Natural Resources Canada | Ressources naturelles Canada

Transport Canada | Transports Canada

Canadian Space Agency | Agence spatiale canadienne

# Canadian Industry Study
# Real Time High Accuracy Satellite Positioning

**Prepared for Geodetic Survey Division**
**NATURAL RESOURCES CANADA**

**June 20, 2000**



ARTHUR ANDERSEN

# TABLE OF CONTENTS


| | Page |
|---|---|
| **Executive Summary** | 1 |
| **Acknowledgements - Interview Participants** | 3 |
| **1 Project Scope and Objectives** | 4 |
| 1.1 Project Scope | 4 |
| 1.2 Critical Issues and Project Objectives | 5 |
| 1.3 Project Methodology | 5 |
| **2 Real Time Satellite Positioning - Canadian Industry Analysis** | 6 |
| 2.1 Industry Analysis Framework – Innovation Centred | 7 |
| 2.2 Canadian Industry Analysis | 9 |
| Users | 10 |
| Market Scope and Ambient Environment | 12 |
| Manufacturers and Applications Developers | 18 |
| Industry Substitutes | 19 |
| Innovation and Competition | 21 |
| Barriers to Entry | 22 |
| **3 Bibliographical References** | 24 |
| 3.1 Studies and Reference Documents | 24 |
| 3.2 GPS World Magazine Articles | 26 |

## Executive Summary

Canada has historically played an important role with respect to the development and utilization of Global Positioning System Technologies. Driven by demand from several Canadian economic sectors, the Geodetic Survey Division of Natural Resources Canada has been tasked with the development and operation of one of the worlds leading 24 /7 continuous tracking GPS network infrastructures, the Canadian Active Control System.

In an effort to enhance the Canadian Active Control System for industry end users, the Geodetic Survey Division in partnership with Transport Canada and the Canadian Space Agency has undertaken this study on real time high accuracy satellite positioning. The study is tasked with identifying critical issues with regards to the development of positioning technology, and with the provision of recommendations for the Geodetic Survey Division so that they can align their development projects with end user needs as well as providing its partners with information on the Canadian Industry.

The study, which was entirely completed prior to the elimination of Selective Availability on May 1, 2000, and included forty interviews with stakeholders as well as a thorough review of secondary published resources, has uncovered the following recommendations:

- Federal and Provincial authorities should support the establishment of a central repository for high quality Canadian GPS industry sector information, and share in the funding for such costs with private sector companies or industry groups;
- The standards for a Canadian service for Real Time Corrections must seek to optimize the design and application of user equipment and user services/applications to address tradeoffs between accuracy, coverage, availability, cost, complexity and commercialization/export potential;
- Infrastructure costs for Canadian precision DGPS users may be substantially eliminated through governmental support of a centralized real time wide area precision GPS•C service. Key long term and stable financial sponsorship by a broad coalition of Federal and Provincial Agencies will accelerate standards, encourage broad based industry participation through long term investment, and substantially benefit Canadian industry;
- A Canadian wide area precision GPS service should be developed as a real time standard for DGPS2 (1m 2DRMS) applications, but should include a specific timeline for the introduction of wide area services at the DGPS1 (20cm 2DRMS) application level. Moreover, the standard must consider and encourage the export potential of such a service by Canadian Industry. This will necessarily include the selection of appropriate RTCA standards, and architectures to facilitate co-production agreements between Canadian and non-Canadian manufacturers;
- The broadest possible base of Canadian GPS manufacturers and value-added service providers should be made full and active participants in the development and commercialization of the Canadian wide area precision GPS service;
- Canada's academic community should be encouraged to participate in the development of Canada's wide area precision GPS service, as the world's only system capable of sub-metre performance through the development and implementation of advanced modeling techniques capable of reducing error sources beyond that of existing systems and approaches;
- Finally, the consortium charged with the cooperative development of the Canadian wide area precision GPS service should undertake a special study to examine future

alternatives in satellite systems and develop a long term plan for the identification of solutions which will lead to maximum accuracy, functionality, and cost differentiation.

**Acknowledgements - Interview Participants**

Arthur Andersen would like to express its appreciation to the following organizations and individuals for their contribution to the findings of this report.

| *Organization* | *Individual* |
|---|---|
| Geographic Data BC | Mr. Amin Kassam<br>Mr. Gary Sawayama |
| British Columbia Provincial Government | Mr. Chuck Salmon<br>Mr. J.E. Sutherland |
| Wright Focus | Mr. Mike Taylor |
| Premier GPS | Mr. Adel Tabsh |
| CSI | Mr. Grant Shewchuk<br>Mr. Walter Feller |
| Usher Canada | Mr. Roger Leeman |
| NovAtel | Mr. Pat Fenton |
| The University of Calgary | Dr. Gerard LaChapelle |
| GeoSurv | Mr. Paul Mrstik |
| Agriculture Canada | Mr. David Kroetsch |
| Transport Canada | Mr. David Sim<br>Mr. Adrio Taucer |
| NAV CANADA | Mr. Ross Bowie |
| TMI | Ms. Donna Lyson<br>Mr. Dale Wyman |
| Business Development Office, Earth Science Sector | Mr. Gordon Plunkett<br>Mr. David Carney |
| Natural Resources Canada, Earth Science Sector | Mr. Steve Lucas |
| GIAC | Mr. Ed Kennedy |
| FERIC | Ms. Isabelle Forgues |
| Canadian Marconi | Mr. Hubert Pellerin |
| Softmap | Mr. Guy Rochon |
| ViaSat | Mr. Denis Parrot |
| Leica Geosystems | Mr. Marc Boulanger<br>Mr. Andrew Hurley |
| The County of Forty Mile, Foremost Alberta | Mr. Nathan Ogden |
| The Canadian Space Agency | Mr. Sunil Sharma<br>Mr. Stephane Lessard<br>Mr. Arvind Bastikar<br>Mr. John Marone |
| The Canadian Hydrographic Service | Mr. Rick Sandilands<br>Mr. Julian Goodyear<br>Mr. Mike Crutchlow |
| The University of Laval | Dr. Rock Santerre |
| The Geodetic Survey Division | Mr. Kim Lochhead<br>Mr. Denis Hains |
| Land Information Ontario | Mr. Brian Maloney |

# 1 Project Scope and Objectives

## 1.1 Project Scope

As a new millennium is now upon GSD and its community, there is a recognition that the precision GPS sector is evolving more rapidly than at first thought. Factors are many, although the top six below tend to be the major drivers of this continuing evolution:

- Manufacturing and service costs – One can now purchase GPS chipsets that are channel-dense and DGPS ready for under CDN$100. Hand held real time DGPS units can be found for under CDN$450. So called "closed" products that now incorporate extensive precision GPS features, communications links, etc. abound in low cost versions from the major GPS manufacturers. DGPS broadcast services are also becoming more readily and freely available from commercial and government sources in Canada, and around the world.
- Improvements in peripheral technologies and techniques for integration – GPS and DGPS work best in many markets when integrated into larger technology suites that include, among other things, CD-ROMs, special displays, communications systems, and other navigation or positioning sensors. As these peripherals increase in capability and fall in price, whole new combinations become possible and will from time to time instigate competitive races built upon innovation and shorter product design cycles. Also, the role and benefits of the Internet is just beginning to be understood in the GPS community today.
- Emerging standards – Many communications and data protocols have been ironed out through active user group programs. Users can expect to enjoy further performance improvements and cost savings. New DGPS services may emerge if manufacturers choose to support specific standards and applications. All this increases competition and accelerates market acceptance.
- Changing user preferences – DGPS is no longer a technology chasing markets. In many of the user sectors found in the table above, so called "market leaders" have demonstrated means of using precision real time DGPS to achieve unprecedented cost benefits. These market leaders have enabled whole sectors such as forestry and agriculture industries to access metre level positioning to achieve productivity and financial gains. Inherent in several of these sectors are underlying environmental challenges, such as prescriptive use of fertilizer or chemical applications.
- Accuracy and utility compulsion factors - Sector by sector, user preferences have changed during the process, and now more sophisticated customers seek greater accuracy (accuracy is addictive), competing services (DGPS broadcast service providers) and products (varying in price and utility), greater ease of use, etc.
- New communications systems and capabilities – Several communications satellites will provide ideal platforms for enhanced real time DGPS services, including M-Sat, Iridium, Globalstar, ICO-P and others. The introduction, or service restructuring, of such satellite systems may result in rapidly falling costs in the next two years. Programs such as WAAS also provide unique capabilities within regions that will include the more populated areas of Canada.
- Government DGPS services and systems - Still perceived by many as an essential infrastructure service, many users are compelled to await the outcomes from massively

funded US government programs such as the WAAS or the USCG/CCG RTCM beacon systems. Canada participates in these.

Thus based upon these and other changes taking place in the industry today, the Geodetic Survey Division of Geomatics Canada asked Arthur Andersen LLP to undertake a comprehensive review of the need for real-time precision DGPS services in Canada. As GSD is a highly unique scientific/technical knowledge repository for many aspects of this capability, its role as supporter of the Canadian sector was most urgently in need of careful analysis.

### 1.2 Critical Issues and Project Objectives

The following critical issues have been identified for the primary market surveys to be conducted for the NRCan, and will be used to frame questions, and prepare analysis to support our conclusions and recommendations.

- What changes have occurred in the Canadian DGPS industry in the past five years (since the Geodetic Survey Strategic Plan of 1995)?
- What is of FUNDAMENTAL IMPORTANCE to end users (in the resource sector and secondary sectors) and stakeholders with respect to their future needs for real time metre level positioning in Canada?

Hence the objectives of the project were to:

- Review the current and future situation of real-time, metre-level and better accuracy, satellite based positioning and report findings in a Canadian context.
- Evaluate the need for real-time, metre-level and better accuracy, satellite based positioning in Canada and recommend a course of action.

The findings and recommendations found in this report have sought to fulfill these two objectives.

### 1.3 Project Methodology

To accomplish the objectives, Arthur Andersen undertook to analyse the precision DGPS industry in Canada, and then based upon these findings, recommend alternative methods that would contribute to the Geodetic Survey Division's mission as the leading scientific and technical institution in the sector. Five tasks to the program were undertaken:

- We reviewed existing studies, reports and information on real-time satellite positioning systems and augmented satellite systems for positioning and navigation. Systems included present and future systems such as GPS, GLONASS, GALILEO, the Wide Area Augmentation System (WAAS), Canadian WAAS initiatives, the Local Area Augmentation System (LAAS), the Canadian Coast DGPS Service, the U.S. Coast Guard DGPS Service, the National DGPS (NDGPS) system, Natural Resources Canada's GPS•C, commercially available systems and other planned systems.

- We evaluated Canadian user needs for real-time, metre-level and better accuracy satellite positioning capabilities in transportation, maritime, farming, forestry, mining, energy, etc.
- We applied the findings of Tasks 1 and 2 to the Canadian situation (based on geographic area and population) and estimated impacts of a national positioning service offering metre level and better accuracy. We quantified impacts where possible. Then we formulated recommendations on which systems would apply to Canadian users.
- We developed and validated a set of critical issues facing the matter and objectives before GSD. We involved various Canadian user groups of satellite based positioning (maritime, land based applications, forestry and farming) from the start and verified important findings with in-person interviews with several industry groups (see acknowledgements).

This document is the final report, and includes our findings and recommendations from the Canadian industry study on real time satellite positioning. The study is accompanied by a separate document, which outlines our recommendations with respect to Federal Sponsorship of the Proposal for GPS•C, as put forth by British Columbia and Ontario in the fall of 1999.

## 2 Real Time Satellite Positioning - Canadian Industry Analysis

Vast and pristine natural resources have long been a source of pride for Canadians. These resources are directly linked to many levels of Canadian industry and society. For the technologically driven "New Economy" the Canadian people have placed a strong emphasis on the stewardship and preservation of their natural surroundings as evidenced by the following statement:

> *For the next century Canada must become the world's 'smartest' natural resource developer: the most high-tech, the most environmentally friendly, the most socially responsible and the most productive.*[1]

In order to realize the full potential of the natural resources of the country, the natural resource sector must be ready and willing to invest in the development of a "Knowledge Infrastructure," embracing advancements in communications and information technologies. Within the new economic model, information resources such as the Internet and spatial referencing systems such as the Global Positioning System should be included, and have already been identified to be the "utilities" of the next century.

But what is the role, and more importantly the value, of precision spatial positioning in the new economy, given Canada's bountiful natural resources? And will its investment thus far in geospatial positioning knowledge enable related industries to compete more favorably in the global arena? These questions and others are explored in the sections below.

Differential Global Positioning has been acknowledged and embraced as an appropriate application methodology for many years now. However, the Global Positioning System per se was not designed with metre or sub-metre usage in mind. United States military doctrine, historical radionavigation system commitments between military and civil users,

[1] Honorable Ralph Goodale, Minister of Natural Resources Canada, 1999

special undertakings of governments over the years, needs-based investments from a multitude of government agencies such as Natural Resources Canada, and commercial pressures have come to shape current policies and technologies in the GPS arena.

GPS-specific augmentations go beyond just accuracy, and are often intrinsically "tied" to other systems. GPS-specific augmentations include differential techniques that are applied to the satellite signals, integrity determination, alerting systems, and sources of additional ranging signals. Differential technology is the transmission of a correction message that is derived from calibrating measurements made on the ground to users via a data link. By applying the correction information, the user can reduce the satellite ranging errors. Integrity decisions can be made by the ground facilities and added to the message that is transmitted to these users. Several data link alternatives operating on different frequencies to support differential technology augmentations have been suggested. The characteristics that a data link should meet include a sufficient number of channels, sufficient update rate, sufficient capacity, resistance to interference and ability to meet integrity, continuity, and availability requirements.

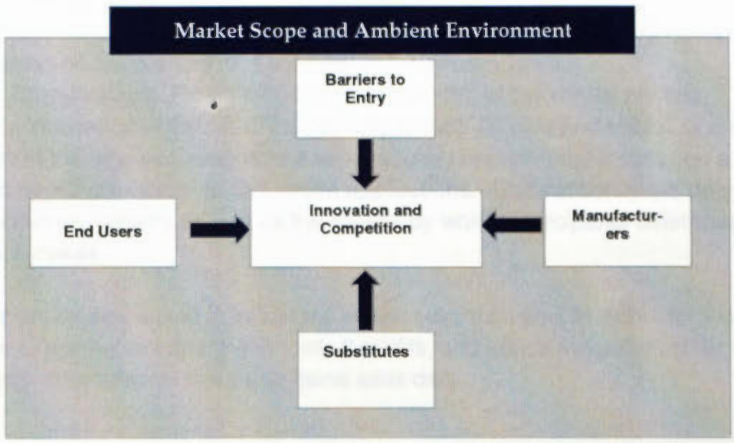
One of the goals of GSD in its precision GPS programs has always been to foster innovation and encourage competition in the relevant Canadian industry sectors including many identified in Table 1 below. To take into consideration this unique role of GSD in Canada, we sought an industry analysis framework that would offer insights and point to new benefits for the Canadian economy.

> "The primary responsibility of the Government is to provide an even playing field so that industry can develop and foster the growth of technology"
>
> *Software Provider*

### 2.1 Industry Analysis Framework – Innovation Centred

Professor Michael Porter of the Harvard Business School created a useful industry analysis model that allows for the development of a holistic view of any industry. It is a derivation of his model that we use to dissect the real time satellite positioning industry in Canada. The Porter model below presents an ideal framework for this study and highlights five basic forces that are common to any industry. These forces must be understood within the context of a unified framework to formulate a view of the sector from all stakeholder perspectives. The modified Porter model, including the five forces, with innovation at its core, is outlined in Figure 1 below:

**FIGURE 1 THE MODIFIED PORTER ANALYSIS FRAMEWORK**[2]




This model is useful to gain insights of a highly dynamic, competitive and rapidly evolving industry from the point of view of any participant. This approach is applicable to the Canadian GPS and precision positioning industry given the current role of the Geodetic Survey Division and the proposal to sponsor GPS•C, and the opportunity for all the participants and sponsors to accelerate innovation.

The starting point for this framework, and for any comprehensive industry review, is a determination of the actual scope, characteristics and potential size of the industry. The Ambient Environment illustrated above reflects the general and specific environmental factors such as market need, technological, regulatory, and economic and even social matters. It is the demand-specific foundation upon which industries function and compete. Table 1 shown earlier provides an excellent indicator of the breadth of the market in Canada for precision geospatial applications. The ambient environment for each of those applications overlap in some areas, and even collide in others, as we will discuss.

Over top of this ambient environment are the forces defining the industry dynamics as applied in the context of the real time precision positioning industry. The five forces have been modified to fit the scope of this industry review. A brief description of the five forces follows:

- **End Users**: Porter originally termed this force "Buyer Power." It is the influence that end users can exert over the success of a product in the market place. It takes into account buying criteria, in the case of satellite positioning it is both the end user's, and the value-adding service provider's, fundamental requirements.
- **Manufacturers and Value Chain Providers**: This force is an overview of the influences that industry suppliers can exert over potential participants in the industry. In the context of real time satellite positioning the "suppliers" that GSD needs to consider are the manufacturers of GPS receivers, and the communications systems and associated technologies needed to tap the full potential of the system and its applications.
- **Barriers to Entry**: A survey of the obstacles that any industry participant faces upon entering, or surviving within, a competitive and rapidly evolving

> "Once affordable value added applications are developed for industry specific tasks, the market for differential GPS applications should explode"
> *Provincial Agency*

[2] Porter, Michael, *Competitive Advantage* The Harvard Business School, 1996

industry with a product or service. Barriers in the GPS industry can include government regulations, a high degree of brand loyalty, or high initial capital investment.

- **Substitutes:** This force highlights the potential influence that other competing types of technology can exert on the product of a potential industry participant.
- **Innovation and Competition:** Finally with the Porter model, at the centre are two complex notions. Innovation is the act of introducing something new and useful, and is an important idea in the new economy where technological breakthroughs occur on a daily basis, often needing a "push" to find useful applications. Competition is the degree of competition within an industry as well as the means by which participants differentiate their products or services.

These relationships are closely linked in industries where advancements in technology and invention create value and extraordinary economic benefits, and where the potential for obsolescence through step-function like value gains exist daily.

### 2.2 Canadian Industry Analysis

The Canadian GPS industry can be defined loosely as the providers and users of GPS products and services. We treat the natural resource sectors, namely forestry, mining and metals, and energy production, as the primary focus of Natural Resources Canada. However, precision real time geospatial positioning could benefit many other industry sectors as well. We will include several of those industries in order to place the resource sectors within the context of the larger precision positioning industry.

In our research and interviews, we identified several elements that provide an excellent environment for precision positioning in Canada, including:

- Shifts in user and consumer demand, driven by improved cost and utility (translating into true productivity breakthroughs), safety and environmental considerations, and increased awareness created by market innovators. Examples of these include proven benefits from applications of DGPS developed for all types of precision legal, GIS and engineering surveying, safer maritime channel and harbor navigation and vehicle location, where leading companies have fielded systems that have solved perplexing problems. These innovators have been able to isolate a range of economic, safety and environmental benefits in specific terms.
- Economics of scale created by high volume applications, but more importantly the shear number of participants in the market developing and applying mass-produced systems, often in cross-over applications areas. This allows the innovators to bring low cost benefits of certain high volume markets to specialized niches where further customization is necessary, without all of the incumbent costs. Productivity drives that yield improved results gain greater understanding and when potential benefits are translated into well understood financial gains, this has the ability to move markets more rapidly to new levels of efficiency and economy.

> "More people buy GPS equipment now, because it is affordable, and because they understand the technology better than they did five years ago"
> *Equipment Manufacturer*

- Technological innovation across the range of component systems needed to tap the full potential of the applications, in this instance the rapid advance in capabilities of microprocessors, GPS technologies, communications systems, and even displays. Important notions here are component functionality (accuracy, size, weight and power consumption), usage (tools for development and application that also improve in functionality) and so forth.
- Access to large markets is also important. The ability of Canadian manufacturers and service providers to offer their goods and services to customers within the NAFTA trade zone, and to markets abroad, make investment in innovation an easier proposition. Many Canadian industry players contend that their investment decisions were made by necessity on the basis that access to markets outside Canada.

Quantifying the industrial impact of these in Canada would be extremely valuable. We were surprised that no governmental or industry body has yet to monitor or regularly develop industry metrics or statistics on products, services, benefits, users, applications, or other important statistics on GPS usage in Canada. Given the high degree of utility of precision real time DGPS applications across both the natural resource sector, and other sectors of the Canadian economy, we thought that Canadian industry would be significantly advantaged by having a central repository for such information, and sector benchmarks between Canada the U.S. and Europe. This is a position enjoyed by U.S. industry through special resources administered by the U.S. Departments of Commerce, Transportation (U.S. Coast Guard Civil GPS Information Centre USCG/CGPSIC is the information centre operated by the U. S. Coast Guard) and Defense, the USGPS Industry Council, and other organizations.

***Recommendation 1:*** *That the Federal and Provincial authorities support the establishment of a central repository for high quality Canadian GPS industry sector information, and share in the funding for such costs with private sector companies or industry groups.*

*Users*

Precision GPS applications and benefits have been well defined. Different levels of functionality have been developed to serve users with disparate needs. The economic impacts of implementing DGPS, which we will attempt to quantify later in this section, will reverberate throughout many sectors of the Canadian economy. The information in Table 1 summarizes many of the industries that have potential to be supported by precision spatial positioning.

**TABLE 1 DGPS - PRIMARY USER ECONOMIC SECTORS AND APPLICATIONS (SHADING REPRESENTS HIGHEST POTENTIAL CANADIAN APPLICATIONS)**

| SURVEYING, MAPPING AND GIS | FARMING/FORESTRY LAND VEHICLE | MARINE | CIVIL AVIATION |
|---|---|---|---|
| Engineering Surveys | Precision Farming | Dredging Control | Flight Instrumentation |
| Geodetic Control | Earth Moving | Pylon Positioning | Feature Mapping |
| Fault Monitoring | Highway Constr. | Rig Positioning | Cat II/III Landing |
| Legal Surveys | Surface Mining | Docking | Crop Dusting |
| Geodynamics | Forestry Surveys | Charting - Dredging | Initial/Final Approach |
| Resource Mapping | Prescription Farming | Buoy Positioning | |
| One-Call | | Seismic Surveys | |
| Utility Mapping | | Channel Navigation | |
| Legal Surveys | | | |
| GIS Data Collection | AVLS Trains | | |
| Photo Control | AVLS Airports | Cabling | |
| Photogrammetry | AVLS Automobiles | Research | |
| | AVLS Emergency | Ship Trials | En Route Navigation |
| Highway Surveys | Public Transit | Harbour Entry | Cat I Landing |
| Navigation | AVLS Trucking | Harbour Approach | Cat II/III Landing |
| Reconnaissance | Long Haul Dispatch | Area Navigation | Ground Taxiing |
| IVHS Database GIS | IVHS Navigation | Fishing | Aerial Photo Recon |

The key to success in the satellite positioning market, as with any market, is to provide a product that the end user can utilize to derive substantial benefits of a cost or performance nature (say safety improvements). Arthur Andersen surveyed several end user groups and was able to identify the following fundamental needs that end users require of their real time products and services going forward:

- **Accuracy:** Present DGPS services lack the precision needed to "unleash" the potential of the technology for many applications – some with the greatest appeal – in the real

time area. Related to this was the need to have all things spatial in the same coordinate system.

- **Coverage**: Currently one of the major concerns that end users voiced with regard to their Differential GPS service (both real time and post processed) was the fact that there were often limitations to the areas in which they could receive currently available service. Aside from the lack of nationwide real time positioning coverage in Canada, there are various reasons for the limitations that end users experienced with local services, such as shadowing as a result of dense foliage, or steeply graded terrain, as well as urban scatter.
- **Availability**: Most end users highlighted the importance that real time corrections be available 24 hours a day, seven days a week. Unexpected system down times was a primary concern that users voiced primarily because system down times hindered end user operations. The fact that end users did not know when this down time would happen compounded the problem.
- **Price**: Stakeholder were consistent in their views that, for mass market applications such as intelligent vehicle navigation systems to catch on, the price of these systems including bundled software (value added applications) must fall at or below the $300 CDN mark. This figure was often cited due to the fact that when Magellan and Garmin stand alone GPS receivers fell below that point several years ago, the general public began to take an interest in those products for recreational use.
- **Simplicity**: Equipment and supporting services must be easy to use. Most stakeholders point out that the ideal level of complexity requires the end user to simply turn on the system, and immediately begin the application process. Training time was a concern expressed by end user groups as a cost item that they would like to avoid.
- **Receiver Functionality:** Due to the fact that there is a wide range of uses for this technology, receiver manufacturers will be challenged to develop means of modifying receiver technology to perform well in various environments. For example, in the context of precision farming or forestry receivers will likely need to be mounted in tractors or logging vehicles. In these applications durability will be an important component to perceived receiver quality. In the automotive market, aesthetics will be a concern, especially for high-end automobiles.

> "End users want a tool in GPS that will make their lives a little easier, save them some time, and make them more effective without causing them added difficulties. Simplicity and functionality is essential"
>
> *Applications Developer*

***Recommendation 2:*** *That the standards for a Canadian service for Real Time Corrections seek to optimize the design and application of user equipment and user services/applications to address tradeoffs between accuracy, coverage, availability, cost, complexity and commercialization/export potential.*

*Market Scope and Ambient Environment*

We relied upon past market studies, augmented by facts gathered through interviews with Canadian users and manufacturers, to assess Canadian market scope. The analysis that follows begins with an estimate of market size, and afterwards discusses the existing user profile.

In order to determine the potential market size and resulting economic impact of real time satellite positioning for the Canadian GPS industry, a methodology was adopted to analyze and extend acknowledged market projections and models used by the U.S. National Research Council (NRC)[3], and we refer to these starting projections as the "*NRC GPS Study*". These projections, developed for the NRC by Booz, Allen & Hamilton in 1995, were based on a rigorous market forecast model originally presented by KV Research[4], and included Canada, the U.S. and Mexico.

The NRC GPS Study estimated the total GPS industry in North America to be US$42.27 Billion if SA (the U.S. DoD mechanism by which accuracy is substantially degraded to the Standard Positioning Service level of 100m2dRMS) were switched off in 1995. The figure was cumulative (1994-2003), and included DGPS products, data communications equipment, network services, software and system integration for GPS systems of every practicable accuracy range. The figure for North America included data for Canada, Mexico and the United States. . In May of 2000, President Bill Clinton announced that SA would be permanently switched off, a surprising and monumental decision that will instantaneously improve the accuracy of GPS based positioning by a factor of ten.

We extracted the Canadian portion of the North American GPS market projection. The ten year forecast figure was US $1.4 Billion. This figure was also closely proportionate to Canada's contribution to North American GDP, approximately 7%. We assumed that this market extraction figure would be a reasonable approximation of direct economic activity in the Canadian GPS industry sector, including civil government, manufacturing and services. This figure represented all GPS and DGPS services and accuracy ranges and included all components of the GPS market highlighted in Table 1.

> "One strategy would be to pick a market like the land vehicle market with high sales potential, and launch a GPS service within that market to start. Then, as the technology gains favor, expansion into other industries will occur naturally"
>
> *Equipment Manufacturer*

There are four general categories of real time GPS systems treated in the NRC GPS Study and conveniently defined as:

- SPS (accuracy range no more precise than 100 Metres 2dRMS),
- DGPS4 (accuracy no more precise than 10 Metres 2dRMS),
- DGPS3 (accuracy no more precise than 2 Metre 2dRMS),
- DGPS2 (accuracy no more precise than 1 Metre 2dRMS),
- DGPS1 (Accuracy no more precise than 20 centimetres 2dRMS) and
- DGPS0 (accuracy as precise as .02 Metres 2dRMS).

Since a national real time satellite positioning system could have a potential accuracy of 1 Metre 2dRMS and higher, and given the anticipated low cost of implementing the system in volume, we can project that the demand forecast should could encompass all categories of DGPS accuracy including and up to 1 Metre 2dRMS (DGPS4, and DGPS3/2). Users with requirements for less than one metre accuracy will not generally have the use for DGPS

[3] US National Research Council, *"Charting the Future – GPS"*, Washington DC, May, 1995

[4] Dyment, Michael J., *Differential GPS Markets in the 1990's A North American Cross-Industry Study*, KV Research Inc, Cincinnati OH September 1992

services until the system is enhanced to meet their requirements (a future possibility). Thus the real time metre level 10 year DGPS Canadian industry potential was estimated to be CDN$1,970 Million. By industry sector for the ten year 1995-2004, and five year 2000-2004 period, it is detailed in Table 2 below. This table projects the "market potential" of metre level DGPS real time products and services in Canada of CDN$1,398 Million over the 2000-2004 period.

**TABLE 2: 10 YEAR CANADIAN MARKET REVENUE FORECAST[5]**

| SECTOR | SECTOR 10 YEAR 1M ESTIMATED MARKET POTENTIAL (PRODUCTS AND SERVICES) CDN$M | SECTOR 2000-2004 YEAR 1M ESTIMATED MARKET POTENTIAL (PRODUCTS AND SERVICES) CDN$M |
|---|---|---|
| Land Vehicle | 689 | 489 |
| Maritime | 217 | 154 |
| Geomatics | 374 | 266 |
| Aviation | 414 | 294 |
| Consumer | 217 | 154 |
| Military | 59 | 42 |
| **Total:** | 1,970 | 1,398 |

Our interviews in support of this study found that the market in both the United States and Canada for real time precision positioning at the DGPS2, DGPS1 and DGPS0 accuracies has been somewhat constrained for several reasons:

- Missing or competing high precision standards for the dissemination (format and means of broadcast) of correction data. While for DGPS4 applications, standards such as RTCM-SC104 have been available, and DGPS services widely broadcast through Canadian Coast Guard and USCG radio beacon transmitters, this has not been the case with metre or sub-metre level applications. Missing standards at the DGPS2 and DGPS1 levels and in particular, agreed upon approaches for wide area systems, have clearly inhibited development of products and services at this important accuracy level;
- Slow speed of maturation of peripheral high accuracy "enabling technologies" such as high (or matching) resolution digital maps, affordable inertial navigation components, etc.
- Costly wide area data links. Many applications for real-time precision DGPS will depend upon the affordability and increased functionality these will bring.
- The cost of real time precision DGPS receivers has been prohibitive. Most real time systems, capable of either high accuracy code differential or kinematics DGPS, have been manufactured in very small volumes. With receiver costs in this performance area high, this depresses sector investments that could lead to volume-driven market innovation.

[5] The Current Proposal for Canada's wide area precision GPS service is not intended to be a certifiable air navigation system. However this does not preclude non-official civil use of this technology in applications such as general aviation and crop dusting.

The particular factor of importance here is that the standards problem at the metre or better accuracy level, which clearly inhibits growth with the very high yield DGPS2 applications. Closed systems utilizing local area DGPS code and carrier phase processing have been offered by the manufacturers for some time, and private sector service providers such as John Chance will sell services, but these costly and non-standardized approaches restrict opportunities for smaller companies and users alike.

Satellite positioning is dependent upon a frame of reference must be generally accepted throughout an application group, for technical and sometimes legal reasons. Generally speaking the need for a reference frame can be either relative to another object, as one would expect with construction engineering surveys or a Category III aircraft landing, or (somewhat) absolute, as in provincial and federal mapping. While for relative position needs, the choice of a spatial referencing system is of secondary importance, one can imagine substantial benefits from all users sharing the same system. Data interchange between user groups is one such benefit.

> Unless we [Canada] get our acts together and concentrate on a common standard for GPS, we will be running around in circles here and we will never realize the full potential benefits that this technology has to offer"
>
> *Software Manufacturer*

For the most part, the NAD reference frame serves Canada as the accepted reference system for Geomatics applications at the Federal level, and provides a common national system for the Provinces to tie in their coordinates and maps. While there are subtle differences (around 1 metre) between NAD 83 and NAD 83 CSRS, they are minor when compared to the large shift between NAD 27 and NAD 83. In order to support large cross-province projects such as intelligent vehicle navigation systems, it will be essential that Canada agree upon and adopt a common reference frame that can provide the common language needed, and as well, will make the export of high precision real time DGPS products and services much easier.

Another type of standardization, one that is unique to real time corrections for GPS, is the data link standard. The data link standard is important in that it dictates the format of the data sent from the source of differential corrections (ie a geostationary satellite, or a DGPS Beacon Tower) to the end user's receiver. Development of a data link standard will allow Canadian industry to focus development efforts on fewer types of receivers. The benefits of a focused effort include gained efficiencies in production on the receiver end, as well as focused Research and Development on ways to improve the adopted data link standard to maximize its efficiency.

Currently there are two major types of data link standards, both of which originated in the United States. The first is RTCM (Radio Technical Committee for Maritime). The Canadian Coast Guard utilizes this maritime standard for their beacon differential GPS system. RTCM is also widely used in the United States, as it is the standard for the growing beacon DGPS system.

The RTCA (Radio Technical Committee for Aviation) format was specifically designed for use in wide area applications. This broadcast data standard, which maximizes bandwidth

and has potential to support both DGPS2 and DGPS1 type services, was originally designed for use in aviation applications (such as WAAS). The RTCA standard was the standard identified by most stakeholders as the ideal data link standard for wide area real time systems.

We also were told of factors unique to the Canadian GPS industry, including but not limited to:

> Canadian industry is hampered by the fact that, without a clear case for a large number of users over which to spread development costs, there will never be an incentive to invest in a GPS infrastructure. Something needs to start the process moving forward"
> *Provincial Agency*

- Substantially lower infrastructure investment in GPS by federal agencies in relation to the U.S. and Europe (examples include the U.S. DoD investment in GPS of over US$12 billion, and the FAA investment in the WAAS of over $500 million) which translate into market stimuli and greater benefits to companies in their respective countries. Industry leaders commented that pursuing business with large U.S. agencies often was frustrated by factors including the U.S. government's own unfamiliarity with NAFTA rules permitting such competition by Canadian companies, and tax or other matters penalizing Canadian bidders;
- Canadian industry's difficulty in accessing investment capital, even though a clearly defined business case for precision GPS products and services could be made. In our interviews mentioned factors included the smaller size of Canada's potential customer base, and higher costs in areas where a manufacturing cost advantage would be essential for success;
- Specifics of regulation of telecommunications, and resulting higher cost structure in Canada, owing to the country's vast land mass and the need to maintain an equivalent infrastructure for a smaller population. Several interviewees indicated that they concentrated their efforts on the more densely populated United States market, or a key local market such as Southern Alberta or Toronto.

Examples from the U.S. experiences with the Wide Area Augmentation System being developed by the Federal Aviation Administration, and the USCG beacon system, indicate that proposed infrastructure programs that set standards, offer free services, and involve industry in their design, in turn drive user and manufacturer research and development efforts years in advance of the introduction of such public services. The Canadian industry participants who we interviewed indicated the importance of precision real time positioning in their businesses, but stated that the above inhibitors would need to be addressed in order to make real time precision GPS a primary growth and investment area.

***Recommendation 3:*** *That infrastructure costs for Canadian precision DGPS users be substantially eliminated through governmental support of a centralized real time wide area precision GPS service. Key long term and stable financial sponsorship by a broad coalition of Federal and Provincial Agencies will accelerate standards, encourage broad based industry participation through long term investment, and substantially benefit Canadian industry.*

We learned from the research and discussions with several industry luminaries that there is potential in Canada for above-average user adoption for DGPS2 and DGPS1 precision positioning products and services, provided several fundamental requirements are met:

- Greater accuracy equates to higher utility, and increased accuracy will translate into high utility and resulting productivity gains for users. The first requirement is for accuracy to be better than what is available today from DGPS systems such as WAAS, and always improving.
- The cost of real time service should be very low cost or free of charge to end-users. This requirement is predicated upon the fact that competing systems in the United States will offer free service, and most suppliers currently acknowledge that end users prefer one time fixed costs for their systems, as opposed to subscriber service fees.
- The cost of receivers for the real time GPS system must be in line with the costs that end users currently pay for low-end receivers. Most users interviewed projected a dramatic increase in demand if receiver technology costs were to drop to the point that manufacturers could offer products with real time corrections capability at or below $300 CDN. Prices above this mark are seen as prohibitive to most volume market commercial, industrial or personal users.

> "People really started to buy the Magellan and Garmin receivers for recreational use when their price fell below CDN $ 300"
> *Receiver Manufacturer*

If these three fundamental requirements remain unfulfilled, then the market for real time GPS corrections in Canada will be limited to well-financed "professional" users. From these findings, we make a key recommendation designed to lower obstacles and encourage full GPS industry participation in the development of wide area precision real time DGPS.

***Recommendation 4:*** *That the wide area precision GPS service be developed as a real time standard for DGPS2 (1m 2DRMS) applications, with a specific time line for introduction of wide area services at the DGPS1 (20cm 2DRMS) applications level. The standard must consider and encourage the export potential of the wide area precision GPS service by Canadian industry - manufacturers and users - through a range of commercial mechanisms available to them from the sponsoring federal and provincial agencies. This will necessarily include selection of appropriate RTCA standards, and architectures to facilitate co-production agreements between Canadian and non-Canadian manufacturers.*

*Manufacturers and Applications Developers*

Globally there are about 30 "primary" manufacturers of GPS equipment, that is – primary designers of proprietary technology - and the number is now relatively stable. Two of these are Canadian: Novatel and Canadian Marconi Company. Several of the primary manufacturers are focused on the survey market, others on navigation or timing, and a few are broadly based, offering a wide variety of equipment, or general-purpose hardware, to participate in many market segments. As with any new consumer electronics product, the price decline of GPS equipment with time has been phenomenal. Higher degrees of integration, larger volumes and the amortization of initial research and development costs have brought prices of GPS gear down by an order of magnitude in the last 10 years. Size and performance factors have, at the same time, improved dramatically. Most of the GPS equipment manufacturers offer dedicated base or reference station hardware, capable of interfacing with any communications facility. The majority will also integrate some sort of communications facilities and deliver a turn-key, real-time (local area) differential system, if desired.

Arthur Andersen interviewed several Canadian manufacturers and value added suppliers of receiver products that could be adapted or developed to supply the real time market in Canada. These suppliers already have experience with real time correction products, such as beacon DGPS receivers. However, the focus of Canadian suppliers today is the global markets where volumes are more attractive, and programs such as WAAS which provides DGPS4 infrastructure and services free of charge to aviation users. One Supplier indicated that in excess of 90% of its sales of DGPS products were targeted at export markets, particularly the U.S., and the remaining 10% ended with Canadian users. We found by talking with other Canadian suppliers of receivers that the focus upon export markets is not uncommon.

> "There is no real need for an under funded, poorly planned Canadian Government system, in light of all of the commercial and American competitors. Let's spend that money on something else"
> *Applications Developer*

Aside from receiver manufacturers, the designers of value added software applications that will bridge this technology to the needs of the end user must be considered important suppliers. Canadian manufacturers, software companies and system houses are devoting considerable effort to GPS and differential GPS related activities. In addition, and perhaps more importantly, many small companies are springing up with the dedicated aim of producing GPS software or performing GPS systems integration. Many struggle or state that they are at a distinct disadvantage without a concerted effort by Federal and Provincial agencies to sponsor infrastructure development, and in turn leveling the playing field.

To be successful, the development and launch of a world-class wide area precision DGPS service in Canada will require hardware solutions and applications development that will be unique and exportable. The GPS manufacturers and value added suppliers in Canada, who already have extensive export market experience, and as well, are on their 4$^{th}$ or 5$^{th}$ generation products, will have valuable views on commercialization potential. It will be essential for their involvement in the program.

***Recommendation 5**: That the broadest possible base of Canadian GPS manufacturers and value-added service providers be made full and active participants in the development and commercialization of the wide area precision GPS service.*

*Industry Substitutes*

In the real time satellite positioning industry in Canada there are a number of entities that already offer real time corrections, or that could do so in the near future. Industry service substitutes are both private companies and federal or provincial agencies.

The table below outlines the best known current and potential major competitors in the real time DGPS market in Canada, and underscores the fact that the market is best considered as North America. Many stakeholders interviewed speculate that the real reason for the limited market in Canada has been the lack of complete coverage nationwide. Canada's northern latitudes are difficult to cover from geostationary satellites with equatorial orbits, which has been one of the two most common means of broadcasting differential corrections, the other being beacon towers.

Ironically the substitute that may be the driving force behind real time corrections in Canada has yet to become operational. The Wide Area Augmentation System (WAAS) in development in the United States could potentially become a predominant means of DGPS3 or DGPS4 differential GPS corrections in North America. Canadian industry has responded to this possibility, and companies such as NovAtel in Calgary and Nav Canada in Ottawa are cooperating in the development phase of the WAAS system. While WAAS is geared towards the aviation market, the free signal will be available to other applications as well. Any entrant into the real time satellite positioning market will need to differentiate from and improve upon the services that WAAS offers.

**TABLE 3 PARTIAL LIST OF INDUSTRY SUBSTITUTES**

| ALTERNATIVE SUPPLIER | CURRENT OR POTENTIAL | DESCRIPTION OF SERVICE |
|---|---|---|
| Omnistar | Current | • Commercial American L-band Satellite-based corrections<br>• Fee for service $1800 Annually |
| LandStar (Racal) | Current | • Commercial American L-Band System<br>• Fee for Service $1200 Annually<br>• Satellite based service utilizing AMSC Geo. Satellite at 101 Degrees West Longitude |
| Canadian Coast Guard and USCG Beacon | Current | • Canadian Government operated<br>• Free service in areas near Canadian waterways<br>• Beacon-delivered differential corrections |
| US Differential Beacon / NDGPS | Current | • United States Government operated<br>• Free service to areas close enough to US border to pick up coverage<br>• Planned Nationwide US coverage late 2001-early 2002 with the modification of Cold War GWEN radio sites<br>• Beacon delivered differential corrections |
| Wide Area Augmentation System | Potential | • United States (FAA) operated<br>• Satellite based corrections<br>• Free Service<br>• In Mar Sat Footprint covers most of Southern, Maritime, Western Canada |
| Current Private Real Time Kinematic (ie Pleiades) | Current | • Small Private Canadian Corporation (s)<br>• Real Time Differential CDPD broadcast service for fee<br>• RTK service for fee |

Other private fee for service competitors will likely have to adapt their business practices to meet the growing availability of free service systems. While the availability of free service may hurt these companies' bottom line at the beginning, many companies could take advantage of the free service offered by government groups such as the FAA or GSD, and re-adjust their business focus to incorporate this technology into an improved product. Nevertheless, most stakeholders interviewed agreed that provision of a free service across

Canada was a needed utility that will keep Canada competitive in the knowledge-based economy.

*Innovation and Competition*

It is important to understand the ways in which competitors in any industry attempt to differentiate their products, because an understanding of areas of differentiation provides an example as to the ways in which the industry will develop over time. With the seeming proliferation of free service systems such as WAAS, competitors in the real time corrections market currently strive to differentiate their products from that of the opposition. Innovation begets customer benefits. Competition leads to differentiation. Combined, both innovation and aggressive competition translate into faster market transitions and growth. The key is to differentiate products and services in a technical and a service sense. In this sense it is of importance for the final architecture of the wide area precision GPS service to support innovative end user applications.

> "The government would not really be competing with small providers, rather they would be providing these small entities with the opportunity to enhance their service offering for their customers"
> *Provincial Agency*

The three main technical areas where innovation and competition can lead to substantial product differentiation are:

- Accuracy;
- Functionality; and
- Cost.

> "One tremendous opportunity would be to enhance to accuracy of the system [GPS•C] to the sub-metre level. This would be truly remarkable"
> *Federal Agency*

These are very important to end users, and through research and development investment will drive improvements in these areas with input from end user markets. However each of these categories must be addressed differently.

While the majority of end user applications can support metre level accuracy, most stakeholders that were interviewed indicated that sub-metre or decimetre accuracy is actually much more beneficial to end users. All stakeholders seemed familiar with the popular expression "Accuracy is addictive." Accuracy improvements with wide area systems requires a unique set of expertise generally not found in the private sector alone. Additionally, the challenges of producing sub-metre real time corrections with the current constellation of SPS configured GPS satellites is enormous. While the next generation of GPS satellites will have more than one available commercial frequency, the focus today must be upon available signals.

Canada's academic community is one of the most advanced in the world when it comes to wide area DGPS technology and science. This capability is resident in, but not limited to, the University of New Brunswick and the University of Calgary. In order to improve wide area accuracy, manufacturers and service providers would greatly benefit by tapping expertise in the academic sector to improve the performance of base station networks, and the ability of modeling techniques to further reduce wide-area error sources such as ionospheric and tropospheric modeling errors.

***Recommendation 6:*** *That Canada's Academic Community, through its GPS centres of excellence, be encouraged to participate in the development of GPS•C as the world's only wide area system capable of sub-metre performance, through advanced modeling techniques capable of reducing error sources beyond that of existing systems and approaches.*

Improvements in system functionality and cost will need to be handled by future service providers working in conjunction with manufacturers. Key to both functionality and cost will be the choice of data link service, and the means by which the service is "integrated" into the end user's problem solution set.

It will not be possible for one data link service alone to satisfy all potential end user applications. Both satellite and terrestrial communications systems have their strengths and weaknesses. What will be the appropriate mix of these, in the short and longer term, to provide the greatest flexibility and functionality to users at the lowest possible cost? Perhaps satellite-based transmissions will become a commodity in the decades ahead, driven by the increasing number of competing systems available today or just on the horizon – ICO-P, Iridium, Globalstar, Ellipso and M-Sat to name just a few. Complicating matters here is the offsetting needs of high latitude coverage, which only a few system choices will satisfy today until the next generation of low and medium earth orbit satellites are fully operational, and ultimately cost.

***Recommendation 7:*** *That the GPS•C consortium undertake a special study to examine the future alternatives in satellite systems, and develop a long term plan to seek innovative solutions with the manufacturing sector to foster innovative approaches that will lead to maximum accuracy, functionality and cost differentiation.*

The choice of communications service driven by its applicability to Canada's unique geographical location will become less difficult as time goes on. Selection of a satellite system whose receiver terminal can be used elsewhere in the world will be critical in order for manufacturers to recoup development costs.

The ideal system architecture for GPS•C would leave open many mechanisms for competitive impetus. As touched upon above, the means by which the real time precision DGPS service is "integrated" into the end user's problem solution set also provides opportunities for innovation and product differentiation. By developing a system architecture that leaves open most avenues for manufacturers and value added service providers to create differentiated products and services, participants in Canada's real time satellite industry can position their products optimally for Canadian and export markets.

*Barriers to Entry*

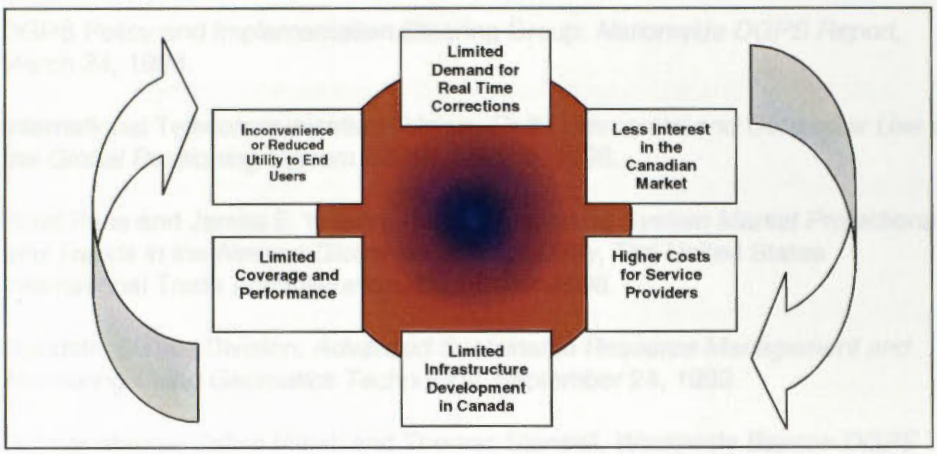
Historically there have been several barriers to entry and development of the real time positioning industry in Canada. One area touched upon above has been the lower level of government investment in GPS over the years, and the relative advantages

> "Low end user demand for GPS technology in Canada is symptomatic of the limited infrastructure that has been deployed here "
>
> *Federal Agency*

U.S. industry has gained through the multi-billion dollar GPS and DGPS development programs supported by the Departments of Transportation and Defense over the years. These have induced barriers through cross-subsidization deficiencies suffered by Canadian manufacturers. While it is true that some U.S. program funding comes their way, this is small in proportion to funding that stays in the U.S. for indigent firms.

The following cyclical relationship depicts one of the major reasons why the Canadian industry has not been able to take full advantage of the market potential that precision real time positioning can offer it.

**FIGURE 2 THE REAL TIME GPS MARKET ENTRY DILEMMA**




In order to break the cycle, the development of infrastructure becomes a logical first step. Through our interviews, we were able to validate the cycle and identify a much larger and more vibrant industry sector through the proposed GPS•C infrastructure project. Key to boosting demand is to encourage broad participation of important sectors, including manufacturers, academia, end users and federal and provincial agencies. The absence of any of these sectors may perpetuate the cycle.

## 3 Bibliographical References

### 3.1 Studies and Reference Documents

Position Location and Navigation Symposium (PLANS) General Meeting 1999, Resource Document.

Institute of Navigation Meeting 1999 (ION) Resource Document and Papers.

The Geodetic Survey Division: *Background for Arthur Andersen Working Session meeting on Real Time Satellite Positioning Requirements Analysis*, Presented September 29, 1999.

DGPS Policy and Implementation Steering Group: *Nationwide DGPS Report*, March 24, 1998.

International Telecommunications Union*: Civil Commercial and Consumer Use of the Global Positioning System (GPS)*, April 16, 1998.

Scott Pace and James E. Wilson*: Global Positioning System Market Projections and Trends in the Newest Global Information Utility*, The United States International Trade Administration, September 1998.

Geodetic Survey Division: *Advanced Sustainable Resource Management and Monitoring Using Geomatics Technology*, September 24, 1999.

Gunner Mangs, Satish Mittal, and Thomas Stansell, *Worldwide Beacon DGPS Status and Operational Issues*, Leica Geosystems, May 1999.

Charles A. Chamberlain: *Ontario Active Control System Strategy, User Needs Assessment*; Chamberlain Consulting, August 24, 1999.

Marshall, Macklin, Monaghan Ltd and Pleiades Data Corporation: *Final Report on Differential GPS Tests in Ontario*, June 1999.

Jack Rigley: *Delivery of Differential GPS Data in Canada, Review of Potential Solutions*, Communication Research Center, June 1999.

Sheryn McGregor-Suave and Douglass Scott: *Providing Access to the Canadian Spatial Reference System*; Geodetic Survey Division April 1998.

Pierre Heroux and Jan Kouba: *GPS Precise Point Positioning with a Difference*, Geodetic Survey Division, June 1995.

Richard Fuller, Todd Walter, Sharon Houck, Per Enge: *Flight Trials of a Geostationary Satellite Based Augmentation System at High Latitudes for Dual Satellite Coverage*; Stanford University, October 1998.

Robert Duval, Pierre Heroux, Norman Beck: *Canadian Active Control System- Delivering the Canadian Spatial Reference System*; Geodetic Survey Division, Revised February 1997.

Dr. Elizabeth Cannon, Kim Lochhead, Pierre Herou:, *Performance Evaluation of the NRCAN Wide Area System*, Department of Geomatics The University of Calgary and The Geodetic Survey Division, Presented at the Institute of Navigation GPS-1996 Meeting, September 1996.

Geodetic Survey Division: *GPS-C Real Time Correction Service of The Canadian Active Control System*; January 1997.

Michael J. Dyment, *Strategic Planning Project for Geodetic Survey Division*; Booz Allen and Hamilton Ltd., April 6, 1995.

Geomatics Canada: *Geomatics for the New Millennium*, Natural Resources Canada 1999.

Michael Dyment, Michelle Martin, and Scott C. Lewis: *Differential GPS Markets in the 1990's A North American Cross Industry Study*; KV Research Inc. September 1992.

Gary Sawayama and Brian Maloney: *National GPS-C Solution*, Land Information Ontario and Geographic Data BC, Presented to The Canadian Council on Geomatics September 14, 1999.

The European Commission: *Galileo, Involving Europe in a New Generation of Satellite Navigation Services*, Brussels February 10, 1999.

Commission of the European Communities*: Towards a Coherent European Approach for Space*, Brussels July 6, 1999.

Communication Research Center: *Galiloe, European Strategy towards GNSS-2*, Presented March 22, 1999.

The International Telecommunication Union: *World Telecommunication Development Report 1998*, Geneva Switzerland, March 1998.

Amin Kassam: Global Surveyor Beta Test Experiences- Reconnaissance Bathymetric Survey of Adams Lake, Geographic Data BC, August, 1999.

Arthur Andersen: *Stakeholder Feedback and Planning For The Future Workshop*, Presented to the Geodetic Survey Division March 1999.

Amin Kassam, Brad Hlasny and Vern Vogt: *The Global Surveyor Real Time DGPS Service*, Delivered to the GIS-99 Conference in Vancouver BC, 1999.

### 3.2 GPS World Magazine Articles

*Deep Sea Geodesy: Monitoring the Ocean Floor*, September 1998, p. 44.

*Gauging the Tides, Monitoring Subsidence around the Chesapeake Bay*, May 1999 p. 34.

*From the XY Files: Mapping Death Valley's Wandering Rocks*, April 1997, p. 34.

*Keep off the Eelgrass, Protecting a Vital Puget Sound Habitat*, February 1997, p. 38.

*A View form Above: Characterizing Plant Growth with Aerial Videography*, April 1998, p. 34.

*The NSTB: A Stepping Stone to WAAS*, June 1998, p. 73.

*Standards: Potential GPS Trade Barrier*, June 1998, p. 16.

*Getting the Drift: How Water Moves out of the Surf Zone*, March, 1997 p. 46.

*Farming Pays: Andalucia's Agriculture Application of GPS*, July, 1998, p. 30.

*Polar Positioning: Tracking Greenland's Ice Sheet*: July 1999, p. 42.

*OMB Attacks National DGPS*, February 1998, p. 14.

*Redd Recon: Mapping Chinook Spawning Habitat*: January 1999, p. 28.

*GLONASS to GPS: A New Coordinate Transformation*, January 1999, p. 54.

*Mining Down Under: RTK GPS Surveys Take Hold in an Australian Colliery*, March 1999, p. 44.

*Sensors at Sea: Homing in on Stray Electrical Currents*, November 1997, p. 40.

*Situation Critical: GPS Modernization for Civil Use*, January 1998, p. 32.

*A RIN Report: The News About GLONASS*, February 1998, p. 44.

*What's Good for the Grower: Assessing Goose Damage to Northwest Crops*, March 1998, p. 30.

*Leadership in Satellite Navigation and Timing: Past Success and Future Challenges*, October 1999, p. 48.

*GPS and GLONASS: Towards Sub-Nanosecond Time Transfer*, November 1998, p. 30.

*On Track and on Time: Commuting with GPS*, January 1999, p. 20.

*Show us the Money: ITS/GPS Roundtable*, October 1997, p. 44.

*Precision Spraying: Working Towards an Ideal*, February 1999, p. 38.

*Opportunity Knocks: Will GPS Modernizaton Open Doors?*, September 1999, p. 36.

*Unearthing Soil Compaction: The Hidden Effects of Logging Machines*, March 1997, p. 40.