is used by a variety of clients, from municipal authorities to resource industries including forestry, wildlife management, hydrographical surveys, road construction and oil and gas development.



BCACS ACP locations across the Province of British Columbia

3. WHY ACS/CORS?

The principal day-to-day uses of GPS around the world are recreational. This means that the accuracy of recreational grade GPS receivers is adequate with out the need for special techniques to enhance accuracy. There other more involved GPS users, which include surveyors, scientists, engineers, transport personnel and many others in related disciplines that require a much higher accuracy and reliability for spatial data. There have been a number of techniques and equipment developed to achieve this. The technique that this paper focuses on is the use of an Active Control System which could be implemented at the local, regional or national level. The ACS records GPS data from all visible satellites at a known control point in an automated manner; the data can then be used to achieve very accurate relative positioning, in the order of centimetres, for surveys in the vicinity (maximum 20-30 km radius).

The base receiver is established on a control point with precisely known coordinates and it will observe all types of GPS signal transmitted by the satellite vehicles in the sky above it. All this data is logged, stored and made readily available for GPS user to improve their surveys either through post processing or through a real time RTK network. The ACPs are unmanned, but are remotely managed by an ACS manager through specialized software who oversees the receivers operations and maintenance in order to produce quality control and assurance for the users. The ACS stations are also used for other scientific purposes such as monitoring plate tectonics and even clock correction data when incorporated into a monitoring GPS network. When analysing an ACS there are a few things that need to be considered: hardware configuration, site configuration and the handling of data. These will be explained in the next sections.

3.1 Hardware Configuration:

One of the most critical decisions is choosing appropriate hardware devices that will work harmoniously together in order to construct a center for accurately monitoring and logging vital GPS data. The heart of an ACS system is the receiver itself, the operator must choose one of high geodetic quality that is able to track all satellites in view and the GNSS signal transmitted from them particularly GPS P-code and C/A pseudo-ranges and L1, L2 phase signals. The ability to track future Galileo and GPS signals is advantageous and will be addressed as part of the ongoing BCACS upgrading process. Other important abilities to consider are; the data collection rate, real time output capabilities and remote access to the receiver. Other hardware to consider includes the type of antenna used and finally the connection to the outside world via a modem and telephone lines or a router and a cable connection.

3.2 Site Configuration

Choosing an appropriate location to setup an ACS is vital to maintaining the integrity and accuracy of data produced by an ACS station or network. ACPs should be placed in areas where relative positioning surveys are carried out. These sites must be secured in a safe place at the location to prevent damage from the elements and from vandalism. The antenna needs to have an unobstructed view of the sky from at least 5 degrees above the horizon. Another issue it to make sure that there is no other facility near by that might generate radio or microwaves that would interfere with the GPS signals. Finally, all antennas should be securely fastened to a sound solid structure or to a column imbedded in the bedrock.

3.3 Data Handling

An ACS is continuously observing and recording GNSS data. Reliable communications are required to transmit the data to a central facility where a software application such as Leica’s GPS SPIDER or Trimble’s GPSNet operates. These software applications can perform a variety of QA/QC tests on the data, perform conversions from the raw GPS format to other formats such as RINEX and then make it available via an FTP site to be accessed for post processing. The software also creates corrections for RTK correction data to be transmitted to surveyors in the field.

4. CURRENT USES FOR BCACS

Below are sections that describe a few of the current everyday uses of the BCACS

4.1 Municipal Active Control Systems - BCACS^{m}

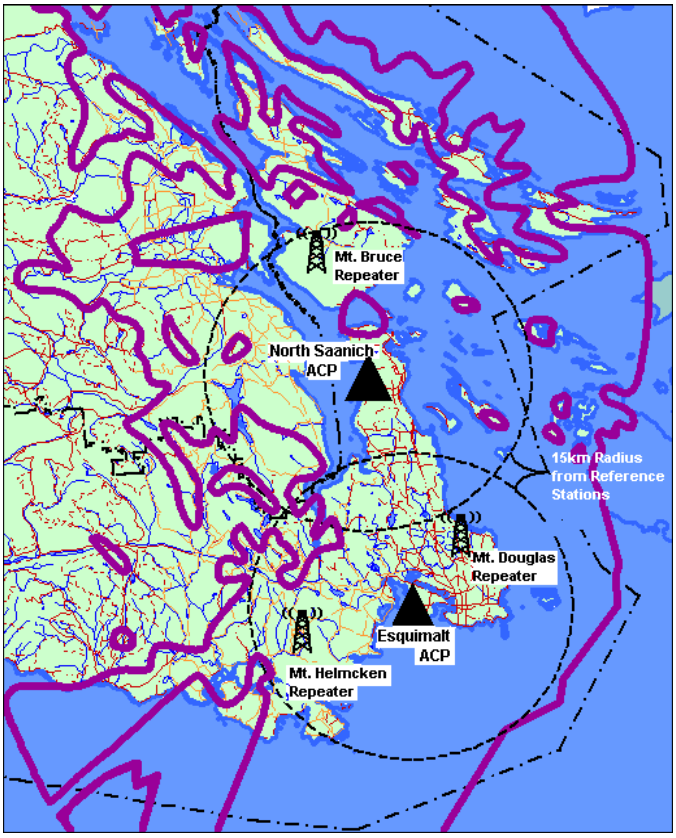
In the late 1960's the Province initiated a program to establish dense survey control within urban areas. This program, known as Integrated Survey Areas, as well as establishing horizontal and vertical control in urban areas provided legislation to ensure legal surveys were tied to this control. The ISA program worked well for many years, but the advent of GPS supported a new initiative to ensure that horizontal and vertical control is available for municipal applications while providing for a considerably sparser network than previously required. This new program, known as the Municipal Geo-Spatial Reference, is advantageous due to the cost of creating a new network as well as the high cost of ongoing maintenance of the network, replacing damaged and destroyed monuments. Additionally, this sparse network does not have the requirement that the monuments are intervisible, allowing them to be sited in locations less likely to be damaged and providing more secure access by users, away from traffic flow for example.

The urban topography of these areas is constantly being changing through development and construction. As they expand, a need a rises to have an accurate and reliable Geo-spatial reference system that can be used by various levels of the municipal government and private sector firms to provide quality geomatic services to the communities in the area. Before the BCACS was put into operation, a dense layer of land monuments and benchmarks were laid across the both regions that were used as the sole reference points to carry out any form of geo-spatial reference for the purpose of surveying, mapping and earlier forms of GIS. These monuments served the surveying community well because of their accuracy and reliability. However, as in most parts of the world, they had their drawbacks of being costly to maintain and expand, difficulty to apply any changes on the national datum to and a sizable crew was needed to complete a successful survey operation. These drawbacks were unavoidable until the early days of GPS when GPS technology was still extremely costly. As receivers got cheaper and the impracticality of having a physically monumented system to the modern surveyor grew, it eventually gave rise to the economical pressure on the provincial governments to shift to a digitally monumented system for the benefit of the province and it related geo-spatial activities. Currently in the Greater Vancouver Regional District (GVRD) and Capitol Regional District **(**CRD), the BCACS provides both real time and post mission services to both government and private users of GPS within the area. Typical uses of the BCACS^{m} include:

- Land surveying - Cadastral surveys, land development, etc.
- Engineering surveys - as-built surveys, utility and infrastructure layout, inspections, etc.
- GIS data collection - GIS pickup, thematic mapping, utility data capture
- Police and Enforcement - incident analysis, tracking, spills, etc.
- Fleet Management - vehicle routing, emergency response

The network that has been set up at the GVRD and CRD are essentially the same. The achievable accuracies (at 95% confidence level) are shown below:

Dual frequency RTK	3 — 4 cm	Single frequency code differential (quiet, P Code)	– 1m
Single frequency phase differential	4cm — 1m	Single frequency code differential (recreational)	– 3m



Both municipal networks covering the regions are part of the provincial network spanning the whole of BC. The CRD has 2 ACS stations where as the GVRD has 5 stations. Each network provides RTK correction to the communities surrounding it through CMR and/or RTCM 3.0 formats, making it receiver independent. The stations also log RINEX data to a central FTP for those who do not require RTK or for projects that are too far away from a reference station to make use of RTK. The CRD broadcasts corrections through 3 radio repeaters on the UHF band strategically located to provide coverage over the urban part of the CRD. Corrections in the GVRD are broadcast to users through Bell's 1x wireless network (cellular).

CRD ACP locations

GVRD ACP Locations

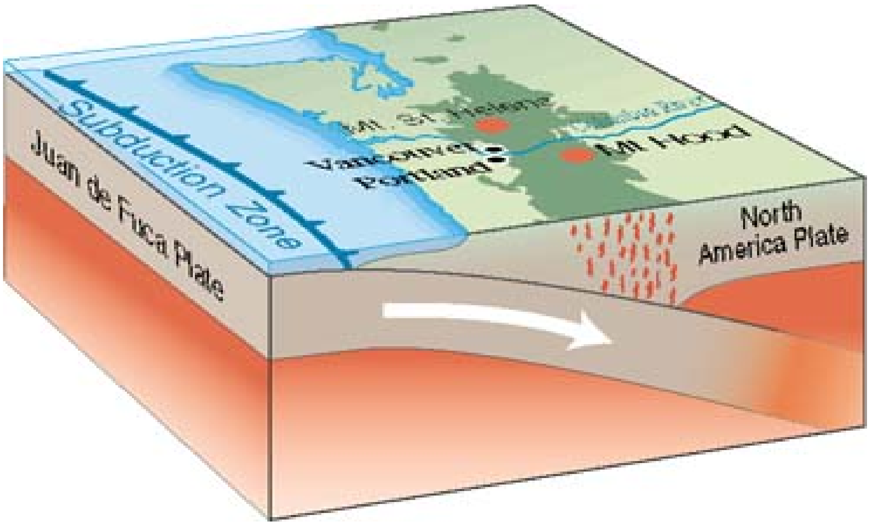
To ensure compatibility between the sparse physical network of control monuments and the GPS reference stations, a High Precision Network (HPN) was established across the CRD and GVRD. A network spacing of 2km-3km in built up areas and 10km in non-urban areas was created by selecting existing monuments and installing new monuments as necessary. This network was surveyed using 1st order levelling and GPS ties to ensure that the HPN network was compatible with the ACPs to the centimetre level. The remainder of the existing network was adjusted using historic observations to ensure the GPS, HPN and existing ISA control was compatible horizontally and vertically. The non-HPN monuments in the network will not be maintained or replaced, thus saving considerable maintenance costs over the coming years.

4.2 BCACS uses in Scientific Applications

Below are two separate and important uses of the BCACS to scientific applications in North America

4.2.1 Western Canada Deformation Array (WCDA) "How does BCACS link to this?"

The WCDA is a network of 16 active control stations located through out the SW region of British Columbia. The array is used to monitor the region as a part of a multidisciplinary quest to undergo studies of the dangers of seismic activity on the densely populated lower mainland BC and Vancouver Island. The SW region of BC is located on the western edge of the North American plate on top of the actively subducting Juan de Fuca plate (please see figure below).



Before the WCDA was established, measurements of the strain on the subducting zone were carried out by repeated laser ranging and GPS surveys. The results were reliable, but were limited temporally due to the fact that the data acquisition was not continuous.

The problem was solved by implementation a network of ACPs otherwise known as the WCDA, which continuously log GPS observations. The first station, DRAO, opened at Penticton BC in February 1991 and gradually expanded to 16 stations.

The WCDA was primarily put in place to provide continuous positional data for regional crustal deformation analysis under the earthquake hazards program of Geodetic Survey Division Canada. Other operational tasks that the WCDA is responsible for includes providing a precise and common reference frame for all deformation surveys carried out in the active seismic region and serve as a strain meter to map regional strain and to monitor transient strain signals that can be used to refine the observed positional data. WCDA also contributes to the scientific studies on post glacial rebound that are being conducted across Canada and the United States.

4.2.2 BCACS and its Contribution to NAREF

The North American Reference Frame (NAREF) has been created primarily to densifiy the ITRF frame in North America. The densification is achieved by gathering GPS data from CORS facilities across North America that are not part of the IGS global network. The data is gathered weekly to compute coordinate solutions as well as accuracy and velocity information that are stored and analyzed to refine the frame. The BCACS is a contributor of data to this project through bodies such as the Natural Resources Canada.

4.3 BCACS Benefits to Industry

GIS software applications are used extensively as an essential tool for different agencies to manage and map their resource inventories. The Province of British Columbia is no exception to this trend, it has made use of this tool in many different industries that generate and maintain the wealth of the province. Since GIS relies on the geo-spatial information of resources as one of its main components, this provides an incentive for authorities to use a highly accurate reference system when conducting its GPS surveys to ensure up to date accurate data. This is where the BCACS comes into play. The BCACS ensures that the spatial framework used for data capture is consistent and homogeneous across the Province, enhancing the possibility for data sharing between public and private agencies, and ensuring that different data types are spatially compatible. Although many applications can be mentioned here, this paper will focus on the forestry industry, GVRD and CRD Street hardware and the oil and gas industry in the NE section of BC.

4.3.1 Forestry

The forestry industry in British Columbia accounts for 50% of Canada's total softwood inventory. Approximately 49.9 million hectares of land is considered to be productive land, 48 million of which is Crown land and 13 million hectares of protected land. All these vast resources of land and its elements need to be effectively managed and inventoried in order to control a myriad of activities ranging from logging and fire control to forest harvesting and habitat protection. In the past hardcopy forest cover maps were used to oversee, manage and study these areas. However, forests are very dynamic and always changing. The most effective way to reflect this is through the use of GIS. Forestry officials and surveyors rely on the BCACS to provide accurate spatial data in order to map out and populate GIS databases for the sake of resource management.

An example of how BCACS aids in the forestry industry involves the monitoring and containment of the pine beetle infestation currently causing havoc with pine forests in BC. Normally the cold winters kill of the beetles and hence control their numbers in the wild, but due to the unseasonably warm weather over the past decade they have been surviving in greater numbers and spreading further and faster then they normally would. Scientist are now keen to control this epidemic before it gets even worse and possibly spreads to the province of Alberta, which borders BC. Monitoring and sampling of infestation sites are achieved by having accurate spatial location of infested area, which is done through DGPS using the BCACS as a reference point. This guarantees that the scientist can return to the same spot repeatedly, with greater certainty. This also gives them the opportunity to make accurate maps and GIS database to track the infestation. Another use for the BCACS is to plan cut blocks in the forest to stop the infestation.

4.3.2 Oil and Gas Industry

The oil and gas sector provides a significant component of British Columbia's economy, primarily in the Peace River block in north-eastern BC. In the past, well site, pipeline, seismic and other surveys related to the industry were based on ties to existing infrastructure, for example, well heads. The result of this was errors in the original surveys propagated into the new surveys, degrading the positional accuracy of all subsequent surveys. Further, positions had to be located through lengthy (and expensive) traverses through remote areas to the area of interest. All surveys are now tied using GPS and the BCACS provides an important component to ensure maximum accuracy and homogeneity in the resulting positions.

4.3.3 City Infrastructure Mapping and its Applications

Cities and towns across the globe are very dynamic entities, constantly changing and adapting with society. Municipal bodies that govern the cities need to have efficient and optimum methods to carry to various urban activities such as planning, maintenance and repairs. Prior to the establishment of GPS as a standard tool of the survey trade, city features such as lamp posts, fire hydrants and man holes were located and mapped using conventional practices by surveying from control points. This required a relatively larger field crew to ensure work was done right and for security of the crew's expensive equipment. In many cities, CORS facilities such as the BCACS has dramatically increased the efficiency of crews in such a way that a one man crew if needed can produce a sufficiently accurate survey of the street hardware and store the data in a municipal GIS which s used to facilitate city management. The BCACS achieves this by providing a digital control for GPS surveys and allowing the surveyor to correct his observation in real time through RTK correction where it can be applicable or in post mission.

5. FUTURE USES

The BCACS has consistently proven itself to be an invaluable investment for the province of BC and to the nation as a whole, with a multitude of users ranging from urban municipal workers to research scientists making use of the real time and post mission services it provides. As useful as it is, the future applications and benefits of the BCACS is currently being planned and implemented by BMGS to further enhance all geomatics activities in the province and nation wide. Discussed below are two plans for the near future that will extend the services to an even larger community, which include; expanding the network by increasing the number of ACS in the network and aiding in the nation wide quest to modernize the height system by developing and modelling a precise geoid for orthometric heights.

5.1 Height Modernization

The current established vertical datum in Canada is the Canadian Geodetic Vertical Datum 1928 (CGVD28). This system of heighting was initiated almost a century ago by surveyors performing spirit levelling, commencing at tide gauges placed at the Atlantic Ocean and Pacific Ocean. The surveyors walked from coast to coast levelling more than a hundred thousand kilometres to establish benchmarks that helped define the vertical datum. In the days prior to the advent of GPS, or affordable GPS receivers, the physical datum was adequate for surveyor's purposes and to the surveying community. Modern times have proven the CGVD28 to be expensive to maintain and expand, this is further aggravated by the fact that benchmarks are constantly being damaged and destroyed across the country. Surveyors of today are deeply immersed in the GPS culture, using the satellite-based systems in conjunction with survey techniques to obtain accurate 3-dimensional positions for various industries from forestry to land development. But the height component has yet to be utilized efficiently because lack of a dependable vertical datum that is compatible with GPS; hence spirit levelling is still preferred for geodetic accuracies.

According to investigations done by the Geodetic Survey Division, Natural Resources Canada, the state of the CGVD28 network has degraded at a rate of about 15-20 percent over the past 20 years throughout Canada, and an even higher rate of 35 percent for urbanized areas. The rates take into account the destruction of benchmarks due to construction and natural degradation. The entire network was resurveyed in the period from 1972 to 2000, which amounted to 124000 km of levelling. Up until 1993, about 4000 to 5000 km were levelled annually, most of it for maintenance with the rest for expansion purposes. From 1994 onwards this was dramatically reduced to 1200 km annually due to the overwhelming cost to carry out the levelling operations. Other disadvantages of the datum also results from the way it was created in a piece-meal fashion across Canada, resulting in significant distortions within the network of up to a metre, when comparing region to region. Regionally, relative height differences can be accurate up to sub-centimetre level, but when GPS is used, it is difficult to obtain heights consistent with the CGVD28 datum.

An alternative approach to the CGVD28 datum is to adopt a geoid as a surface that will approximate the mean sea level in Canada and models it to be used as the vertical datum to which all orthometric heights are referenced. In theory, it should describe the same mathematical datum as the CVGD28 does but it will be derived through modern instruments such as gravimeters, satellite altimeters, high precision points and ACS stations across the country, hence making it much more mathematically rigorous and accurate. ACPs across the country would be used in conjunction with the other methods stated above to determine the geoid's mathematical surface by providing RINEX files that can be used to monitor the 3D coordinates and positions of fixed locations and how they vary as a function of time. The BCACS will be used to provide GPS observations to GSD to help with defining the geoid surface across the Province of British Columbia. This new geoid will provide a consistent surface to which all GPS elevation surveys can be referenced, making it compatible with modern space based applications. The implementation of a geoid will dramatically decrease the reliance on benchmarks and reduce inconsistencies in data between regions. The physical benchmarks will still be in place, but will gradually phased out through attrition, while the geoid becomes the standard vertical datum.

5.2 Expanding the RTK Network

The BCACS network is currently consists of 20 active control stations that are distributed around the Province of British Columbia, with the highest concentration in the highly urbanized municipalities of the CRD and GVRD. Both of these urban areas have sufficient RTK coverage for surveyors in the area due to strategic placement and the number of stations in place that ensures that a GPS survey is carried out in the vicinity of an ACP. As a whole, the network of 20 stations is too sparse to have a functioning provincial RTK network that will enable users across BC to engage in RTK surveys everywhere. BMGS is currently addressing this situation with plans to extend the network to include 20 more station in the province bringing the total to 40 stations in all. The objective is to have 200 km spacing between the ACS stations to achieve optimum efficiency in the usefulness of a provincial RTK network with a focus on densifying the network near more populated regions.

The need to expand the network is a necessary progression for the BCACS as more surveyors rely on GPS to get accurate and reliable and productive work done in both real time and through post mission methodology. Communications for real-time DGPS and RTK is in fact the most difficult component of GPS networks to provide, particularly in remote areas where commercial cellular coverage is not available. However, cellular providers and constantly expanding their networks, and developments in technology will provide other alternatives through satellite communications (for example) to allow RTK in remote areas.

As mentioned earlier, the extension on the network will be of great benefit to all surveyors in the province but there will are a few applications that I will mention that will be greatly enhanced in the post expansion period.

As a more mathematically vertical datum, namely a geoid, is put to practical use across the country, accurate coordinates are needed to get the geoid separation at a given point which can then be used to derive the orthometric height. With a provincial RTK system, very accurate coordinates can be obtained instantly at a point by a surveyor to calculate its heights hence making GPS leveling an accurate and reliable technique. The Hecate Straight in western Canada has long been a heated area of debate due to its potential to have vast reserves of oil and gas deposits. Environmentalists have been fighting to prevent the oil and gas industry from exploring and drilling in the area and have so far been successful in their quest. A moratorium has been in place to prevent any activity there that might damage the ecosystem, but recently there has been discussion that it might be lifted to give the go ahead for the Ministry of Energy, Mines and Petroleum resources to proceed with exploration in the area. In the event that the moratorium is lifted, the high traffic of marine vehicles would need an accurate and reliable reference system to support safe navigation in the straight and to return to potentially important locations with confidence. Expanding the BCACS network so there are an appropriate density of ACPs along the coast in this area of interest will aid in the marine activities that might go on in the straight and help increase productivity and efficiency for companies working there and for the province.

REFERENCES

Base Mapping and Geomatic Services, date N\A, http://ilmbwww.gov.bc.ca/bmgs/index.html
IAG, 04/13/05, www.naref.org
Natural Resources Canada, 06/06/2006, http://www.geod.nrcan.gc.ca/hm/index_e.php
Stone, W.A., Date N\A, An Overview of Global Positioning System Continuously Operating System, http://www.ngs.noaa.gov/PUBS_LIB/GPS_CORS.html
The NGS Geoid Page, last update 10/19/2005, http://www.ngs.noaa.gov/GEOID/
Western Canada Deformation Array, 02/12/2006, http://gsc.nrcan.gc.ca/geodyn/wcda/index_e.php

BIOGRAPHICAL NOTES:

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Practical experience: Helped with the national datum transformation for the Province of British Columbia. Assisted in monitoring and maintaining the BCACS network integrity and with network adjustments.

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