MODERNIZATION OF THE NOVA SCOTIA COORDINATE REFERENCING SYSTEM THROUGH ACTIVE CONTROL TECHNOLOGY

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The Nova Scotia Coordinate Referencing System (NSCRS) is Nova Scotia's current framework for providing location-based information. The NSCRS is the foundation for the province's geographic data holdings including the land administration system. It also enables various legislation, including the Land Registration Act, the Crown Lands Act and the Land Surveyors Act. Over the past several decades, there has been a steady decline in the state of the province's coordinate referencing infrastructure as the program's human and budgetary resources have been reduced. As a result, risks and inefficiencies associated with decaying infrastructure have increased. By 2010, it was becoming clear that action would be required to address these concerns as well as accuracy and accessibility challenges.

In 2012, the province began developing a strategy to better execute its coordinate referencing program. At the core of the strategy were Global Navigation Satellite Systems (GNSS) and Active Control Stations (ACSs). By placing ACSs across the rovince, the surveying industry would gain access to real-time, centimeter-level positioning. Additionally, significant economic opportunities would emerge with respect to machine automation in agriculture, construction and navigation industries.

A test phase was conducted over 2013–2014 that provided the necessary business case information to pursue province-wide implementation. It was determined that 40 ACSs would be needed to provide Nova Scotia with access to high-accuracy GNSS positioning services. The efficiencies introduced by the technology would easily pay for the cost of the system in a short period. Most importantly, the technology provided a viable method of maintaining NSCRS infrastructure going forward.

Le Système de référence des coordonnées de la Nouvelle-Écosse (NSCRS) est le cadre actuel de la Nouvelle-Écosse pour fournir de l'information basée sur la géolocalisation. Le NSCRS est le fondement des collections de données géographiques de la province, y compris le système d'administration des terres. Il habilite également diverses lois, y compris la Loi sur l'enregistrement foncier, la Loi sur les terres domaniales et la Loi sur les arpenteurs-géomètres. Au cours des dernières décennies, on a assisté à un déclin constant de l'état de l'infrastructure de référencement des coordonnées de la province puisque les ressources humaines et budgétaires du programme ont été réduites. En conséquence, les pratiques non efficientes et les risques associés à l'infrastructure en déclin ont augmenté. En 2010, il est devenu évident qu'il faudrait prendre des mesures pour répondre à ces préoccupations ainsi qu'aux problèmes d'exactitude et d'accessibilité.

En 2012, la province a commencé à développer une stratégie pour mieux exécuter son programme de référencement des coordonnées. Au cœur de la stratégie, il y avait le Système mondial de satellites de navigation (GLONASS) et les Stations de contrôle actif (SCA). En installant des SCA partout dans la province, l'industrie de l'arpentage obtiendrait un accès au positionnement en temps réel au niveau centimétrique. De plus, des possibilités économiques importantes émergeraient en ce qui a trait à l'automatisation des machines en agriculture et dans les industries de la construction et de la navigation.

Une phase d'essai a été effectuée en 2013–2014 et elle a fourni l'information requise sur l'analyse de rentabilisation pour poursuivre l'implantation à l'échelle de la province. On a déterminé qu'il faudrait 40 SCA pour donner à la Nouvelle-Écosse un accès à des services de positionnement de haute précision du GLONASS. Les gains en efficacité réalisés grâce à la technologie permettraient facilement de défrayer les coûts du système en peu de temps. Plus important encore, la technologie a fourni une méthode viable pour maintenir l'infrastructure du NSCRS pour l'avenir.

Introduction

Since 1968, the Province of Nova Scotia has carried out a mandate of providing a coordinate referencing system for its citizens. A coordinate referencing system allows users to locate property and infrastructure in a framework that can be related to other systems around the world. In the late 1970s, over $10 million was invested into developing the Nova Scotia Coordinate Control System (NSCCS)

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system through the Land Registration and Information Service (LRIS). The NSCCS was the predecessor to the current framework for providing location-based information which is known as the Nova Scotia Coordinate Referencing System (NSCRS).

Since the 1990s, the province's coordinate referencing mandates have been carried out through the NSCRS. The NSCRS is the foundation for the province's geographic data holdings, including the land administration system. It also enables various legislation, including the Land Registration Act, the Crown Lands Act and the Land Surveyors Act. The system enables surveyors to spatially relate properties, objects and features. The resulting survey plans provide the underlying data set for Property Online, which is the province's primary tool for managing property and property rights. The NSCRS provides transformation tools to allow historic surveys performed in previous coordinate referencing systems to be related to present day.

The NSCRS requires ongoing maintenance of the Nova Scotia Control Monuments (NSCMs) (sometimes referred to as survey monuments) used to realize the coordinate referencing systems. The NSCMs provide a physical manifestation of the mathematical coordinate system used to spatially relate property boundaries and other locations. The infrastructure is spread across the province so that surveyors can readily connect their work to the system. At its peak, the NSCCS had over 23 000 NSCMs demarcating the reference frame. The NSCRS was realized in the late 1990s with 153 NSCMs, known as the Nova Scotia High Precision Network (NSHPN).

Over the past several decades, NSCMs across the province have been destroyed by construction work and overgrown by vegetation. It is estimated that 75% of the 23 000 NSCCS reference frame is now unusable. Many of the NSHPN monuments have also been destroyed or become overgrown. With insufficient human and financial resources to maintain the infrastructure, this outcome was inevitable. These issues are not unique to Nova Scotia. Generating support for infrastructure whose functionality is not generally well understood has been an ongoing challenge across Canada.

As NSCMs disappear, risks and inefficiencies associated with decaying infrastructure rise. In recent years, it became clear that action would be required to address risk concerns and accuracy and accessibility challenges raised by Nova Scotia Land Surveyors (NSLSs). In 2012, a strategy to modernize the NSCRS with an emphasis on sustainability began to be developed. The strategy adopted technologies that had emerged in an effort to better address coordinate referencing mandates with fewer resources. At the core of the strategy were Global Navigation Satellite Systems (GNSS) Active Control Stations (ACSs). ACS technology has been used for well over a decade in other jurisdictions. Innovative data models, strategies and policies have been developed to leverage the technology in pursuit of a sustainable solution to address the province's coordinate referencing challenges.

A summary of the evolution of the NSCRS is presented to provide context for the modernization effort (for a more detailed discussion on the history of the NSCRS, see *Bond and Robertson* [2015]). A description of the technologies used in the modernization effort is provided and the results of applying the technology in a test phase are summarized. Finally, the extension of the test phase implementation to the rest of the province is discussed.

Evolution of Nova Scotia's Coordinate Referencing Systems

In 1965, the three provincial Maritime governments agreed to establish the Council of Maritime Premiers (CMP) to provide a framework for implementing joint initiatives. One key interest for such initiatives were opportunities for collaboration in delivering land use and tenure programs [*LRIS* 1977]. In 1966, a proposal was submitted to the Atlantic Development Board by Willis Roberts, Director of Surveys of New Brunswick at that time. The visionary proposed a four-phase plan that would modernize surveying and mapping in the Atlantic region. Through this initiative, Nova Scotia's first coordinate referencing initiative was born on March 22, 1968, when the Atlantic Development Board approved the concept of establishing the Atlantic Provinces Surveying and Mapping Program (APSAMP) [*Sebert* 1999].

In Nova Scotia, APSAMP was implemented through the Control Surveys, Surveys and Mapping Division of the Department of Lands and Forests. The Division placed a total of 8000 second-order NSCMs during the first five years of operation. Most of these monuments were located throughout the developed areas of the province [*NSLUC* 1995].

In 1973, a new program called the Land Registration and Information Service (LRIS) was created and administered by CMP [*Sebert* 1999]. The staff previously employed by APSAMP formed the core of the organization [*LRIS* 1977]. LRIS had the same four phases as APSAMP. The coordinate referencing system put in place through Phase I of LRIS was state-of-the-art. The system was commonly referred to as the NSCCS. Practically every inhabited road in Nova Scotia had a NSCM with 1-km spacing or less.

By 1983, 23 000 NSCMs had been installed in Nova Scotia. Unfortunately, the 1983–1984 budget cut survey monument maintenance. Despite cutbacks, the overall quality of the coordinate referencing system remained high for several years, largely because of the abundance of NSCMs. By the end of the 1980s, it was apparent that the lack of funding to maintain the infrastructure was taking its toll as NSCMs were being destroyed by construction and overgrown by vegetation. In 1989, a proposal was put forward to do a single cycle of maintenance on the reference frame. This involved inspecting and densifying the existing network over a five-year period, at a total cost of $2.25 million. The proposal was rejected due to the high cost [*NSLUC* 1995].

As LRIS was struggling to maintain the NSCCS, the Global Positioning System (GPS) was emerging as a new technology to perform geodetic surveys. GPS offered higher accuracy measurements over longer distances than conventional theodolite and EDM technologies. Additionally, GPS did not require line-of-sight between adjoining monuments.

In 1986, LRIS commissioned a study for control surveys for LRIS. The main recommendation of that study was that LRIS should develop expertise in GPS so that it would be immediately able to take advantage of the technology [*Hamilton and Doig* 1993]. As GPS became more commonplace through the 1990s, it began to reveal distortions in the NSCCS network, which was observed using conventional survey instrumentation including theodolites and electronic distance measurement (EDM) equipment. LRIS continued to operate using provincial funding until it was closed on March 31, 1994 [*Sebert* 1999].

Prior to the LRIS being disbanded, *Hamilton and Doig* [1993] made a number of recommendations for the Maritime provinces to deliver upon their coordinate referencing mandates. One of these recommendations was to adopt a new, GPS-based, coordinate system. With the assistance of Geodetic Survey Division, this was acted upon. The framework was named the NSHPN. Coordinate values were derived from the Canadian Spatial Referencing System (CSRS) using GPS observations, and are referred to as NAD83(CSRS) values. By 2000, 153 NSHPN points were established, with an average spacing of about 20 km. The implemented system was named the NSCRS.

Although most provincial geographical data layers are currently based upon NAD83(CSRS), the majority of survey work in the province is still performed in the older Average Terrestrial System of 1977 (ATS77) datum. Due to the lesser density of the NSHPN compared to the NSCCS network and the significant compilation of survey plans in ATS77, NSLSs avoid using the NSCRS. Consequently, Nova Scotia is the last province in Canada not to be surveying in the GPS-compatible NAD83 datum. GPS continues to expose distortions and accuracy limitations in the NSCCS. NSLSs often end up distorting their GPS results through local coordinate transformations to fit the older NSCCS coordinate referencing system. In doing so, NSLSs must be vigilant to avoid using NSCMs with inaccurate coordinate values caused by:

a) Movement of the monument by natural causes (e.g., slope creep) since it was last observed;
b) Disturbance of the monument by construction activity;
c) Inherent errors from using equipment with lesser accuracy than what is currently available; and
d) Gross blunders which have gone undetected.

In 2011, Nova Scotia's first Coordinate Control Officer retired. He was succeeded by the NSCRS Geomatics Technologist. These were the only resources in the provincial government with an intimate knowledge of the NSCRS observation and coordinate databases. Over 30 years of knowledge pertaining to a critical piece of the province's infrastructure was gone, leaving an irreplaceable void. Similar situations had arisen in other provinces across Canada.

In 2012, the province filled the Coordinate Control Officer position to provide oversight and direction for the coordinate referencing program. As a first step in addressing the existing NSCRS deficiencies, a survey was conducted with NSLSs. Two key user needs were identified:

1. Improved accessibility to the NSCRS reference frame; and
2. Improved coordinate accuracy to support Global Navigation Satellite Systems (GNSS) technology.

Without additional human resources to support the coordinate referencing program, developing a strategy to address the above needs would pose significant challenges. Even if a solution were identified, there was no guarantee that the initiative would be supported in a sustainable manner. Substantial effort would be required to create awareness about the importance of the infrastructure.

Leveraging Technology

Since the NSCRS was first implemented though the NSHPN in the late 1990s, several key technologies have emerged which collectively presented a significant opportunity to modernize the system, as subsequently discussed.

Active Control Stations

Permanent, Global Navigation Satellite System (GNSS) stations known as Active Control Stations (ACSs) (or Continuously Operating Reference Stations (CORS)) allow for real-time kinematic (RTK) GNSS positioning to be performed. RTK surveys are a method of Differential GNSS positioning that utilize a reference (or "base") station to generate high accuracy coordinates up to about 25 km from the reference station. Horizontal positioning accuracy is typically ± 2 cm + 1 ppm (1 mm/km) and vertical positioning accuracy is typically ± 3 cm + 1 ppm in real time. Higher accuracy can be achieved by using longer observation periods for the point of interest. When longer observation periods are used to improve accuracy, the observation technique is known as a static survey.

In essence, the ACS eliminates the need to have a dedicated surveyor operate a reference station in the field using traditional reference and rover receiver setups. By locating the GNSS equipment in secure locations, it can run continuously so that the Differential GNSS requirement for simultaneous measurements can be easily achieved. The ACS technology makes observing NSCMs to maintain the NSHPN more achievable with fewer human resources.

Network, Real-Time Kinematics GNSS Surveys and Cellular Communications

GPS software has also evolved so that by locating ACSs across a large region, corrections can be modelled and used for Network RTK (NRTK) positioning. By forming a polygon with ACSs, GNSS corrections can be interpolated and the distance dependent positioning error can be reduced from 1 ppm to 0.5 ppm (0.5 mm/km). These corrections can be broadcast over the Internet to users in the field. Users require a cell modem or can tether to another Internet-connected device. Approximately 85% of Nova Scotia has cellular coverage, providing a unique opportunity to offer RTK positioning services throughout the province. By utilizing NRTK, NSCM observations can be made in minutes to update coordinates to NAD83(CSRS) values.

Crowd Sourcing

The widespread development of communications networks has also enabled users of various technologies to generate and submit data for specific causes. This crowd sourcing technique can also be used to allow NSCRS users to contribute to the maintenance of the NSCRS infrastructure. By implementing appropriate quality control, the technology provides an efficient way to keep data current.

Test Phase Design

In order to adopt the above technologies to modernize the NSCRS, several practical considerations needed to be addressed. In the summer of 2012, a project steering committee was formed to oversee the implementation of GNSS Active Control Station technology through a test phase. The objectives of the test phase included:

1. Evaluate how well ACS technology meets government's needs;
2. Evaluate how well ACS technology meets NSLSs' needs;
3. Analyze business model options and make a recommendation;
4. Analyze technology uptake;
5. Conclude required technology;
6. Determine required ACS coverage;
7. Finalize specifications for ACS to meet first-order geodetic control network requirements;
8. Determine the most sustainable model for delivery of the program and services.

Several key challenges existed in deciding how to adopt the technology in Nova Scotia. The first was that three companies already offered NRTK GNSS positioning services in the province. The majority of this infrastructure resided around urban areas. The developed strategy needed to avoid negatively impacting existing business operations. The second challenge pertained to the NSCRS program having only one human resource. The developed solution could not exceed this capacity. Finally, the devised solution needed to be sustainable. The previous two attempts to update the coordinate referencing infrastructure in the 1970s and 1990s were followed by a deterioration in the networks, which resulted in an inability to fully carry out NSCRS mandates. The desired solution would allow maintenance to be performed and the infrastructure to be sustained on an ongoing basis, as depicted in Figure 1.

In the winter of 2013, the province issued a Request for Proposals (RFP) to provide an ACS-based solution that would help address the coordinate referencing needs previously described. Recognizing that the ACS data would become the primary access point to the NSCRS, it was specifically requested in the tender that any devised solution would allow the archived data from each station to be made freely available to the public. This open data effort would allow Differential GNSS surveys to be conducted within the province with a direct connection to the NSCRS at no cost to the user.

Recognizing that the ACS technology has a significant information technology component requiring redundant server management, it was requested that proponents present a model that would leverage their existing IT infrastructure to manage the real-time data streams. It was also necessary that the proposed model avoided creating a monopoly situation for GNSS NRTK services in the province. Substantial effort was dedicated to generating installation specifications for the new ACSs that would be put in place, with a particular focus on maximizing station stability, minimizing thermal influences and minimizing GNSS error sources.

Some of the highlights of the successful proposal included:

a) The contractor would install the ACSs to the design specifications set out in the RFP.
b) The contractor would host the IT infrastructure required for delivering the live data from each ACS.
c) The contractor would manage the maintenance of the ACSs with specific uptime and accuracy deliverables as set out in the RFP.
d) The real-time data feeds from each station would be licensed to each NRTK GNSS service provider annually and would be made available using a Network Transport of RTCM via Internet Protocol (NTRIP) caster. The data licence fees would offset the warranty, firmware, data plan and other operational costs required to maintain the ACS infrastructure using a cost recovery model.

By organizing the GNSS NRTK service provision effort in Nova Scotia, the province could ensure that its coordinate referencing mandate was carried out across the entire province, not just in urban regions. The quality of the services could be upheld by providing specifications for the construction of the ACSs, which would serve as the foundation for the NSCRS. The ability to utilize existing provincial

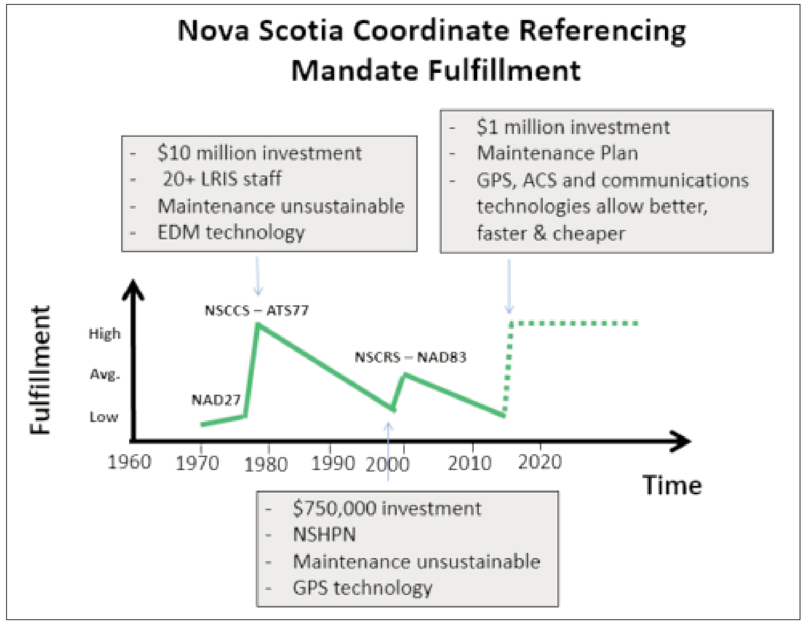

Figure 1: Depiction of ability to carry out coordinate referencing mandates over time.

buildings to host ACS sites significantly reduced infrastructure, power and communications costs. It was desired to create a cost-effective solution for private industry partners looking to offer GNSS NRTK services in the province.

In the spring and summer of 2013, eight ACSs were installed in the southwest region of Nova Scotia, as shown in Figure 2. This infrastructure was named the Nova Scotia Active Control Stations (NSACS) network. The NSACS test phase infrastructure forms

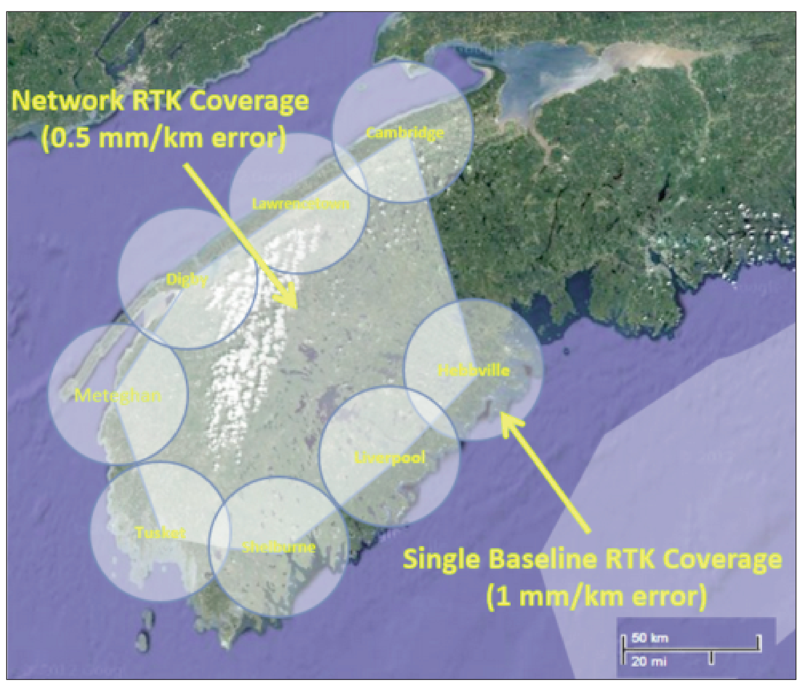

Figure 2: NSACS test phase coverage.

Figure 3: NSACS at Shelburne Regional High School.

a polygon that allows NRTK accuracy to be obtained within it. Outside of the polygon, accuracy is dependent upon a single ACS resulting in a 1-ppm error. The NSACS network provides additional NSCMs in the NSCRS reference frame to help address the accessibility and accuracy needs of NSLSs.

Each station consists of a GNSS receiver, choke ring antenna, uninterruptible power supply and lightning protection. All sites currently use Trimble NetR9 antennas, which track GPS, GLONASS, Galileo, QZSS and COMPASS satellite constellations. In many rural areas, schools tended to be the only masonry or steel structure buildings available that had excellent satellite visibility. Consequently, six of the first eight sites were located on schools. Figure 3 illustrates one of the ACSs installed at the Shelburne Regional High School. One ACS was located on a Canadian Base Network (CBN) concrete pillar in Tusket, which was made active by permanently installing the equipment. It was desired to directly integrate the NSACS into the Canadian Spatial Referencing System by occupying the CBN.

Figure 4 illustrates the main techniques in which the NSACS network can be used to conduct a GNSS survey. In the NRTK scenario, data from each ACS is streamed over the Internet to a server which can calculate differential corrections. Users have a subscription which allows them to connect

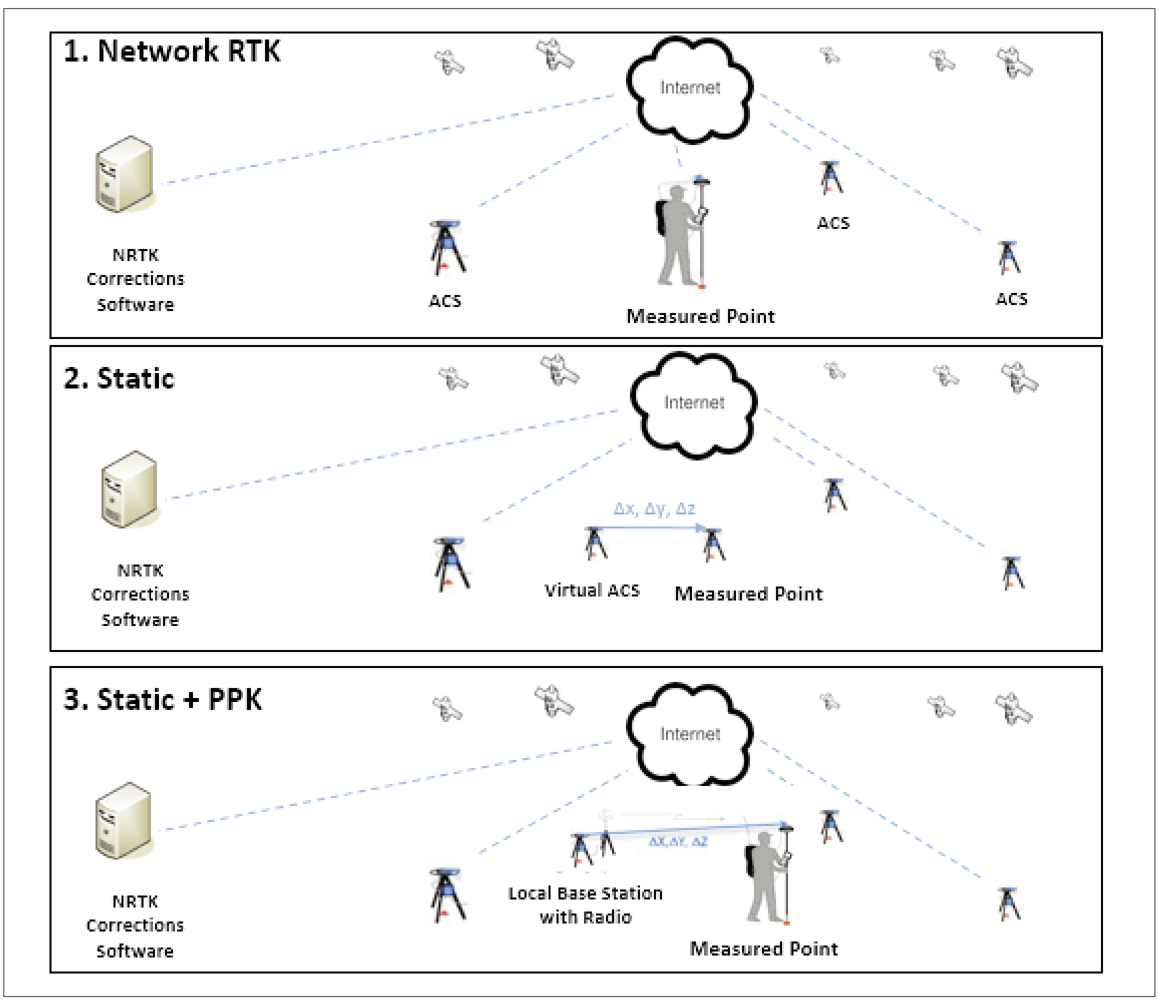

Figure 4: Main survey techniques with ACS technology.

to the server while in the field. Based upon the user's position, a differential correction is calculated and transmitted to the user over the Internet. If the user is not within the network polygon, the differential correction is based upon the nearest ACS.

In the second scenario, the user is outside the cellular coverage region and cannot receive differential corrections in real time. Data is logged in a static manner over a known point. With appropriate software, the user can download data for a virtual reference station located at an arbitrary location near the measured point. The virtual reference station data is generated using the NSACS network data. The virtual reference station allows a high-accuracy position to be calculated for the measured point using a short observation period (seconds to minutes). A fixed ambiguity solution will not likely be achieved using a short observation period and data from a single ACS over long distances. When users are outside the NSACS network, they have no choice but to increase session length to help ensure that a fixed ambiguity solution can be achieved.

In the third scenario, the user does not have access to NRTK services and employs a traditional reference station and rover station setup. In this case, the reference station can be deployed in a convenient location near the work site to perform an RTK survey. The reference station should be configured to log data so that its position can be precisely calculated relative to the nearest ACS. The local reference station helps to ensure that distances to the roving station are kept short so that ambiguities can be resolved. If the work site is within a few kilometers of an ACS, it may not be advantageous to establish a local reference station. Once the reference station's position is accurately determined, the entire survey can be post-processed using appropriate software in post-processed kinematic (PPK) mode. A variant on this third technique is to conduct a RTK survey using approximate coordinates at the local reference station, and then shift the entire survey by assigning accurate coordinates for the reference station once they are calculated. The advantage of this approach is that there is less chance of not being aware of unresolved ambiguities for points observed in kinematic mode.

Test Phase Findings

Over 2013–2014, users of the NSACS network in southwest Nova Scotia were consulted to obtain feedback that would help in achieving the test phase objectives previously described. That feedback is summarized below as it pertains to each objective.

Evaluate How Well ACS Technology meets Government Needs

Four different business areas within provincial government were consulted to evaluate the impact the technology had on their operations. The following feedback was received:

Nova Scotia Topographic Database Program: The NSACS was successfully used in the Nova Scotia Topographic Database's (NSTDB) targeting operations for establishing ground control for geo-referencing aerial photography. The technology shaved days off the preparation and planning time before going to the field. Traditional approaches required suitable NSCMs to be identified for targets. Often, these would be destroyed or overgrown upon arrival at the site. With the NSACS and GNSS, targets could be placed with high accuracy wherever convenient and more importantly, in remote areas where no survey monuments existed.

Nova Scotia Coordinate Referencing System: Over a seven-day period, the NSACS enabled 30 NSCMs to be updated with NAD83 coordinates by one person. Each NSCM was observed three times using 10-minute sessions, providing accuracies typically better than ± 2 cm in three dimensions. When the NSHPN was observed in the late 1990s, it took five years to update 150 using a team of five surveyors or more. The technology is allowing what used to take several months to be accomplished in several days with fewer resources. The updated coordinates will allow a better transformation to be defined between the older ATS77 datum and the newer GPS-compatible NAD83 datum.

Natural Resources Crown Lands Surveys: The Department of Natural Resources (DNR) is responsible for the surveying and maintenance of approximately 17 700 km of Crown Land boundaries relating to 1.5 million ha of Crown lands and 311 600 ha of land administered by the Department of Environment. DNR employs over 40 survey staff that make up 11 teams and an administration section. The NSACS created efficiencies estimated at over $400,000 annually. The technology eliminated the need to find local NSCMs to integrate survey work with the NSCRS. Time was saved by each survey crew not having to setup and remove local reference stations. The quality of the surveys improved because of the excellent satellite visibility at the ACSs. Survey crews were able to make better use of their GNSS hardware by turning reference station receivers into rover units.

Transportation and Infrastructure Renewal: The Department of Transportation and Infrastructure Renewal (TIR) is responsible for building new highways and maintaining the province's 23 000 km of roads and 4100 bridges. The test phase demonstrated that the NSACS could create efficiencies of over $1 million annually through internal and contracted work. The majority of these efficiencies were realized by allowing heavy machinery to reach finished grade more quickly through the use of digital elevation models and machine automation. Similar to the experiences of DNR, time was saved by each survey crew not having to set up and remove local reference stations. The quality of survey work improved because of the excellent satellite visibility at the ACSs. Survey crews were also able to make better use of their GNSS hardware by turning reference station receivers into rover units.

Evaluate How Well ACS Technology meets NSLS Needs

The NSACS demonstrated that it could address both the accessibility and accuracy needs of NSLSs. A letter of support from the Association of Nova Scotia Land Surveyors (ANSLS) was provided to support the business case to pursue province-wide rollout. Efficiencies were gained by NSLSs not having to setup and remove a local reference station. Productivity was improved by converting reference station receivers into an additional rover that could be used by another field crew with the NSACS network.

Analyze Business Model Options and Make a Recommendation

During the fall of 2012, significant time was dedicated by the NSACS project steering committee to determine an appropriate business model for implementing ACS technology and delivering its services. Four GNSS-NRTK service providers were consulted for their feedback on the initiative and their preferred course of action. Additionally, the ANSLS was consulted for their view on what role the province should take in the business. Three models emerged as options, with some variations on implementation:

1. The province invests in infrastructure, software and human resources to run the IT component of the business (1–2 dedicated full-time employees).
2. The province does nothing and waits for GNSS-NRTK service providers to expand their services throughout the province to address the NSCRS program needs.
3. A private-public partnership be pursued whereby the province invests in infrastructure and makes the data available to industry for service delivery.

Option 1 was not favored because it placed the province in the situation of competing with existing businesses, which was against the wishes of both service providers and the ANSLS. Option 2 was not feasible because there would be little motivation for private industry to offer services in areas of the province without sufficient demand. Option 3 was the favored approach by private industry and made the most sense to the committee. This was the model solicited in the RFP and was the recommended model for pursuing provincial rollout of the technology.

Analyze Technology Uptake

During the test phase, the technology was used by land surveyors, municipalities, government departments and the construction industry. The biggest challenge in adopting the technology was convincing people to use it. Once the technology was used, it appeared that few would abandon it. Ongoing effort will be required to create an awareness of the technology and to illustrate how it creates efficiencies.

Conclude Required Technology

It was determined that the NSACS network would benefit from having a redundant Internet connection (cell modem) at each site in the event that local Internet service is disrupted. To facilitate this, routers which could sense inactivity on the local area connection would be required. Having this technology in place would allow for more time to respond to ACSs that may go off-line in remote areas of the province.

In the original design for providing NRTK services, each GNSS NRTK service provider accessed data directly from the ACS receiver. To reduce bandwidth demands at the ACS, it was determined that a better approach would be to stream the data back to a server running an application which could redistribute the data. This was particularly important for stations streaming data by only using a cellular modem with limited bandwidth.

Determine Required ACS Coverage

The spacing of stations within the NSACS network was designed to be approximately 50 kms to satisfy the accuracy needs for survey work. This spacing was based upon a 0.5 ppm accuracy degradation from the nearest ACS for NRTK positioning. To finalize the NSACS network in southwest Nova Scotia, stations would also be required in Caledonia and Barrington.

Field checks using the NSHPN illustrated that the desired accuracy was being achieved except in coastal areas that extended more than 20 km outside the network polygon. In these areas, it was primarily the vertical solution that suffered. Occupation times would need to be increased to 30 minutes or longer to ensure accuracies of better than 3 cm in the vertical component. In these situations, it is often prudent to employ the aforementioned Static and PPK survey approach (Scenario 3).

Finalize Specifications for ACSs to meet First-Order Network Requirements

Best practices for the installation of the ACSs were developed to serve as a guide for contractors performing the work. This document has evolved based upon the lessons learned from each installation and will continue to evolve as new knowledge is acquired. This document has been utilized federally.

Determine the Most Sustainable Model for Delivery of the Program and Services

A major challenge with effectively delivering the NSCRS program is maintaining both the active and passive infrastructure that spans the entire province. Travel time greatly limits what can be achieved when relying upon a single person to perform maintenance. Given the budgetary constraints of the program, it was recognized that maintenance must be engrained into the workflows of those who utilize the infrastructure on a daily basis.

Despite embracing ACS technology as the backbone of the NSCRS, passive NSCMs still have important functions. They a) serve as quality control checkpoints for surveyors conducting NRTK surveys, aerial surveys and GIS data collection; b) provide locations for surveyors to set up a reference station using conventional reference and rover GNSS surveys, which can be important where cell coverage does not exist; and c) provide a physical manifestation of the provincial reference frame which is the foundation of the property boundary fabric. This infrastructure is directly used to relate current and historical surveys.

NSCRS infrastructure maintenance includes: a) removing vegetation overgrowth around NSCMs; b) updating site sketches and/or photos; c) re-observing NSCMs to ensure that coordinates reflect the present location; d) reposting NSCMs with signs which may get destroyed; and e) repairing NSCMs that may be deteriorating or disturbed. Additionally, it may be necessary to install a new NSCM in areas where they do not exist to provide an accessible checkpoint for NRTK surveys.

For the NSCRS program to be successful, it must align itself with the people who depend on it, both within the provincial government and in private industry. Specifically, the following items were identified as critical to achieving a sustainable NSCRS program:

a) **Integration of NSCRS maintenance into NSLS's workflows:** NSLSs utilize the NSCRS on a daily basis. By having NSLSs submitting GNSS observation data on NSCMs that they have acquired while performing normal work, coordinate values can be kept current. By clearing vegetation around the NSCMs, the usability of the infrastructure remains high. A well-maintained system benefits the surveying profession.

b) **Integration of NSCRS maintenance into DNR workflows:** DNR is the only department within the Nova Scotia provincial government having licensed land surveyors. The distribution of this group across the province and their specialized skills sets needs to be leveraged. DNR must play a role in maintaining both passive and active systems, delivering key messages at ANSLS zone meetings, distributing NSCM infrastructure (signs, posts, monument hardware) and providing user feedback. This integration with NSCRS operations will also help to reduce the risk of the entire program depending upon on a single person.

c) **Integration of NSCRS maintenance into TIR workflows:** TIR has the largest contingent of survey technologists with the Nova Scotia government. This group needs to leverage its provincial distribution to help maintain the passive system. It also has an important role to play in installing new NSCMs in new civil infrastructure.

Additionally, to ensure the success of the program, the following strategies and policies have been or are in the process of being implemented:

a) **Adopt a monument:** It is desired to maintain the NSCRS with a five-year observation cycle on NSCMs. Presently there are 100 NSLSs in the province and there are at least as many geomatics technologists. If each user maintained five NSCMs every five years, then theoretically 5000 NSCMs could be maintained in the province as NSHPNs. It is desired to maintain between 500 and 1000 NSHPNs using this approach. To facilitate this strategy, a client portal has been developed on the NSCRS web page to allow NSLSs to submit observations, photos and raw data.

b) **Monument a bridge:** A cost-effective solution has been identified for installing new NSCMs. The hardware can be embedded into the crash block of new overpasses and bridges or retrofitted to existing ones. Because overpasses and bridges are generally in open areas, these sites are favorable for GNSS observations. The strategy allows new infrastructure to be put in place with minimal cost.

c) **Planning stage, NSCM scan:** Many NSCMs are destroyed during construction because of a lack of planning and lack of knowledge of the purpose of the infrastructure. Once a NSCM is disturbed, its connection to historic surveys is lost. To combat this destruction, it is critical that a new step is inserted into the processes for approving new developments. The area of development must be scanned prior to any development work to identify what impact it will have on the NSCRS infrastructure. When possible, arrangements should be made to preserve the infrastructure. At the very least, coordination should occur with the coordinate referencing program to survey the positon of the monument to create a link to historic surveys based upon that NSCM. The scanning steps need to occur within planning departments of municipalities and within public works bodies.

Business Case

Using the information obtained during the test phase, a business case was developed to pursue expanding the NSACS network across the province. From the feedback that was obtained, it was very clear that the proposed solution would not only help to address the needs of the surveying profession, but it would also create various other technological and economic opportunities. The technology was being utilized by towns and municipalities to perform asset management, by the construction industry to automate heavy machinery and by other government departments to create operational efficiencies.

The findings supported what was reported by *ACIL Allen Consulting* [2013]. In that report, it was estimated that economic benefits to Australia included an increase in its real Gross Domestic Product (GDP) by over $2.3 billion through ACS technology. This was expected to triple by 2020. Accounting for the different scales of economies, if Nova Scotia could realize the same benefits, its real GDP could increase by over $70 million. The total cost of implementing the technology in Nova Scotia was just over $1 million.

Canadian Geodetic Survey, NRCan

Since the inception of the NSCRS, the Canadian Geodetic Survey (CGS, formerly Geodetic Survey Division) of Natural Resources Canada (NRCan) has provided the foundation infrastructure needed to execute the NSCRS program. CGS continues to plays a crucial role in the modernized system. The CGS Canadian Spatial Referencing System IT infrastructure has provided a valuable mechanism for distributing NSACS data to the public. The North American plate velocity models generated by CGS are an important technology for relating new surveys in NAD83(CSRS) to those made in the past. Specifically, the velocity model has allowed the province to accurately migrate its coordinate data from NAD83(CSRS) 1997.0 (which was used at the time of the NSHPN implementation) to NAD83(CSRS) 2010.0. The new Canadian Geodetic Vertical Datum of 2013 (CGVD2013) has also provided superior repeatability to the old Canadian Geodetic Vertical Datum of 1928 (CGVD28) using GNSS, as subsequently described.

CGVD2013

In November of 2013, NRCan released a new gravity-based vertical datum known as CGVD2013. It became the federal standard for heights across Canada. CGVD2013 replaced CGVD28, which was adopted in 1935. Unlike CGVD28, which is based on geodetic levelling observations from tide gauges, CGVD2013 is based on geoid modelling using satellite observations. CGVD2013 is more compatible with GNSS in that it enables elevations to be determined with respect to a more consistent datum everywhere across Canada [*NRCan* 2015]. The new vertical datum also eliminates dependencies on local, NSCMs to re-establish elevations.

With the adoption of the NSACS, the adoption of CGVD2013 as the standard vertical datum for Nova Scotia is only logical. Efforts are underway to update policies and standards to reflect the new vertical datum. Figure 5 illustrates the difference in CGVD28 and CGVD2013. Halifax is 64 cm below what would be considered 0-m elevation in CGVD28. CGVD2013 elevations have been published for all NSHPNs, derived from both NAD83(CSRS) 1997.0 and 2010.0 ellipsoidal values.

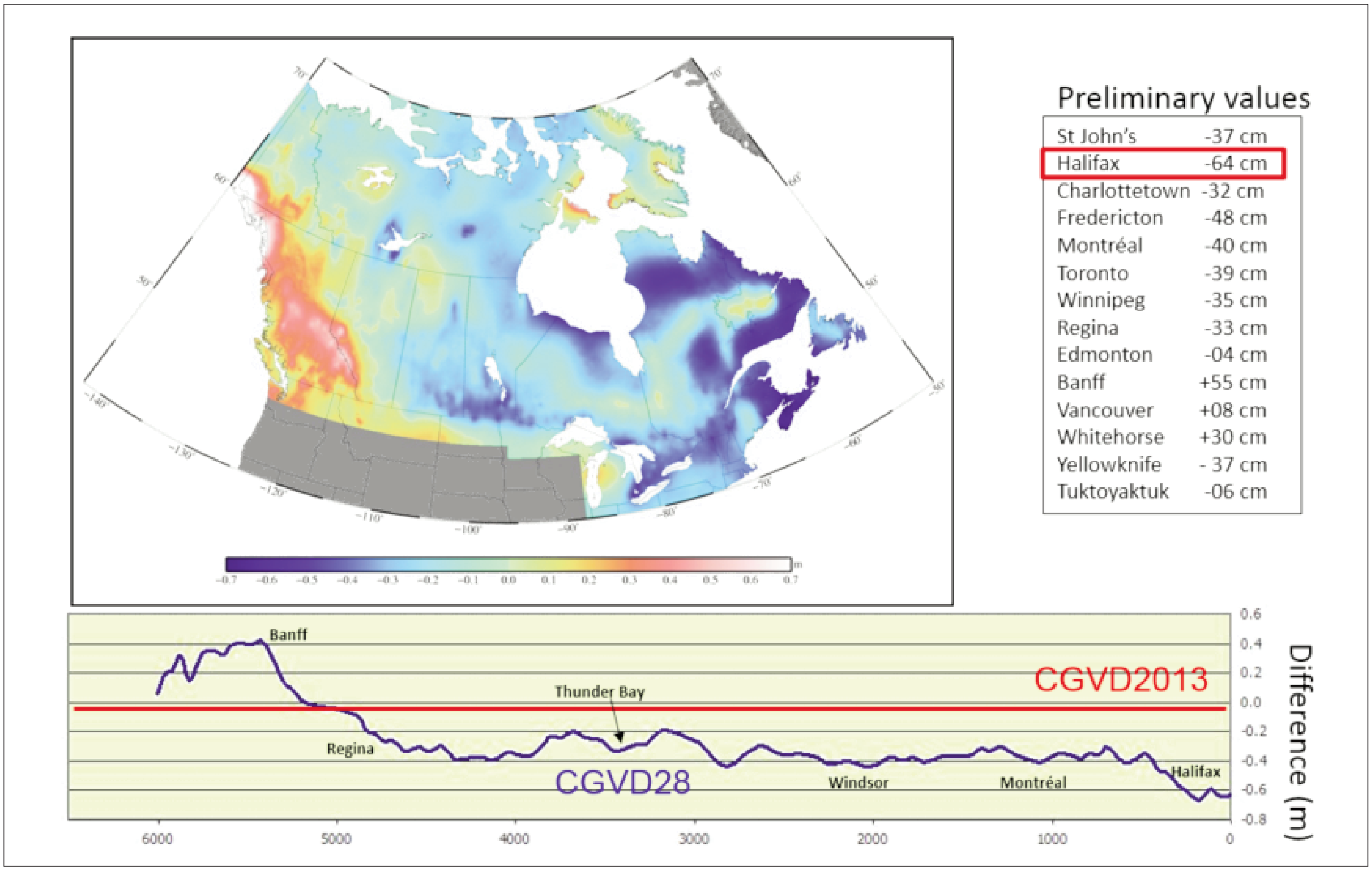

Figure 5: CGVD2013 in Canada [*NRCan* 2015].

Provincial Rollout

In December of 2014, it was announced that funding to complete the NSACS network in Nova Scotia would be granted in April of 2015. The project would be completed in two phases over two fiscal years. During the first phase in 2015–2016, the remaining ACS stations would be installed across the province. Forty ACSs would be installed in total. Figure 6 illustrates the final design of the network. In the second phase over 2016–2017, the focus would be on densifying the NSHPN network so that a better grid shift model can be generated between ATS77 and NAD83(CSRS) 2010.0. It is desired to update between 500 and 1000 NSCMs with NAD83(CSRS) coordinates. Figure 7 illustrates conceptually what the densified NSHPN may look like.

Moving Forward

Putting the NSACS infrastructure in place is an important first step in modernizing the NSCRS. The challenge moving forward is convincing the user community to change existing practices and adopt the technology. It is hoped that this will happen naturally as the technology simplifies workflows and creates efficiencies for early adopters.

Nova Scotia is the last province not conducting survey work in NAD83(CSRS). Databases of ATS77 survey plans from the past 35 years make the industry resistant to change. As time goes on, it is becoming apparent that ATS77 coordinates are becoming more difficult to re-establish. This is due to the NSCCS reference frame disappearing, creating an inability to model the distortions that exist.

In the modernized system, the 40 NSACS and NSHPN are the NAD83 reference frame. With the NSCCS, there were over 23 000 NSCMs that provided surveyors with access to the ATS77-based NSCCS. Although there are fewer NSCMs in the NAD83 framework, the NSACSs are NSCMs that are always occupied with GNSS technology and therefore provide a higher level of access to the NSCRS anywhere in the province. This new approach of connecting to the NSCRS through NSACS data requires a change in mindset where NSLSs have traditionally had to physically occupy an NSCM.

Figure 6: NSACS network.

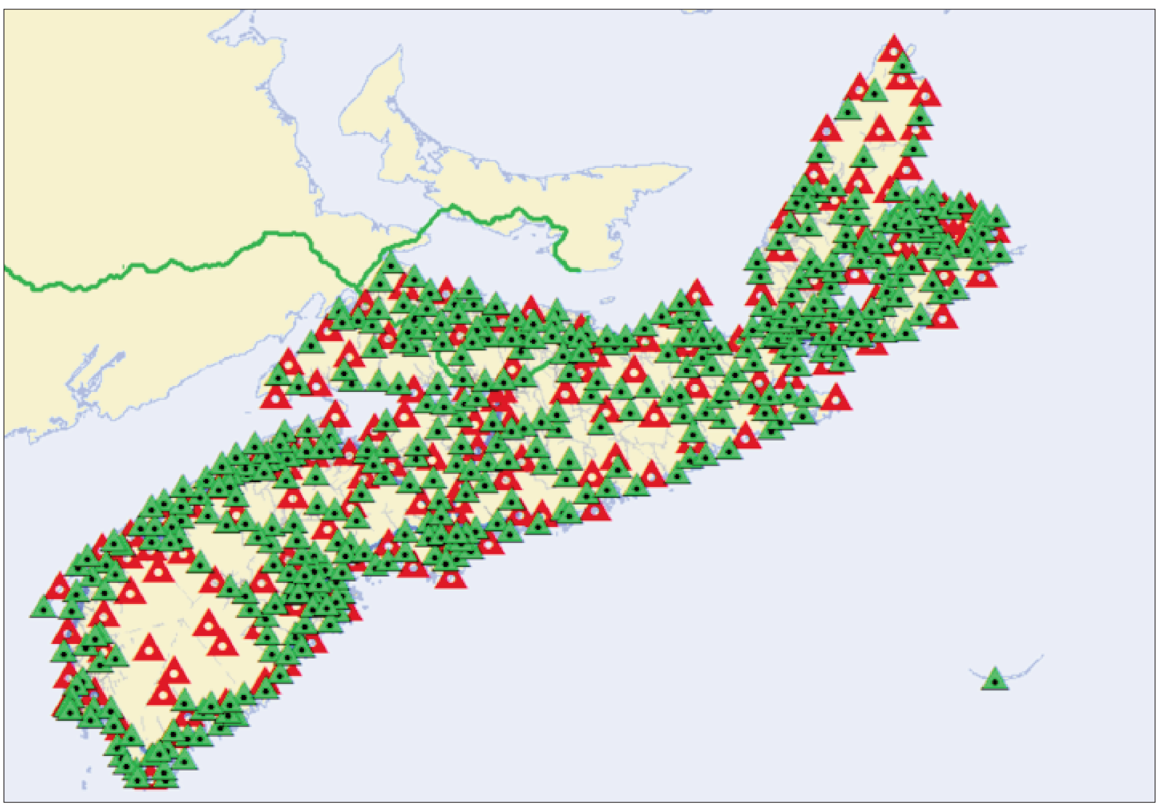

Figure 7: Conceptual illustration of densified NSHPN (red triangles are existing NSHPNs, green triangles are proposed NSHPNs).

There are untapped opportunities to leverage the NSACS for machine automation and spatial data collection. Examples of the technology being used in agriculture, vehicle guidance, earthquake detection and marine applications exist worldwide. It will be up to industry to see these opportunities and capitalize upon them. The role of coordinate referencing programs across the country will continue to grow in importance as the user group of public and private GNSS NRTK services expands into new sectors and expertise is required to integrate the data into these application areas.

Summary

A strategy for modernizing the NSCRS has been identified to help address the coordinate referencing needs of Nova Scotia. At the core of this strategy is the NSACS network. The NSACS allows greater access to a NAD83-based coordinate referencing system than traditional passive control approaches. It provides opportunities to maintain passive control with low cost and provides opportunities to create a sustainable maintenance plan by licensing the real-time data streams and implementing a cost recovery model.

The NSACS was originally intended to address the coordinate referencing needs of the surveying profession, but the technology has widespread applications. The NSACS has already been used for machine automation in highway construction, aircraft positioning for the capture of aerial imagery and asset management. In the future, it is expected that the technology will be applied to new sectors in the province as the benefits of automated precise positioning are realized.

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References

ACIL Allen Consulting. 2013. The value of augmented GNSS in Australia. *www.acilallen.com.au/cms_files/ACILAllen_AugmentedGNSS.pdf* [accessed 14 August 2015].

Bond, J. and W. Robertson. 2015. The evolution of Nova Scotia's spatial referencing system from its origins until 2012. *Geomatica* 69(4): 407–418. doi: dx.doi.org/10.5623/cig2015-403

Hamilton, A. and J. Doig. 1993. Report of the task force on control surveys in the Maritime provinces.

LRIS. 1977. A new approach to land registration and information. Land Registration and Information Service, The Council of Maritime Premiers.

NRCan. 2015. Height reference system modernization. Natural Resources Canada. *http://www.nrcan.gc.ca/earth-sciences/geomatics/geodetic-reference-systems/9054* [accessed 17 August 2015].

NSLUC. 1995. A coordinate referencing policy for the Province of Nova Scotia. Nova Scotia Land Use Committee.

Sebert, L.M. 1999. Provincial topographic mapping. Chapter Four in *Mapping a Northern Land. The Survey of Canada 1947–1994.* McGill-Queen's University Press, Montreal. 116–139.

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