HARVEST TRACKING AND NAVIGATION WITH GPS

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PREFACE

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PREFACE

This technical report is a reproduction of a thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Forestry in the Department of Forestry and Environmental Management, March 1998. The research was supervised by Professor Glen Jordan, of Forestry and Environmental Management, and by Dr. David E. Wells, of Geodesy and Geomatics Engineering. The research was supported by the industrial partners of J. D. Irving Woodlands and Weldwood of Canada and by the National Centres of Excellence, Sustainable Development in Forestry and Fundy Model Forest.

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ABSTRACT

Substantial growth in civilian applications of the Global Positioning System (GPS) is evident across North America and around the world. Forestry applications have not lagged. GPS is involved in diverse applications in forestry, ranging from logging truck fleet management to harvest block layout. This thesis reports on a study that investigated the viability of using GPS to navigate forest harvesting equipment. The focus of the research investigation was to determine the *viability* of on-board, real-time GPS technology, teamed with GIS, in partial harvesting navigation. The *viability* of the system was determined on the basis of its ability to satisfy the same *post-harvest quality assessment* criteria and *harvest productivity* rates as exist in present practice.

Motivated by the savings that would result if costly harvest block layout procedures could be eliminated, the study examined GPS navigation performance using Valmet and Timberjack single-grip harvesters in partial harvesting experiments in Sussex, New Brunswick and Hinton, Alberta, respectively. The New Brunswick experiment involved a late autumn harvest in a mixed-wood condition, while the Alberta experiment was carried out in a pure softwood condition under severe winter conditions. The treatment involved GPS-assisted navigation of the desired harvesting pattern displayed over covertype map detail on a pen-based PC computer connected to a real-time differential GPS receiver. The control for the test used a portion of the harvest block in which no navigational assistance was utilized.

Harvest performance criteria recorded during treatment and control harvesting were productivity (trees/hour) and post-harvest quality (coverage). Since physical objects interfere with GPS reception, it was expected that tree cover, would be the single most influential factor determining harvest productivity and post harvest quality for GPS assisted harvest navigation. For this reason, each experimental site was characterized by stand density (trees/ha) and tree cover type (% softwood and hardwood) in a pre-harvest survey with uniformly distributed sample points. In both control and GPS-navigated harvesting, reception quality was indicated (recorded) by the number of blocked satellites. The analysis examined the harvest block conditions and satellite reception.

The findings showed that the introduction of the GPS in harvest navigation did not adversely effect the quality of the harvest but it may decrease the production rate of the harvest, especially at higher harvest rates, as was witnessed in the Alberta test site. The study also showed that there is a relationship between the stand density under which the harvest machinery is operating and the GPS reception quality, as indicated by the number of blocked satellites.

Key words: GPS, GIS, forestry, navigation, harvest methods, mobile mapping.

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CHAPTER 1 INTRODUCTION

The Global Positioning System (GPS) has emerged as the foremost navigational system in several diverse fields. This thesis proposes that forestry operations in general, and harvest operations in particular, can also benefit from the navigational capabilities of GPS. The research examined the application of GIS and GPS technologies in a *Harvest Navigation System* (HNS). The primary objective was to *assemble* an on-board, real-time GPS-GIS system and to *investigate* its viability in partial harvest navigation in a variety of forest conditions.

1.1 Problem Definition

Timber harvest operations proceed according to long-term management schedules that identify the specific location of harvest blocks for certain harvest treatments at particular times. In current practice, harvest block boundaries are manually transferred from the management schedule map and laid out in the field with flagging tape or spray paint to guide subsequent harvest operations.

While one-pass clear-cutting remains the dominant harvest intervention, multiple-pass harvesting, or so-called selective cutting, is becoming common. Selective cuts, unlike clear cuts, represent a more complex harvest navigation problem, indicative of what will occur in landscape, or ecosystem management. More convoluted patterns will arise from landscape managed harvesting practices. For reasons of harvesting efficiency and treatment effectiveness, selective or partial cutting operations must proceed in a more systematic fashion than when a clear cutting system is employed. Typically, selective cutting involves navigating harvesting equipment along a series of equidistant parallel lines that transect the harvest block. In present operational practice these lines, like the harvest block boundary, are often laid out and flagged manually before harvesting begins.

Because recent corporate downsizing has created a slimmer work force with fewer people working in our forests, those still working have had an increase in work load and responsibilities. Therefore, industry is currently looking toward new methods and technology to assist reforming forest operations. In the context of harvest operations, the foreman is responsible for cutblock layout. An automated process could replace this time-consuming task, allowing personnel to carry out other duties.

Digital navigation systems have been used in marine, air and ground vehicles with increasing frequency. It is almost inevitable that forestry vehicles will see some form of digital navigation system implemented in the near future. The navigation of a harvest vehicle in selective cuts is a suitable application of this technology.

The objective of this research was to *assemble* an on-board, real-time GPS-GIS system and to *investigate* its *viability* in partial harvest navigation across a range of forest conditions. *Viability* of the system was determined on the basis of its ability to satisfy the same *post-harvest quality assessment* criteria and *harvest productivity* rates as exist in present practice, that is, to follow the objectives of the harvest operating plan.

It was known, however, that GPS performance in the forested environment is poor. GPS signals can be significantly attenuated and can be entirely blocked by the tree canopy. Current forest operations that utilize GPS have experienced difficulty working under tree canopies. Tracking and navigating a harvest vehicle with GPS in selective cutting operations would have to deal with the GPS signal and tree canopy problem.

1.2 Potential Impact

This research has potential economic benefits for any forestry operation conducting mechanized harvesting methods. If an on-board GPS-GIS navigation system can be demonstrated as viable, significant cost and time savings might be realized if implemented across a company's harvesting operations. The automated guidance of the harvest vehicle could supplement or replace the manual demarcation of the cutblock. It is anticipated that the savings would surpass system costs in just a fraction of an operational season [Celeste and Gagnon, 1996]. A study conducted for the Forest Engineering Research Institute of Canada (FERIC) by one of its industry stakeholders showed that annual savings of $160 000 Cdn could be realized in the surveying and marking out of cut blocks for the company's total forest operations [Courteau and Lévesque, 1995].

In addition, there would be added benefits of having a spatial information system housed within harvesters and integrated with a navigation system. This could lead to an effective decision support system for specific harvest operations, as well as a better information flow between the harvest operator and the harvest management system. For example, detailed timber inventory could be created by the harvester with an integrated GPS-GIS system. Spacing objectives (stems/ha) could be calculated on-the-fly and used to aid the harvest operator in selecting specific trees to be felled. In the study cited above, a savings of $360 000 Cdn was attributed to the additional decision support for better control of species mix. Efficient information flow to-and-from the harvest operator is essential for effective harvest operations. The harvest operator could have a real-time decision support system in the cab as harvesting progresses.

Similarly, spatial information gathered by the harvester could augment the forest inventory database. Information flow from the harvest operation back into the resource management database could be facilitated with an integrated GPS-GIS system in the harvester cab. For example, the cut block limits, trail locations, harvest rates and product data, could all be spatially located and uploaded into the management database, thus, giving the forest managers a better decision making mechanism.

Of longer term significance, an operational GPS-GIS configuration could provide the navigational intelligence that the new, more complex array of harvesting and silviculture interventions emerging within landscape management require for efficient and effective execution.

1.3 Thesis Outline

To achieve the primary objective the project followed a simple format of Harvest Navigation System design, development and assessment. Recall that the primary objective was to *assemble* an on-board, real-time GPS-GIS system and to *investigate* its viability in partial harvest navigation in a variety of forest conditions. The assembly of the HNS is recounted in the design and development Chapters (2 and 3). The evaluation of the HNS is described in the assessment Chapter (4). The purpose of the design phase was to isolate specific factors and issues that would permit successful assembly of a HNS prototype. The development phase served to evaluate equipment and procedures that ultimately led to a working prototype. Finally, the HNS viability was assessed in two ways. First, the HNS prototype was assessed for its ability to meet the viability definition. Then, secondly, the specific GPS performance was evaluated in the forest environment.

The design phase was initiated with a user needs study in which operational performance requirements were established for a HNS prototype. These performance requirements aided in setting specifications for the HNS design. The design phase also involved a literature and technology review. This review helped reveal factors that would affect the operation of the HNS. Specifically, the review looked into base mapping data, software-operator interface, antenna protection, GPS limitations in the forested environment, and mechanized harvest operations. In addition, the review established the current state of HNSs and identified where this study fits in contemporary research. Chapter 2 elaborates upon the design phase.

A development phase followed the design phase, and involved extensive field trials. The purpose of the field trials was four fold: observe harvesting procedures, evaluate design equipment, train harvest operators in GPS navigation, and help formulate experimental testing for the assessment phase. From the field trials, an evaluation HNS prototype was assembled. Following refinements, two operational prototypes were assembled. The evaluation prototype served as an initial test of GPS-GIS technology in the specific setting of the harvest vehicle. Different hardware, software, and procedures were then introduced until the operational prototypes met the project objectives.

The work was conducted in two typical Canadian forests, the Acadian Forest of New Brunswick, and the Boreal Forest of Alberta. These two locations were selected for a number of reasons. They represent two different forest environments in which stand yields (volume of standing timber) vastly differ, and hardwood-softwood species mix differ, thus affecting the HNS performance. Together, the test sites are typical of a large majority of the forest environment in Canada. Also, two different HNS configurations were created for the project sites. The differences entailed the source of GPS differential services, and the computing devices used. Chapter 3 summarizes the findings.

The purpose of the assessment phase was to *investigate* the HNS *viability* in partial harvest navigation. *Viability* of the system was determined on the basis of its ability to satisfy the same *post-harvest quality assessment* criteria and *harvest productivity* rates as exist in present practice. The assessment phase consisted of formulating an experimental design, conducting field tests and investigating the viability of the operational HNS prototype. Test and control blocks were created for the two forest locations. The control block utilized the traditional harvest layout method, and the test block utilized the operational HNS prototypes. The investigation of the HNS viability involved several steps. Each block was assessed for harvest quality and harvest productivity, the criteria set for testing viability. Then, an investigation of the relationship between the GPS operating parameter, number of blocked satellites, and the environmental parameters, stand density, slope and aspect was carried out. This investigation was made to see if there were operating limitations of the GPS tracking and navigation component imposed by the forested environment itself. Chapter 4 provides details of the assessment phase.

The results from the assessment helped determine where improvements can be made and indicated whether further development is warranted. Final recommendations and conclusions are drawn from the assessment of the HNS and are presented in Chapter 5.

1.4 Contributions

This research demonstrated how a harvest navigation system can be integrated into a mechanized harvester, and identified some of the limitations which may be encountered with the system in the forested environment. It provided performance criteria to aid in the design, development, and assessment of an operational Harvest Navigation System. These performance criteria may be used by others wishing to undertake similar endeavor.

This research contributes to the working knowledge of the GPS in a forested environment. Very few published studies have been done in this area and, since there have been many changes in GPS technology, an up-to-date study is warranted. An evaluation of the GPS performance in the context of mechanized harvesting was investigated by analyzing the relationship between specific environmental parameters (stand density and terrain slope and aspect) and the number of blocked GPS satellite signals.

CHAPTER 2 HARVEST NAVIGATION SYSTEM DESIGN FACTORS

The aim of the design phase was to investigate specific factors and issues that would contribute to the successful assembly of a Harvest Navigation System prototype. The design of the HNS was initiated with a user-needs assessment to gather information from harvest operations personnel to set specific performance criteria in the design of the HNS. The performance criteria served as operating specifications for the design of the HNS. Stemming from discussions with the harvest operations personnel, a set of HNS design concerns were also isolated to help address the performance criteria. This design process led to the basic concept of a HNS prototype.

An extensive literature search and review into specific technologies and procedures was conducted. Specifically, software-operator interface design, digital mapping issues, antenna protection, GPS limitations, and mechanized harvest operations were investigated prior to field trials. This review: (i) established the current state of GPS research and navigation systems in the forested environment; (ii) revealed the particular difficulties and limitations that occur when operating GPS in a forested environment; and (iii) led to design decisions that ultimately revealed which GPS receiver would be suitable for this project application.

2.1 Performance Requirements

The design phase began with a user-needs assessment in which operational performance requirements were established. The user needs study consisted of an initial planning meeting with the local industrial partner (J.D.Irving Ltd. of Saint John, NB) and a subsequent meeting with the western partner (Weldwood of Canada Ltd.of Hinton, AB).

The user-needs committee consisted of key personnel such as the harvest operators, the harvest foreman, the district forester, and the in-house GPS coordinator. Expected capital outlay, system costs, operating costs and scheduling were discussed. The potential benefits and expected savings in time, money, and operations were stated by the industrial partner in informal discussions (summarized in Section 1.2).

The key personnel helped to identify the expected performance requirements of an operational HNS. Performance requirements addressed issues such as the accuracy, reliability, ruggedness, and the user friendliness of the operator interface of the proposed HNS. The performance criteria served as design goals for the HNS and, as noted earlier, would be used as part of HNS viability assessment. The performance criteria deduced from the user needs study were:

(i) the system should not disrupt the normal operation of the harvest equipment.

(ii) the system must be able to operate for 24 consecutive hours with minimal operator interaction.

(iii) the spatial accuracy of the positioning system should correspond to the spatial resolution of the harvest trail, that is, the width of the harvester wheel track. Thus the desired accuracy is $\pm$ 2 m.

(iv) the external hardware(antennas) should be ruggedized or protected sufficiently to withstand occasional impact from debris, including falling timber. Internal hardware (receivers, CPU, display) should be vibration and impact resistant.

(v) the operator interface must be very simple to operate and convey all necessary information for navigation within the cut block.

Further discussions with operations personnel revealed specific issues that arose in identifying the performance criteria which helped to focus the research. These included:

(i) The spatial information content which is useful to the harvest operations consists of: boundaries, buffers, harvest trails, and topography. The navigation indicators are: waypoint navigation (particularly left-right display), and a moving vehicle indicator (blinking cursor on a moving map);

(ii) It was determined that the navigation functionality would be limited by: the accuracy of digital map input, quality of on-board real-time map display and guidance mechanism, simplicity of operator interface, timeliness of satellite availability, and topography.

(iii) Other techniques to improve the navigation reliability, may be required to supplement the GPS signal loss under forest cover. These include filtering algorithms and dead-reckoning devices.

(iv) Provisions for the on-board equipment must be met. These include hardware mounting and hardware interface specifications, such as power supply, protocol and ruggedness;

(v) It was determined that the GIS software would be selected on the basis of customization, user interface, sophistication.

(vi) The computing hardware would be selected on the basis of computer power requirements relative to the costs.

(vii) The antenna should be securely mounted and protected;

(viii) Adequate operator training and support would be provided.

(ix) There should be a cost analysis of the prototype system.

2.2 Operator Interface

It was felt that one of the keys to the success of the HNS was a simple operator interface. This was reflected in the performance criterion: the operator interface must be very simple to operate and yet convey all necessary mapping information for navigation within a cut block. The operation of a single-grip harvester is very complex. Two joysticks, foot pedals, and numerous finger switches are constantly manipulated during harvest operations. To keep productivity rates high, the operator has very little time to interact with the navigation system. Hence the interface should be user-friendly, icon driven, and the display of the map information should be visually comprehensible, with just one glance. The location of the harvest vehicle with respect to its surroundings can be portrayed with a moving map display. The harvest operators indicated that an audible alert should indicate when the harvester (GPS position) is in the vicinity of the block boundary or riparian buffer zone (GIS data). As determined from the user needs study, the basic requirements for the mapping navigation interface included:

(i) display tools: zoom, auto-pan, and redraw;
(ii) drawing tools: pen, text, lines, and polygons;
(iii) edit tools: select, cut, copy, and paste;
(iv) measurement tools: distance, bearing and area; and
(v) drawing layer management.

2.3 Mapping Issues

Several digital mapping issues were investigated. The visual display of the mapping information, map content, coordinate systems, and spatial accuracy were primary concerns, as identified in the user needs study.

The overall display of the mapping information must be clearly comprehended by the operator. The display of information is an amalgamation of the properties from the computing device, the software interface and the map information. The viewing screen has to be glare resistant and have suitable contrast and brightness properties so that the image can be clearly viewed in different levels of light, i.e. full sun, overcast, and night.

Additionally, the pixel size should be small enough to display fine line detail with clarity. The software interface should have drawing layer management facilities such that graphical information may be manipulated by colour and symbology. Different line weights, patterns, and colour (or gray scales) help convey various geographical information features, such as, block and buffer boundaries, streams, and contour lines. The mapping data must convey all necessary information for navigation and decision making within the cut block.

Various types of mapping data such as stand boundaries, riparian zones, topography and digital photography can be used by the harvest operator to aid in the navigation of the partial cuts. These data are generally managed jointly by the industrial license holder and the government forest agency. The specifications and quality of these geomatics products varies greatly depending upon the source. Data source, data format, file size, ground coverage extent, significant topological coverage display (stand boundaries, contours, water bodies), mapping projection and datum should be investigated to ensure sound GPS/GIS integration.

Another difficulty can occur when different coordinate systems are used in the GIS data and for the HNS positioning. Mapping products have associated coordinate systems that spatially locate the data. Most mobile mapping software have transformation utilities that handle a set number of projections and datums. However, these transformations do not take into account all the factors which may be required to fully register the GIS and GPS data, such as local distortions in the mapping coordinate systems. Even if the available transformations are used, there can still be a mis-registration of the GIS map data, with the spatial information gathered by the GPS component. Local coordinate transformations may be applied in the form of lateral shifts to correct for mis-registration.

There are various sources in the mapping process that account for spatial errors. Users of these media have to accept the errors and be wary of them. For example, there are many georeferencing errors in the photo-interpretation of the forest inventory data base. The stand boundaries are not defined lines but fuzzy boundaries. These boundaries conflict with drainage and transportation patterns and may be moved to give clarity to the data. It is important to be aware of this cartographic manipulation.

For the GIS data to be useful in GPS applications, the spatial accuracy of the mapping should be comparable to spatial accuracy requirements of the GPS positioning. As stated in the performance requirements, the application resolution was identified as the width of the harvester or approximately two metres. Hence, it is also the spatial accuracy identified for the GPS positioning. In many cases the mapping data do not meet this spatial accuracy. As a rule of thumb, the ground accuracy of a base map is usually at least equal to the width of the smallest line or, in other words, the linear resolution is comparable to the spatial accuracy of the map. For example, a 0.5 mm line on a 1:12 500 mapping scale (a typical forest inventory mapping scale) is equal to 6.25 m on the ground. Thus, a stand boundary on a GIS map may have an uncertainty of at least $\pm$6.25 m. Certain features, like the cut block boundary, property line and riparian buffer zones should have a higher spatial accuracy, comparable to the resolution of the harvest operations. Hence, it is recommended that these features be field digitized with a GPS data collector. For the field trials, the cut block boundary and drainage features were located with GPS mapping techniques (See Section 3.3).

2.4 Antenna Protection Investigation

Antenna protection was investigated with the help of FERIC. They have designed a prototype dome made of a dielectric material (Lexan) which could withstand an impact from a 200 kg log falling from 15m [Courteau, 1996a]. The GPS antenna is mounted inside the protective dome. The dome is then mounted onto the cab of the harvester with three magnetic pads. The antenna cable is fed through a hole on the side of the dome protector. The personnel from FERIC visited the test site with the prototype dome protector but it was not available for mounting due to other obligations. Damage to the antenna was considered to be a low risk for the short duration of this study. It was decided that, as a cost saving measure, a protective cover would not be manufactured or acquired for the study. Cost estimates were approximately $1200 Cdn for the initial prototype cover and $400 Cdn for each subsequent unit.

2.5 Differential GPS

To achieve the ± 2 m spatial accuracy appropriate for vehicle navigation, real-time differential GPS (DGPS) had to employed. Autonomously, without DGPS processing, positional errors will typically amount to 100 m. DGPS processing eliminates or reduces errors and biases significantly. Various DGPS services and costs were investigated, along with the possible limitations that could be encountered with this technique in the forested environment. A comprehensive investigation of real-time DGPS techniques was conducted to ensure that a reliable DGPS method was employed in the HNS prototype design. Two different real-time DGPS systems were utilized in the two field sites for the final design of the HNS.

The basic DGPS technique involves determining the relative positions between GPS receivers which simultaneously track the same radiopositioning signals [Wells et al., 1986]. Through differential processing, the relative position of the receivers or, in other words, the baseline coordinate differences, can be determined accurately. If one data set is collected at a precisely known stationary reference receiver, the second receiver is positioned relative to the stationary receiver when the DGPS corrections have been applied.

The primary sources of error or biases are atmospheric delay errors, satellite data errors, and the intentional data error- Selective Availability [Wells et al, 1986]. The atmospheric delay errors occur when the GPS signal passes through the ionosphere and troposphere. The satellite data errors include clock and orbital biases. Clock biases occur at the satellite transmitter and the user's receiver. The largest contributing satellite orbital and clock bias is Selective Availability (SA), which is an intentional degradation of the spatial accuracy, introduced by the U.S. Department of Defense for strategic reasons. SA can contribute up to 100 m in positional error. DGPS processing eliminates or reduces these errors significantly. There are also measurement errors, such as multipath, that occur when the signal arrives at the receiver along two or more paths. This phenomenon arises when the signal is reflected from a physical obstacle such as a vehicle, building or even a group of trees. DGPS corrections cannot eliminate this error. A more detailed discussion of multipath will follow in Section 4.3.

Real-time DGPS is essential to produce navigational data that has improved accuracy and reduced error bias. Achievable accuracies are also dependent upon receiver characteristics and local environmental variables. Real-time positioning or navigation is accomplished with a DGPS communication link. This transmitted DGPS message is required to supply the remote GPS receiver with the DGPS corrections.

A standardized correction message has been defined by the Radio Technical Commission for Maritime Services, Special Committee Number 104 and is commonly identified as the RTCM SC-104 Standard (currently Version 2.1, Version 2.2 pending) [Radio Technical Commission for Maritime Services, 1994]. All differential GPS services utilized in this project used Version 2.1.

The pending Version 2.2, has certain advantages. Specifically, it will be able to support the Russian satellite navigation system GLONASS, utilize non-standard datums, introduce a GPS/GLONASS offset to support a combined operation, record the GPS time complete with the GPS week and hour, and support higher precision reference station antenna phase center location [Kalafus, 1996]. The 2.2 standard will not be officially released until early 1998 and it will take some time before the GPS industry introduces it into navigational systems.

The digital correction message contains information on the reference station position and its health, satellite constellation health and, most importantly, the differential correction values (pseudorange corrections) [Wells et al, 1986]. The various types of messages are sent at different times, depending upon the urgency of the message type. For example, the reference station parameters are only sent periodically (every half hour) whereas the range corrections may be sent on a continuous data stream of 200 bps [Canadian Coast Guard, 1995]. This ensures that the differential corrections for each satellite are sent frequently. The continuous data stream ensures that the total latency for the corrections is minimized.

Latency is an important issue to address when dealing with real-time DGPS. Basically, latency is the time delay between the observed pseudorange at the base station, and the applied pseudorange correction made at the rover. Several processing steps take place. Specifically, at the GPS base station pseudoranges are observed, corrections computed, and the corrections and supplementary information formatted. These are then sent to a radio modem, where they are modulated and transmitted. The corrections are then received at the rover radio modem, de-modulated, sent to the GPS receiver, re-formatted, and finally applied to pseudorange measurements made at the rover. Over the latency period, the error conditions at any satellite may change considerably. Thus corrections which are no longer valid are applied at the rover. The longer the latency period, the more invalid the corrections, especially in the presence of high S/A [Geographic Data BC, 1997]. The latency period may be minimized by ensuring that a high data transmission rate is utilized and the optimal message format is selected (RTCM Type 9-3) [Canadian Coast Guard, 1995].

The roving GPS unit must be able to accept the RTCM SC-104 message format and have real-time differential processing capabilities The roving unit will have a radio receiver operating at the same broadcast frequency as the real-time DGPS reference station. The radio transceiver may be a separate component or fully integrated into the GPS receiver chassis and antenna. The DGPS message is transmitted on different government licensed frequencies, depending upon the service provider.

The real-time DGPS data is available from a variety of sources in the public and private sector, due to the increase in customer demand in the marketplace and the proliferation of technology in the telecommunications field. Nationwide service coverage is provided by communication satellites [Miller, 1995]. Many service providers in urban areas broadcast over normal radio frequencies with a Radio Data System (RDS) that utilizes an FM sub-carrier band [Weber and Tiwari, 1993]. Coast guard agencies in Canada and the United States have a network of Continually Operating Reference Stations (CORS) which provide full coastal and extensive inland differential service[Canadian Coast Guard, 1995]. Another method involves a site specific DGPS system where a local reference station and a low powered radio modem is installed and operated by the end user.

The utility of these systems in the forested environment is largely untested. Radio Data Systems (RDS), carried over the FM radio band, are currently established in urban centres where broadcast ranges attenuate quickly with terrain relief [Jasumback, 1996]. An optimal urban coverage may range 50 km in radius from the transmitter. The range is heavily dependent upon the transmitter power and terrain.

The communication satellites that currently provide DGPS service are typically geostationary, with equatorial orbits. Thus, they are low in the southern horizon and coverage for Canada is poor. Additionally, a clear line of sight between the receiver and communication satellite is required for good data transmission. The treed environment and the continually moving timber harvester could not guarantee a clear line of sight to a geostationary satellite. A larger extent for communication satellite coverage is currently being implemented, but is not yet operational at this time. The communication satellite systems and RDS were not used in this project.

Two different DGPS delivery methods were utilized in the design of the HNS. For the New Brunswick site, the Canadian Coast Guard CORS was used in conjunction with a Trimble ProBeacon DGPS receiver. The CORS, located approximately 100 km from the test site in the port city of Saint John, New Brunswick, was known to have good signal coverage over the local area [Topple, 1996]. Discussions with the Regional Surveyor for the Canadian Coast Guard [Topple, 1996] revealed that the low frequency, long wave length DGPS correction signal was not affected by tree coverage and hence would be suitable for the HNS application. Since no real-time DGPS service was available in Alberta, a local GPS basestation and radiomodem transmitter system were set up on site.

Both DGPS systems were integrated into the HNS and their performance assessed. The development and assessment of the DGPS link will be described in later sections (see Sections 3.5.2 and 4.9.2 respectively).

2.6 GPS Limitations in the Forested Environment

Current forest operations that utilize GPS know the difficulty of working under tree canopy. Tracking and navigating a harvest vehicle with GPS in selective cutting operations must deal with the GPS signal and tree canopy problem. This section reviews the difficulties of working with GPS in a forested environment. Performance results from past studies have shown what types of problems and limitations can occur in forests. The studies investigate the effects of tree foliage, humidity, and terrain characteristics on GPS performance. This examination helped to determine design specifications for the GPS receiver technology in the HNS project.

The specific characteristics of the receiver affect how well the GPS signal is tracked and ultimately processed as positional data. Specifically, the number of dedicated channels and associated signal processing techniques define the receiver quality. In the research studies, all were single frequency receivers with five to ten channel acquisition. The number of dedicated channels equates to the number of satellites that can be continuously tracked at a given time. More satellites acquired by the receiver increased geometrical strength of the positioning solution and increases observational redundancy which, in turn, increases the positional accuracy and reliability. Some of the more recent GPS receivers utilize narrow correlator processors which reduce tracking errors caused by noise and multipath [Van Dierendonck et al. 1992, Karels et al. 1994, and Megland et al. 1994] and, hence, yield better accuracy (optimally <1 m).

It is the physical properties of the GPS signal and the environment through which it must pass that limits GPS use in the forest. The GPS signal operates in the microwave frequency of the electromagnetic radio band. This frequency was intentionally selected since the signal propagates in a straight line of site and, thus, contributes to the high accuracy of the positional data. However, another property of the signal is that its strength is weakened very rapidly when it encounters physical obstructions. This "signal masking" occurs with tree foliage. The GPS receiver obtains a multitude of signal conditions when under tree canopy. The amount of foliage in the signal path can change rapidly due to wind moving the leaves, antenna movement and satellite constellation changes [Jasumback, 1993].

The "signal masking" or "shading" effect is illustrated in a study from northern Alberta [Gehue et al, 1993]. The study shows how the tree canopy blocks a certain percentage of the GPS signals. For this study, a six channel Magnavox 4200D receiver was used with a CMT MC-V data collector. Individual satellite tracking helped to describe the interaction of the satellite signal and tree canopy. The term "shading" describes satellites that are behind the tree cover and whose signals are not fully blocked. Figure 1 illustrates the track of six satellites (black lines with identification number) with respect to the local coniferous treeline (green line) for one hour of data collection.

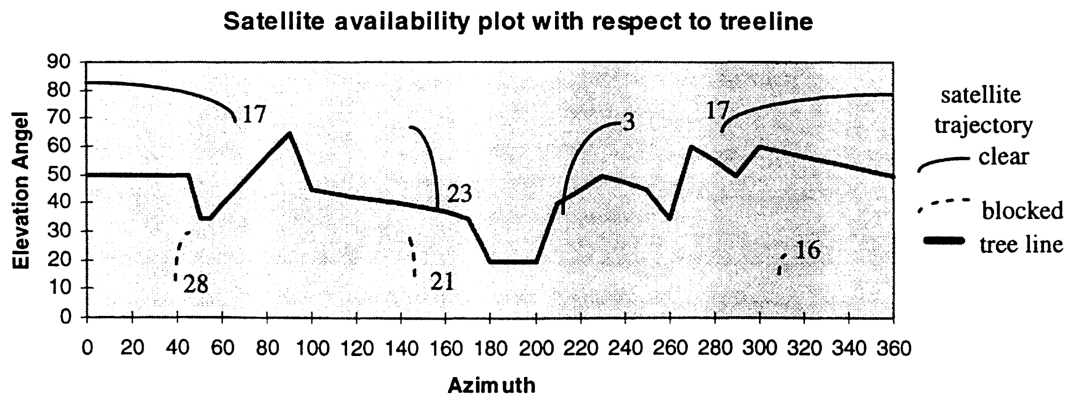


Figure 1. Satellite availability plot with respect to treeline.
(Adapted from Gehue et al., 1993)

Figure 1 shows three satellites above the treeline (solid black line) and three satellites below the treeline (dashed black line) on a horizon plot (elevation angle versus azimuth, i.e. the angular height with respect to the horizon versus the compass direction). An analysis on the data loss and GPS signal strength was performed. The GPS data was declared unusable when it was not recorded, entirely blocked or when it failed to pass a minimum signal-to-noise ratio. Table 1 shows the percentage of unusable data for the same data set illustrated in Figure1.

Table 1. Percentage of unusable data , Pincher Creek [Gehue et al., 1993

SV ID	*Data Loss (%)*
3	0
16	53
17	0
21	58
23	0
28	63

The position of the satellite with respect to the treeline and the percentage of blocked satellites clearly illustrates the spatial relationship of tree foliage and good satellite data. The satellites higher in the horizon were not affected by the treeline, whereas approximately 60% of the GPS data from signals penetrating the tree canopy were lost.

The seasonal effect of tree foliage, GPS signal availability, and GPS receiver characteristics is illustrated in a study performed by the Department of Geomatics Engineering at the University of Calgary [Lachapelle et al, 1994]. This study is similar to the current research in that the GPS receiver is used in a differential mode for vehicle navigation. There is, however, a significant difference in the setting. This study was performed along the tree-lined streets of Calgary, not a fully forested environment. The details help to illustrate the foliage effect and, since several types of receivers were used, the study provides some insight into GPS receiver performance differences.

The investigation pin-pointed several parameters which would affect satellite availability, signal quality and positioning accuracy. These parameters are: thickness of leaves and branches; density of foliage; humidity; season, in the case of deciduous trees;

number of GPS receiver channels; tracking loop robustness; code accuracy; and, re-acquisition time.

The goal of the Calgary study was to analyse the above parameters with two objectives in mind. First, to assess the impact of deciduous foliage on signal availability and accuracy and, second, to compare various C/A (coarse/acquisition) code receivers. Three different receivers were used. They were: Navstar XR5M- wide correlator spacing, all-in-view, 12-channel, C/A code L1 receiver; Motorola LGT 1000™ - wide correlator spacing, six-channel, C/A code L1 receiver; and, NovAtel GPSCard™ 951R- narrow correlator spacing, all-in-view, 10-channel, C/A code L1 receiver.

The methodology for evaluating the GPS receiver performance in this study involved tracking a passenger vehicle around the residential area of Calgary. The residential streets are lined primarily with elms and birches, 10 to 20 m high which, in effect, cause signal blockage 20° to 40° above the horizon on either side of the vehicle (across track). All of the GPS receivers were tested concurrently in three test periods, performed in 1994. One was conducted in April, when no leaves were out, two tests were conducted in June, during full foliage, on a rainy day, and a dry day. The time of day was selected to ensure good PDOP (Positional Dilution of Precision: an accuracy indicator deduced from satellite constellation geometry) and maximum satellite availability. Also, all tests were time synchronized to ensure that the same satellite configuration was approximated, eliminating constellation geometry effects.

In general, the results showed that tree foliage affected receiver performance significantly and, yet, there was no significant effect produced by an increase in humidity for any receiver. A receiver with a lesser number of channels than the number of available satellites has a slower acquisition time and satellite searching scheme [Lachapelle et al, 1994]. This result was reflected in the 6-channel receiver, where good (≤ 2) HDOP (Horizontal Dilution of Precision) availability was down to 70% of the time during full tree foliage. It was stated that deciduous foliage may reduce HDOP availability by only 5% when using an all-in-view receiver. It must be noted that the tree canopy closure is very small along a residential street corridor. For a forestry related application, such as those which arise in the harvest navigation scenario, a greater tree canopy influence is expected.

A similar study was performed by the same research group in 1993, which compared GPS receiver performance in a residential area and the downtown core of Calgary [Melgard et al, 1994]. Results showed that a multi-channel (10-channel), narrow correlator receiver proved to have better satellite tracking performance and better signal re-acquisition delay than 6-channel standard (wide) correlator spacing receivers. The performance of the tested receivers was poorer in the downtown core where the ***urban canyon*** effect is produced by large standing office buildings. This "terrain" effect would be analogous to cliffs and canyons in a wilderness setting. It was speculated that the urban setting would produce a greater occurrence of multipath, due to the electromagnetic reflectivity properties of some building surfaces, than would occur in a typical forested environment.

2.7 GPS Performance Discussion

The findings of the literature and technology review revealed what type of GPS receiver would be most suitable for a HNS. It was determined that the GPS receiver should include certain characteristics to ensure navigational reliability in the forested environment.

It must be a multi-channel (>8 channel), all-in-view satellite tracking system. A multi-channel receiver will ensure that all visible satellites are used for the navigation/positioning solution. The GPS constellation is designed to have eight satellites in the sky. Occasionally, a ninth or tenth satellite will appear low in the horizon. Since it is not advisable to use low horizon satellite data because of poor signal strength and increased atmospheric errors, these satellites may be filtered out with an elevation mask. The elevation mask omits any satellite signals from a stated elevation angle (typically 15°above the horizon). Hence, an eight channel or greater receiver was decided upon.

It was also determined that the receiver should have a quick re-acquisition time for blocked satellites. High quality receivers have dedicated channel processing. This ensures that re-acquisition of blocked satellites is performed in a quick and timely manner. As well, it must possess narrow-correlator spacing which increase GPS performance. The narrow correlator technology increases GPS receiver performance by improving the range resolution, reducing susceptibility to multipath effects, and shortening the recovery time after loss of track [Karels et al.,1994]. The narrow correlator technology results in lower noise code and better multipath rejection. Only a few GPS receivers such as Ashtech, Leica, NovAtel, Sercel and Trimble, incorporate these new technologies that will ensure the best performance under tree canopy.

Other, less technical considerations had to be taken into account for the selection of the GPS equipment for the HNS. The availability, familiarity, cost and technical support of the equipment were considered, to ensure that the project could proceed in a timely manner and within budget allowances. Compatibility with other components (field computer, radio modem and mapping software) was also a design consideration. The Trimble Differential Survey Module (DMS) was selected with the performance criteria and extraneous considerations in mind. For a full description of the receiver specifications and settings, refer to Appendix II.

2.8 Mechanized Harvest Operations

The two industrial partners J.D.Irving Ltd. in Sussex, New Brunswick and Weldwood of Canada in Hinton, Alberta use contractors who own and operate single-grip harvesters. To understand the dynamics of a single-grip harvester and to identify how the HNS would work within it, the cut-to-length single-grip harvest system and selective cutting method were studied. The working environment of a single-grip harvester is very complex and harsh. It was essential to understand the harvest machinery, method and prescription in order to design an operational HNS prototype that could be integrated into the existing process with minimal impact. This investigation shed light on the specifics of the working environment of the timber harvest operations.

The harvester is just one component of the harvest system, which is composed of the equipment, skills, and knowledge used to harvest an area. The *harvesting method* describes the form in which the wood is delivered to roadside. The *harvest prescription* describes what type of harvest pattern, objectives, and subsequent stand density will be left at the end of the operation, i.e. thinning , selective cut, and clear cut.

2.8.1 Cut-to-Length Single-grip Harvesters

A single-grip or one-grip harvester refers to the configuration of the cutting head. The cutting head consists of a hydraulically driven mechanism with two roller-feed wheels, generally four gripping knife arms and a pivoting chainsaw-blade cutting device. The cutting head is mounted on a hydraulic arm. In contemporary terms, a single-grip harvester can also infer that the cutting head and arm are mounted on a multi-wheeled carrier. The two models used in this study were six-wheeled carriers, articulated in the middle (front section cab, rear section engine). The two models were the Valmet 911 and Timberjack 1270. These machines are of similar design, with the major difference occurring in the cab mounting and hydraulic arm configuration. The Valmet 911 has a rotating cab with a telescopic arm whereas the Timberjack 1270 utilizes a fixed cab placement and pivoting articulated arm.

Figure 2. Valmet 911-C (courtesy of Totem Equipment)

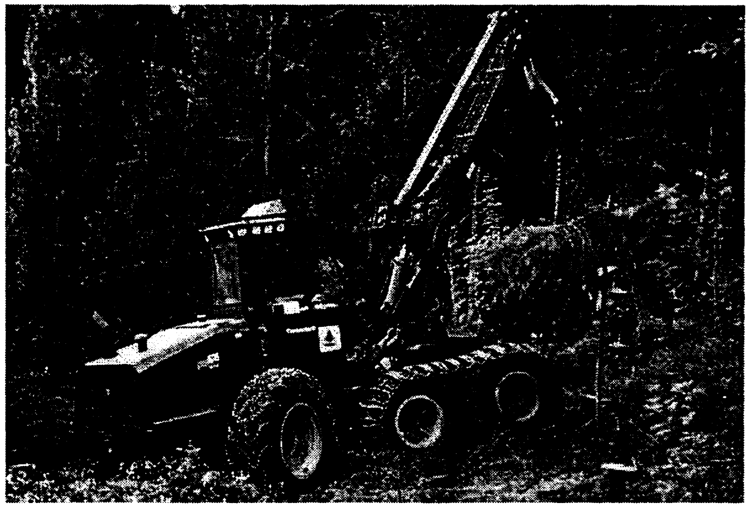


Figure 3. Timberjack 1270 (Courtesy of Dr. Pulkki, 1997).

The placement of equipment for the HNS must take into account the various vehicle movements and cutting head as it conducts its harvesting tasks. Figure 4 illustrates the proposed placement of the GPS antenna, clear of obstructions, yet not vulnerable to falling timber.

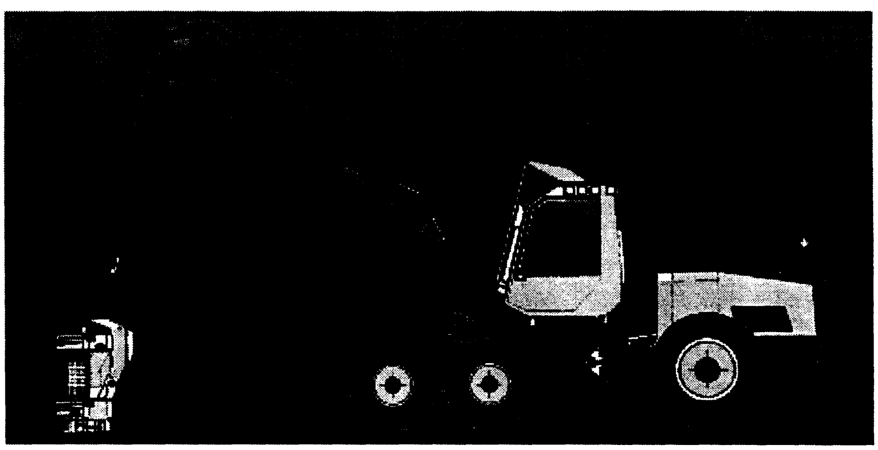


Figure 4. Timberjack 1270 Harvester [Modified from Timberjack, 1994]

Generally, the method of cut-to-length harvesting involves felling the tree, delimbing it and bucking it (cutting to specific lengths) directly at the stump. The logs are sorted into product specific piles (sawlogs, stud wood, pulp wood) and later transported to the roadside. Since the wood is carried off the ground and the slash (tree limbs) are left on site, the method is considered to have a "softer" environmental impact area [Pulkki, 1997]. Cut-to-length harvesting now accounts for about 20 percent of the volume harvested east of Alberta in North America [Pulkki, 1997].

The cut-to-length method is best suited for commercial thinning, shelterwood cutting, and selective cutting but may also be used in clear cutting operations. A major disadvantage with the single-grip harvester over other types of mechanized harvesting is its complexity and, thus, the high skill required by the operator. For this reason, training operators is very expensive and it may take up to two full years for an operator to become totally competent in its operation [Pulkki, 1997]. However, within several months most operators become sufficiently proficient. To ensure that the HNS operator interface did not add to the complexity of an already very complex operation, the design had to be simple and the interface easy to learn and use, as stated in the performance criteria.

2.8.2 Harvest Patterns and Prescriptions

Harvest patterns such as thinning, shelterwood cutting, and selective cutting can be performed with cut-to-length methods. All involve removing a targeted tree type and leaving healthy standing timber for harvest at a later date. The ramifications for the GPS reception is that a partial tree canopy will still be present for the entire harvest operation. For most of the operation a full tree canopy will be present in the vicinity of the harvester.

A prescription contains specific details of which characteristics are preferred for each category of wood product desired for harvest-- pulp wood, stud wood and sawlog. The prescription is usually very site specific. An example prescription is given in

Appendix I for a selective cut block that was used during the development phase of the HNS. The prescriptions for the test sites are also detailed in Appendix I.

The layout of the cut trails also constitutes part of the harvest pattern. Specifically, the trails are laid out at an optimal distance apart to optimize the cutting pattern and to minimize the number of trails. The cutting pattern may contain main trails and ghost trails. The wood product is piled within reach of a main trail to allow the product to be hauled to road side. This task is usually handled by a forwarder or a porter. The slash is deposited on the trail to help minimize the soil compaction and erosion that is caused by the heavy harvesting machinery. The following figure details a typical selective cut harvest pattern (Fig. 5). Also refer to Appendix IX, Site Maps, for an encompassing view of the harvest pattern (Fig. 6 and 7).

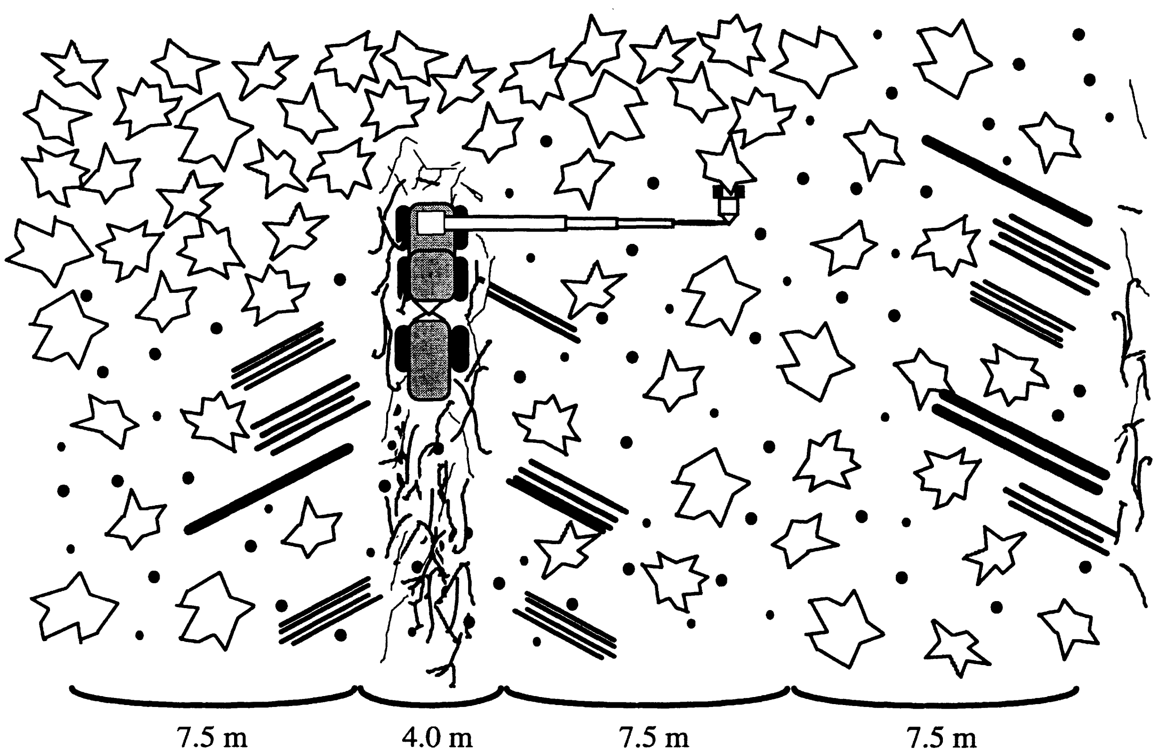


Figure 5. Typical Selective Cut Pattern.

The layout takes into account several factors such as, slope and terrain roughness, drainage, block boundary shape, road access, landscape aesthetics, and product extraction.

It was envisioned that the HNS would aid the operator in the harvest pattern layout by supplying digital map data and a real-time GIS decision support system. The map display could contain and convey spatial information such as the roadways, drainage, contour lines, forest inventory and the cutblock boundary. The harvest operator could use this information to help layout a cutting pattern that takes into account these factors. Drawing, measuring and editing (identified in section 2.2) would facilitate an automated layout of the cutting pattern by allowing the operator to simply draw equidistant lines for use in subsequent harvest navigation. The pattern may be quite convoluted to match the cut block boundaries, drainage and slope. A moving map display would keep the tracked location of the harvest vehicle (a blinking cursor) within the field of vision automatically. The display would be redrawn if the cursor location moved off the map display. Modifications to the cutting pattern could be made on-the-fly if the operator had to change the pattern due to local influences.

2.9 Existing Harvest Navigation Systems

Investigations into integrated technology for mechanized harvesting have been conducted by the Swedish Institute of Forestry, Skogforsk for the past few years. The integration of computerized measurement systems and GPS was presented by Ingemar Eriksson at the GPS in Forestry Workshop '96. Two Swedish case studies of GPS integration in mechanized forestry operations were illustrated [Eriksson, 1996].

The first case study involved integrating the output stream from a bucking computer (cut-to-length timber parameters) with GPS positions via a PC field computer to optimize harvesting. The objective was to monitor the basal area harvested per hectare. The system was not used for navigation and no spatial information was presented. It is interesting to note that Sweden has a nation-wide DGPS Radio Data System (RDS) service carried over the FM band [Eriksson, 1996].

The other case study showed how GPS positioning was used to monitor harvesting productivity [Eriksson, 1996]. An integrated solution was found by creating output streams from electronic devices such as tilt meters and harvest computers and synchronizing them with GPS positions. The objective was to monitor the performance of the harvester over different environmental conditions.

There is no mention of the spatial accuracy requirements for these projects. It seems that monitoring of the harvester performance is at a larger scale, the stand or cut block level (100 m^2), in contrast to this project, where positioning of the harvester is at the individual trail level (2 m). Discussions with Mr. Eriksson revealed that the method of positioning the harvester should be improved if accurate vehicle tracking and GIS integration is to be achieved [Eriksson, 1996]. One method that was being actively tested at SkogForsk was positional smoothing by utilizing real-time moving average algorithms.

At the outset of this project only one Harvest Navigation System was known to be commercially available. Mobiway, a division of Stra Conseil Inc. of Longueuil, Quebec has developed the Forest Navigation System (FNS). The development of this product was initiated with personnel at FERIC's eastern division, who are now currently employed by Mobiway.

The development of the FNS was based upon field studies initially conducted with E.B. Eddy Forest Products in 1994, with a feller buncher on a clearcut prescription. The objective of the project was to identify turnkey, accurate and low-cost GPS-based navigation systems for the forest industry, and to incorporate features like GIS tools, operator friendly interface, and navigation accuracy of 3 m within 50 km of a reference station and to be able to automatically geo-reference field data [Levesque, 1994].

The initial study identified system components that met the objective of the project. No specific details are given regarding the GPS receiver or the software interface. With the help of FERIC suitable antenna protection was designed, built and tested to withstand the impact of a falling tree. As stated in a later study, the impact was tested by a 200 kg log dropping 15 m [Courteau, 1996]. The largest limitation identified was a suitable real-time differential system that could meet the 50 km requirement. At the time of testing only a 17 km range was achieved. The system was not fully deployed since the real-time DGPS did not meet the operational range for the scheduled work at that time, namely 25-30 km. It was stated that an accuracy of 3 m or better was achieved inside the range of the DGPS correction message [Levesque, 1994].

Shortly after the initial development by FERIC, the project was turned over to Stra Conseil Inc., a telecommunications firm. Further progress was made in improving the range of the DGPS transmission, up to a stated 55 km [Courteau, 1995]. One method employed to improve the range was the installation of a large whip antenna and transmission tower at the base station site.

Since the system has become commercially available, the specific details of the technology are not public and may be considered proprietary. The design of the HNS in this project involved comparable components to that of the Mobiway system. Specifically, the GPS receiver, operating software, and computing device are similar. A statement used several times throughout their product literature and presented at workshops and conferences is..."*an accuracy of 2 m even under dense forest canopy*" [Stra Conseil, 1995, Courteau n.d., and Courteau, 1996]. Yet no accuracy tests and no clearly stated definition of *dense forest canopy* have been published to date.

2.10 Field Trials

Consultation with the user-needs committee aided in locating the project sites and scheduling an initial field study phase. The field trials were used to aid in the design and development of the HNS and, ultimately, to assess the viability of the HNS in selective cutting navigation on a single grip harvester.

The field trials for the design phase involved observations of the single-grip harvester operations. It was observed that the vehicle is very slow moving and stationary for a large period of time during which trees are cut. Typically the harvester is stationary for 10 minutes then moves five to 10 m along the harvest trail. It was speculated that the slow movement would help facilitate several GPS position fixes while the harvester is stationary. It was during the field trials that the decision not to protect the antennas was made. It was observed that the incidence of debris falling on the cab roof was infrequent and not a threat to the antenna security, at least during this project.

Most of the system design and subsequent development took place in the Fundy Model Forest since it was close to the University of New Brunswick, Fredericton Campus. The field studies were performed on cut blocks scheduled for harvest. The test sites represent typical working conditions for each region, that is, a mixed hardwood-softwood Acadian forest and a *pinus contorta* (lodgepole pine) - *picea mariana* (black spruce) Boreal forest.

2.11 Summary

This Chapter has detailed a set of performance criteria derived from a user needs study. The design phase consisted of an investigation of relevant technologies, literature and harvest processes. The design process was aimed to address the performance criteria prior to the assembly of a HNS prototype. This process led to a basic conceptual design of a HNS. The HNS design consisted of a portable moving map display with a simple, pen-based graphical user interface, cutblock data and vehicle tracking provided by multi-channel narrow-correlator real-time DGPS receiver. Although antenna protection was a performance criterion, cost did not justify its inclusion in this short-term project.

With the knowledge gained from the design phase the HNS development phase was initiated.

CHAPTER 3 HARVEST NAVIGATION SYSTEM DEVELOPMENT

This Chapter elaborates upon the HNS development process, and the final HNS configuration. Using results of the design phase, as presented in Chapter 2, HNS development initially involved assembling available hardware and software into an evaluation prototype. Following field refinements, two operational prototypes were assembled, one for each of the New Brunswick and Alberta project sites. This phase also influenced the experimental design subsequently used to assess HNS viability.

A series of field trials were conducted over the summer and fall months of 1996 at the two project sites. In each case, GPS-GIS configurations were physically installed in a single-grip harvester, base map and harvest block data were downloaded into the system, a real-time DGPS service was established, and partial harvests were navigated. Trials were carried out in a variety of stand types, topographic sites, weather conditions, satellite configurations, baseline ranges and harvest line orientations. Post harvest surveys, based upon criteria provided by the harvest foremen were part of an informal evaluation process. These field trials also involved harvest operator training as an essential part of assembling an operational HNS.

The following section summarizes the development and evolution of HNS prototypes. Subsequent sections detail field hardware (GPS receiver and DGPS) and field software components selection, antenna protection, power source and digital mapping issues. The last section deals with equipment costs.

3.1 Prototype Development

The development phase began by assembling an initial on-board GPS-GIS configuration using readily available, commercial, "off-the-shelf" technology. This evaluation prototype configuration took into account performance criteria established in the user needs study. The evaluation prototype served as a proof of concept and was used to demonstrate HNS functionality to the industrial partners. This involved demonstrating that GPS could be used to identify the spatial location of GIS forest inventory basemap data in real-time in partial cut operations. A critical issue was "real-time tracking" with the DGPS system. The initial prototype, the *Trimble Aspen Pro* system, consisted of an eight channel, narrow correlator, single frequency receiver, integrated with a map-based data capture system. It employed the following components (refer to Fig. 8):

(i) Trimble Aspen GIS/GPS Mapping Software
(ii) Trimble 8 Channel Pro XL GPS Receiver
(iii) Trimble ProBeacon RTCM-104 Receiver
(iv) Texas Micro Hardbody Field Computer
(v) Coast Guard Navigation Beacon CORS.

During this initial development phase, the specifications and formats of the base mapping data were discussed with the GIS support providers in the Fundy Model Forest. This task was essential to ensure that the data would be compatible with the GIS software component of the evaluation prototype. Data source, data format, file size, ground coverage extent, mapping projections, datum transformations, and significant coverage display (stand boundaries, contours, and water bodies) were investigated in this initial phase.

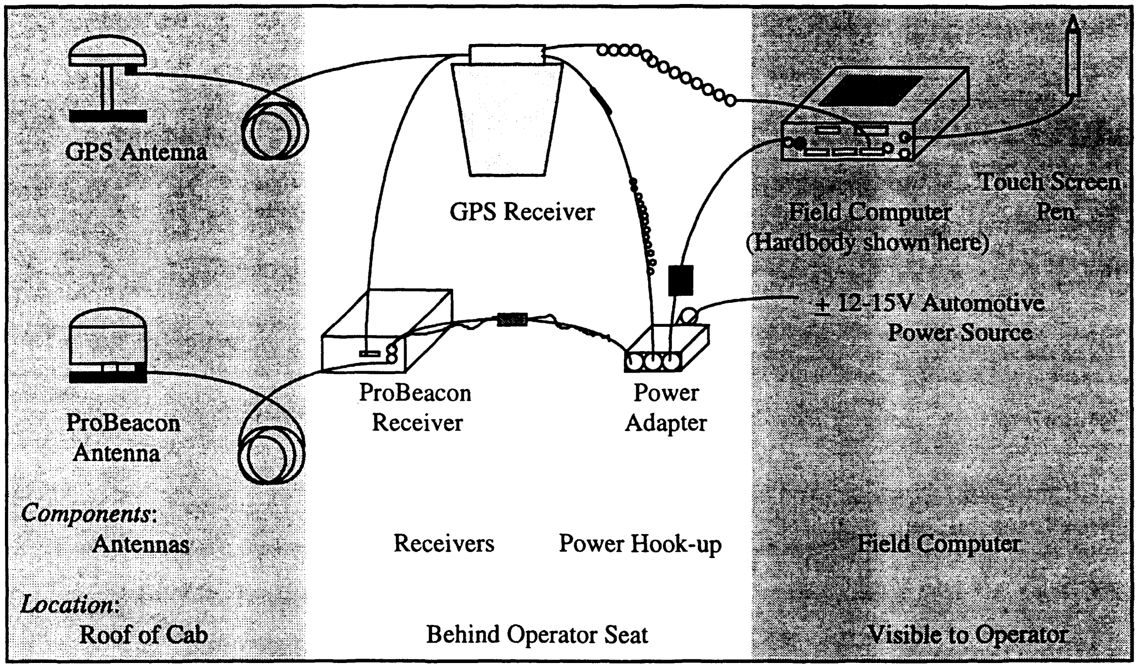


Figure 8. Navigation System Hardware Schematic: Evaluation Prototype.

It was concluded that the evaluation prototype was inadequate for operational use and hence further development was pursued. In summary, the Aspen Pro software was too structured and inflexible for HNS application and was more suitable for GIS data collection. The software interface could not be manipulated or customized. The omission of certain software features would have made the interface less cluttered and easier to use by the harvest operators. The Texas Micro Hardbody field computer was just not rugged enough. However, the real-time DGPS system (Trimble Pro XL and ProBeacon) served to show that the real-time differential corrections would function adequately in the forested environment.

At the end of the evaluation prototype phase, options were explored with the development teams. Initial information and experience gained from the preliminary field trials were used to help the development of operational prototypes. Preliminary research found that there were many options for almost all the components that constitute a navigation system. Hardware and software options were further explored.

Two operational prototypes were developed and evaluated on partial harvest sites with single-grip harvesters, prior to the formal assessment. The New Brunswick site utilized the Coast Guard Navigation Beacon and the Hinton site utilized a local basestation. Both used the same GPS receiver and GPS support software and the same GIS software interface. They did, however, differ in the specific portable computing platform.

3.1.1 New Brunswick Prototype Development

The first operational system, developed in New Brunswick, involved several phases of development. The harvest plan and mapping data were transformed for download into the harvest navigation system. The hardware system was installed in the harvester. The software components - navigation interface, moving map display and DGPS signal acquisition - were developed from the initial design recommendations. The system was operated on different site conditions (topography, tree canopy, satellite configurations) to help refine its operational capabilities and explore its limitations. The system was considered operational when uninterrupted harvesting could commence without being threatened by equipment failure in the HNS. This usually was one full shift of operation after a modification was introduced. Once satisfied that the operational prototype was acceptable for testing, and adequate operator training completed, the formal assessment commenced. This assessment is detailed in Chapter 4. The final configuration of the NB prototype consisted of:

(i) FieldNotes for Pens ,
(ii) Trimble 8 Channel Pro XL GPS Receiver,
(iii) Trimble ProBeacon RTCM-104 Receiver,
(iv) Huskey FC486 Field Computer
(v) Coast Guard Navigation Beacon CORS.

3.1.2 Alberta Prototype Development

The operational development shifted to the Weldwood of Canada site in Hinton, Alberta, during an early winter season in November. A development team was assembled and an operational navigation system was set-up on site. This involved installing the navigation system hardware and transforming the base maps and harvest block data for download. A certain amount of feedback was expected from this phase, and refinements were made to the navigation system. The total development period in Hinton took approximately two weeks. Similar to the NB prototype development, the system was considered operational when harvesting could commence without being interrupted by equipment failure in the HNS. The HNS operated for about a week uninterrupted, until the assessment took place. This assessment is detailed in Chapter 4. Over the development period the harvest operator was trained. The following components were used in the Alberta operational prototype:

(i) FieldNotes for Pens,
(ii) Trimble 8 Channel DSM Rover,
(iii) Trimble 12 Channel DSM Base,
(iv) Pacific Crest 15 watt Radio Link ,
(v) MicroSlate 400L20 Field Computer.

3.2 Hardware Selection for Operational Prototypes

Relevant performance criteria were important in the selection of the hardware components for the two operational prototypes. Meeting the HNS performance criteria, however, was not always feasible, given time, monetary, and technical constraints. The field trials revealed the weaknesses and strengths of various hardware components. This section details the examination and selection of GPS receivers, real-time DGPS links, and field computers.

3.2.1 GPS Receiver

To operate with optimum efficiency in the forested environment, the GPS system should meet a number of specifications as stated in Chapter 2. The receiver should be multi-channel (8 to 12), have narrow-correlator technology, with low noise and high gain, and a low power consumption. In addition, the GPS receiver should be able to accept RTCM SC-104 differential corrections for real-time navigation and tracking. A few GPS platforms fit these specifications, such as ones produced by Ashtech, Leica, NovAtel, Sercel and Trimble.

All GPS equipment used were Trimble products. An eight channel Trimble DSM (Differential Survey Module) was used as the remote receiver (Refer to the Appendix II for specifications and settings). The receiver hardware was encased in a vibration and impact resistant metal chassis (black box). No problems were encountered during any of the field trails with the GPS receiver. The black box GPS receiver was configured with support software patched through a laptop computer. The receiver tracked up to 8 satellites above a masking filter of 15 degrees above the horizon of the antenna. All tracked satellites were used to calculated the receiver position in an "over-determined" mode (Weaver, 1997).

3.2.2 DGPS Link

The real-time differential signal was generated by two separate methods in the two project sites. For all the prototype development in New Brunswick, a Coast Guard

Navigation Beacon DGPS signal was used (CORS) [Canadian Coast Guard, 1995]. The beacon was located in the port city of Saint John (Partridge Island, 45°14'N, 66°03'W), approximately 100 km from the project site. The DGPS message is broadcast at 295 KHz with an effective radiate power of 20 w. The service unofficially covers a nominal range of 300 km out to sea and 150 km inland. This DGPS service is free for all users and covers a large extent of southern New Brunswick. The low frequency, long wavelength transmission will characteristically attenuate with major topology relief and large weather patterns. Like most radio transmissions, lightning may temporarily disrupt the data stream. Local terrain, tree cover, rain, and fog should not affect the transmission significantly. It was observed, however, that the DGPS signal was lost during a preliminary test of the ProBeacon system while driving to the study site on a high ridge top. The large ridge morphology falls into the category of major topographic relief. This phenomenon was verified by personnel at the Canadian Coast Guard [Topple, 1996].

The physical extent or coverage of the communications link was determined within the region of the NB project sites. The DGPS hardware was a Trimble ProBeacon which consisted of a dome antenna and a receiver box. The ProBeacon automatically acquires the strongest Coast Guard DGPS correction signal in the broadcast area. A rough estimate of the extent of the local coverage area was determined by mounting the real-time DGPS system on a roadway vehicle and driving the field unit around the study sites. The DGPS signal reception was monitored on the road and under the nearest forest canopy. It was determined that adequate DGPS signal coverage was available at the study sites.

The Canadian Cost Guard DGPS Navigation Service continuous basestation consists of an Ashtech Z12 dual frequency receiver. The dual frequency receiver has the ability to solve ionospheric and tropospheric biases, thus increasing the differential correction accuracy beyond that of a single frequency receiver. Although the accuracy of the differential service was not tested, the expected positional accuracy was approximately two metres.

The differential data source in Alberta consisted of a local basestation and a low powered radio modem communication system (see Fig. 9). A 15 Watt Pacific Crest radio modem transmitter was set up to broadcast the real-time DGPS data. The effective range of transmission is dependent upon radio line-of-sight, transmitter and receiver line losses, power output and receiver sensitivity, transmitter and receiver antenna gain, and path loss (Pacific Crest, 1994).

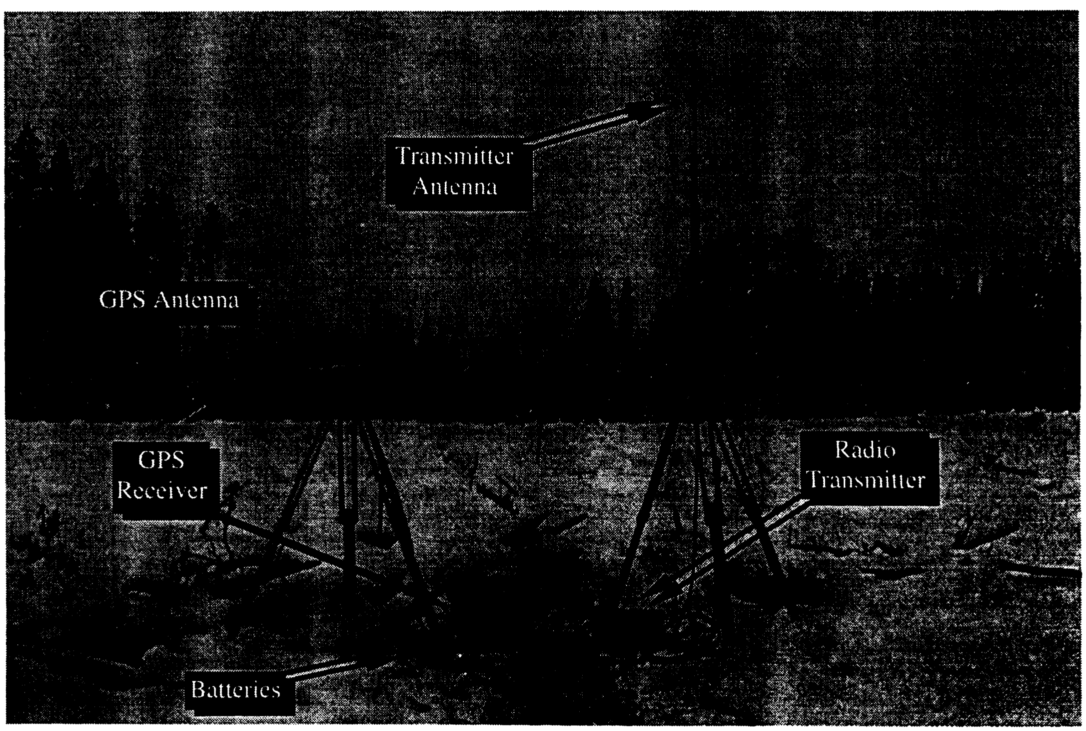


Figure 9. Real-time Differential GPS Basestation, Embarrass site.

The baseline length from the base station to the remote GPS receiver was less than one kilometre. The differential corrections were expected to yield one metre accuracy. Although the effective range could be estimated by seeking the solution for the above parameters, a simple field test was devised to estimate the effective range of the radio modem system in situ (for the specific test site).

The GPS basestation and DGPS transmitter were set up in the project site and the remote GPS receiver and DGPS radio modem were installed in a pickup truck. The truck proceeded to drive away from the transmitter station along logging roads to an adjacent cut block which was actively being logged. The truck drove through the cut block as the DGPS signal was monitored. The active logging operation was indicative of the conditions to be expected in the test block. Several passes were made to verify the signal loss, which occurred at approximately 1.5 km. This range was acceptable since the transmitter would be within approximately 600 m of the test block.

3.2.3 Field Computers

Field computer evaluation was performed with three pen-base micro-computers. Pen-based computers provide an easy to use operator interface through the use of a touch screen without the use of a keyboard. The selection of these field computers was limited because of the availability of such hardware. They are in great demand for police and military applications and, as a result, are quite scarce and very costly. The three micro computers were: the Texas Micro Hardbody, Trimble's Field Data Collector - TFC1(manufactured by Huskey as a FC486), and the Microslate 400L20.

The Hardbody had 260Mb of storage, a clock speed of 75Hz and was powered through a cigarette lighter adapter (see Fig. 10). The Texas Micro Hardbody meets military specifications (MIL-SPEC 810) which would imply that it is field rugged. The unit tested, however, did not meet the performance requirements of this project for several reasons. The CPU performed well but there were some key flaws that should be investigated by the manufacturer in order that the Hardbody can truly become a rugged field unit:

(i) All ports should have good rubber seals; no seals were provided for the ports on the rear panel and the PC Card seal kept flopping open.

(ii) The contrast on the display screen kept changing throughout the operating period. This occurred indoors and outdoors, but it was especially true during bright sunny periods.

(iii) The battery reliability was questionable. One Duracel battery completely malfunctioned as indicated by the flashing 25% light indicator. The on-screen power indicator would change from the current power level to Zero frequently. A replacement battery acquired directly from Duracel solved the field computer power problem.

(iv) The external floppy drive was not configured properly and, hence, was never operational.

(v) The pen stopped working. It is believed that the pen-port connection became loose, thus causing a power failure to the pen device.

The other two field computers did not share the Hardbody's frequency of flaws, and thus were more appropriate for the operational prototypes. The TFC1 field unit only had 20 Mb of storage, a clock speed of 50Hz, and less than two hours of battery power (see Fig. 11). It did, however, have a very rugged casing and a built-in keyboard which was very convenient. For the New Brunswick field trails, located in Dubee Settlement, the TFC1 field computer was used. The limited storage was circumvented by downloading the field data on a daily basis. The power limitation of two hours was not encountered since an automotive power adapter (via the cigarette lighter) was used.

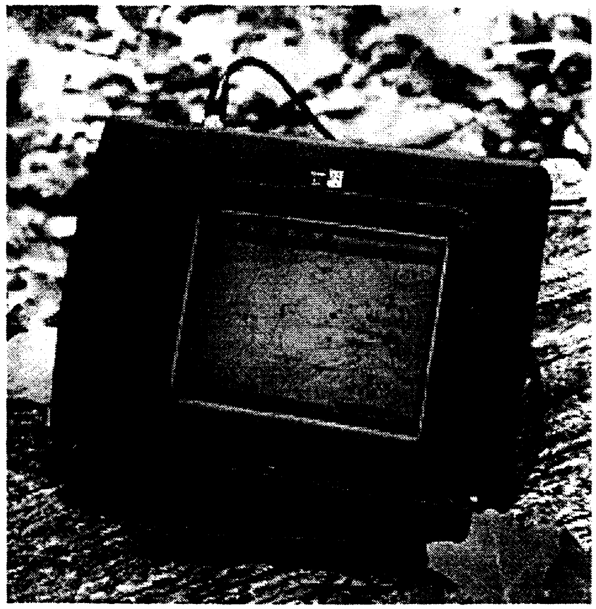


Figure 10. Texas Micro Hardbody field computer (Courtesy of Texas Micro, 1996).

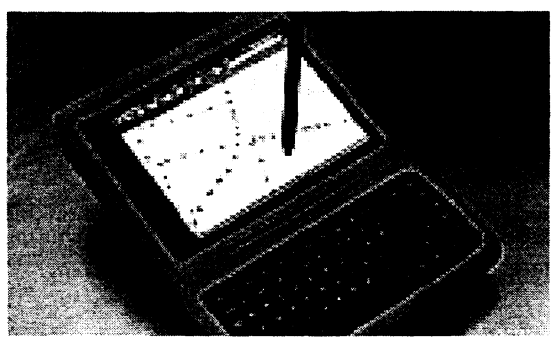


Figure 11. Trimble's TFC1 field computer (Courtesy of Trimble, 1997).

Finally, the Microslate 400L20 was evaluated at the Alberta test site (see Fig. 12). It had adequate disk storage (250Mb), very good rubber seals and a large touch screen display. One of the possible limitations was its processor clock speed of 20 MHz. This limitation was minimized by limiting the file size of the GIS dataset used as the background map. The smaller geographical extent of the map data sped up display time. The Microslate performed very well even in extreme winter conditions. Outside the operator's cab temperatures were as low as -30°C. The large-faced touch screen was clear and easy to operate. The relatively slow clock speed did not impede operations.

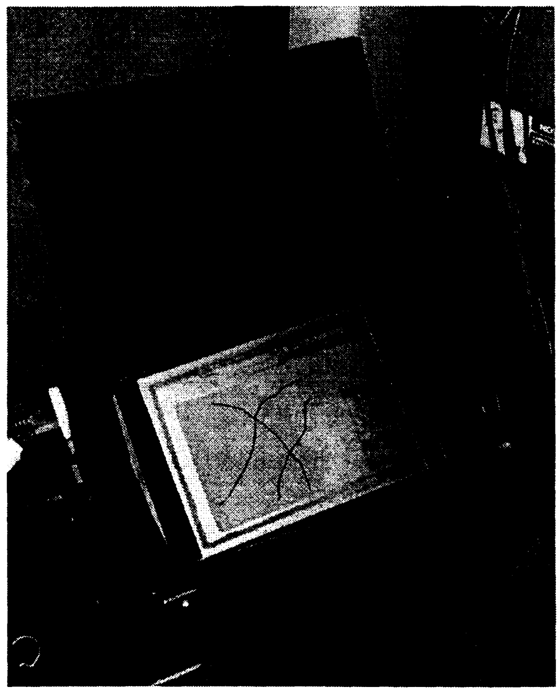


Figure 12. MicroSlate 400L20 field computer.

3.3 Software Selection

Several operator interface software packages were investigated. The software systems could be classified into two categories: programmable software and turnkey software. Blue Marble Geographics' GeoApplication Tools and ESRI's MapObjects fall into the first category and are programmable with Visual Basic or C++. These types of mapping utilities are very flexible since specific functions can be programmed directly into an icon driven interface. The drawbacks in this project were that specific programming skills and additional development time were needed to fully exploit these utilities.

Two turnkey packages, Trimble's Aspen Pro field software and PenMetrics' FieldNotes were investigated. Both are intended to function as field data collection systems. The Aspen Pro software, used in the evaluation prototype, was inflexible and not well suited as a mapping navigational aid. Extensive field trials were performed in New Brunswick with the Aspen system. The Aspen software proved to be close to operational as long as the harvest operators had extensive training, even after which the interface proved to be a time consuming task. Also, several tools within the Aspen system are not applicable to harvest navigation and clutter the screen. The interface is fixed and no customization is possible. Geographic transformations for map projections and datums could not be customized. The interface was more suited to the collection of GIS data in a feature and attribute structure. This type of interface was too structured and inflexible for an HNS.

As determined from the user needs study, the basic requirements for the mapping navigation interface include:

(i) display tools: zoom, auto-pan, and redraw;
(ii) drawing tools: pen, text, lines, and polygons;
(iii) edit tools: select, cut, copy, and paste;
(iv) measurement tools: distance, bearing and area; and
(v) drawing layer management.

In PenMetrics' FieldNotes all these tools were available and customizable through an icon or Graphic User Interface (GUI). Most of the icons can be made visible or hidden under a preference menu. In addition, FieldNotes has a very good coordinate transformation utility that was developed by Robin Steeves of Microsearch. This software system was very well received by the harvest operators, most of whom had very little computer training prior to this project.

The following illustration is a screen snap shot of an operational prototype interface, using FieldNotes software (Fig. 13). It illustrates the partial cutting trails, and elements of the interface, such as, GPS data, GPS information window and the various tools for operation.

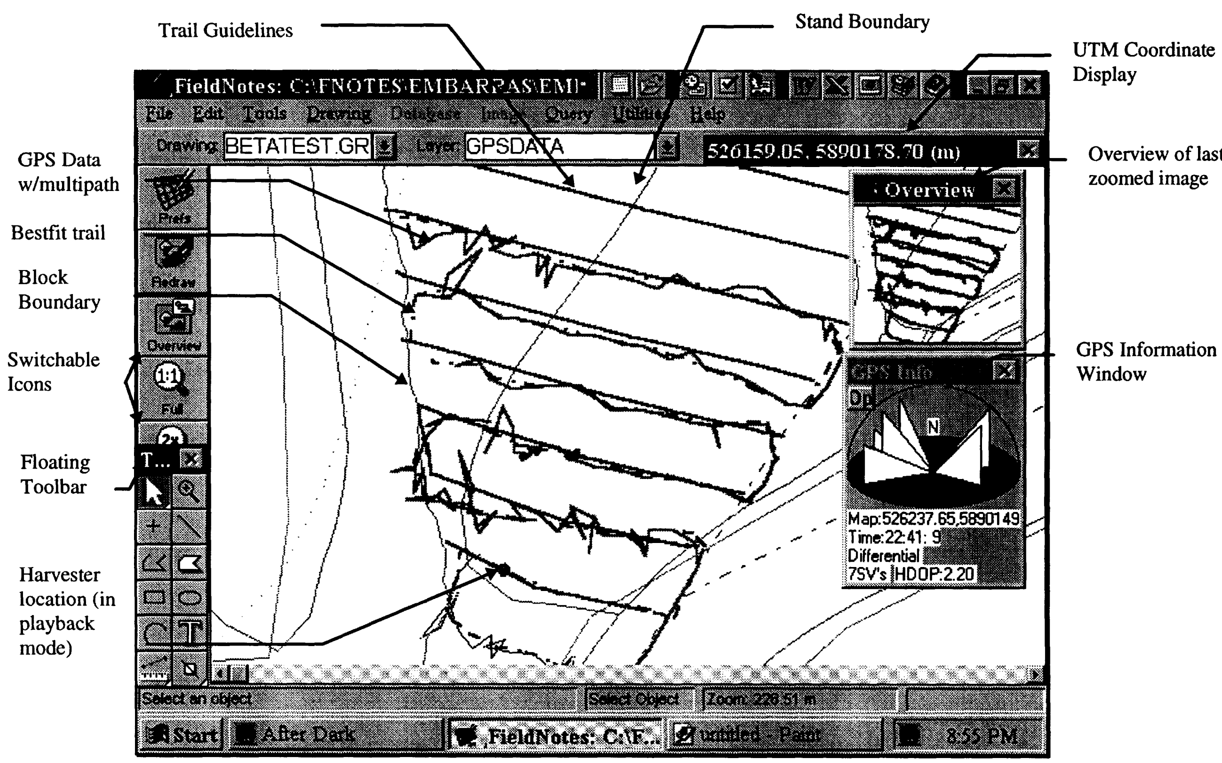


Figure 13. Operational interface with PenMetrics' FieldNotes.

Although the FieldNotes interface was very simple and easy to use, it did fall short of one of the performance criteria. The interface should have been further simplified and additional information conveyed. Certain custom software tools, specifically an audible proximity alert and a buffer zone creation tool, were not developed. It is speculated that these software tools may be easily programmed with a software development kit and the right programming skills. Refer to Appendix IV for two training manuals which will give an insight into the Aspen and FieldNotes software and how they were utilized in the harvest navigation application.

3.4 Antenna Protection

Although no antenna protection was utilized for the field trials, certain precautions were taken. The existing unprotected dome antenna mounts were magnetic (the Trimble GPS and DGPS ProBeacon) and were designed to shear off the roof of the cab during an impact. The operators were instructed to avoid dropping slash and debris on the cab for their own safety and the security of the antennas. Impacts to the antenna were negligible during the field trials. Although no antenna protection was used in the research, it would be recommended for operational use in a commercial system. The replacement cost of the GPS antenna is approximately $1000 Cdn.

The DGPS antenna used in Hinton was secured on the harvester by a breakable mount. The short wire radio modem antenna was simply fastened to a stick with black tape and the stick fastened to the cab with the same black tape (Fig. 14). It was speculated that if the antenna succumbed to an impact, the stick would shear off first, leaving the antenna dangling by the cable lead. The shear stick performed very well during the field trials and worked as designed on one occasion. A more permanent system should be designed for commercial operational use.

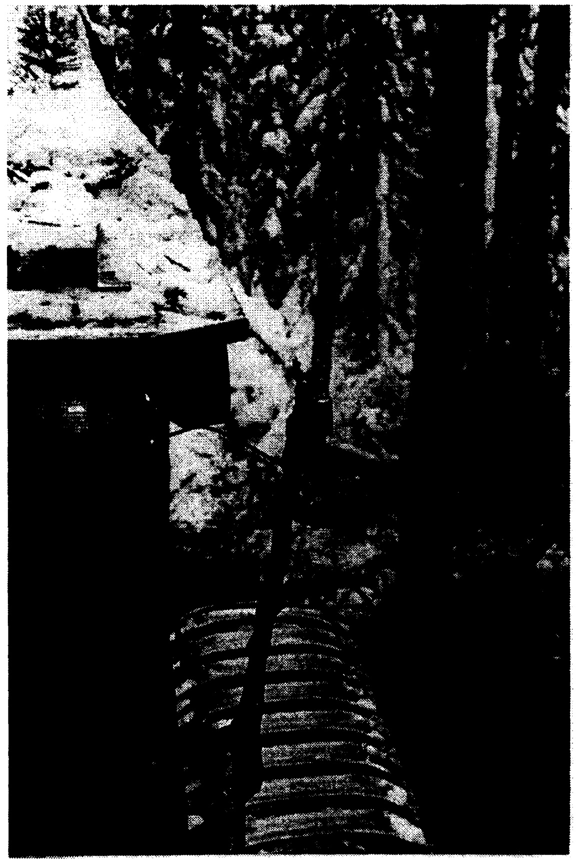


Figure 14. *Shear Stick* DGPS antenna mount.

3.5 Power Source

All the hardware components could run on battery power. The battery life varied from 24 hours, as was the case with the real-time base station set up, to less than two hours for the field computers. Except for the real-time base station, which ran on a rotation of two-12 volt car batteries every 24 hours, all in-cab electronic components could run on an automotive adapter (cigarette lighter). The in-cab components, the field computer, GPS receiver, and DGPS link, could be plugged into a simple automotive power adapter. Black electrical tape held all connections fast, for the duration of the field tests. For an operational system, an integrated power source and hardwiring is recommended. Proper grounding and shielding from electrical interference is also recommended.

3.6 Digital Map Processing

Several map data processing steps were involved, such as clipping, formatting, downloading, transforming, and registering the digital mapping data. The integration of GPS field digitized boundary lines was also involved.

The study areas were spatially located and digitally clipped out of the larger extent of the forest inventory GIS base map using Arc/Info. This data was supplied by the industrial partners and the clipping task was handled by the in-house GIS personnel. Clipping involves selecting a specific geographical extent and creating an individual map coverage from an existing coverage. The smaller extent was used for several reasons. The file size is smaller and, hence, the time needed to draw the digital image is reduced. Also the smaller file size is easier to download into the portable computing device since it can usually fit on a diskette.

The new mapping extent was then transformed, by the GIS personnel, into a file format that is compatible with the portable mapping software. In this case, a Drawing Exchange File (.DXF) or an Arc/Info shape file (.shp) was used. This process involved converting each mapping layer or coverage (roads, stream, forest inventory) into individual files. Most GIS software has formatting or exporting utilities to facilitate this process.

The data was then downloaded into the portable mapping system. Downloading simply involves transferring the data from the office system to the portable system. The downloading may be done with a diskette or through a cable. For this project, all files were downloaded by the researcher with a serial cable and support software, since the portable computing devices did not have diskette drives.

Since the GPS utilizes a world wide coordinate system and datum, WGS-84 (World Geodetic System 1984), coordinate transformations and map projection had to be used to correctly overlay the GPS positions onto the digital forest inventory map. The two systems, GIS and GPS, must utilize a common datum. In other words, the GPS positions and the GIS map have to share a common coordinate system. Additionally, the GIS coordinates are usually stated in a local map projection. To accommodate this, transformations and map projections may be facilitated in either the office GIS or the portable GIS/GPS software. For this study, GPS positions were transformed into the mapping data with a routine within the FieldNotes software. For each project site, a different datum and mapping plane coordinate system were used. For the NB site, the GPS positions were transformed into the ATS-77 (Atlantic Terrestrial System 1977) datum with the New Brunswick Stereographic Grid map projection. The AB site used the NAD-83 (North American Datum 1983) datum and the UTM (Universal Transverse Mercator) projection.

Spatial errors can still be evident even if the most rigorous transformations are utilized. Because of mapping errors, the GPS locations as indicated on the field computer can be offset from the map display. To make the digital mapping and the GPS positions spatially compatible these errors should be minimized. Simple localized transformations can be used to register the GIS data base with the GPS positions. There are several types of transformations that can be used to register this data (involving rotation, scale, and shift). In this project, a simple lateral shift was invoked in the mobile mapping software, FieldNotes. Several registration points must be used to determine an average offset value and may be corrected by a simple transformation (shift). The intersection of linear features such as roads and rivers are ideal locations for registration. This *ground truth* registration method was used in the HNS with the road layer data. Roadway intersections were positioned with GPS in the appropriate local coordinate system. The GPS roadway intersections were visually compared to the digital base map data. A coordinate shift was applied to the base map data to match the GPS ground truth points. For the Alberta test site an 8 m shift, due south, was used to register the data sets. This was most likely due to inconsistencies in the base mapping. No ground truth registration shift had to be applied to the New Brunswick mapping data.

As stated in Section 2.3, features like property boundaries and riparian buffer zones should be field digitized with a GPS data collector to ensure an adequate spatial accuracy. For the test sites, the block boundary and water courses were field digitized and downloaded into the mobile mapping data base. In the accompanying maps (Fig. 15 and 16) one can see the differences that occur between base map streams (dark blue) , the forest inventory data (black lines) and the prescribed cutblock boundary (red lines). Since the cut block boundary, riparian boundary (light blue) and the mobile navigation system are located with DGPS, they can be considered as ground truth. Both data sets, boundaries and navigation, have similar accuracies since they are created with directly comparable methods (DGPS).

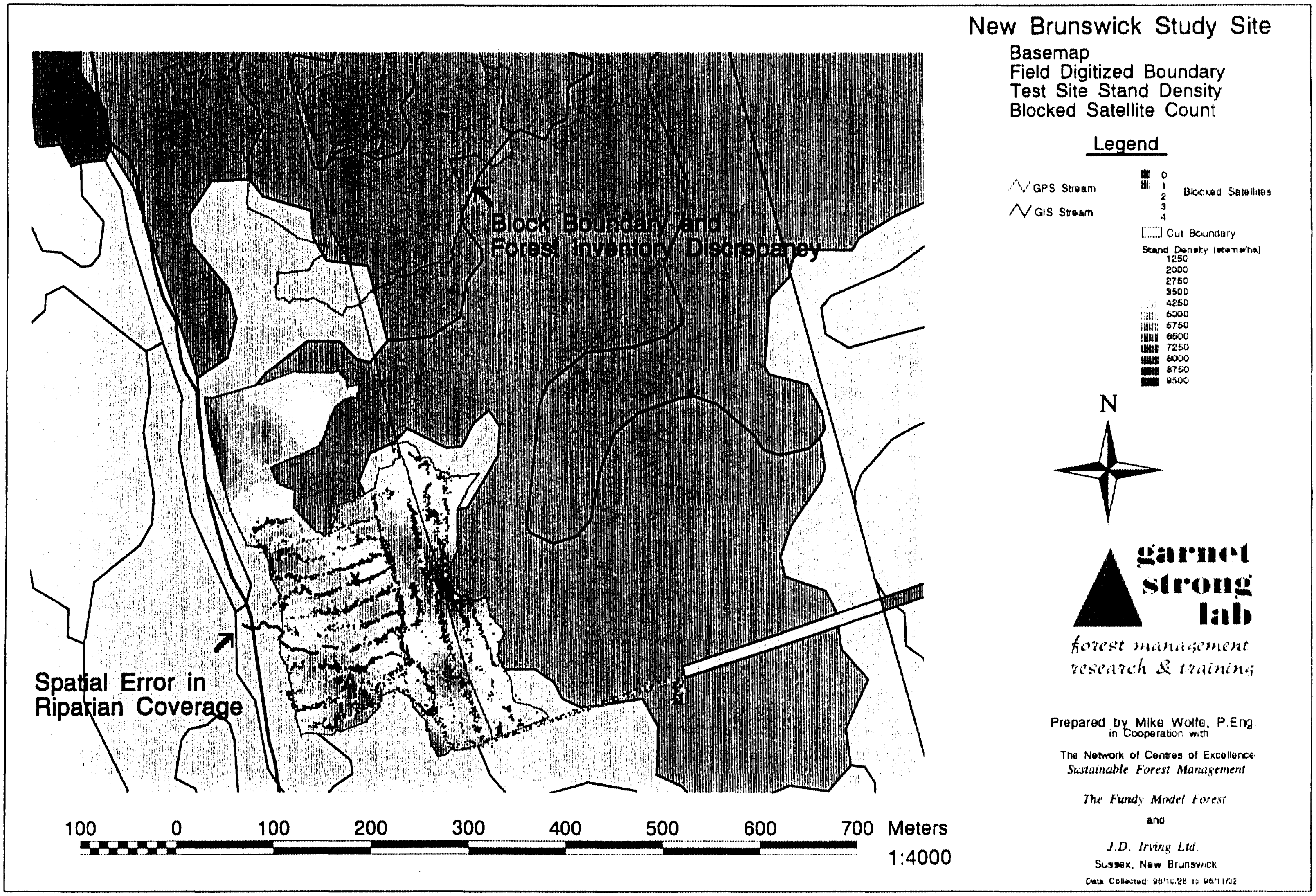
3.7 Costs

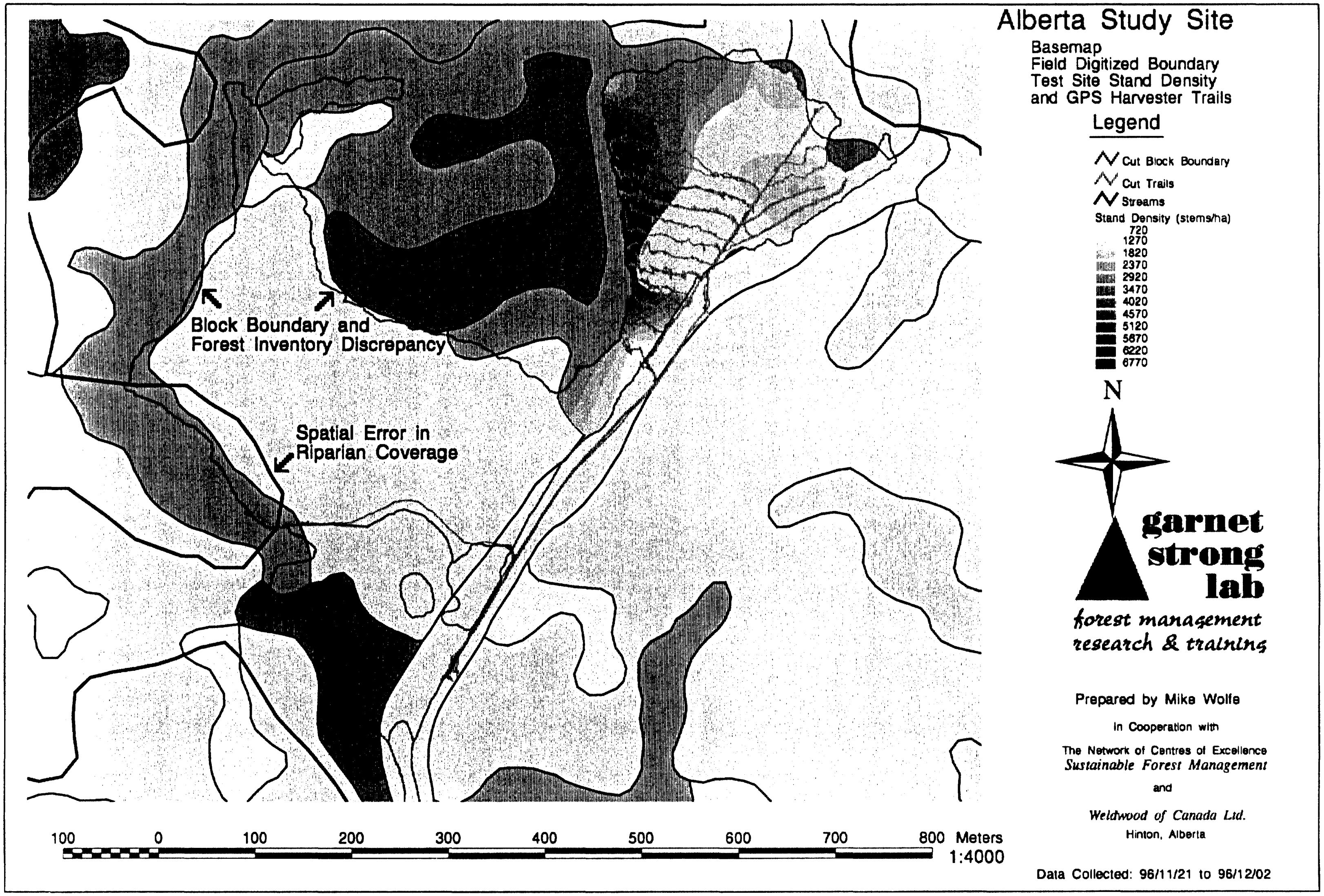
The prototype equipment costs would not be directly related to commercial system costs. It is anticipated that integrated circuit component (OEM) costs would be less than stand alone components- such as the ones compiled for this project, but development costs would be higher. To reduce costs in this project, all systems were rented or were on special loan from the suppliers for the duration of the project. The only equipment that was purchased was an automotive power adapter, an automotive 12Volt battery charger, tape, and fuses. An estimate of each hardware and software component is stated in Appendix V. For the NB Operational Prototype, which utilized the Coast Guard navigation beacon, the estimated equipment cost was $21 117 Cdn. The AB Operational Prototype system used a local basestation and radio modem. This extra hardware is reflected in the total cost, $37 517 Cdn. It should be noted that the purchase price of the commercial system, Mobiway FNS is approximately $70 000 Cdn.

The real-time DGPS costs vary depending upon what type of service is used. The private service providers usually work on a yearly subscription rate and have different products that vary in accuracy (10 m to 1 m) and price ($75-$800US) [DCI, 1997 and OnmiStar, 1997]. The coast guard DGPS broadcast service is free of charge. Site specific reference stations can be quite costly since the GPS base station and radio transmitter have to be rented or purchased by the end user. Additional costs are incurred for the specific hardware required to receive the radio transmissions from all of these DGPS services. Hardware costs range from $400US for the FM sub-carrier receiver to $20 000 Cdn for a site specific DGPS system (radio modem and DGPS receiver).

This chapter elaborated upon the evolution and final design of the Harvest Navigation System. Initially, an evaluation prototype proved real-time tracking feasible to the industrial partners. Subsequent field refinements and equipment evaluation helped produce two operational prototypes. The two operational prototypes, one for each of the New Brunswick and Alberta sites, differed in their use of the real-time DGPS service and the specific computing device used to process and display the navigation and tracking data. Various hardware and software system components were evaluated and the results summarized in this Chapter. It was found that several processing steps were required to integrate the digital mapping data and GPS field data with the HNS. Spatial errors in the base map data can be significant. System costs vary significantly depending upon the type of differential service selected.

The two operational prototypes were then assessed to determine their viability. This is explained in the next chapter.


New Brunswick Study Site
Basemap
Field Digitized Boundary
Test Site Stand Density
Blocked Satellite Count
Legend
GPS Stream
GIS Stream
0
1
2
3
4
Blocked Satellites
Cut Boundary
Stand Density (stems/ha)
1250
2000
2750
3500
4250
5000
5750
6500
7250
8000
8750
9500
N
Block Boundary and
Forest Inventory Discrepancy
Spatial Error in
Riparian Coverage
100 0 100 200 300 400 500 600 700 Meters
1:4000
garnet
strong
lab
forest management
research & training
Prepared by Mike Wolfe, P.Eng
in Cooperation with
The Network of Centres of Excellence
Sustainable Forest Management
The Fundy Model Forest
and
J.D. Irving Ltd.
Sussex, New Brunswick

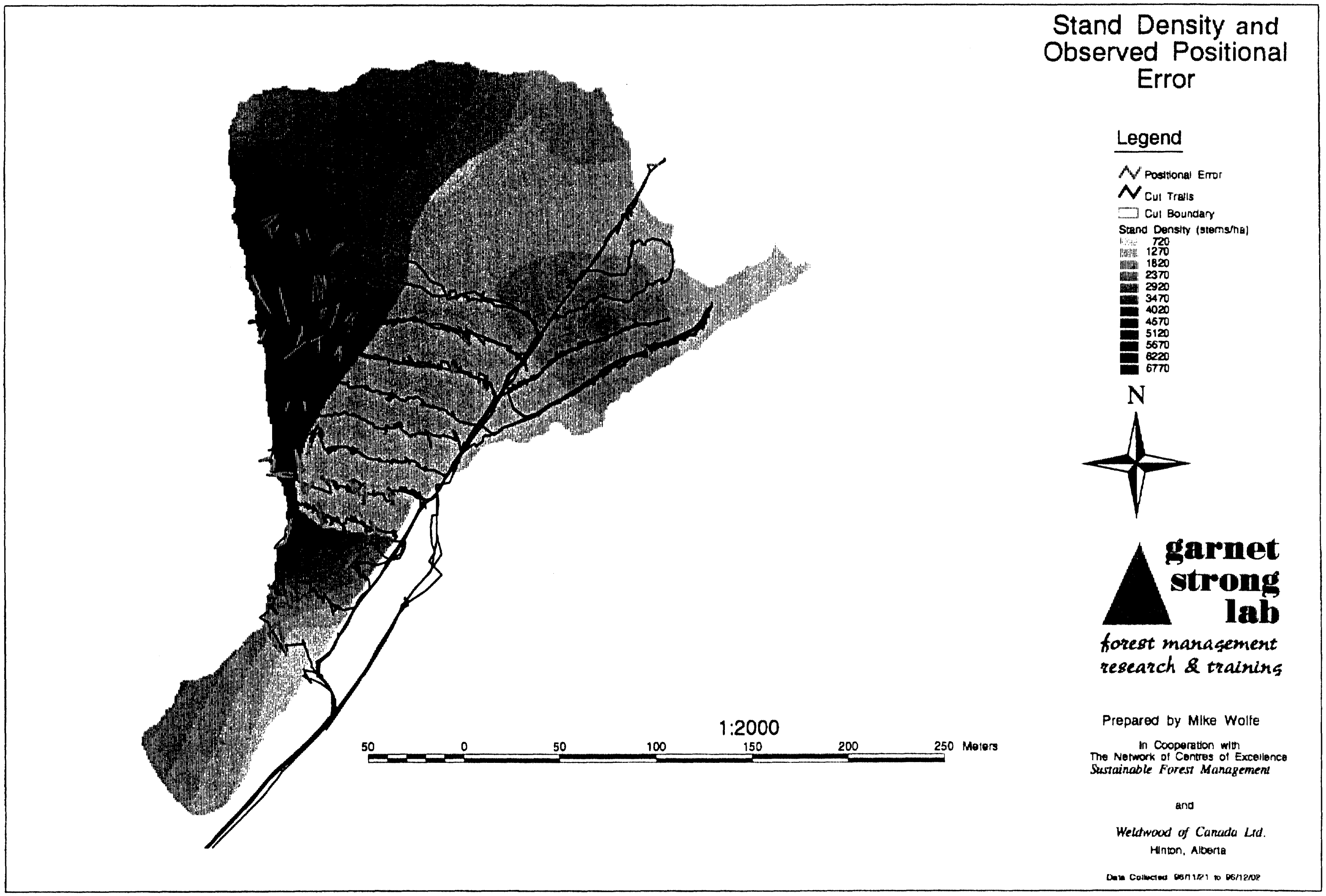

Alberta Study Site
Basemap
Field Digitized Boundary
Test Site Stand Density
and GPS Harvester Trails
Legend
Cut Block Boundary
Cut Trails
Streams
Stand Density (stems/ha)
720
1270
1820
2370
2920
3470
4020
4570
5120
5670
6220
6770
N
Block Boundary and
Forest Inventory Discrepancy
Spatial Error in
Riparian Coverage
100 0 100 200 300 400 500 600 700 800 Meters
1:4000
garnet
strong
lab
forest management
research & training
Prepared by Mike Wolfe
in Cooperation with
The Network of Centres of Excellence
Sustainable Forest Management
and
Weldwood of Canada Ltd.
Hinton, Alberta
Data Collected: 96/11/21 to 96/12/02

CHAPTER 4 HARVEST NAVIGATION SYSTEM ASSESSMENT

This Chapter elaborates upon the methodology and findings used to determine the viability of the assembled HNS prototypes. The assessment phase consisted of formulating an experimental design, conducting field tests, investigating the viability of the operational HNS prototypes and performing an analysis of the GPS navigation component to the HNS. There were two distinct parts of the assessment.

The first part addressed HNS *viability* as defined in the primary objective. *Viability* was determined on the basis of its ability to satisfy the same *post-harvest quality assessment* criteria and *harvest productivity* rates as exist in present practice. A formal experiment was conducted at each of the New Brunswick and Alberta project sites. Test and control partial harvest blocks were created for the two forest locations. The control block utilized the traditional harvest layout method, while the operational HNS prototype was used to navigate the test block. Each block was assessed for post-harvest quality and harvest productivity. The comparison between control and test blocks determined whether the harvest navigation system was viable. Section 4.1 details the experimental methodology and describes the field test sites, while Section 4.2 summarizes the results.

The second part of assessment addressed GPS performance in a forested environment. The investigation stemmed from a simple visual observance of numerous positional spikes in HNS moving map display while operating under the tree canopy. These spikes were larger than the expected spatial accuracy of 2 m using the differential technique, previously described. Spikes larger than 5 m are highlighted


Stand Density and Observed Positional Error
Legend
Positional Error
Cut Trails
Cut Boundary
Stand Density (stems/ha)
720
1270
1820
2370
2920
3470
4020
4570
5120
5670
6220
6770
N
garnet strong lab
forest management research & training
Prepared by Mike Wolfe
In Cooperation with
The Network of Centres of Excellence
Sustainable Forest Management
and
Weldwood of Canada Ltd.
Hinton, Alberta
1:2000
50 0 50 100 150 200 250 Meters

in red in Figure 17 for the Alberta site. Because of the slow movement of the harvest vehicle along the cutlines, navigation can be easily facilitated with just a few good positional fixes. However, poor GPS positional fixes create poor tracking data and display, which significantly jeopardizes some of the spin-off benefits of an operational HNS. Specifically, this compromises the capability to create GIS-ready data of cutblock boundaries and cutlines for forest inventory updating.

An extensive investigation was undertaken. First, reliability of DGPS ground-based signals was determined for both sites to ascertain whether they might explain the positional spiking. They did not. Methods and results are presented in Section 4.3. Following this, GPS signals were investigated as the only other source of the positional spiking. It was speculated that an increase in stand density would block more satellites; an increase in terrain slope would tilt the GPS antenna so as to give a poor view of the satellite constellation; and certain antenna orientation (Northern aspect) would also yield a poor view of the sky and hence the satellite constellation. Relationships were found. Details are provided in Section 4.4.

4.1 HNS Viability Testing

An experimental design was formulated to assess the viability of the HNS. Viability was determined based upon the ability of the HNS to satisfy harvest productivity rates and post harvest quality assessment standards. It was examined by applying these industry standards to control and test blocks in both study sites.

4.1.1 Harvest Productivity and Post-harvest Quality Assessment

Harvest productivity was calculated as the number of stems cut per hour for the purpose of this study. A numerical comparison of the productivity on the control and test blocks was performed. Hourly logs were kept by the harvest operators. The logs recorded their hourly productivity rates, down times and repair stops, weather conditions, and other comments. These productivity rates were separated by operator and shift, since the rates differ due to operator skill and time of shift. Productivity rates can also differ due to environmental effects, such as the stand density and terrain. These influences were not investigated since the harvest blocks were relatively homogeneous and, furthermore, standard industry practice is to calculate average productivity rates for entire harvest blocks. That practice was followed in calculating harvest productivities for each operator in the test and control blocks.

It should be noted that in the context of this study harvest productivity is defined for only the actual tree harvesting operation and hence the machine/man hours used to perform this task. The total harvest operation could also include the man hours required for the layout of the harvest trails. It should be noted that if the productivity definition was to include this task, the overall man hours would be reduced and labour productivity increased with the introduction of the HNS. The manual layout of the harvest trails would be eliminated with the introduction of the HNS. However, for this study only the productivity of the mechanized harvester was analysed.

The post-harvest quality assessment methods differed for each of the test sites. J.D. Irving Ltd. in New Brunswick has initiated a formal assessment program that is conducted by the harvest foreman. Weldwood of Canada Ltd., on the other hand, allows the contractor to perform the quality assessment. The contractor's quality assessment methods are approved by the industrial forest manager after a period of time, during which the contractor has been monitored and a standard of quality maintained.

4.1.2 Control and Test Block Field Operations

For these field operations the HNS was used in the test blocks to keep the harvester on an optimal cutting pattern path and within the block boundaries. The HNS was not used in the control blocks.

The field layout commenced with the traditional flagging of the cut block boundary and any possible riparian zones by the operational foreman. The flagged block boundary was digitized with a GPS field data collector; a Trimble Pro XL. Likewise, the centreline of riparian zones were also digitized. These GPS data formed an essential part of the navigational dataset.

For the New Brunswick site, the control and test blocks were part of a 6.6 ha scheduled selective cut prescription. The prescription was set to harvest all merchantable softwoods and to leave the hardwoods, with spacing of 1200-1500 stems per hectare. Refer to Appendix I for a complete description of the harvest prescription. The harvest date was intended to commence prior to autumn, so a full hardwood leaf cover would be experienced during the test. The system development and preparation, however, took longer than expected and, as a result, most of the hardwood leaves had fallen by the October 28, 1996 commencement date. The field assessment lasted five working days. Weather conditions were very wet and ground conditions were quite soft.

Two harvest operators conducted the tests on a Valmet 911. A total of nine shift rotations were executed. The shift duration varied widely, mainly due to maintenance and repairs to the harvester. The mixed forest conditions are very harsh on the cutting head of the harvester. Hardwoods, in particular, can be very difficult to de-limb and as a result, can be hard on the cutting knives, in addition to impacting on the rest of the machinery. This resulted in numerous interruptions to the harvest operations.

The Alberta harvest block consisted entirely of lodgepole pine and black spruce. The selective cut test site was part of a 28 ha clear cut prescription, Embarrass 3, Block 184, with an estimated timber volume of 6160 m^3 of softwood. The selective cut was approximately 5 ha in area. The selective cut operation was only a test, as clear cutting is still the sole harvesting practice in the Weldwood FMA. The field tests started on November 21, 1996 for a duration of three days. There was a full-week break and then the test resumed on December 1, for three more days. Weather conditions were characterized by daily snow falls and highs of -15°C and lows of -30°C. At the beginning of the study there was 20cm of snow an the ground. By the end of the study the total fall had accumulated to 30 to 50cm. The ground was firm but not yet fully frozen.

Only one harvest operator worked on the Embarrass test site. Productivity rates were significantly higher in the Alberta Boreal forest and, hence, only one shift was performed by the contractor. The harvest operation was performed by a Timberjack 1270. A total of six shifts were executed. Relatively few repairs were conducted over the test period. The most serious repair was a broken fuel line due to the extreme cold. The lodgepole pine and black spruce are very similar in character. The trees delimb very easily, especially in freezing temperatures.

4.2 Viability Testing Results - Productivity

Table 2 presents a summary of the average productivity rates for the control and test blocks in New Brunswick. The individual hourly rates are presented in Appendix VI.

Table 2. Productivity Rate (stems/hour) Summary for New Brunswick

Control Block (Traditional)	Average	Std. Dev.	High	Low
Operator (1)	79	9	94	58
Operator (3)	65	11	79	51
Day Shift	75	11	94	58
Night Shift	65	11	79	51

Test Block (HNS)	Average	Std. Dev.	High	Low
Operator (1)	82	9	102	69
Operator (3)	67	5	73	62
Day Shift	82	9	102	69
Night Shift	67	5	73	62

Productivity in the test block shows slightly higher rates, 3% increase, compared to the control block (traditional method) for both the operator and shift subsets. It should be noted that test and control rates fall within one standard deviation of each other. This signifies that productivity was not significantly affected by the introduction of the HNS. The sample sizes are comparable, with 29 observations in the test block and 21 in the control.

Table 3 presents productivity rates for the Alberta site. The rates differ significantly; specifically, a 30% decrease in test versus control. It should be noted that sample size in the control block was rather small. Because of time constraints, only one day's data was collected. Therefore, only six observations were collected, compared to a much larger data set of 30 observations in the test block section. It also should be noted that the one day of harvesting in the control block occurred on relatively flat terrain, whereas, the test block was conducted on the slope of a hill, thus, possibly hampering productivity. One may also surmise that the introduction of the HNS in high yielding stands, such as those encountered in Alberta, could significantly impact harvest productivity.

Table 3. Productivity Rate (stems/hour) Summary for Alberta

Control Block	Average	Std. Dev.	High	Low
Operator (1)	172	7	179	165

Test Block	Average	Std. Dev.	High	Low
Operator (1)	122	25	160	93

Regrettably, the results are inconclusive for the Alberta field trials; however, testimony from the harvest operator favoured the notion that the harvest navigation system did not impact upon the productivity of the harvest. If one compares the time to process one tree in the test and control blocks, it takes an average of 29.5 seconds versus 20.9 seconds, respectively. That is an 8.4 second difference. Over the average rate of 147 trees per hour, that is an additional time of 20 minutes versus the control block. The harvest operators observed that each time the HNS was used, it required no more than two minutes to determine whether the harvest vehicle was on track. Approximately five to eight such visual inspections of the software interface were performed per hour. This equates to approximately 10 to 16 minutes of operator time per hour utilized for navigation. It is speculated that this rate would be reduced with operator experience and a better HNS user interface.

4.3 Viability Testing Results – Post-harvest Quality

A formalized post-harvest assessment program has been implemented in Sussex New Brunswick by the local industrial partner, J.D. Irving Ltd (J.D. Irving, 1996). The company foreman evaluates a number of plots within a completed harvest block to assess the harvest quality. The assessment is based upon a point system used for final payment of the contractor. It includes noting remaining tree damage, recording post-harvest stand density, observing the percentage of area that is occupied by the harvester's trail, determining whether or not the targeted tree component has been harvested, and noting that cut piles have been correctly sorted by size and product type. The cut block boundary must be followed with certainty by the harvester as it was laid out by the foreman. This *block boundary integrity* is assessed in the field during the post-harvest survey. Quality assessment is an admittedly subjective exercise but this assessment system was developed with the harvest contractors and, hence, has been agreed upon as an equitable assessment and payment method.

The quality assessment is based upon three criteria: *product quality*, *select cut quality*, and a *Better Management Practice* (BMP) checklist. The foreman is responsible for weekly inspections, wherein five to ten sample plots are observed for any given cut block operation. The harvest quality assessment program changed several times over the course of the research and development of the harvest navigation project. Two different grading sheets were issued. During the course of the project, the harvest operator was not required to have a quality assessment performed, since his historical track record of good quality jobs had been established and accepted. The obligation of harvest quality assessment had been passed on to the harvest operator. For testing integrity in this project, however, the harvest foreman was asked to perform the quality assessment.

The wood product is inspected on site to determine product quality. It is graded on its ability to meet criteria such as, target length, lack of defect, delimbing quality, stump height, as well as, how well the product is sorted and piled. The various product categories (pulp wood, stud wood, and sawlogs) would have different specifications for quality. For example, pulp wood may contain a certain amount of rot, and stud wood may not.

A second section is reserved for select cutting quality assessment. The select cutting operation is graded based on how well the post stand density goal is met, how well the target product is selected, percentage of standing timber damage, and area taken up by the harvester trail . A bonus is awarded on the basis of the select cut quality.

The final quality assessment is based upon a Better Management Practice (BMP) checklist. There are a number of topics of concern, such as site and water protection, operating procedures and safe work conditions. Specifically, site and water protection may include road and culvert damage, fuel and oil procedures, garbage disposal, and rutting stream crossings. BMP for operating procedures involves respect for boundary lines, prescription guidelines, and acceptable timber waste. Safe working conditions consider communications, fire suppression, and general safety guidelines. This part of the assessment is not directly rewarded points for financial gain, but it does help instill a higher quality work ethic by utilizing a formal monitoring system.

The J.D Irving Ltd. quality assessment procedures were used as part of the evaluation of *viability* for the Sussex test block. The contemporary harvest quality assessment procedures were slightly modified at the time of test block evaluation. At the time, it had become customary for the harvest operator, not the foreman, to perform the quality assessment. Spot checks are still done by the foreman to maintain quality control. Since all historical records on harvest quality were performed by the same foreman, it was preferable to have the same person perform quality assessment on the test site. The historical records would be used to support evidence of any appreciable change in quality in the test site.

The quality assessment procedures on the Weldwood test site had progressed to a point where the harvest contractor is responsible for self-assessment. Once the contractors have a proven track record of acceptable quality, they then police themselves or any harvest subcontractors that might have been hired. The contractor, Ro-da-cor Ltd., performed the post harvest assessment in the test block using the Weldwood standard. Here too, the post harvest assessment quality was used as part of the evaluation for *viability* of the Harvest Navigation System. The assessment procedures may be considered as not as formal or rigorous as the JDI Ltd. program, but they nonetheless form part of the standards at Weldwood. A guide book on product quality is published by Weldwood and distributed to the harvest contractor [Weldwood, 1996].

A tabular summary of New Brunswick results is given in Table 4 and 5. The results from the quality assessment show that there is no appreciable difference between the control and test blocks. The control was assessed at a 97% Product Quality with a 38% Bonus, whereas the test block was evaluated at 98% Product Quality with a 36% Bonus. Both blocks passed the Better Management Practice assessment.

The Alberta quality assessment was conducted by the harvest contractor following the Weldwood guidelines. As stated earlier the assessment is not exact. Post harvest quality merely has to meet the subjective approval of the contractor. Here, too, the comparison between the control and test blocks proved to be equal. The contractor could find no appreciable difference between the blocks, giving them both a pass grade.

Table 4. Quality Assessment: New Brunswick Control Block.

Control Block

Product Quality Section

	PRODUCT SPECS 30 pts	PRODUCT SORT 30 pts	PILING 25 pts	IMPROVEMENT PROJECT 10 pts	IDEAS 5 pts	BMP's Pass or Fail	TOTAL SCORE 100 pts
Sample Size	20 pieces	20 pieces	20 pieces				
Acceptable	18	18	20	10	5	Pass	94
Score	27	27	25				
Sample Size	20 pieces	20 pieces	20 pieces				
Acceptable	20	20	20	10	5	Pass	100
Score	30	30	25				
							97

Select Cutting Quality Section

	POST DENSITY	CROP TREE SELECTION	CROP TREE DAMAGE	TRAIL % and WIDTH	
	+/-300=6%bonus	85-89%=6%bonus	<7%=6%bonus	<18%=1%bonus	
	+/-200=9%bonus	90-95%=9%bonus	<5%=9%bonus	<15%=3%bonus	
	+/-100=12%bonus	95.1+%=12%bonus	<3%=12%bonus	<13%=5%bonus	
PLOT#	POST DENSITY	CROP TREE SELECTION	CROP TREE DAMAGE	TRAIL % and WIDTH	TOTAL BONUS
1	1400				
2	1200				
3	1200	9%	12%	5%	
4	500				
5	900				
	1040stems/ha= 12%				38%

Table 5. Quality Assessment: New Brunswick Test Block.

Test Section

Product Quality Section

	PRODUCT SPECS 30 pts	PRODUCT SORT 30 pts	PILING 25 pts	IMPROVEMENT PROJECT 10 pts	IDEAS 5 pts	BMP's Pass or Fail	TOTAL SCORE 100 pts
Sample Size	20 pieces	20 pieces	20 pieces				
Acceptable	18	19	20	10	5	Pass	97
Score	27	30	25				
Sample Size	20 pieces	20 pieces	20 pieces				
Acceptable	19	20	20	10	5	Pass	100
Score	30	30	25				
							98

Select Cutting Quality Section

	POST DENSITY	CROP TREE SELECTION	CROP TREE DAMAGE	TRAIL % and WIDTH	
	+/-300=6%bonus	85-89%=6%bonus	<7%=6%bonus	<18%=1%bonus	
	+/-200=9%bonus	90-95%=9%bonus	<5%=9%bonus	<15%=3%bonus	
	+/-100=12%bonus	95.1+%=12%bonus	<3%=12%bonus	<13%=5%bonus	
PLOT#	POST DENSITY	CROP TREE SELECTION	CROP TREE DAMAGE	TRAIL % and WIDTH	TOTAL BONUS
1	400				
2	1500				
3	700	12%	9%	3%	
4	1400				
5	1700				
	1140stems/ha= 12%				36%

In summary, the comparison between control and test harvest blocks determined that the harvest navigation system was viable in the Acadian forest of New Brunswick. Both productivity rates and post-harvest quality were acceptable in NB, but only quality was acceptable in Alberta. At high harvest productivity rates there may be an appreciable difference with the introduction of a harvest navigation system. Only one day of data was collected for the control block in Alberta and hence, because of the small sample size, the results may not be conclusive.

4.4 DGPS Reliability

The reliability of the DGPS correction signal, as received by the remote GPS receiver in the harvester, was calculated. Simply, reliability was calculated from the amount of time the DGPS correction signal was received by the field unit over the total time of the field operating period. The real-time DGPS systems utilized for the two test sites performed with similar reliability. In each case, reliability was monitored using the National Marine Electronics Association standard output string (NMEA-0183) [Kalafus, 1996], generated by the GPS receiver. One of the output fields records whether the GPS position fix was differentially corrected. From this, the DGPS reliability was determined. Reliability was calculated as the percentage of time that the DGPS correction signal is received by the HNS. The Coast Guard system and Trimble ProBeacon utilized in New Brunswick made DGPS corrections for 86.47% of all position fixes. The radio modem system used in Alberta had a DGPS reliability of 89.19%. The slight increase of the DGPS reliability at the Alberta site may be due to the shorter distance between the base station and the HNS GPS receiver and hence stronger signal reception, or possibly the higher data rate (9600 bps) of the local basestation as compared to the Coast Guard Beacon (200 bps). Refer to Appendix III for the daily DGPS reliability summary. It should be noted that only differentially corrected positions were recorded and displayed for the tracking component of the HNS, hence no positional spiking can be attributed to non-differentiated (autonomous) positions.

4.5 GPS Positioning Analysis

A GPS signal investigation looked for explanations for the positional spiking in tracking data. First, the source of the positional spiking was investigated. Then, an examination of the relationship between the GPS operating parameter; the number of blocked satellites (Section 4.4.1), and several environmental parameters (Section 4.4.2); stand density, slope and aspect. Data filtering, and temporal and spatial analyses were performed to determine whether or not a relationship existed and if explanations could be isolated.

4.5.1 Sources of Positional Errors

The spatial relationship of the GPS antenna and the path of the incoming GPS signal can create erroneous positional data. These erroneous positions take the form of two phenomena - multipath and a change in the satellite configuration.

Multipath occurs when the GPS signal is reflected off solid objects, such as trees, resulting in a longer path over which the signal has traveled [Wells et al., 1986]. This results in an erroneous position which cannot be easily deciphered from the normal GPS signal transmission. The erroneous ground position can be detected since it is usually outside of the normal measurement accuracy. In the current research project a spike in the tracked position of the harvester may have resulted from multipath.

Another type of positional error can give rise to consecutive positions that are farther apart than the expected measurement accuracy of the system (<2 m). This occurs when the GPS constellation changes. The constellation change is due to blocked or noisy signal that can no longer be tracked by the GPS receiver. Tree canopy interference is the major contributor to the GPS interruption in the forest [Wilkie, 1989, Gehue et al., 1993, Jasumbask, 1993, Lachapelle et al., 1994, D'Eon, 1995, and Deckert and Bolstad, 1996]. Although there may be a sufficient number of satellites (>4) to yield a three dimensional position fix, the change in GPS constellation configuration can dramatically change the errors and biases associated with the position solution. Each satellite has its own unique SA bias, which is a large contributing error to the position solution. Therefore, the calculated ground position may greatly differ from that of the previous position. This error can also have the characteristic positional spike.

In the GPS performance investigation multipath was not uniquely identified. No method was devised to separate it from other positional errors. Recently new GPS receivers have been developed in which the multipath effect can be rejected [Hatch et al, 1997]. This type of receiver was not available at the time of the project development. Instead, the GPS signal analysis focused on blocked satellites as influenced by environmental factors, stand density, slope and aspect.

4.5.2 GPS Parameters

The GPS receiver recorded various operating parameters during the field trials. Positional fixes were recorded every 10 seconds. This rate was primarily selected as a suitable update rate for the slow movement of the harvest vehicle. Not only was a positional coordinate recorded, but the number of satellites used to calculate that position was also stored. Another GPS parameter that was recorded was the GPS fix quality, which specifies if the recorded position was differentially corrected. The GPS information was stored as a NMEA (National Marine Electronics Association) 0183 Standard log which is the standard format for data protocol for the communications between different types of navigational aids (LORAN-C, GPS, etc.) [Bennett, 1996]. The data structure is in a printable ASCII text format. Specific navigational information is contained in individual lines or sentences. For this application the following NMEA messages were used: $GPGSA - GPS DOP and active satellites, $GPGSV - Satellites in view, and $GPGGA- GPS fix data, including DGPS fixes.

In summary, every data point that was recorded during the field trials has a positional coordinate, time, differential link indicator, total satellite count, and HDOP (Horizontal Dilution Of Precision, an accuracy indicator as determined by the satellite geometry). Other parameters were recorded but were not used in the study, such as the satellite elevation and azimuth angle.

The GPS positional dataset was recorded during the field test of the harvest navigation system. A simple ASCII text log of time, position, differential lock, number of satellites used, and HDOP was recorded in the NMEA-0183 standard. Extensive data processing created a ArcInfo coverage of 6255 points in the Alberta test site. The Acadian test site had over 10 000 data points. Each point had a position, time and GPS parameters associated with it.

To determine whether a satellite was *not* used for a positional fix, because it was "blocked", the *total available* number of satellites and the *total acquired* number of satellites at a given time had to be determined. The total available number of satellites may be predicted from the almanac file. This was performed with the aid of pre-mission planning software (Trimble's Quickplan). This software can predict the various satellite parameters prior to the GPS data collection in the field. This process uses the *almanac*, which is downloaded from the GPS satellite data stream. This dataset informs the user about the location of the satellites (elevation and azimuth angle) relative to the location of the user (i.e. the GPS receiver), and number of available satellites, over a given time period. Hence, one can determine the total available number of satellites during the course of the field trials. Since this is a time-varying parameter, the time was used to link the available and acquired satellites. The total number of acquired satellites is simply the number recorded in real-time for every positional fix. To calculate the total number of blocked satellites one simply subtracts the total number of acquired satellites from the total available number of satellites, i.e.:

No. of Satellites (Blocked) = No. of Satellites (Available) - No. of Satellites (Acquired)

It must be noted that this is only an estimate of the number of blocked satellites. The dynamics of the harvester make it such that the GPS antenna will not always be horizontal and, hence, there is a possibility that satellites that are low on the horizon may be acquired and those in the opposite side of the horizon may be unduly "blocked". The analysis of the terrain parameters, slope and aspect may shed some insight into the effects.

4.5.3 Environmental Parameters

The stand density measurements were collected by means of a prism cruise, and diameter at breast height (DBH) measurements. Sample points were positioned with a GPS data collector on a 75 m grid pattern in the test site. The geostatistical method of Kriging allowed the point sample data to be converted into an area coverage throughout the test site stands. Kriging is based on the *regionalized variable theory* which assumes that the spatial variation, in the stand density, is statistically homogeneous at all locations on the surface [ESRI, 1995]. The Alberta test site had two distinctive stands inside the test site. They were processed separately into polygon coverages. The mature stand had an average density of 1000 stems/ha. The younger stand had varying density of 1000 to

6700 stems/ha. The stand boundary can be seen as a distinctive line crossing the study site form the southwest to the northeast. The New Brunswick site had two distinctive tree types, hardwood and softwood. Here too, the data sets were processed separately into polygon coverages. A total stand density coverage was also created for the Acadian forest.

The amount of biomass, the physical volume of material, is the major cause of signal attenuation and blockage in the forest canopy. It must be noted that stand density is only an indirect indicator of the amount of biomass above the GPS antenna. The density of tree canopy is, among other variables, species dependent. It is also site, age and height dependent. For the purpose of this assessment the stand density was used as the variable that indicated the amount of biomass in the forest canopy.

A terrain effect was previously identified as a statistically significant parameter [Deckert and Bolstad, 1996] but to a lesser extent than canopy type. That study classified terrain into the three categories of ridge, valley, and slope. In this research, the terrain type has not been predetermined and the variability of the terrain class is unknown. Thus the classification of terrain was separated by the variability of slope and aspect, that is, the percent slope and the orientation of that slope for any given GPS position. The subsequent Section 4.5.4, on GPS performance analysis, will elaborate upon this topic further

Digital Terrain Model (DTM) data was processed to yield slope and aspect parameters. From a simple X,Y, Z coordinate coverage, a Triangulated Irregular Network (TIN) was generated. From the TIN, several terrain parameters were derived. The slope, (percent steepness) and aspect (compass direction) for the study site was processed into polygon coverages.

Humidity was not identified to be a significant factor in the literature and technology review [Lachapelle et al, 1994]. It has been speculated that water on the leaf surface will attenuate the GPS signal to a greater degree [Wells, 1996]. Standing water on a leaf surface will increase the physical size and thickness of the leaf surface. Furthermore, it is popularly thought that snow cover in the tree canopy will also attenuate or block the GPS signal to a greater extent. The occurrence of rain and snow was monitored and logged during the test period of the harvest navigation system.

4.5.4 GPS Performance Analysis

GPS positions were overlaid onto the environmental coverages (stand density, slope and aspect). Thus, each GPS position and the associated number of blocked satellites, could have the environmental parameters linked with it. The frequency of blocked satellites were spatially related with the environmental parameters. An overlay of the number of blocked satellites with the environmental parameter, stand density is illustrated in Figures 18 and 19, for each test sight [see Appendix IX]. A simple cross tabulation was extracted from these spatial overlays.

In addition, the blocked satellite parameter had to be temporally analysed and processed. It was hypothesized that there would be a time varying factor in the positional accuracy of the harvester. As stated earlier, the GPS satellite configuration changes over the course of a day. This satellite constellation repeats on a 24 hour basis but is lagged by four minutes everyday. That is, the satellites will be in the same place in the sky four minutes earlier the next day. Knowing this, it was speculated that there would be a time varying factor in the number of blocked satellites over the course of a working day.

The number of blocked satellites was graphed and smoothed by a moving average algorithm for each of the four working days. Smoothing the data allows for a better trend analysis to be performed. These data were then compiled by synchronizing the data sets. The data sets were overlaid and offset by the appropriate four minute lag. The offset correction was required to synchronize the day-to-day satellite constellation configurations. It was noted that there was a relationship of the blocked satellites with respect to time. Refer to Appendix VIII for a graphical representation of this process. This temporal effect was averaged for the entire time epoch from the daily measurements, thereby yielding the trend of blocked satellites for any given day of the testing. Subtracting the temporal effect (TE) from the observed number of blocked satellites for each positional fix yields an estimated residual that is non-temporal, and mainly affected by the spatial elements of the environmental parameters. This variable was called the temporal effect residual (TER) and was used as the key parameter to detect a spatial relationship between the environmental parameters and the blocked GPS signals. This GPS performance indicator, TER, is analogous to the number of blocked satellites, but reduced with a temporal influence. A higher TER value indicates an increase in GPS signal blockage.

A simple cross tabulation was performed to visually detect a spatial relationship. To illustrate the relationship, a three-dimensional bar graph depicts the environmental parameters and the frequency of occurrence of the TER. To make comparisons within the environmental parameters classes, such as increasing stand density, increasing slope, and varying compass directions for the aspect parameter, the percent frequency of the TER is depicted for each environmental class.

Figure 20 graphs the GPS performance variable, TER, against the stand density class. The TER is depicted as the percent frequency for each stand density class. Thus, the effect of an increase in stand density can be directly compared. The distribution will be unique for each test site, but certain trends may be evident.

Visually, one can detect an increase in the TER as stand density increases for the distribution. This is also supported by the increase in the average TER for each stand density class. The average TER in each stand density class is indicated in a box in the bar graph. There is a trend for the TER value to increase as stand density increases for both test sites, the Acadian (Fig. 20) and the Boreal (Fig. 22) forests. The trend may also be depicted linearly. Figure 21 and Figure 23 are line graphs which illustrate the decrease in GPS performance (increase in TER) as stand density increase for both data sets.

For the Acadian forest site, stand density was stratified into hardwood and softwood species. The average TER in the stand density classes have characteristically different trends (Fig. 24). There is a trend for both species to have a negligible influence on the TER at lower densities, < 2000 stems/ha, but they tend to peak at different densities. The hardwood influences the TER at a higher density (4550 stems/ha) than the softwood (3050 stems/ha). This trend may be explained in the following manner. With the lack of foliage on the hardwoods (Autumn test conditions), the limbs and trunks of the tree tend to block the GPS signal. It is only at the higher density of hardwoods that there is sufficient bare canopy to affect the GPS signal.

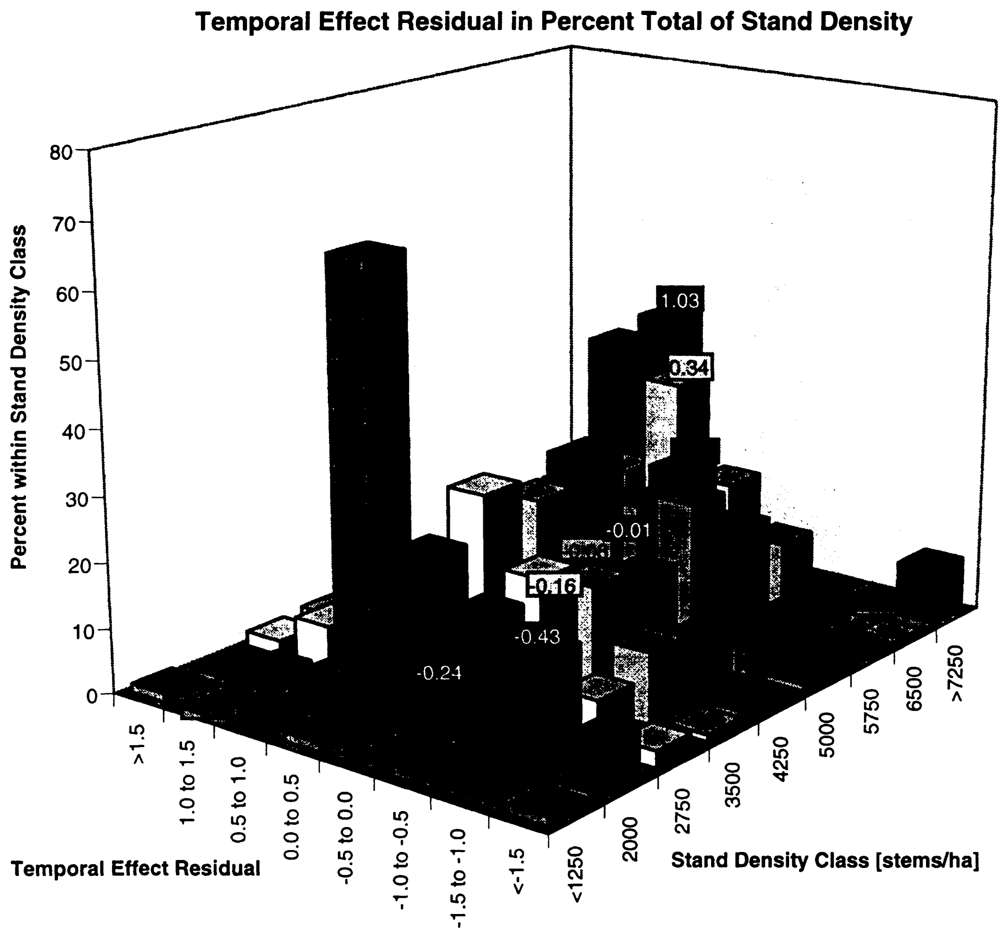


Figure 20. Cross tabulation of the GPS performance indicator, TER, and Stand Density for the Acadian Forest site, Dubee Settlement.

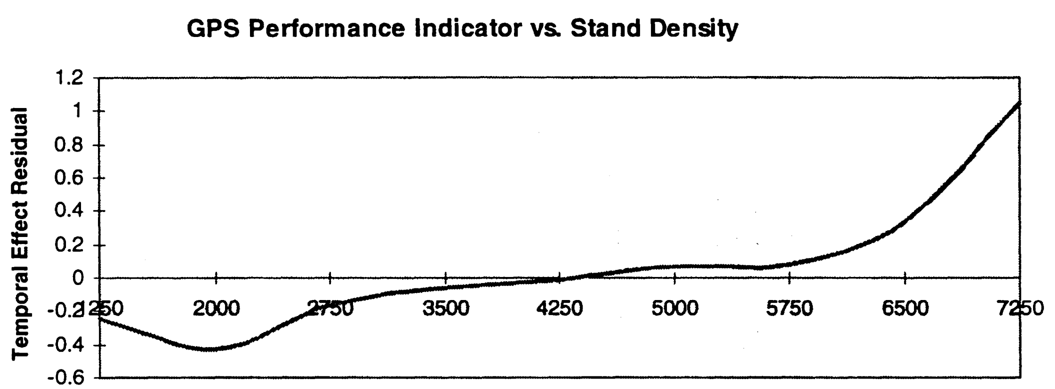


Figure 21. Line graph of the average TER with Stand Density for the Acadian Forest site, Dubee Settlement.

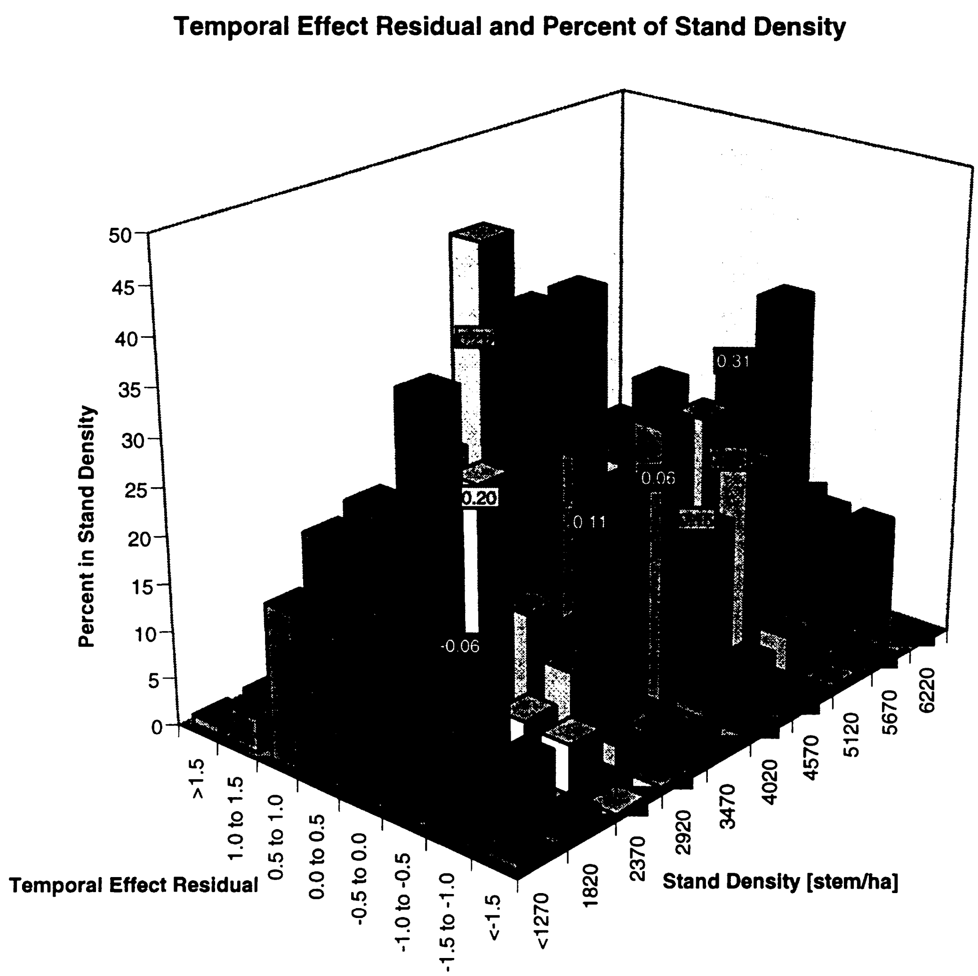


Figure 22. Cross tabulation of the GPS performance indicator, TER, and Stand Density for the Boreal Forest site, Embarrass

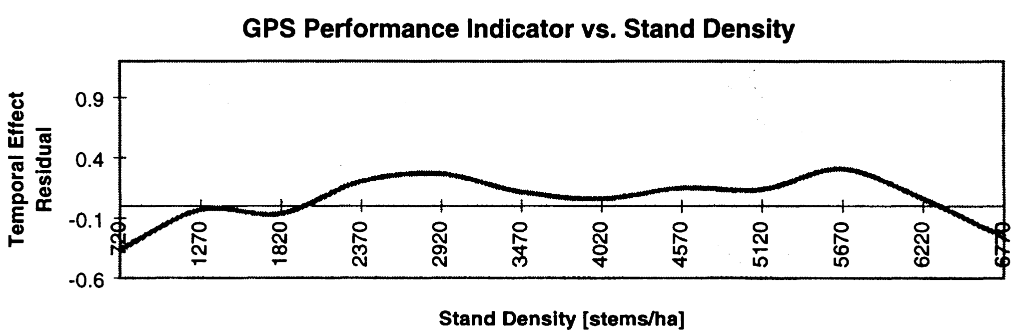


Figure 23. Line graph of the average TER, a GPS performance indicator, with Stand Density for the Boreal Forest site, Embarrass.

The softwoods affect the GPS performance at a lower density (3050 stems/ha) since they maintain a full crown of foliage. One can also observe that there is a trend of decreasing TER at the highest stand densities for both species. It is speculated that at the higher densities, associated with younger and shorter trees, the antenna height is physically above the influence of the stand, thus yielding better GPS performance.

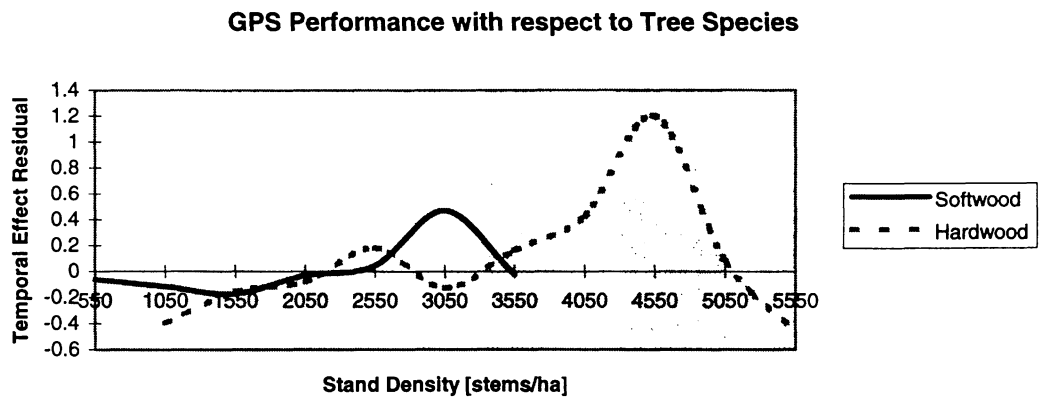


Figure 24. Line graph of the average TER with Stand Density for Hardwood and Softwood tree species in the Acadian Forest site, Dubee Settlement.

The terrain variables, slope and aspect were analyzed in a similar manner. Below is a line graph for the GPS performance variable, TER, versus the slope class in each test site (Fig. 25 and 26).

Both graphs illustrate a characteristic increase in TER as the slope increases. This would indicate that the GPS performance is poor on steeper slopes. Physically, this could be explained by a tilting of the GPS antenna, since it is in a fixed position on the harvest vehicle. An increase in tilt or slope causes a decrease in the exposure to the full view of the horizon for the GPS antenna, thus fewer satellites can be tracked. The effect of aspect is illustrated in the following set of line graphs (Fig. 27 and 28).

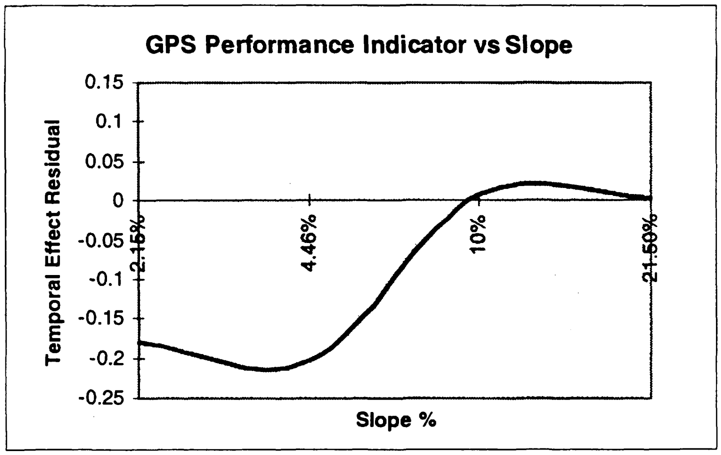


Figure 25. Line graph of the average TER with Slope for the Acadian Forest site, Dubee Settlement.

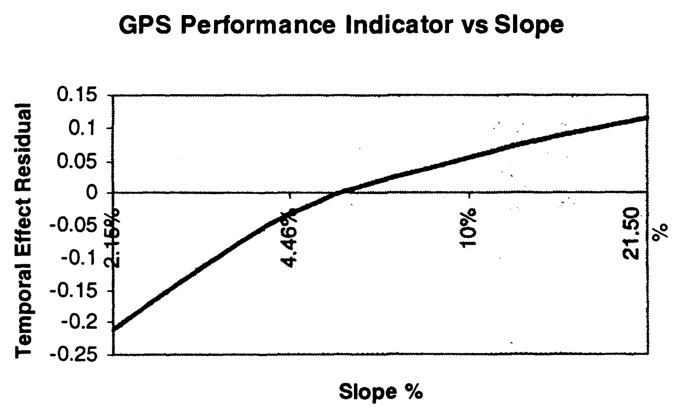


Figure 26. Line graph of the average TER with Slope for the Boreal Forest site, Embarrass.

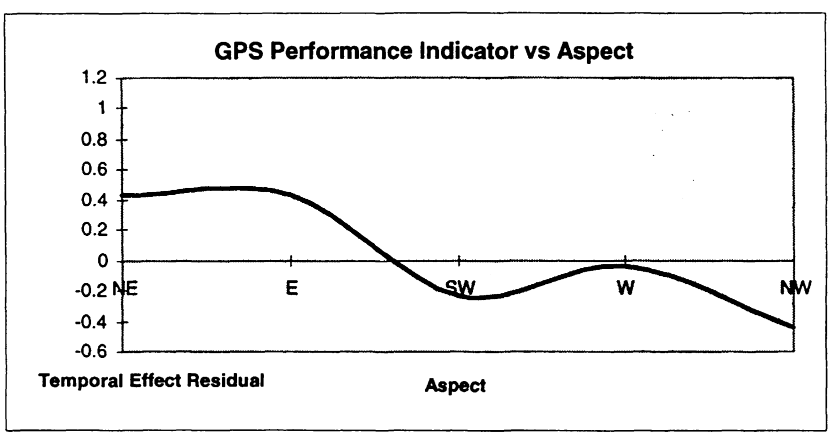


Figure 27. Line graph of the average TER with Aspect for the Acadian Forest site, Dubee Settlement.

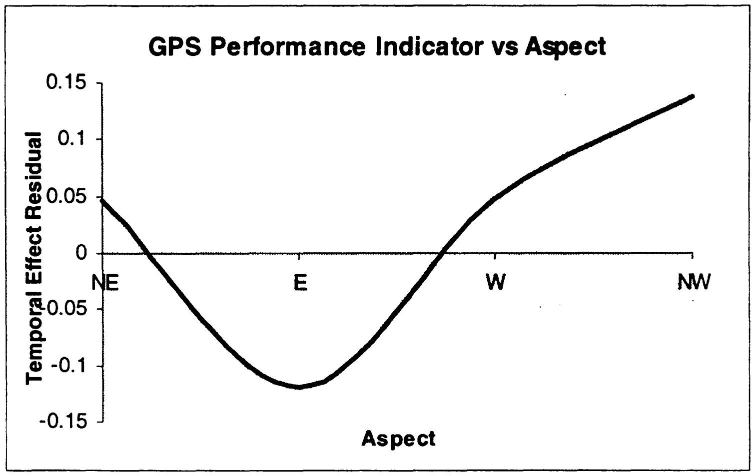


Figure 28. Line graph of the average TER with Aspect for the Boreal Forest site, Embarrass

There is no visible pattern in the above two data sets. There is a lack of variability in the data sets since the morphology of both sites was very homogeneous throughout the cut blocks. The slopes tended to face the same direction in the entire test block. Thus, it is inconclusive whether aspect has an effect on the GPS performance with the data set collected.

It was speculated that aspect would have an effect upon GPS performance. The tracking of the satellites is affected by the orientation of the GPS antenna with respect to the satellite constellation. There are no circumpolar or high latitude satellite orbits. Hence, the satellite constellation pattern is characterized by a void around the polar regions of the planet. Since there are no satellites in the northern region of the sky, it is speculated that a northern orientation of the antenna (and the terrain aspect) would cause poor satellite tracking. The data collected did not support this assumption. A more varied data set across a wider selection of compass directions is needed to perform a thorough analysis of the effect of aspect on the GPS performance.

Notice the smaller variability of the TER in the terrain analysis (slope and aspect), as compared to the stand density analysis. This might indicate that there is less of an influence caused by slope and aspect as compared to the influence of the stand density.

4.6 Assessment Conclusions

It has been shown that the HNS system is viable for some of the testing parameters, but falls short on others. The quality of the harvest is not affected by the introduction of the harvest navigation system. In both test sites the quality assurance was maintained. Depending upon existing productivity rates, the use of the Harvest Navigation System may negatively affect the number of trees cut per hour. It is speculated that the productivity rates would increase back to acceptable limits as the harvest operator becomes familiar with the navigation system. Although productivity rates are key indicators of HNS viability, there are many other factors, such as, increased data flow, navigational intelligence and decision making abilities, which predicate that the HNS is a beneficial tool in the forested environment (Section 1.2). It was also illustrated that the GPS performance in the forested environment is negatively influenced by the stand density and terrain slope. This relationship was also supported by other studies covered in the literature review [Melgard et al, 1994, Deckert and Bolstad, 1996].

CHAPTER 5 SUMMARY, RECOMMENDATIONS AND CONCLUSIONS

Chapter 1 presented the research context, objectives and potential contribution. Specifically, the objective of the research investigation was to assemble and determine the *viability* of a real-time harvest navigation system in partial harvesting. If the viability could be established, it was surmised that significant operating cost reductions could be realized [Celeste and Gagnon, 1996] and forest inventory updating facilitated. Further, a viable harvest navigation system would address the more complex arrays of harvesting and silviculture interventions emerging in landscape management.

Chapter 2 described the design of an HNS, involving a literature review, an investigation of relevant technologies, and a user needs study that set HNS performance criteria. The latter were identified as: *reliability*, *availability*, *spatial accuracy*, *ruggedness*, and *simplicity* of operator interface

Chapter 3 detailed the development of a series of three HNS prototypes, involving investigation of hardware, software, and base map data. Based upon performance criteria and field trials, an initial evaluation protype evolved into two operational prototypes; one for the New Brunswick test site, and another for the Alberta site. Several short comings were observed in the development of the harvest navigation system.

First, the HNS prototypes satisfied the *reliability* criterion as is reflected quantitatively in the productivity rates and the DGPS correction rate of 86 percent; however, improvements need to be made to increase the operator confidence. The DGPS link could be improved for the local base station setup. The following recommendations are derived from the document *UHF/VHF Range Calculations* [Pacific Crest, 1994]. The antenna location should be as high above the surrounding terrain as possible. A long whip antenna can be used on the harvest vehicle and transmitter antenna may be mounted on a service trailer or a portable tower. The length of the cables between the radio transceiver and antenna should be as short as possible. An antenna should be selected to provide maximum gain. A 5/8 wave length antenna should be selected over the standard 1/4 wave length. Repeater stations , which receive information on one frequency, and transmit it on another, will increase the DGPS range. The DGPS data can be relayed over long distances with a network of repeater stations. However, this is the most expensive method to increase the broadcast range. Also, to increase the range of the system, an RF amplifier should be used to increase the power output of the transmitter. Similar recommendations apply to the Coast Guard navigation beacon link. Power upgrades are planned for the Saint John, New Brunswick beacon, and should improve the DGPS reliability and range .

Second, the prototypes met the *availability* criterion. They ran continuously during night and day shifts, and during extreme weather conditions, with the on-board power supply providing electrical power. The computing hardware had sufficient memory to accommodate data storage. It was noted, however, that occasionally the number of available satellites drops to only 4 (for a 20 minute period). During such instances under tree canopy, positioning problems occur. Nothing can be done to improve the GPS constellation coverage; however, supplemental navigation aids, can be integrated to ensure that the system can operate during poor GPS satellite coverage. These navigation aids include dead reckoning devices and inertial systems.

Third, the *spatial accuracy* achieved with the prototypes was worse than the 2 m sought. Frequent positional spikes in the order of 5-15 m occurred under tree canopy. The harvest operators stated that the 'noisy' data lowered their confidence in the system. There was sufficient data to allow for the general layout of the harvest, but these data would not be adequate for riparian buffer navigation, harvest block updating or payment area calculations. There may be several ways to improve the positioning system, by modifying hardware and software elements.

In regards to the hardware, the system may be improved by incorporating an improved antenna configuration such as a choke ring or ground plate. These physical modifications to the GPS antenna help reduce multipath signal reception and can help receive weaker signals, thus, improving the positioning capabilities in the forested environment. Only quite recently have new GPS receivers become available that reduce the occurrence of received multipath [Hatch et al, 1997]. Additional positioning information may be obtained with a dual GPS/GLONASS (GLObal NAvigation Satellite System) receiver (Ashtech, 1996). GLONASS is the Russian equivalent to the American GPS satellite timing, positioning, and navigation system, and adds 24 additional satellites to the constellations. Simply stated, the more satellites, the better positioning capabilities. Although, the GLONASS system is subjected to the same problem as is GPS of attenuated signals in the forested environment, there should remain double the number of visible satellites being successfully tracked with a dual GPS/GLONASS receiver. Investigation and research is recommended to test these specific hardware changes in the forested environment. Furthermore, investigation into the real-time differential services, such as, RDS and communication satellites operating under tree canopy is warranted.

In addition, secondary navigation aids, such as dead reckoning and inertial systems, can supplement the GPS navigation tool [Wise and Murphy, 1993]. These systems utilize gyroscopes, electronic compasses and odometers and support a vector solution in navigation. These systems have been developed for other vehicle navigation systems, such as aircraft and cars, but may not perform well in the very bumpy environment of the forest. The movement of the harvester may not always be in the forward direction of the vehicle due to stumps and bumps. This movement would perturb the navigational solution of *direction* that is solved by these systems. Nevertheless, an investigation into these systems is warranted. These systems- GPS, dead reckoning and inertial may be integrated to improve the navigational solution of the harvester.

Software algorithms that incorporate vehicle position, speed and direction parameters should yield the best results. The vehicle dynamics of the harvester movement through space and time must be analyzed to help develop a navigational solution specific to forest machinery. Only one such algorithm was investigated in this project - a moving average algorithm. Although not conclusive, this type of algorithm does demonstrate some navigational improvements in the forested environment. An integrated system that gathers positional data, vehicle movement (change in position, direction, velocity) and data processing techniques will improve the navigational ability of the harvest navigation system. Other navigational filtering techniques, such as Kalman filtering, have been developed for different types of moving platforms with great success[Wells, 1996]. Similar development is recommended for the harvest navigation solution.

More research should be conducted in the area of tree foliage and GPS performance. Since the cause and effect relationship is due to the physical nature of the

GPS signal, the problem may never be surmounted. Perhaps the *shading* or *texturing* created by the foliage may be modeled, as to yield an expected confidence of GPS performance in specific tree stands or cover types.

Fourth, the prototype systems were *rugged*, but not protected. The antennas were not protected, but relied upon moveable or breakable mounts. A protective dome should be used to safeguard the GPS and DGPS antennas for the long term operation of the harvest navigation system. A Lexan or ABS dome, similar to the unit designed by FERIC is recommended for operational use. The individual hardware components were very rugged, but the electrical connections consisted of standard interface wires and cables which can be susceptible to damage. Also, no permanent mounting system was used for any of the components. The GPS and DGPS receivers were housed in a canvas backpack. This setup made for easy installation, but also made the cables and components vulnerable to damage. The field computer was either placed on a dashboard or simply hung on a coat hook from a carrying case strap. The internal hardware can be integrated into a single hard-shell unit that is ruggedized to withstand the vibrations and moderate impacts which occur within the harvester cab.

Fifth, a *simple operator interface* was selected. The operators were very satisfied with the prototype interface (FieldNotes). All operators were computer novices, yet picked up the operation of the system very quickly. No customization of the interface was conducted, and as a result it lacked an audible proximity alarm for riparian buffers or block boundaries. A supplemental visual display, such as a left-right indicator, was also discussed as part of the user needs study. This light-bar device helps to indicate which side of a desired path the vehicle is tracking. It is used in aerial spraying and precision farming and could be augmented in an advanced navigation system. It is anticipated that an object-oriented software development kit (SDK) and good programming skills could construct the additional functionality.

Chapter 4 described the HNS prototypes' assessment. HNS viability, as defined by the harvest productivity and the harvest quality were documented in formal experiments at the New Brunswick and Alberta test sites, followed by analysis of observed data. A test and control block were created for each site. The control block utilized the traditional harvest layout method, and the test utilized the harvest navigation system prototype. Each block was assessed for harvest quality and productivity. A simple comparison of these values indicated whether or not the harvest navigation system impacted. It was concluded that the harvest quality was not adversely affected by the introduction of the harvest navigation system. At low productivity rates, the navigation system may not have a significant impact, but at the higher rates achieved in this study, there is a reduction in the number of stems cut per hour. It is anticipated that the decrease in productivity can be lessened with increased operator experience and improvements made to the to the navigation system itself.

It has been shown that the HNS system is viable for some of the testing parameters, but falls short on others. The shortfall in harvest productivity rate is only one indicator of HNS viability, there are many other indicators which predicate that the HNS is a beneficial tool in the forested environment (Section 1.2). The total number of man hours used to harvest the cut block would decrease with the introduction of the HNS since the manual layout of harvest trails would be automated in the HNS. If the harvest operator's time is spent harvesting, instead of laying out the harvest block, (as was the case for the New Brunswick test site) the overall harvest productivity would increase. Additional study is needed to investigate the operational impact and cost comparison for the overall harvest procedure.

Chapter 4 also described a secondary investigation into the relationship between the key GPS operating variable (the number of blocked satellites), and the environmental parameters of, stand density, slope and aspect. The analysis showed that there is a relationship between the number of blocked satellites (indicated by the Temporal Effect Residual), and stand density and slope. This relationship was also supported by other studies [Melgard et al, 1994, Deckert and Bolstad, 1996]. Due to the invariability, and hence a lack of data, for the full range of compass directions, the terrain parameter, aspect was not shown to have a relationship with the number of blocked satellites. Further study of this relationship is warranted.

Although the environmental variables did impede the performance of the GPS, it did not detract from the use of such a system for the purpose of a navigational aid in a wooded environment. This conclusion is mainly supported by the testimonial statements by the harvest operators. They stated that the guidance of the harvester was improved by knowing where the machine was located in the cut block and how it related to the active cut lines. The only deterrents were the positional spikes in the tracking data. Since the performance of the GPS navigation system is affected by tree cover, it can be stated that under very high stand densities and canopy closures the GPS navigation system would not work. Hence, the claim "works under dense tree canopy" as made by some navigation systems developers, must be re-examined and the limitations realized. Specific conditions, namely stand density and terrain variability must be accounted for before one can judge the viability of GPS in a forested environment.

Finally, experience with forest cover maps used in this research shows them to have insufficient accuracy and reliability for use in harvest navigation. These GIS data should be used only as supplemental information to guide the harvester. GPS collected data and ground truth information such as flagging should be relied upon for tracking limits of riparian buffers and property boundaries.

It is foreseeable that the spatial accuracy and reliability of forest inventory mapping will increase as time progresses. With the advent of digital photogrammetry, GPS photo control and GPS ground truthing, future forest inventory and base maps could have the spatial accuracy and reliability for metre level forest management and, hence, appropriately integrated with the HNS.

An operational harvest navigation system will provide the *spatial knowledge* that new landscape management objectives demand. More complex arrays of harvesting and silviculture interventions have emerged which require efficient and effective execution. The integration of these techniques with field ready technology and skills will improve forest management. Harvesting convoluted cutting patterns, reducing trespass on blocks, and gathering product inventory spatially could be improved with a harvest navigation system. Valuable forest inventory data collection may be performed by the personnel who spend the most time in the cut block and who "cruise" the entire cut block - the harvest operator.

As landscape, or ecosystem, management evolves over the next decade the array and complexity of harvesting and silviculture interventions, and their geographical configurations will increase. As a result, their execution in the field will prove difficult.

Hence, there is an urgency to develop a viable, operational system to aid in the field navigation of partial cut harvest patterns. This research initiative has taken the first step in a better understanding of the complexities of such a harvest navigation system. It has analyzed existing technologies, studied their capabilities and identified their limitations. The next step is to develop a system which takes these factors into consideration.

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Internet Resources

Because of the nature of internet references, some of these links will be temporary and may have been discontinued.

ag/INNOVATOR
<http://www.agriculture.com/contents/aginn/gps.html> on line site for magazine of the same name specializing in site-specific precision agriculture, information technology and ag computing.

Peter Bennett's NMEA 0183 and GPS Information Directory
<ftp://sundae.triumf.ca/pub/peter/inde.html>

Canadian Space Geodesy Forum (CANSPACE) File Archives
<gopher://unbmvs1.csd.unb.ca:1570/1EXEC%3aCANSPACE> list of URLs of GPS and GLONASS sites

DCI's DGPS and TMS Services
http://www.dgps.com/

The Global Positioning System (GPS)
http://wwwhost.cc.utexas.edu/ftp/pub/grg/gcraft/notes/gps/gps.html

GPS World Home Page
http://www.advanstar.com/GEO/GPS/

Projects at SkogForsk (The Swedish Institute of Forestry)
http://www.skogforsk.se/eng/proj/proj.htm

Pulsearch Navigation Systems Inc.
http://www.tcel.com/~pulsearc/

sci.geo.satellite-navigation
- a very active news group specializing topical discussions on GPS related issues-accuracies, SA, receiver technology, many novices but with that new applications and non-achedemic insight

Secretary Pena's Remarks At GPS Announcement (3/29/96)
http://www.dot.gov/affairs/32996sp.htm

Texas Micro Ltd.
http://www.texmicro.com.

Trimble Navigation Ltd.
http://www.trimble.com

University NAVSTAR Consortium (UNAVCO)
http://www.unavco.ucar.edu/

APPENDICES

Appendix I

Cutblock Prescriptions

Cutblock Prescriptions

J.D. Irving Ltd., Sussex, New Brunswick Development Site Parkendale

Select Cut Prescription

Select Objective:	red pine and spruce
Leave:	white pine
Space:	maple and poplar

Notes: leave big poplar, and rotten standing timber
take a few more sawlogs 16ft x 8in
stud logs to 4in dia
minimize pulp
ensure clean pulp- good delimbing

Springhill / Dubee Settlement Test Site

Selective Cut- cut all fir to 95%
cut oversized spruce
leave hardwood, if above 3cunits/acre
post stand density 1400stem/ha
good growing site

Weldwood of Canada, Hinton, Alberta

Block 184, Compartment Embarras 03
Total Area- 27.7ha
6160m^3 SW 20m^3 HW

Some very wet and low lying areas throughout this block. Considerable porcupine damage to many trees in the block. Wood to accessed onto adjoining initial cut block road. Winter logging recommended

Appendix II

GPS Receiver Specifications and Settings

GPS Receiver Specifications and Settings

Product Source: http://www.trimble.com/cgi/products.cgi/pd_ms005.htm

The DSM™ uses Trimble's Maxwell chip--advanced, low-power, low-noise, high-accuracy technology--to provide real-time sub-meter accuracy. The receiver features 8 or 12 channels of continuous satellite tracking in rugged, weather-proof housing.

DSM Reference Station Unit

12-channel GPS receiver
Highly accurate range and range-rate corrections
Real-time processing
10 Hz maximum position and velocity update rate1
Positioning based on carrier-phase filtered L1 pseudoranges
Velocity computations incorporate carrier-phase data
L1 C/A code and instantaneous carrier-phase outputs2
2Hz maximum RTCM SC-104 output rate
Two RS-232 serial ports
RTCM SC-104 input
NMEA-0183 or RTCM SC-104 output
TSIP Interface Protocol I/O
1PPS output
L1 geodetic antenna with removable groundplane
15-meter RG58 cable, N (male) to N (male) connectors

Mobile DSM Units

8-channel GPS receiver
Submeter accuracy
Real-time processing
10 Hz maximum position and velocity update rate
Positioning based on carrier-phase filtered L1 pseudoranges
Velocity computations incorporate carrier-phase data
L1 C/A code and instantaneous carrier-phase outputs
Two RS-232 serial ports
RTCM SC-104 input
NMEA-0183 output
TSIP Interface Protocol I/O
1PPS output
Software Toolkit
Operation Manual
L1 Compact Dome antenna
15-meter RG58 cable, N (male) to N (male) connectors

Technical Specifications

General:
8- or 12-channel parallel tracking, L1 C/A code with carrier-phase filtering and instantaneous carrier-phase measurements

Update Rate:
10 Hz maximum

Accuracy:

Typically less than 1 meter RMS; Assumes at least 5 satellites, PDOP less than 4, and RTCM SC-104 standard format broadcast from a DSM Reference Station, a Trimble 4000RS, or equivalent base station

Time to first fix:

<30 seconds, typical

NMEA messages:

ALM, GGA, GLL, GSA, GSV, VTG, ZDA

Physical Characteristics

DSM Receiver

Size:

15.9cmW x 7.0cm H x 21.9cm D

Weight:

1.2kg

Power:

4 watts typical, 10 to 32 VDC

Operating temp:

-40°C to +70°C

Storage temp:

-40°C to +85°C

Humidity:

95% non-condensing

Casing:

Dust proof, splash proof, shock resistant

Antennas

Geodetic L1 Antenna: (DSM Reference Unit)

Operating temp:

-40°C to +65°C

Storage temp:

-55°C to +75°C

Humidity:

100% condensing

Casing:

Dust proof, waterproof, shock-resistant

Configuration without groundplane:

Size:

16cm W x 16cm L x 9cm H

Weight:

0.9kg

Configuration with groundplane:

Size:

48cm Dia. x 9cm H

Weight:

2.6kg

Compact Dome Antenna: (Mobile DSM Units)

Size:

15.4cm Dia. x 8.9cm H

Weight:

0.29kg

Power:

4 watts typical, 10 to 32 VDC

Operating temp:
-40°C to +70°C
Storage temp:
-40°C to +70°C
Humidity:
100% condensing
Casing:
Dust proof, splash proof, high-impact plastic

Trimble DMS - 12 channel Reference Station Price $11900.00 CA
Trimble DMS - 8 channel Mobile Price $ 8890.00 CA

DSM 8 Channel Mobile Info

Navigation Processor	- 3.07 12/20/95
Signal Processor	- 3.07 12/20/95
Number of Channels	- 8
RTCM Input	- Default at Clear RAM
RTCM Output	- Not Installed
Output Interval	- ASAP
Maximum Fix Rate	- 10 Hz
Default Fix Rate	- 2 Hz
Reserved	- 1
NMEA Output	- Default at Clear RAM
PPS Output	- Installed
Sync Measurement	- Carrier Phase Installed

NMEA/RTCM I/O Settings

RTCM Input	- 9600
MNEA/RTCM Output	- 9600
Data Bits	- 8
Parity	- None
Stop Bits	- 1
Output Format	- NMEA

Positioning Settings

Positioning Mode	- Manual 3D
Elevation Mask	- 15.00
SNR Mask	- 6
PDOP Mask	- 8
PDOP Switch	- 8
Dynamics Code	- Land
Positioning Rate	- 2 Hz

NMEA Output

Output Interval	- 10 s
Output Message	- GGA, GSA, GSV

RTCM Input

Input Mode	- On
Version	- Auto
RTCM Station	- Any

DSM 12 Channel Reference Info

Navigation Processor	- 3.09 03/22/96
Signal Processor	- 3.09 03/22/96
Number of Channels	- 12
RTCM Input	- Default at Clear RAM
RTCM Output	- Installed
Output Interval	- ASAP
Maximum Fix Rate	- 10 Hz
Default Fix Rate	- 2 Hz
Reserved	- 1
NMEA Output	- Installed
PPS Output	- Installed
Sync Measurement	- Carrier Phase Installed

NMEA/RTCM I/O Settings

RTCM Input	- 9600
MNEA/RTCM Output	- 9600
Data Bits	- 8
Parity	- None
Stop Bits	- 1
Output Format	- RTCM

Positioning Settings

Positioning Mode	- N/A
Elevation Mask	- 7.5
SNR Mask	- 6
PDOP Mask	- 8
PDOP Switch	- 8
Dynamics Code	- Static
Positioning Rate	- 2 Hz

RTCM Output

RTCM Output	- On
RTCM Details	
Correction Method	- RTCM PRC Type 9
Reference Station ID	- 0
Output Options	

ASCII carriage return after message

Appendix III

DGPS Reliability Calculations

Dubee DGPS Reliability

Date	Operator	Shift	%DGPS		
28-Oct	Aarron	1a	92.47%		
28-Oct	Tim	1b	90.90%		
29-Oct		2a	74.98%		
30-Oct		3a	66.67%	*	*Power Disconnect
30-Jan		3b	98.87%		
30-Oct		3c	85.83%		
31-Oct		4a	82.18%		
31-Oct		4b	74.47%		
1-Nov		5a	88.24%		
1-Nov		5b	90.33%		
			84.49%	86.47%	

Embarrass DGPS Reliability

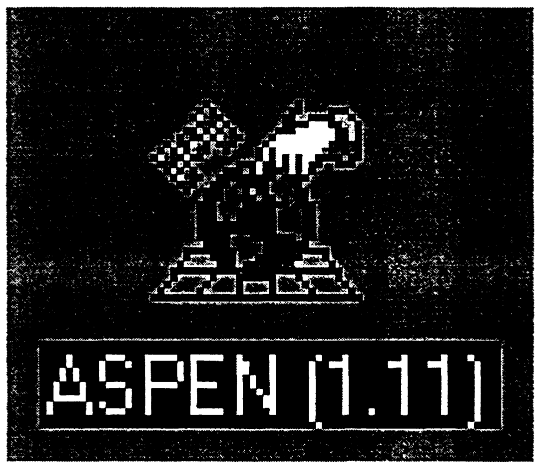
Date	Operator	Shift	%DGPS	
20-Nov	Randy	1a		
21-Nov	Randy	2a	89.16%	
22-Nov	Randy	3a	85.43%	
23-Nov	Randy	4a	83.08%	
26-Nov	Randy	5a	45.57%	*
28-Nov	Randy	6a	93.66%	*
1-Dec	Randy	7a	99.26%	
2-Dec	Randy	8a	86.06%	
2-Dec	Randy	8b	86.06%	
3-Dec	Randy	9a	92.59%	*
			84.54%	89.19%

* Not part of test data
Operator Errors

Appendix IV

Training Manuals and Operators Instructions

Aspen Training Manual for Selective Cut Navigation



by

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in Co-operation with

J.D. Irving Ltd.
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Aspen Pro Field Procedures for Harvest Navigation

The following document will explain the procedures needed to operate the Trimble Aspen Pro GIS/GPS system specifically for the mechanized harvester environment. The procedures will be a step-by-step account and only applies to this specific application. Where at all possible, the actual icons will be graphically displayed in this document to allow quick visual recognition of specific operations. For a more detailed explanation of the Aspen Pro software, a very good on-line help can be accessed by clicking on Help.

Hardware Configuration

The hardware consists of four major components: the receivers, the power hook-ups, the antennas, and the field computer. All components are easily distinguishable and hence only brief description will be made.

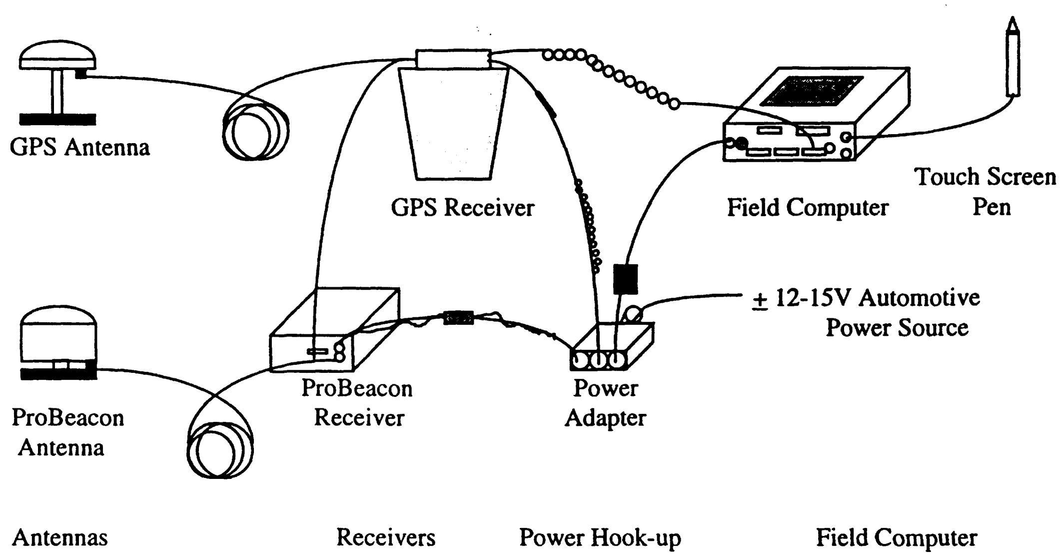


Figure 1.0 Navigation System Hardware

Receivers

The receivers consist of two "black boxes". The Trimble 8 channel GPS receiver is a black box and is housed in a yellow pack. There are four cables to attach to other components. The coaxial cable, which can be identified by having a single screw pin connector and it is the longest cable, attaches to the compact dome antenna. The power connector is a three pin clip plug which connects to a small coil cable with automotive plug. The long coil cable plugs into the field computer with a 9-pin D-type connector (RS232). The shorter 9-pin D-type connector plugs into the other "black box", which in this case is yellow.

The yellow box is a Trimble ProBeacon receiver. It collects the real-time differential correction signal produced by the Canadian Coast Guard, which is located on Partridge Island, near St. John, New Brunswick. This box collects information that is needed to increase the accuracy of the GPS signal. With it, the expected accuracy is 1-3m, without it 15-100m. The ProBeacon has three cables. The twisted red and black cable with the lighter adapter on it, is for the power source. The long coaxial cable is for the short and stocky dome antenna. The short 9-pin D-type cable from the GPS receiver plugs into the port closest to the power plug in. It is identified as *Port 2 RS-232* on the back of the ProBeacon..

Antennas
The two antennas, mentioned above, are mounted on top of the operator cab with magnetic mounts. They should be placed in near the centre of the roof of the cab, and approximately 20 cm (8inches apart). The coaxial antenna cables may be fed through the rear window of the cab and screwed into the appropriate antenna. The screw connectors are slightly different from each other, thus making it impossible to make a wrong connection.

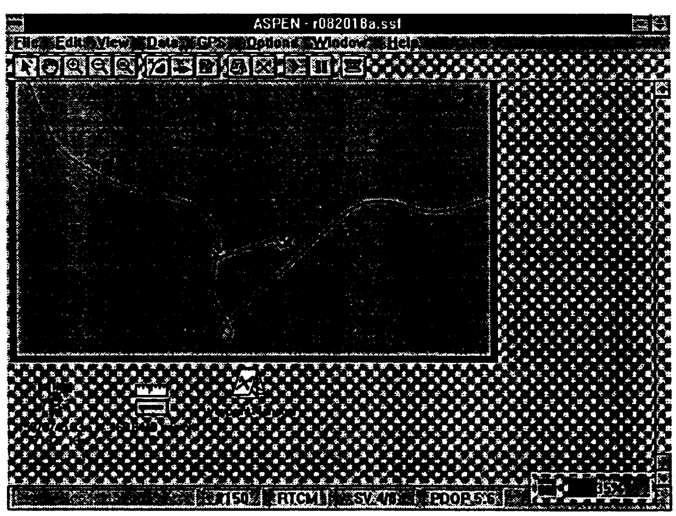
Field Computer
The field computer may be mounted in the front of the cab, clearly visible to the harvest operator. The field computer has many connection ports on its back panel, but only a few are required for this application. The automotive adapter plugs into a single pin connector located on the right side of the computer, near the rubber power switch. The coil cable with the 9-pin D-type connector from the GPS receiver screws in to the port closest to the computer's pen. The field computer's control panel is located at the bottom of the display screen. The control panel provides access to contrast, brightness, and suspend switches. It also has indicator lights for the hard drive, battery and power on. Adjust the contrast and brightness switches for a clear display.

Power Adapter
The power connector is simply a three outlet automotive adapter which plugs into the cabs power source. The three power cables from the computer, the GPS receiver, and the ProBeacon plug into the 3-way adapter. The ProBeacon (the yellow box) should be grounded. A grounding wire is supplied.

Additional Notes:
Please ensure all cables are tightly fastened and any excess cable is neatly coiled away.
Contrast controls on the field computer will remarkably change the clarity of the display.
Please treat the equipment with the utmost care. It is sensitive and we don't own it.

Start Up

To start up the system simply press the rubber power button on the back of the field computer. The Aspen Pro software has been configured to start-up shortly after the power has been turned on. The initial panel is shown in the following diagram.



The Command Line
The Aspen Pro software has a typical Windows *graphical user interface* (GUI or gooy). One can start a command by clicking on the *Command Line* such as **File** or by clicking on a graphic (also referred to as an

icon). Commands can also be accessed from a keyboard by holding down the ALT-key and entering the underscored letter (e.g. ATL-F = **File**). No keyboard will be used in this application. The electronic pen is used to move the pointing device around the display screen. Before the specific procedures are explained, a description of the GUI's will follow.
Below is a close-up view of the command line and the command icons.

The Tool Bar
The Tool bar has a group of icons that perform useful tasks.

 The *Pointer*. The program first starts up with the arrow icon. It is simply a pointer that opens the command line or the other icons when the pointer is clicked on the specific item.

 The hand icon is referred to as *Pan*. When it is selected and dragged over the map, the map will move (pan) in the direction in which the hand was dragged. A line appears to show the direction of movement. It is used to display other areas of the map that are not currently visible. *Pan* can also be accessed under the command line **View, Pan**.

 The magnify glass with the plus sign is used to *Zoom-in* to the map display. When it is selected and dragged over a specific area on the map, a dashed line box will appear. The area outlined by the box will be enlarged. Note that the scale and width numbers at the top of the map display will indicate that scale has changed. This tool is recommended to zoom-in to specific trails or boundary lines. This tool can be accessed from the command line **View, Zoom, In**.

 *Zoom-out* is shown as a magnify glass with a minus sign. It works in a similar manner to the zoom-in icon except it displays a larger scale or smaller image. Use this to zoom-out to the entire block boundary. This tool can be accessed through the command line **View, Zoom, Out**.

 *Zoom-extents* will display all of the map information and GPS data. The extents of all data will be displayed. This may be used to show all the roadway information if it has been loaded into the computer. Zoom-extents can be found under **View, Zoom, Extents**.

 *Create Features*. It is used to collect different types of graphical information. In most cases the harvest operator will collect line information. The line feature represents the trail that is being created by the harvester. This tool can be accessed from the command line **Data, Capture Features**.

 *Capture Quickmarks* is only for capturing a point feature. This tool will not be use for this project

 *Capture Note* is use to write comments at a specific location. This tool does not have to be used for this application.

 *Feature Editor* can change the comments that are made when collecting data for a specific feature. This tool is not used for this project.

Waypoint Manager. This advanced tool is very useful to create, edit, and delete points that aid in navigation. It will be explained in detai,l in a later section. It can be found in the command line **Data, Waypoint Manager**.

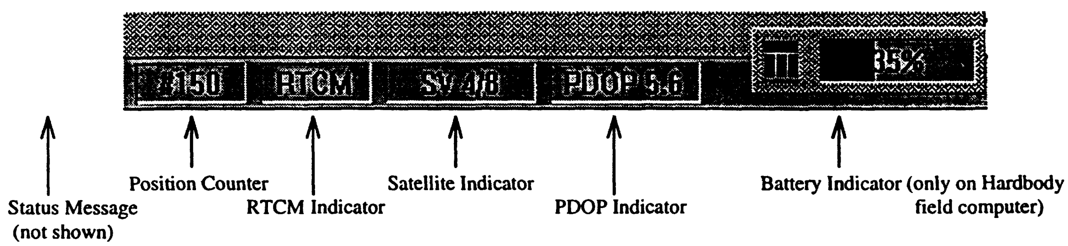
This is the *Pause* button, very similar to the pause button on a tape deck or CD player. It will stop the collection of the GPS information when clicked. One may use it during a break in operations, when a full shut-off is not needed. Pause can be accessed in the command line under **GPS, Pause**.

This button will *Resume* the GPS data collection. It is similar to the play button on audio equipment. Note, ***do not forget to resume data collection when harvesting commences***. Resume can also be accessed in the command line under **GPS, Resume**. The two tools, Pause and Resume act as a toggle switch, and hence, only one can be on at a time.

The *Keyboard* will call up a small representation of a typical computer keyboard. One can access the keys by pointing with the touch screen pen. The keyboard is useful when one needs to type in specific names of files and attributes. Although the electronic pen has hand writing recognition, the pen interface can be very awkward, especially in a moving vehicle.

The Status Bar

The status bar is used to display information on the current status of the GPS receiver. There are five different areas within the status bar. There is also a battery indicator which reports percentage of power remaining within the internal battery power.



The first area, *Status Message*, is to the left of the screen (not shown above). General messages and warnings will be displayed here, like "Logging Paused", "RTCM link lost", and "Too few satellites". If no messages are being displayed, all is well.

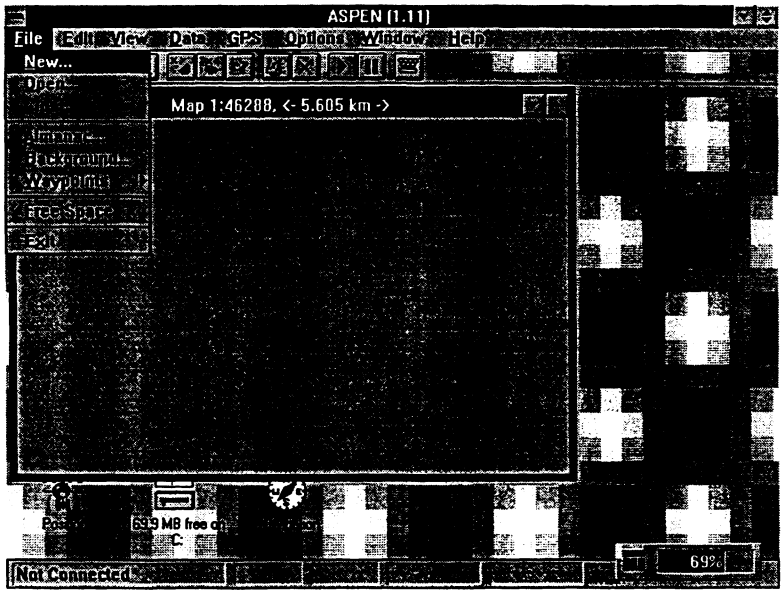
The *Position Counter* shows the number of GPS positions that have been logged for the current feature.

The *RTCM Indicator* shows the current state of the Real-time Differential link. The RTCM link is required to attain metre accuracy, with out it, the typical accuracy will be 15m to 100m. When the link is active RTCM will be displayed, when it is lost, a message will appear in the Status Message area.

The *Satellite Indicator* shows how many satellites that the GPS receiver is using to calculate a position, followed by the number of satellites that are being tracked. In other words the number of satellites being used, over the total available. The top number will change as satellites are blocked out. A minimum of 4 satellites are required for this application.

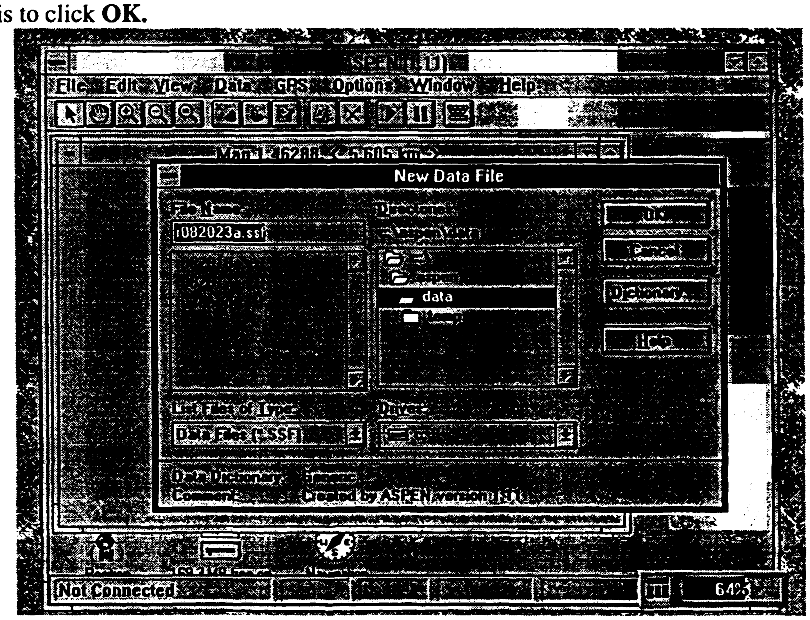
The *PDOP Indicator* shows the current Positional Dilution of Precision. PDOP is simply an indicator of position accuracy. The lower the number, the better the accuracy. No values higher than 8 will be used. If PDOP is too high, no GPS information will be stored and a message will appear "PDOP too high".

Once the computer has powered up, one must start a session (or the start of a shift rotation) by opening a file. Drag the pen over to **File** and a sub-menu will appear. Click on **New** or **Open**. **Open**, accesses an existing file that may have been used by the previous shift or may have cut block boundary information.



When starting a new cut block or a specific area within a cut block a new file should be started. If one is working within an active cut block, the file from the previous shift should be opened. The procedure for starting a **New** file and **Open**ing an exist file are given below.

To start a new file point to the **New** command. A dialogue box will appear. The name of the new file defaults to a standard naming convention. The date and time (Universal Time not Local Time) are coded into the file name, example **r082316a.ssf**. It is recommended that the standard naming convention be used. The location of the file is shown in the *Directories* box. The files are stored in the directory path c:\apsen\data. All the defaults will be used to open a new file, thus the only response required in the new file dialogue box is to click **OK.**



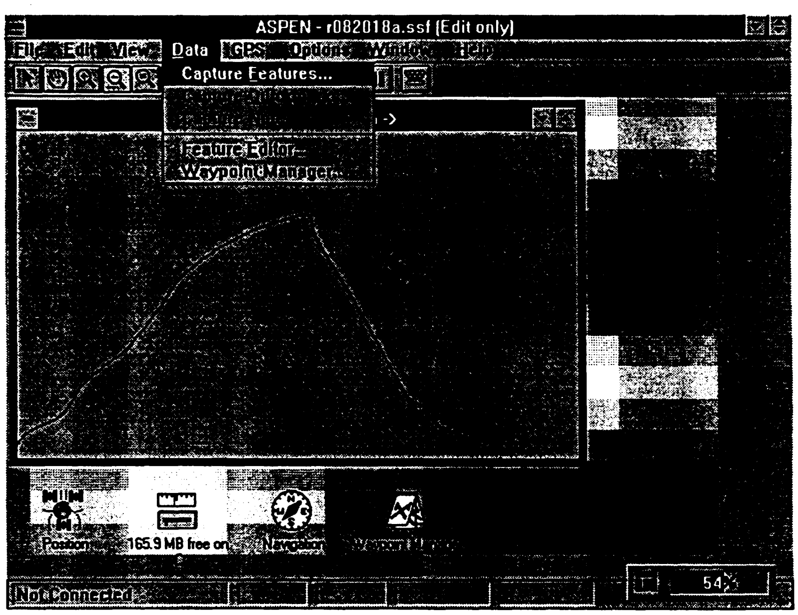
To open an existing file select **File, Open**. A dialog box very similar to the above will be displayed. Please ensure that the Edit/Append button is selected by clicking button . Following that, simply click on the desired file name. Select the most resent file or check with the previous operator to ensure that the right file has been selected. Click **OK** when you are done.

Map Display

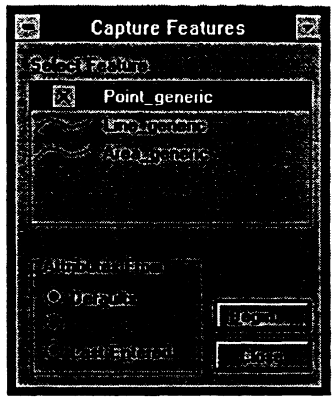
Once a file is active a map view will be created and the GPS system will start to collect data. To view the new positions use a *Zoom Extents* and look for the new positions on the map. The new positions will be a group of points in one of the four corners of the map display. *Zoom In* several times to display the map at a desired scale. A good display scale is between 500m and 100m. Once a desired scale is set, one can set the *Auto Pan to Here* switch which will automatically pan to display the current GPS position within the map widow. The switch is found under **View, Scale, Map....** Click the button beside the *Auto Pan to Here,* then click **OK**. If one uses *Zoom* or *Pan* the *Auto Pan* switch will be turned off.

Data Collection

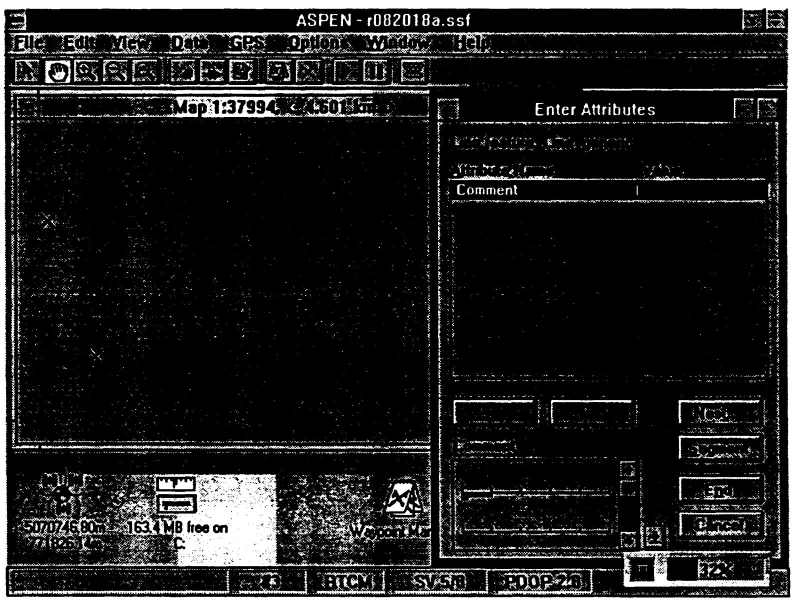
The Aspen Pro system is designed to collect geographic information. There are some basic features that are associated to most geographic information. These basic features are points, lines, and areas. For the harvester application line data will be collected. The line data represents the vehicle track through the harvest cut block. To collect line data one must use the Capture Feature Tool . This tool can also be accessed from the command line **Data, Capture Features.**



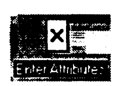
Once selected, the Capture Feature tool opens up a dialog box that allows one to select the type of feature to be captured. Here, the generic line feature can be selected by clicking on it. To start data collection, click **Begin.**



The line will start to appear in the map view. Use the *Zoom* and *Pan* tools to view the new line clearly. Another dialog box opens to allow a comment to be entered (*Enter Attributes* box). Although it is not necessary to key in a comment, one may, by using the pen or call up the keyboard entry tool to enter a description of the line. This description may be the operator name, stand ID, or any alpha-numeric comment.



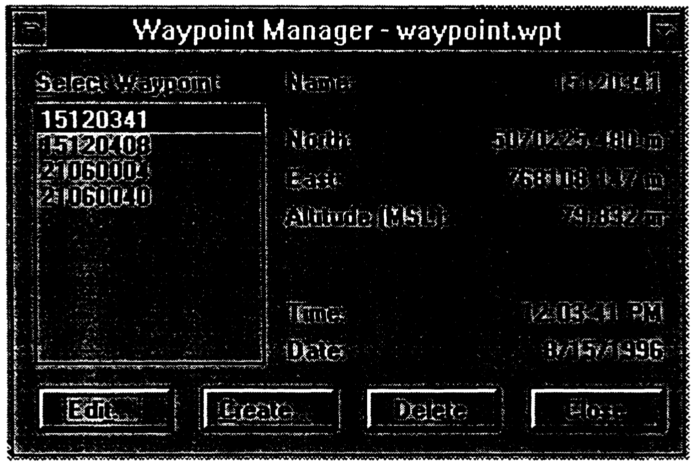
The Capture Feature tool constantly collects data throughout the operation. This window may be tucked out of the way by minimizing it. Simply click the down arrow in the top right corner of this dialog box and the window will shrink down into a small icon.



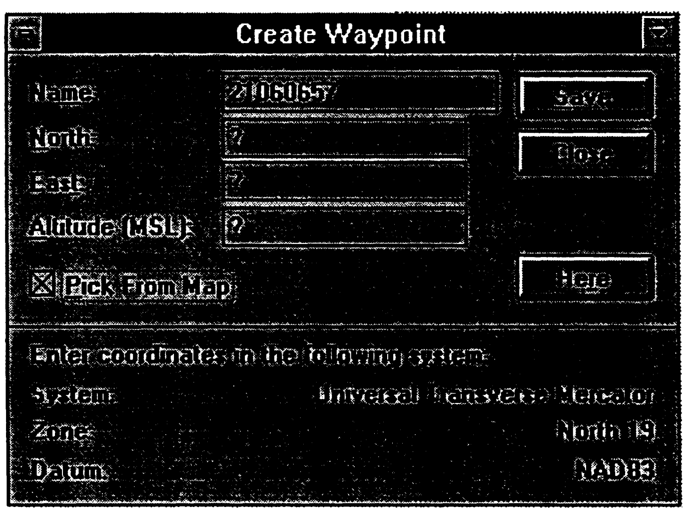
At the end of a session, the *Enter Attribute* icon may be activated by double clicking the above icon. To close the feature click on the **End** button. The new line will change from a highlighted dark line to a lighter shade. A new line may be created by following the same procedure.

Navigation Tools

The Aspen Pro system can guide the vehicle to a set of positions called waypoints. The waypoints can represent the beginning and ending of lines in a specific harvest pattern. The *Waypoint Manager* is used to create, edit or delete waypoints in the current waypoint file. Older waypoint files may be loaded into the system through **File, Waypoints.** To create new navigation data use the Waypoint Manager Tool or select **Data, Waypoint Manager** from the command line. The following dialog box will appear.



The right-hand side of the dialog displays information about the currently selected waypoint. The left-hand side contains waypoint ID numbers from the currently selected waypoint file. Press to create a new waypoint. The Create Waypoint dialog appears.

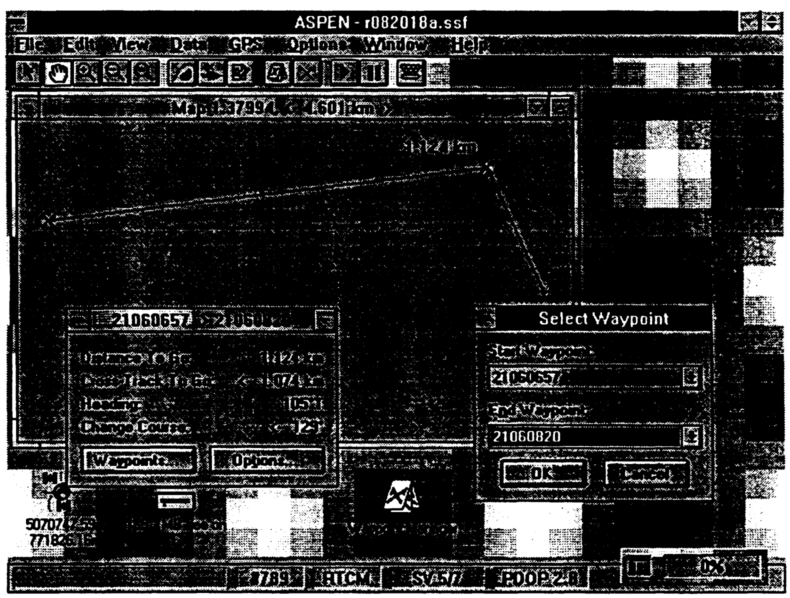


The Aspen software provides a default naming convention. It is based upon the current date and time. Use the default names for quick data entry or overwrite the name. To enter the current harvester coordinates press . One may also point to the map display to enter a waypoint by using the *Pick From Map* check box. When you click on the map, cross hairs appear and the coordinates will be entered into the data fields of the above dialog box. Press save to store the current position from the map. You can minimize the *Waypoint Manager* as an icon by pressing the down arrow in the upper right corner of the dialog box.

By using the Waypoint Manager, a group of points may be created to represent the navigation pattern within the cut block. A set of waypoints represent the beginning and ending of a cut trial. The cutting pattern maybe laid out on the display screen with inside the designated cut block. It will be difficult to lay-out a cutting pattern that is adjacent to a river or other boundary that is irregular in shape. The cutting trail that is displayed on screen will indicate the current cutting pattern, from this, the operator will have to estimate the location of next cutting trail. The geographical display of the map will assist in this type of layout (unassisted navigation).

The following figure shows the Waypoint Navigation. The start and end waypoints of a line are selected from the group of previously created waypoints through the command **GPS, Navigation**. The open window is displayed below. By clicking Waypoints..., the specific start and end points maybe selected (displayed by the window on the right side of the screen). Simply click the appropriate pair of points from the list, or from the map screen directly.

The Options... button is useful to display various navigation information. To display a navigation parameter simply check the appropriate box. Useful parameters are Distance To Go, Bearing To Go, Cross-Track To Go and Change Course. The Auto Zoom check box will automatically perform zoom commands to zoom in, or out, as the vehicle moves towards, or away from the way point that one is navigating to.

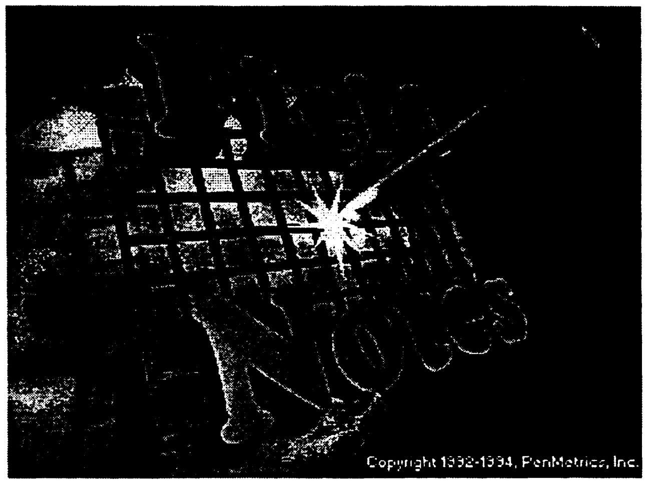


Conclusion

This concludes the initial training manual. Remember that there is "on-line" help available by simply clicking Help, use it. Be patient, a working understanding of this technology will take time. The operator will require a learning period to get acquainted with the software.

If you need technical support call Mike Wolfe (506) 457-4144 (home) 432-2900 (FMF), 453-4961(UNB) or the Trimble Technical Support Line 1-800-SOS-4TAC (767-4822)

FieldNotes™ Training Manual for Selective Cut Navigation



by

Mike Wolfe
UNB Forestry and Environmental Management

in Co-operation with

Weldwood of Canada Ltd.
and
The National Centres for Excellence:
Sustainable Development in Forestry

FieldNotes™ Field Procedures for Harvest Navigation

The following document will explain the procedures needed to operate the PenMetrics FieldNotes mobile mapping specifically for the mechanized harvester environment. The procedures will be a step-by-step account and will only apply to this specific application. Where at all possible, the actual icons will be graphically displayed to allow quick visual recognition of specific operations. For a more detailed explanation of FieldNotes software, a very good on-line help can be accessed by clicking on Help.

This document is the second of two Procedural Manuals prepared for the Harvest Navigation Project. It follows the same format as the other manual written for Springhill field trials in New Brunswick.

Hardware Configuration

The hardware consists of four major components: the receivers, the power hook-ups, the antennas, and the field computer. All components are easily distinguishable and hence only brief description will be made.

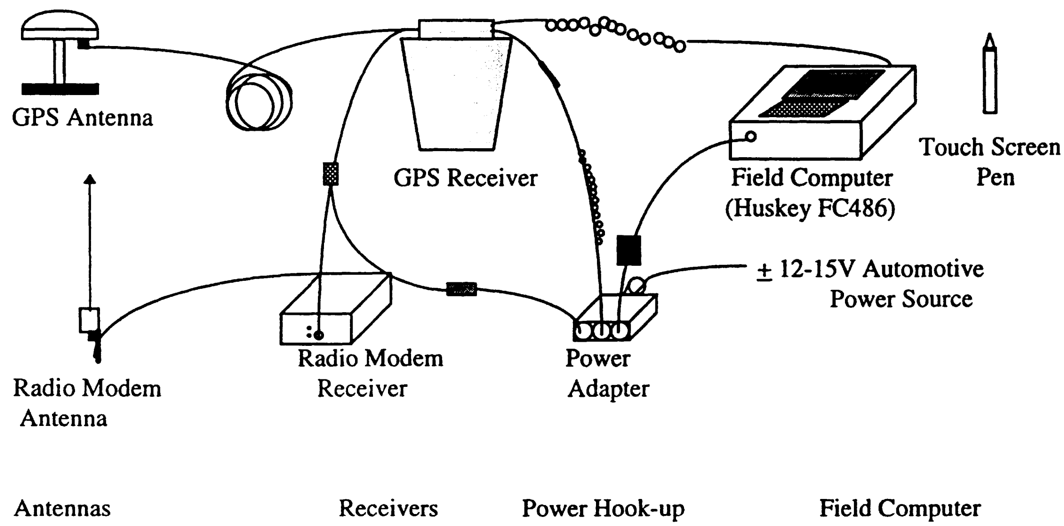


Figure 1.0 Navigation System Hardware

Receivers
The receivers consist of two "black boxes". The Trimble 8 channel GPS receiver is a black box and is housed in a yellow pack. There are four cables to attach to other components. The coaxial cable, which can be identified by having a single screw pin connector and it is the longest cable, attaches to the compact dome antenna. The power connector is a three pin clip plug which connects to a small coil cable with automotive plug. The long coil cable plugs into the field computer with a 9-pin D-type connector (RS232). The shorter 9-pin D-type connector plugs into the other "black box", which in this case is yellow.

The blue box is a Pacific Crest radio modem. It collects the real-time differential correction signal produced by the local base station, located near to the operational cut block. This box collects information that is needed to increase the accuracy of the GPS signal. With it, the expected accuracy is 1-3m, without it 15-100m. The radio modem has three cables. The red and black cable with the lighter adapter on it is for the power source. The coaxial cable is for the chrome wire antenna. The short 9-pin D-type cable from the GPS receiver plugs into blue cable.

Antennas
The two antennas, mentioned above, are mounted on top of the operator cab. The GPS antenna should be placed in near the centre of the roof of the cab. The coaxial antenna cables may be fed through the rear window of the cab and screwed into the appropriate antenna. The screw connectors are slightly different from each other, thus making it impossible to make a wrong connection.

Field Computer
The field computer for this phase of the development is a Husky FC-486. It is the computing component of Trimble's Apsen Pro XL system. It is not the first choice for the field computer, but because of availability problems with other field computers it is the unit of necessity. It is very rugged, and in being so, it is quite heavy for its size. The pen pointer is a separate unit with its own power source (3 watch batteries). It has a built-in standard key board with screen controls that are accessed with function keys. These keys are located along the top row of the key board and the Function key is located on the bottom left **[FN]**. The controls are accessed by holding down the **FN** key and the appropriate control key (eg F1, F2, etc.) Contrast is manipulated with **F1** and **F2**, sound with **F3** and **F4**, and the back light with **F5** and **F6**. The power key [**Pwr**]can be used at any time during the operation of the system to turn the computer no or off.

The GPS data is fed through an RS232 9-pin cable located at the top-right of the computer. The power cable is fed through the bottom left port.

Power Adapter
The power connector is simply a three outlet automotive adapter which plugs into the cabs power source. The three power cables from the computer, the GPS receiver, and the Radio Modem plug into the 3-way adapter.

Additional Notes:
Please ensure all cables are tightly fastened and any excess cable is neatly coiled away
Contrast controls on the field computer will remarkably change the clarity of the display.
Please treat the equipment with the utmost care. It is sensitive and we don't own it.

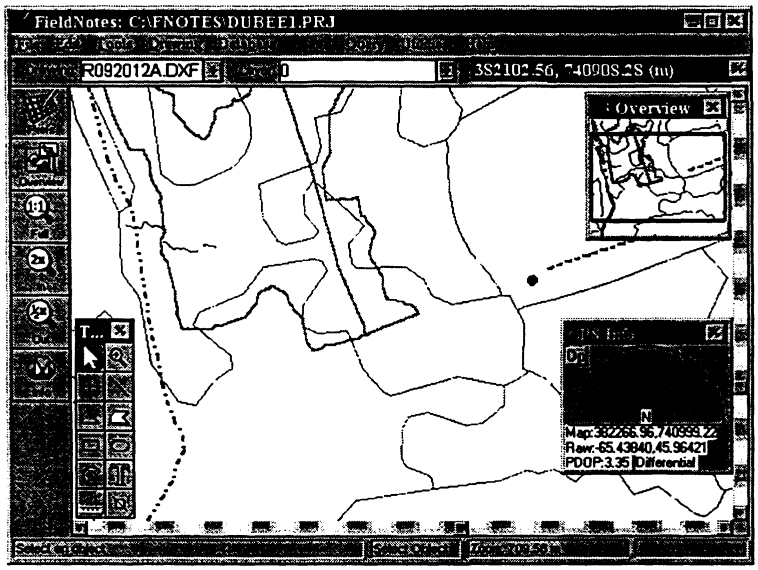
The Software: FieldNotes™

FieldNotes is intended to create maps in the field where the geographical information is located. In this specific application, the added spatial tool of GPS will aid in the navigational requirement of the harvester. A background map with several layers of information (roads, streams, forests, cut block boundary, contours, etc.) will also be displayed. Similar to the Aspen software, viewing tools are provided (zoom-in, zoom-extents). Drawing tools will allow the operator to simply draw a proposed harvest trail pattern over the existing cut block. Distance or area information is displayed on the bottom right, in a status bar. Any one of the icon tools can be switched on or off for display, as they are needed by the operator. Hence only the tools that are needed for this specific application are displayed. Consultation with the operators will assure that the essential tools are made available through the icons.

The GPS controls are also imbedded in the software. They have been developed by GEOsurv Ltd. of Ottawa. Once the proper GPS settings have been selected, the GPS processing runs in the background or maybe graphically displayed to confirm GPS satellite reception . A log of the GPS data should be created for each operator shift for analysis by the researcher. A fully customizable coordinate transformation routine looks after the datum and map projection parameters. The coordinate transformations ensures that the GPS positioned floating dot (which represents the harvester location) overlays with the digital map display in the right geographical location.

Start Up

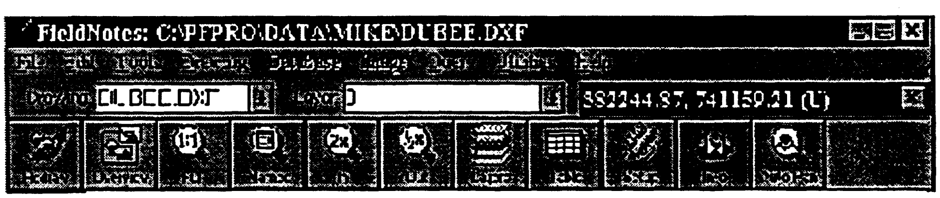
To start up the system simply press the power button on the back of the field computer. The FieldNotes software has been configured to start-up shortly after the power has been turned on. The initial panel will be similar to the one shown in the following diagram.



The Command Line

The FieldNotes software has a typical Windows *graphical user interface* (GUI or gooy). One can start a command by clicking on the *Command Line* such as **File** or by clicking on a graphic (also referred to as an icon). Commands can also be accessed from a keyboard by holding down the ALT-key and entering the underscored letter (e.g. ATL-F = **File**). No keyboard will be used in this application. Before the specific procedures are explained, a description of the GUIs will follow.

Below is a close-up view of the command line and the command icons. Here the icons are displayed horizontally, but typically they will be displayed vertically along the left side of the display screen.



The Tool Bar

The Tool bar has a group of icons that perform useful tasks. They may be switched on or off under the *Command Line* **Edit, Preferences....** Following that clicking on the **Icon Bar** button, and then click on the appropriate box to display the icon under the tool bar. The following tools have been selected and are explained below.

 The *Preferences* icon starts up a window which allows operator to customize the functionality of the system. All the controls can be set within the *Preference* window. Icons can be turned on or off. Pen settings, measurement units, drawing controls, and other settings can all be set from this window. Most settings will be pre-set but the operator may ant to access this window for further customization. It was previously accessed under the *Command Line* **Edit, Preferences....**

 *Redraw*. The program first starts up with the arrow icon. It is simply a pointer that opens the command line or the other icons when the pointer is clicked on the specific item. Redraw maybe accessed after the harvest trail design as to clean up some of the layout lines.

 The magnify glass with **2x In** is used to *Zoom-In* to the map display at twice the scale. This tool is recommended to zoom-in to specific trails or boundary lines.

 *Zoom-out* is shown here as magnify glass with **1/2x Out** designation. It works in a similar manner to the zoom-in icon except it displays a larger scale or smaller image.

*Zoom-extents* will display all of the map information and GPS data. The extents of all data will be displayed. This may be used to show all the roadway information if it has been loaded into the computer.

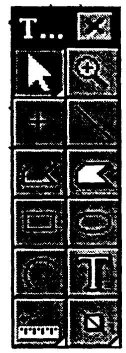
Another Zoom function can be accessed from a floating tool window. It is represented by a magnify glass. When it is selected and dragged over a specific area on the map, a dashed line box will appear. The area outlined by the box will be enlarged. This tool and others in the floating tool window will be explained a little later.

This is the GPS **Info**rmation button. It toggles the GPS information window which displays various GPS parameters such as PDOP, Differential Mode, Map and GPS coordinates. The parameters can be turned on or off by pressing the Option button **[Op]** and selecting the desired options from a menu. The GPS Information window has a graphical display to illustrated the location of the satellites in the sky. The Trimble GPS data format does not support this type of display and hence there are no satellites flying around the graphical display. When the positioning system is configured properly there will be no need to access this window except for curiosity and research purposes. The GPS Information window can be turned off be pressing the **Info** button once again. See the ***GPS Setup*** section to learn how to configure the GPS Info window.

 The *Overview* button toggles a window display that shows the extents of the last zoomed map. This means that only the icon bar zoom controls will change the overview map and the full display map. If one uses the magnify glass in the floating tool bar to zoom-in, the overview window will show a small box around the view that is displayed in the full display map. The Overview may be turned off by touching the *Overview* button again. The map displays will take some time to redraw, especially when there is a lot of line work in the maps.

The Floating Tool Bar

The *Floating Tool Bar* is used to manipulate the active map. There are fourteen different icons within the tool bar. Only a few tools will be use to aid the harvest navigation system. Those highlighted with an asterisks* will be use.



* Select		Tool Magnify Tool *
Create		Point Draw Line Tool *
* Polyline or Continuous		Line Polygon or Area Tool
Create		Rectangle Create Circle
Create		Arc Add Text *
* Measure Distance		Tool Create a Record

Two other tools that are exclusive to a pen based computer are the Draw Ink and Draw Shapes. They will not be used in the harvest navigation system and hence will not be exlaimed any further.

The *Magnify Tool* can be used to zoom into any area on the map display. Simply click on the magnify tool, and with the pen, draw a line around the specific area to enlarge. The area highlighted will zoom to the full map display. To zoom-out use the **½ x Out** Icon or the **1:1 Full** icon.

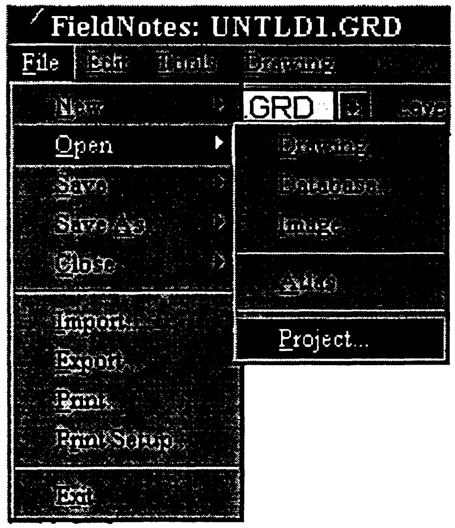
Draw Line and *Draw Polyline* Tools can be use to draw a harvest trail pattern on the map display. Zoom into a workable scale that is large enough to draw the harvest pattern. The closer one zooms, the more accurate will be the layout of the harvest pattern. Click on the screen to start a line, then drag to the location of the end of the line. In the case of a polyline, one has to double click, to stop drawing. The length of the line will be displayed on the status bar that is located at the very bottom of the display. The total length and the individual segment length is reported for a polyline.

Use the *Measure Distance Tool* to layout some desired offsets to the block boundary as guide line for the harvest trail pattern. Select the Measure Distance Tool then click on the block boundary then drag a desired distance and lift the pen off of the screen. The distance is indicated in the status bar at the bottom of the display.

The *Text Tool* may used to type instructions to fellow operators. The text may be used to type the prescription instruction for specific areas within the cut block. That is the post harvest density and targeted tree species.

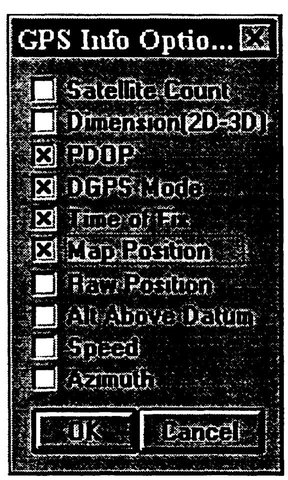
The *Select Tool* can be use to modify the drawing. One can copy, delete, move and edit any object on the map (unless it is protected from edits). The tool window automatically defaults to this tool. To use it simply click on the desired object to modify, say a line drawn to represent the harvest trail. The line segments will be highlighted. The entire object maybe moved, as indicated by the *move cursor* (the hand). If the select tool is moved over the end of a line segment it changes to an *adjust cursor* (four-way arrow). The adjust cursor will move just that end point and not the rest of the line segment. If it select tool is used on text, it can be use to edit the text or change the size and position of that text.

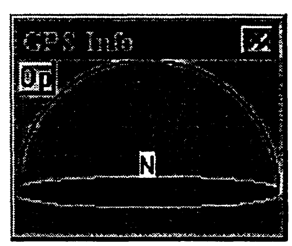
Once the computer has powered up, one must start a session (or start of a shift rotation) by opening a project. Drag the pen over to **File** and a sub-menu will appear. Click on **Open, Project**. This accesses existing files that have been setup for the specific cut block. For the Dubee Settlement Trials open up the **dubeel.prj**. A background map with several layers of information (roads, streams, forests, cut block boundary, contours, etc.) will displayed after a few minutes of processing.



GPS Configuration

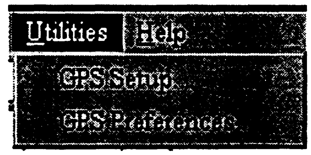
A certain amount of configuration has to be done to assure that the GPS data will be functioning properly. But a certain amount of setup will be required every time the system is turned on. The GPS Info window can be moved to an area that does not obscure the map display. Drag the window to the right hand side of the display. Also, resize the window by clicking on the bottom right corner and dragging the corner to the upper left. This will decrease the size of the window so it does not take-up to much of the map display.



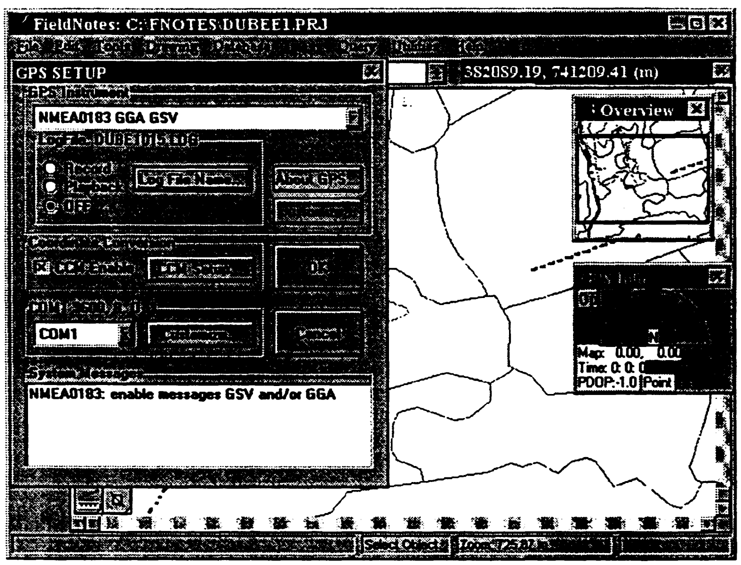


Click on the Option button **[Op]** and select PDOP, DGPS Mode, Time of Fix, and Map Position. Click **OK** to store these settings. This action will display the information in the GPS Info window. Keep an eye on the DGPS Mode indicator. It should display *Differential* to indicate that the real-time differential GPS data is being used from the ProBeacon.

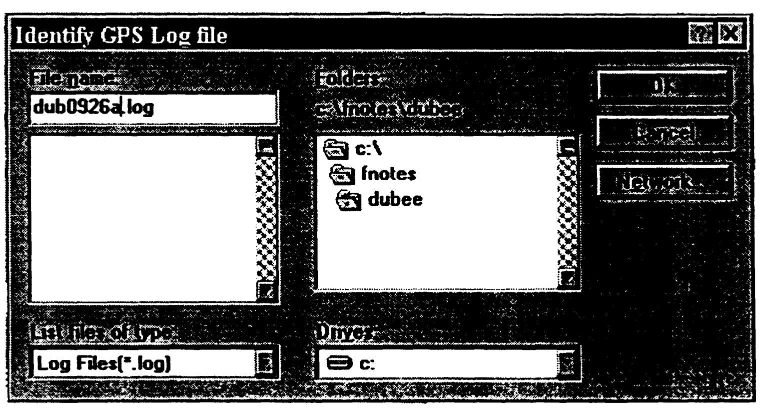
Two commands should be accessed to further configure the GPS information. **GPS Setup** and **GPS Preferences** are found under **Utilities** in the command line.



The **GPS Setup** is used to set the communications between the GPS receiver and the FieldNotes software. Most settings have been worked out in the research phase. But a file should be created for every shift.

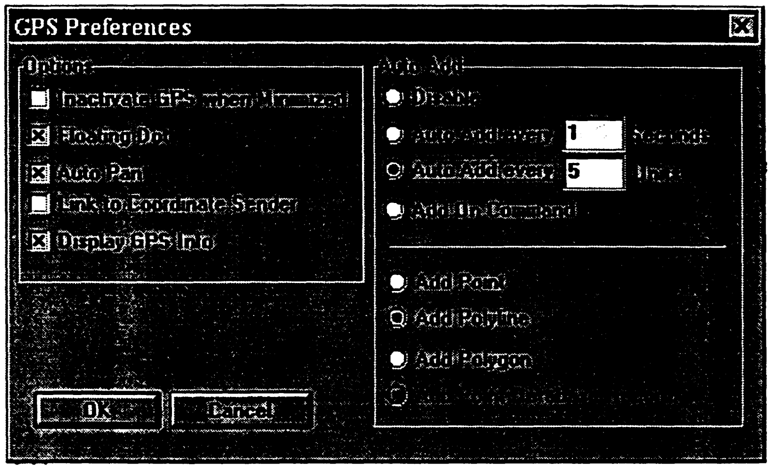


- **Note**: *Start a new GPS log file for every working shift.* This is done by clicking on the *Log File Name* button and creating a new name for that particular shift. The naming convention will most likely be **Dube1016a.log.** The naming structure represents the site: **Dube**, the month: **10**, the day: **16**, and the shift rotation: **a** (first shift, b,c.... for subsequent shifts in one day). Make sure it is in the proper working dirctory by clicking on dubee working directory. Click **OK** when done.



GPS Preferences

The GPS Preferences are set to ensure that the GPS positions are displayed on the map. The following image shows which switches should be set.

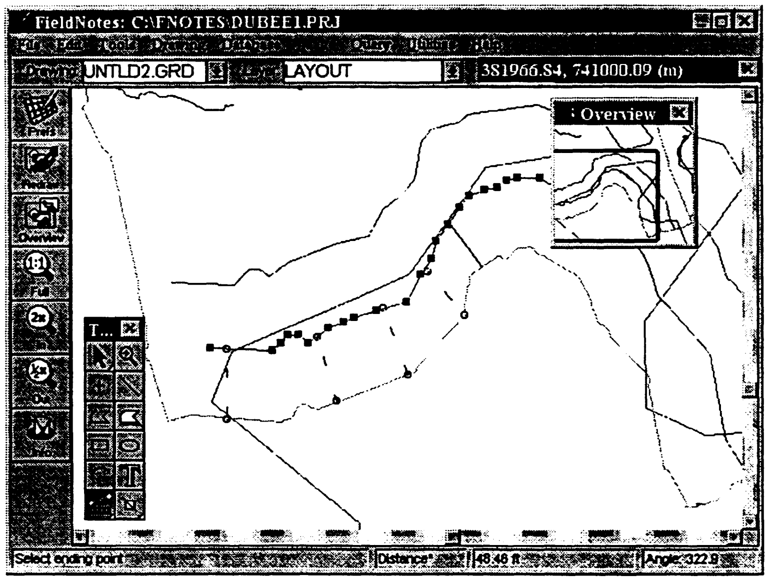


The *Floating Dot* will represent the GPS position as a black dot. The *Auto Pan* will re-centre map with the dot in the middle of the map display just prior to the dot leaving the screen at an edge. The *Display GPS Info* is the sme as the **GPS Info** icon that has been explained earlier.

The *Auto Add* section will store a point, line, or polygon at GPS position at a specified interval. Here a line will be stored and updated when the GPS position has moved more than 5 units (metres). This will ensure that the line is filtered to represent a movement in the harvester and not just a new GPS position that is within the predicted measurement error of 2-3 metres.

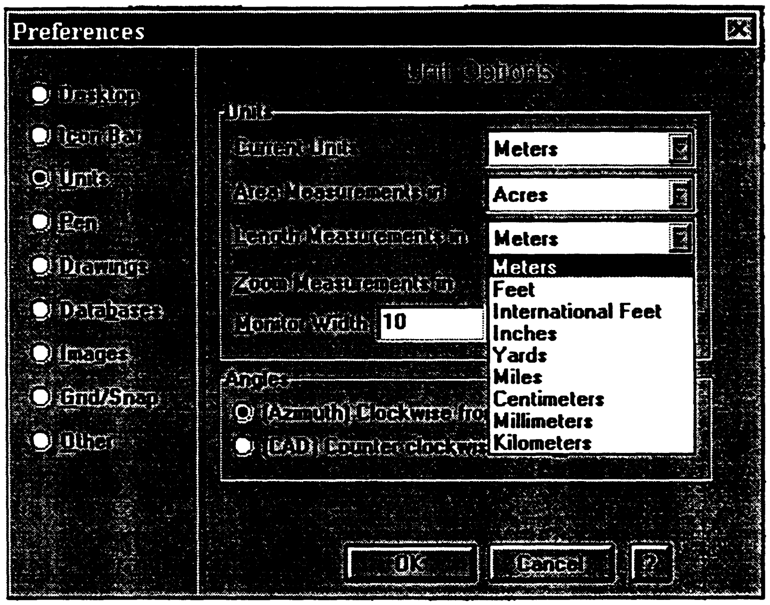
Harvest Trail Layout
Various tools will have to be used to layout the harvest pattern. It will take some practice to get use to the sensitivity of the drawing tools to layout an accurate harvest pattern.

The *Measure Distance Tool*, the *Draw Polyline Tool* and *Select Tool* will be of most use. Use the *Measure Distance Tool* to create several set-out distances, of say 60 feet, from a cut boundary to use as guidelines for the next trail layout. Create a new trail by tracing the existing block boundary with a *polyline*. Then *select* it and move the entire line by dragging it to the endpoints of the set-out line that were created with the *Distance Tool.* Refer to the following diagram. The *Select Tool* can also be use to move individual points or nodes on the line in the Adjust Mode. This is useful to smooth out lines and modify the layout trial round curves.



Units

To change the measurement units that are displayed in the status bar one needs to click on the **Preference** icon. Then click on the Units buttom. This will bring up a window where on can change the units various display parameters. Click on the down arrow in the *Length Measurements* parameter to display the various measurement units options. One would most likely choose metres to layout stream buffers and feet to layout the harvest trail offsets.



Conclusion

This concludes the initial training manual. Remember that there is "on-line" help available by simply clicking Help, use it. Be patient, a working understanding of this technology will take time. The operator will require a learning period to get acquainted with the software.

If you need technical support call Mike Wolfe (506) 457-4144 (home), 453-4961(UNB)
or the Trimble Technical Support Line 1-800-SOS-4TAC (767-4822)

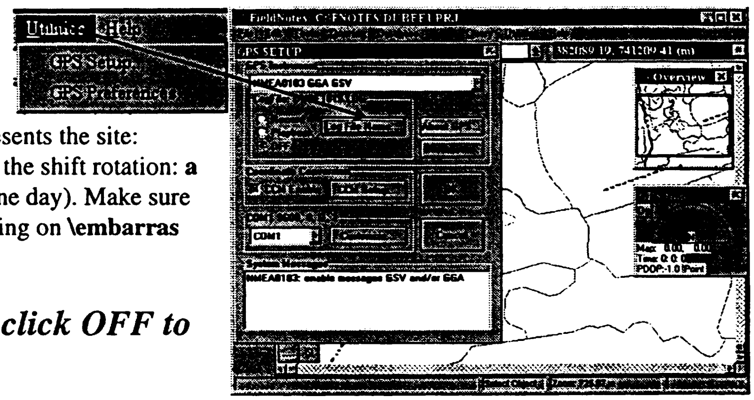
Note: Your comments and feedback are welcome.

GPS OPERATIONS QUICK CHECK

- *Hardware* - check that all cables are hooked up properly and securely- plug in radio link
  - power indicator should be on the cigarette lighter adapter
  - red power light should be on field computer before powering up, if not check cable
  - red light should be on radio receiver and green light flashing, if not *check batteries.*

- Note: ***Start a new GPS log file for every working shift.***

1.........



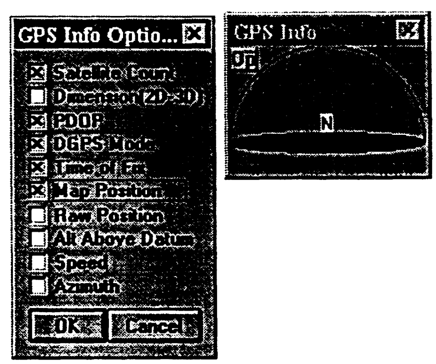
This is done by clicking on the *Log File Name* button and creating a new name for that particular shift. The naming convention will most likely be **Emb1121a.log.** The naming structure represents the site: **Embarras**, the month: **11**, the day: **21**, and the shift rotation: **a** (first shift, b,c.... for subsequent shifts in one day). Make sure it is in the proper working dirctory by clicking on **\embarras** working directory. Click **OK** when done.

- Note: ***At the End of the shift click OFF to close the GPS log file.***

2.........

GPS Configuration

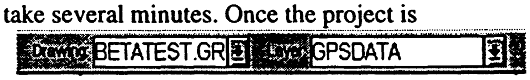
A certain amount of configuration has to be done to assure that the GPS data will be functioning properly. The **GPS Info** window can be moved to an area that does not obscure the map display. Drag the window to the right hand side of the display. Also, resize the window by clicking on the bottom right corner and dragging the corner to the upper left. This will decrease the size of the window so it does not take-up to much of the map display. In the same GPS Info window the **Op** button should be pushed to select desired GPS display options. Check the following options: *Satellite Count, PDOP, DGPS Mode, Time of Fix, and Map Position.* Click OK to complete. During normal operation the GPS Info will graphically display the location of Satellites very 10 seconds as indicated by white triangles. During this display the selected options will also read out. Please observe that **Differential** is indicated, if not, batteries may be low in the radio link system or GPS base station.



3.........

Open Project

Under *File, Open, Project* select the embarras.prj under the working directory *C:\Fnotes\embarras* and then click OK. The maps for the working block will open. This will take several minutes. Once the project is open, ensure that the BETATEST drawing is active and the GPSDATA layer or LAYOUT layer is also acitve.



4.........

Save Project Use *File, Save, All* during the course of the day to ensure the screen information is saved. Also at the end of the shift *Save, All.*

Appendix V

Equipment Costs

System Costs

Note that are prices only approximate. Some price quotations are based upon the value of the Canadian Dollar against the U.S. dollar and are subject to change. No taxes have been applied to the prices.

DGPS Hardware		
Aspen Pro System 8 Channel		$11 130.00
DSM -Reference Station		$11 900.00
DSMPro 8 Channel		$ 6 930.00
ProBeacon (Coast Guard DGPS receiver)		$ 2 730.00
DSM 8 Channel		$ 8 890.00
Pacific Crest Radio System (base, repeater, receiver)		$10 000.00
GPS/GIS Software		
ESRI's MapObjects		$ 4 200.00
Aspen Field Software Kit		$ 3 500.00
FieldNotes by PenMetrics		$ 1 727.00
+ GPS module		$ 927.00
Field Computers		
TDC1 Field Computer		$ 9 730.00
Texas Micro Hardbody		$ 5 565.00
MicroSlate 400L20		$ 5 000.00
Evaluation Prototype		
Trimble Aspen GIS/GPS Mapping Software		$ 3 500.00
Trimble 8 Channel Pro XL GPS Receiver		$ 6 930.00
Trimble ProBeacon RTCM-104 Receiver		$ 2 730.00
Texas Micro Hardbody Field Computer		$ 5 565.00
	Total	$18 725.00
New Brunswick Operational Prototype		
FieldNotes for Pens		$ 1 727.00
Trimble 8 Channel Pro XL GPS Receiver		$ 6 930.00
Trimble ProBeacon RTCM-104 Receiver		$ 2 730.00
Huskey FC486 Field Computer		$ 9 730.00
	Total	$21 117.00
Alberta Operational Prototype		
FieldNotes for Pens		$ 1 727.00
Trimble 8 Channel DSM Rover		$ 8 890.00
Trimble 12 Channel DSM Base		$11 900.00
Pacific Crest 15 watt Radio Link		$10 000.00
MicroSlate 400L20 Field Computer		$ 5 000.00
	Total	$37 517.00

An additional $200 is estimated miscellaneous equipment such as the power adapter, an automotive 12Volt battery charger and mounting apparatus. The dome antenna protector is estimated at $1200.

Appendix VI

Productivity Rates

Productivity: Tree Count
Site: Dubee Settlement

Shift:1A Date: 10/28/1996
Operator: (1)

Time	Count	Total	Adjusted Count/Hour
10:20 AM	1248		
		56	84
11:00 AM	1304		
		71	71
12:00 PM	1375		
		68	82
1:00 PM	1443		
		81	88
2:00 PM	1524		
		48	58
3:00 PM	1572		
	Average	65	77

Shift:1B Date: 10/28/1996
Operator: (3)

Time	Count	Total	Adjusted Count/Hour
8:00 PM	1572		
		70	76
9:00 PM	1642		
		72	79
10:00 PM	1714		
		65	78
11:00 PM	1779		
		27	65
11:35 PM	1806		
	Average	59	74

Shift:2A Date: 10/29/1996
Operator: (1)

Time	Count	Total	Adjusted Count/Hour
7:25 AM	1806		
		45	77
8:00 AM	1851		
		73	73
9:00 AM	1924		
		73	80
10:10 PM	1997		
		52	78
11:00 PM	2049		
		24	72
11:30 PM	2073		
	Average	53	76

Shift:3A Date: 10/30/1996
Operator: (3)

Time	Count	Total	Adjusted Count/Hour
9:30 AM	2073		
		50	60
10:20 AM	2123		
		41	70
11:00 AM	2164		
		64	77
12:00 PM	2228		
		39	52
12:45 PM	2267		
	Average	49	65

Shift:3B Date: 10/30/1996
Operator: (1)

Time	Count	Total	Adjusted Count/Hour
1:10 PM	2267		
		68	82
2:00 PM	2335		
		74	74
3:00 PM	2409		
		55	94
3:35 PM	2464		
	Average	66	83

Shift:3C Date: 10/30/1996
Operator: (3)

Time	Count	Total	Adjusted Count/Hour
10:30 PM	2745		
		64	51
11:45 PM	2809		
		52	57
12:45 AM	2861		
		39	52
1:45 AM	2900		
		67	57
2:55 AM	2967		
		44	53
3:55 AM	3011		
		35	60
4:30 AM	3046		
	Average	50	55

Shift:4A Date: 10/31/1996
Operator: (1)

Time	Count	Total	Adjusted Count/Hour
6:50 AM	0		
		54	81
8:00 AM	54		
		39	78
9:15 AM	93		
		42	84
10:00 AM	135		
		59	71
11:00 AM	194		
		59	71
12:00 PM	253		
		73	88
1:00 PM	326		
		71	85
2:00 PM	397		
		92	92
3:00 PM	489		
		53	80
4:00 PM	542		
		8	69
4:10 PM	550		
	Average	55	80

Shift:4B Date: 10/31/1996
Operator: (3)

Time	Count	Total	Adjusted Count/Hour
10:00 PM	550		
		43	65
11:25 PM	593		
	Average	43	65

Shift:5A Date: 11/1/1996
Operator: (1)

Time	Count	Total	Adjusted Count/Hour
8:20 AM	593		
		110	102
9:25 AM	703		
		61	81
10:10 AM	764		
		26	78
11:00 AM	790		
		92	85
12:05 PM	882		
		32	77
1:00 PM	914		
		95	95
2:05 PM	1009		
		64	70
3:00 PM	1073		
		86	79
4:05 PM	1159		
	Average	71	83

Shift:5B Date: 11/1/1996
Operator: (3)

Time	Count	Total	Adjusted Count/Hour
9:00 PM	1159		
		45	68
10:00 PM	1204		
		73	73
11:00 PM	1277		
		31	62
12:00 AM	1308		
		73	73
2:45 PM	1381		
	Average	56	69

Grouped Statistics for Time Adjusted Productivity

Test Block

	Average	Std.	High	Low
Operator (1)	82	8.9	102	69
Operator (3)	67	5	73	62
Day Shift	82	8.9	102	69
Night Shift	67	5	73	62

Control Block

	Average	Std.	High	Low
Operator (1)	79	9	94	58
Operator (3)	65	11	79	51
Day Shift	75	11	94	58
Night Shift	65	11	79	51

Productivity: Tree Count
Site: Embarras 3 Block 184 (Hinton)

Shift:1 Date: 11/21/1996
Operator: (1)

Time	Count	Total	Adjusted Stems/Hour
1:00 PM	856		
		94	94
2:00 PM	950		
		117	117
3:00 PM	1067		
		106	106
4:00 PM	1173		
		55	55
5:00 PM	1228		
	Average	93	93

Shift:2 Date: 11/22/1996
Operator: (1)

Time	Count	Total	Adjusted Stems/Hour
9:00 AM	1228		
		135	135
10:00 AM	1363		
		74	74
11:00 AM	1437		
		98	98
12:00 PM	1535		
		113	113
1:00 PM	1648		
		109	109
2:00 PM	1757		
		119	89
3:20 PM	1876		
		68	102
4:00 PM	1944		
		128	128
5:00 PM	2072		
	Average	106	106

Shift:3 Date: 11/23/1996
Operator: (1)

Time	Count	Total	Adjusted Count/Hour
1:00 AM	2082		
		138	138
2:00 AM	2220		
		96	96
3:00 AM	2316		
		147	147
4:00 PM	2463		
	Average	127	127

Shift:4 Date: 11/26/1996
Operator: (1)

Time	Count	Total	Adjusted Count/Hour
9:00 AM	2463		
		99	99
10:00 AM	2562		
		160	160
11:00 AM	2722		
		141	141
12:00 PM	2863		
		95	95
1:00 PM	2958		
		149	149
2:00 PM	3107		
		154	130
3:11 PM	3261		
		116	142
4:00 PM	3377		
		147	147
5:00 PM	3524		
	Average	124	124

Shift:5 Date: 11/28/1996
Operator: (1)

Time	Count	Total	Adjusted Count/Hour
9:29 PM	3524		
		81	157
10:00 AM	3605		
		174	174
11:00 AM	3779		
		188	188
12:00 PM	3967		
		136	136
1:00 PM	4103		
BREAK DOWN		63	N/A
3:18 PM	4166		
		138	148
4:14 PM	4304		
		130	159
5:03 AM	4434		
		66	158
5:28 AM	4500		
	Average	145	160

Shift:6 Date: 12/2/1996
Operator: (1)

Time	Count	Total	Adjusted Count/Hour
8:08 AM	7068		
		119	130
9:03 AM	7187		
		146	154
10:00 AM	7333		
		92	162
10:34 AM	7425		
		7	N/A
11:05 AM	7432		
		158	179
11:58 AM	7590		
		170	165
1:00 PM	7760		
		174	174
2:00 PM	7934		
		17	N/A
2:05 PM	7951		
	Average	143	161

Grouped Statistics for Time Adjusted Productivity

Test Block

	Average	Std.	High	Low
Operator (1)	122	25	160	93

Control Block

	Average	Std.	High	Low
Operator (1)	161	17	179	130

Appendix VII

Stand Density Prism Counts

Site: Dubee Settlement Block1

Prism Count: Transcribed from original field sheets

Stand Density

Trees/ha = 2/b x count

Diameter Class (dbh cm)

$b=dbh^2 \times 0.00007854$

Line	Species	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	>	#	Trees/ha
Plot																												
1	SW					1	1	2		2	2		1						1		1	1		1	2		15	1104.19
2	HW				1	3	1	1	1								1	1									9	1614.96
1	SW			1	1		1		1	1		1							1		1						8	1548.32
1	HW					1	3	1		2			1														8	1116.48
1	SW						1	3	2	2	3		1	3	2					1							18	1353.54
4	HW						1	1			3																5	497.75
1	SW			1	3			1		1												1					7	2123.97
3	HW			1	1	5	2		2	1			1			1											14	3082.20
10	SW								1																		1	99.47
99	HW							4	2	1		1	2					1						1		52	13	972.32
10	SW									1																	1	78.59
98	HW				2	2		1	1		1	3	1					1	1				1			52	15	1864.42
10	SW		1	1	3			1															1				7	3635.63
97	HW		1			1	3	1	1	1	1		1	2		1					1						14	2912.12
10	SW			1		1								1					1				1				5	1032.47
96	HW				1	1		2	1	1	2	1		1	1		1			1								1383.03
10	SW			2	2			1	1	1			1	1	1			2									12	2676.89
95	HW			3		2		3	2							1											11	3248.36
10	SW						3	1	1	2			2														9	1005.52
94	HW						1	1	2		1																5	569.37
10	SW				1	4	1				2	1	2	1		1	2										15	1977.37
93	HW					1					2	1		1													5	472.25
2	SW							1		1			1	1				2	1		1						8	370.02
8	HW		1	1	1	1			1	2									1					1			9	3239.78
3	SW				3	1	1					1		1	1	2	1			1				1			13	1859.03
92	HW					1	1	1	3	1	1		1	1			1	1									12	1130.85
3	SW			2	1		1				1				1												6	2085.57
11	HW			1	2	3	2	3	2																		13	3209.45
3	SW							1			2	1	1	2		3			1	1							12	551.57
93	HW							2			1																3	323.51

[redacted]	[redacted]																										[redacted]	[redacted]
2	SW						2			1					1					1	1		1				7	511.46
7	HW			1	2		2	2	5	3		1							1								17	2922.05
[redacted]	[redacted]																										[redacted]	[redacted]
3	SW				2	1		4	2		2	1	1			1		1									15	2043.52
10	HW						1	1										1	1								4	348.44
[redacted]	[redacted]																										[redacted]	[redacted]
3	SW						1	1	1		1	1				1											6	550.80
9	HW			1	2		2	1	1	1				1				1		1							11	2242.12
[redacted]	[redacted]																										[redacted]	[redacted]
12	SW					1		1	3	2	3		2	1		1											14	1185.54
91	HW					1	1	2		1																	5	769.92
[redacted]	[redacted]																										[redacted]	[redacted]
12	SW					1		1			1	1		1			1				1		1				8	592.45
90	HW				2				1				1		1				1							54	7	1000.32
[redacted]	[redacted]																										[redacted]	[redacted]
12	SW						3	2	1	4	4				1	3											18	1576.22
89	HW					1	2	1	2																		6	937.19
[redacted]	[redacted]																										[redacted]	[redacted]
12	SW										1				2	2		1	1	1							8	244.52
88	HW		1		4		2	3	1	2	1										1						15	4262.77
[redacted]	[redacted]																										[redacted]	[redacted]
12	SW															1		1						2			4	74.39
87	HW			2					1	1		3	2	1		1		1									12	1927.02
[redacted]	[redacted]																										[redacted]	[redacted]
4	SW		1	1		2								1										1			6	2857.90
18	HW				1	1	4	6	3	2	1	1															19	2711.30
[redacted]	[redacted]																										[redacted]	[redacted]
2	SW										1			1				1	2	1			1				7	193.45
80	HW						1	1	1	2	1		1														7	671.29
[redacted]	[redacted]																										[redacted]	[redacted]
2	SW					1	2	1					1				1	1	2				2				11	894.96
79	HW			2	1	3	4	1							1												12	3446.29
[redacted]	[redacted]																										[redacted]	[redacted]
11	SW			1	1									1			1	1		1							6	1207.44
81	HW					1		2		2		1		1			1										8	786.83
[redacted]	[redacted]																										[redacted]	[redacted]
11	SW				2	2	1	1		1			1		1	1	1	2									13	1864.33
83	HW				1			3				1	1		1	1											8	945.25
[redacted]	[redacted]																										[redacted]	[redacted]
11	SW			2		1					1	1					1	1									7	1832.53
84	HW				2	4		2		1	2			1		1											13	2346.09
[redacted]	[redacted]																										[redacted]	[redacted]
11	SW				1	1	2	5	1				1														11	1799.50
85	HW				2	1	2		1				1	1			1		1								10	1629.96
[redacted]	[redacted]																										[redacted]	[redacted]
11	SW	1	1	1	1	2			1				1									1					9	3364.20
86	HW		1	3	1	2	4	2		3	1		1	1													19	5969.31
[redacted]	[redacted]																										[redacted]	[redacted]
11	SW					1			1	1			2	2	1		2	1	1		1		2				15	762.59
82	HW						2	1					1														4	527.81
[redacted]	[redacted]																										[redacted]	[redacted]

13	SW					1				1		2			1		1									6	379.24
78	HW					3			2	1	1	1	2													10	923.53
13	SW												1			1		1	1	1						5	115.74
77	HW			2	2	2	1		1	2		1	1	1	1	2	1									17	2209.00
13	SW		1			2	1	4	1	1	1	1		2	1											15	1921.17
76	HW					2			1		1															4	484.88
12	SW		3	1	2		2		1									1	1			1				12	3418.12
75	HW			1						1	1		2	1	1											7	650.28
5	SW		2				3	3	1	2		2	2	2	1											18	2565.82
19	HW				1	1	1	1		1		1	1													7	806.42
5	SW	1				3	3	4	1		2	2			1						1					18	3224.68
74	HW				1				2																	3	411.84
5	SW			1											1					1						3	442.10
73	HW		1	1		4	2	3		1	2	1			1		1									17	2634.27
14	SW					2		2	1	3		2					3		1			1				15	1007.49
72	HW		2				1			1	1		1							1						7	1714.49
14	SW									1			1		1						1	1				5	157.21
71	HW	1	1		1	3	4	2	4		1	3	1													21	4339.98
14	SW									1				1				1			1	1	1			6	155.41
70	HW						2					1		1			1			1	1				90	8	392.06
14	SW												1			1										2	62.54
69	HW		2		1			2	1	1	4	1	3		1	1			1		1					19	2463.46
14	SW		2	2	3			3	1	5	1															17	3722.35
68	HW		1	3	1	1	2	1				1														10	2736.02
15	SW		1	2		1		3	3	1	1	1		1	1						1		1			17	2461.89
67	HW		1	1							1			1												4	1190.33
15	SW	1								1	2	1			1		1	1				1				9	1887.77
66	HW								1	1	1	1	1			1		1								7	321.27
15	SW								1		2				1	1	1		1							7	276.65
65	HW			1	1	4	2		1	2	1		1			2										15	1965.67
2	SW			1	1	2	3	1		1	1	1		1												12	1688.41
4	HW				2	1	2	1				1		1	1			1								10	1170.08
2	SW								2			1		1	1				1		1					7	294.24
5	HW			1	1		2		2	1				1			1	1		1	1					12	1237.74

2	SW										1			1		1			2	1		1					7	200.99
6	HW				2	1		2	1	1			1	1	1	1	1		1								13	1675.50
3	SW				1		1		2		1	1			1		1										8	947.29
12	HW				2	3		2	2					1	1	3		2			1						17	2233.51
3	SW				2	2	1					1		1	2					1			1				11	1667.94
13	HW					1	1	1	2	1	2		1		2	1	1			1	1						15	1162.15
4	SW				1	1		1	1				1	1							1						7	979.72
14	HW					2			1					1	1	2			1					1			9	767.19
4	SW			1		1			1		1	2		1			1		1	1							10	1330.18
15	HW				2					1			1		1	1			1	1							8	1016.64
4	SW									1			1														2	107.87
16	HW				2	1	3	3	1	3	1		1		2	1	1		1								20	3258.95
5	SW										1																1	63.66
17	HW			1	2		4	3	3		1	2	1			1	1	1									20	3186.95
6	SW						2		2	1	2	1	2				1	2		1							14	986.13
20	HW			2				1		1	1	1			1				1		1						9	1807.54
7	SW									1		2	1		1	1	1	1		1							9	353.34
21	HW				1	1	3	2			2	1		1			1										12	1685.37
	SW	1	5	22	27	25	29	36	35	30	40	17	29	21	17	25	12	20	15	11	8	7	14	7	2			
	HW		5	21	35	42	61	64	41	39	28	23	25	21	8	9	10	10	7	2	4	1	1	2				

Site: Embarras 3 Block 184

Prism Count: Transcribed from original field sheets

Stand Density

Trees/ha = 2/b x count

Diameter Class (cm)

$b = dbh^2 \times 0.00007854$

Line	Species	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	>	#	Trees/ha
Plot																												
1/1	SW			1	3	5	6	8	1	2	1		1														28	5639
	HW																										0	
1/2	SW			2	2	6	9	4	5	3	1	1															33	6699
	HW																										0	
1/3	SW		1	3		3	3	5	7	4				1													27	6706
	HW																										0	
1/4	SW		2	1		1	1		3	1	1			1		1											12	4829
	HW																	1									1	
1/5	SW					1	1	1		6	1	5	1														16	1404
	HW																										0	
2/1	SW									3	2	2	2	3	2	1	1	1		1							18	828
	HW																										0	
2/2	SW								1		4	5	2	5	2			1			1						21	997
	HW																										0	
2/3	SW				1		3	1	9	3	5	2				1											25	2641
	HW																										0	
2/4	SW					2	1	6	8	1	4		1														23	2639
	HW																										0	
2/5	SW						4	4	8	3	5		1														25	2621
	HW																										0	
3/1	SW						1		3	1	2			2		1		1									11	807
	HW																										0	
3/2	SW							2		3	3	5	1	5													19	1182
	HW										1																1	64
3/3	SW							1		1	1	2	2			1											8	494
	HW																										0	
3/4	SW				2	1	2	5	5	4	1																20	2929
	HW																										0	
4/1	SW			1		1		3		1	1	2	4	2	3												18	1949
	HW																										0	

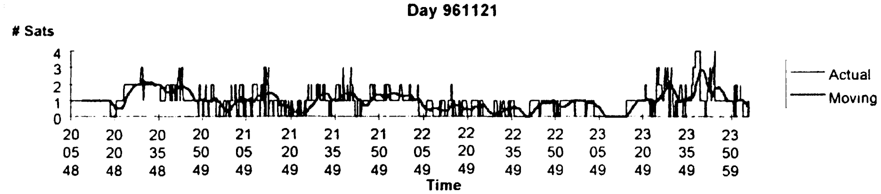
[illegible]	[illegible]																										[illegible]	[illegible]
4/2	SW				1	1		1				1	2	1	2			1									10	1048
	HW																										0	
[illegible]	[illegible]																										[illegible]	[illegible]
4/3	SW					1		1	3	3	4		3	3	4												22	1549
	HW																										0	
[illegible]	[illegible]																										[illegible]	[illegible]
5/1	SW							1	2	4	4		1														12	942
	HW																										0	
[illegible]	[illegible]																										[illegible]	[illegible]
6/1	SW						1			1	2				1			1		1							7	455
	HW																										0	
[illegible]	[illegible]																										[illegible]	[illegible]
7/1	SW				1			2		2	2	2	2	3	3	2											19	1403
	HW																										0	
[illegible]	[illegible]																										[illegible]	[illegible]
	SW	0	3	8	10	22	32	45	55	46	44	27	23	26	17	7	1	5	0	2	1	0	0	0	0	0		[illegible]
	HW	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0		

Appendix VIII

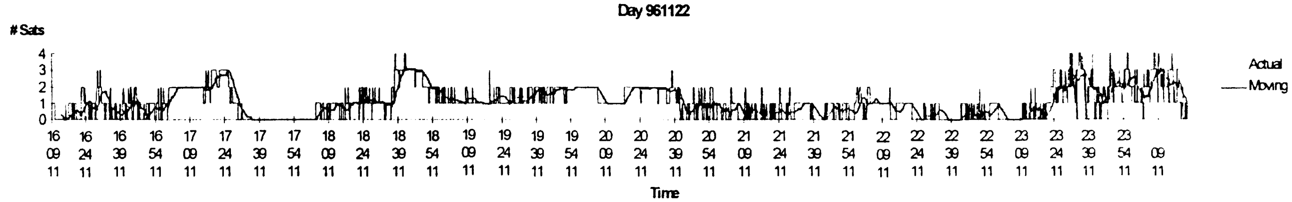
Temporal Analysis

The following time series illustrates the number of blocked satellites over the entire working day of each measurement session. The data has been smoothed by a moving average filter. This helps to show trends in the data. The purpose of these graphs is to show if any temporal relationship exists between the daily sessions. This may occur since similar satellite configurations repeat on a 24 hour basis. That is, the satellites are in the same place in the sky. There is a 4 minute lag from one day to the next. i.e the same satellite configuration occurs 4 minutes earlier the following day. A visual inspection indicates that a temporal relationship exists between the daily data sets. Location: ***Embarrass Test Site***

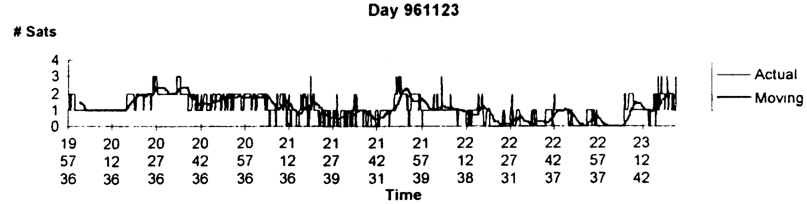
Day 961121



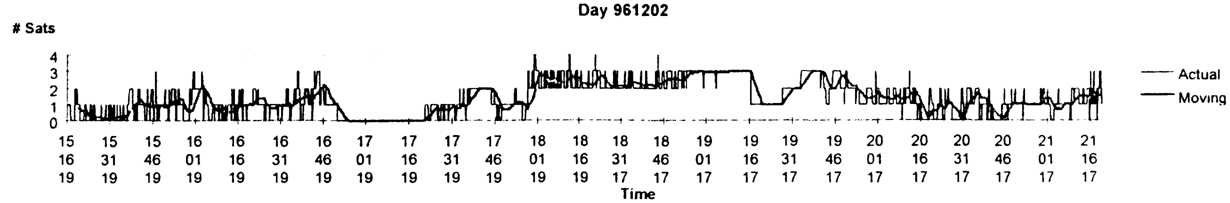
Day 961122



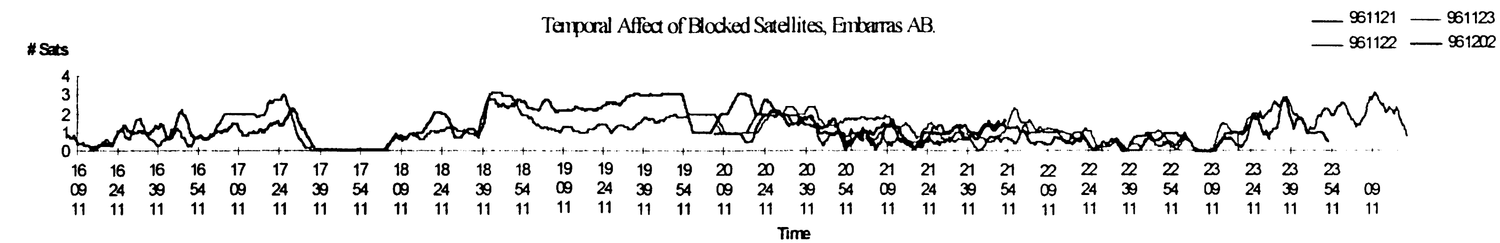
Day 961123

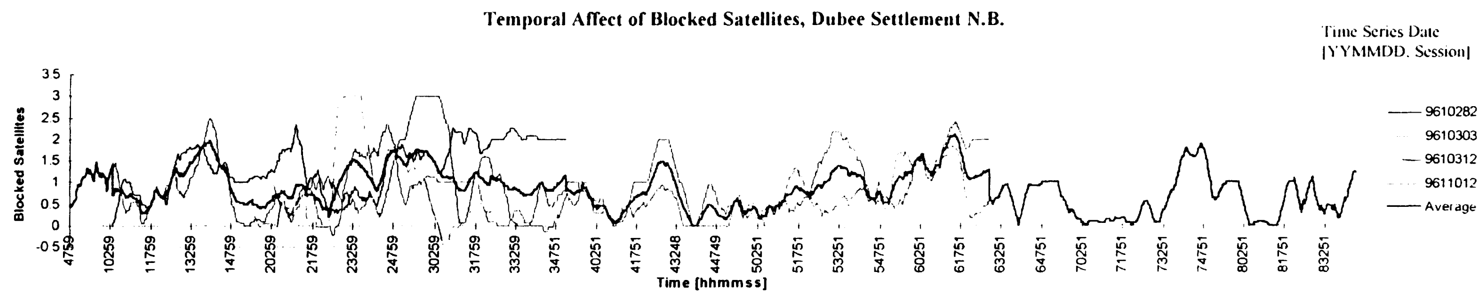


Day 961202



The following time series illustrates the combined temporal data sets for each study site. They have been sequenced by shifting consecutive daily data sets by 4 minutes. In addition, the Dubee, NB data shows the average trend for all data, i.e. the temporal effect.

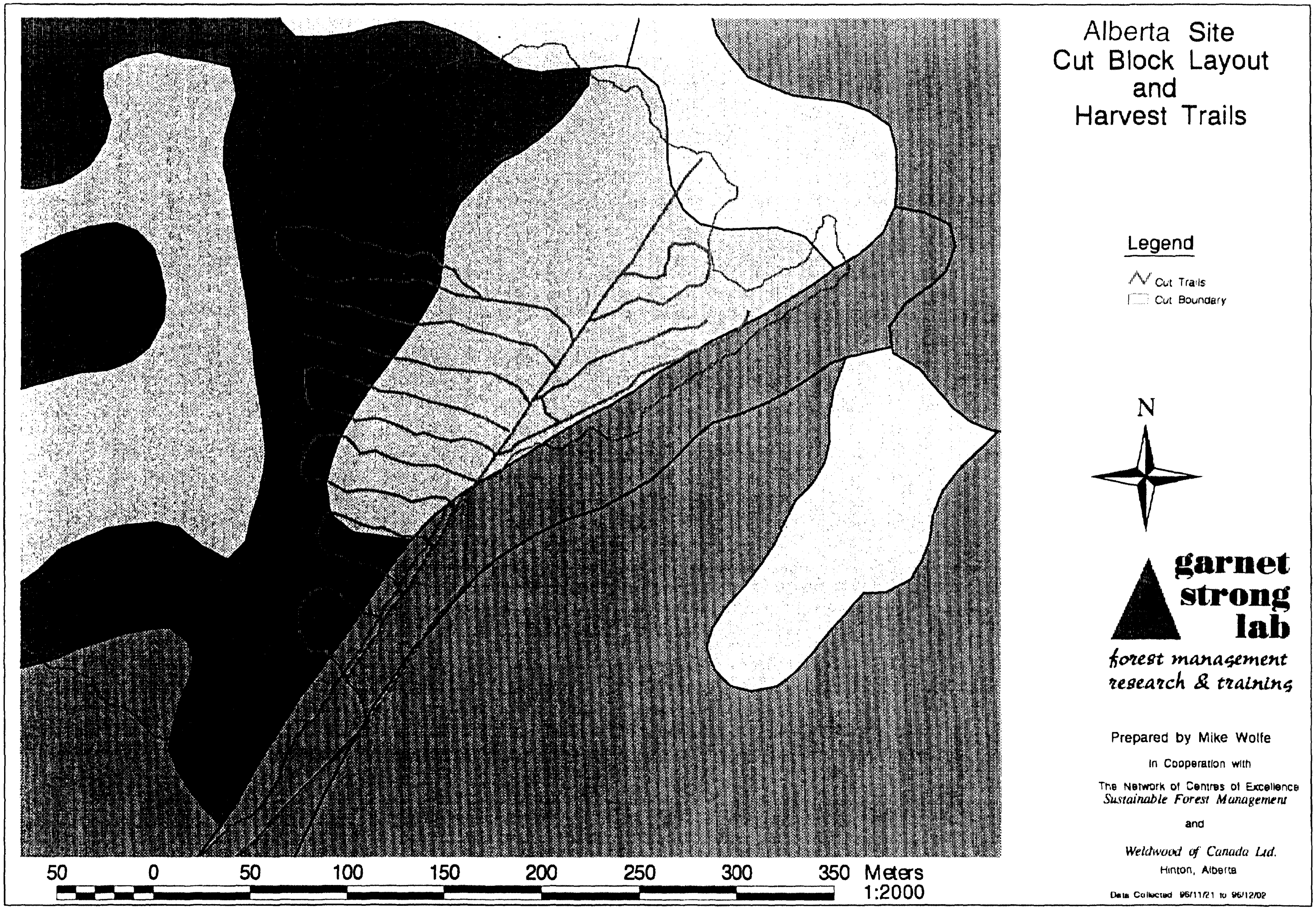


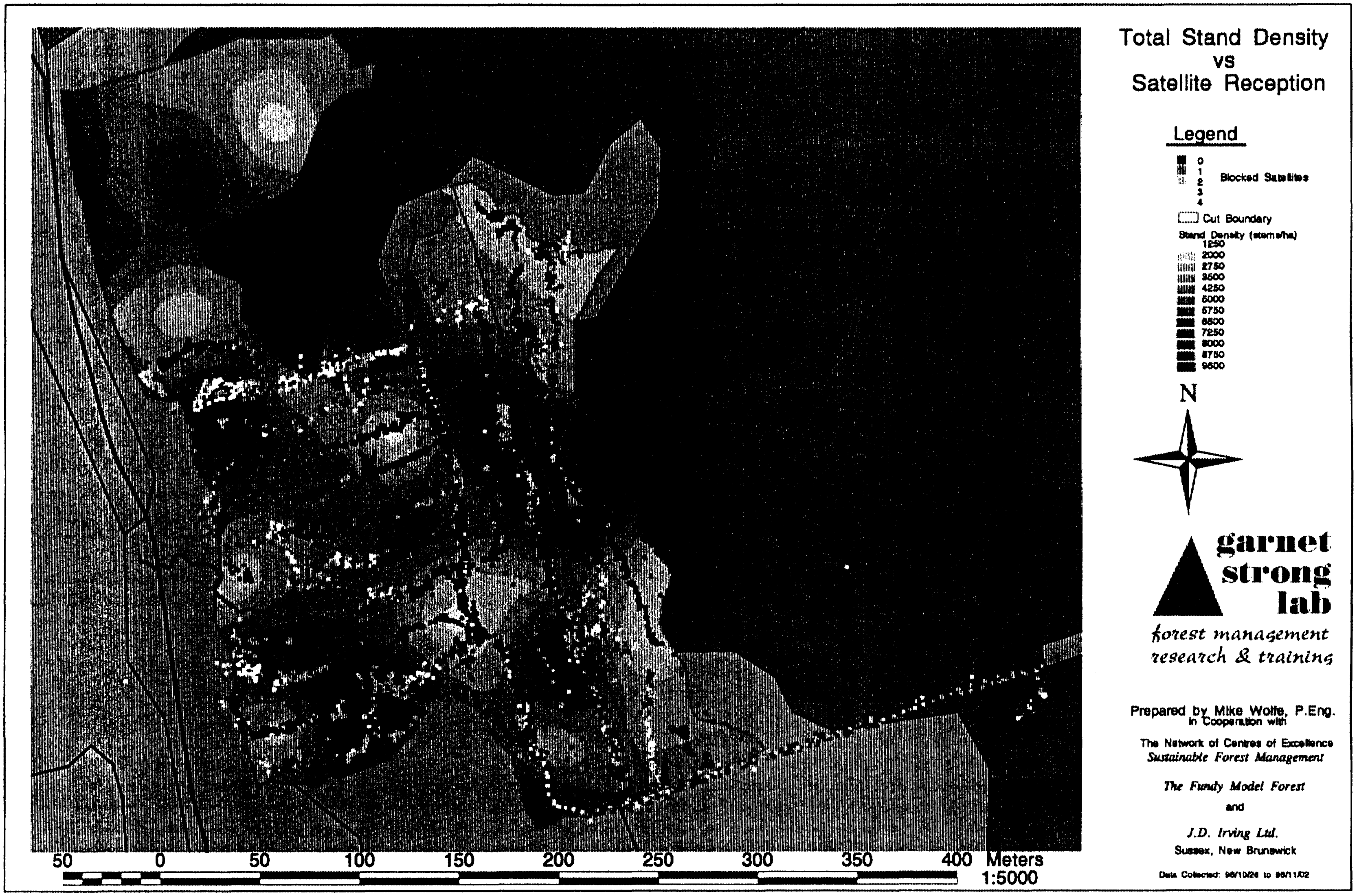


Appendix IX

Site Maps


New Brunswick Site
Cut Block Layout
and
Harvest Trails
Legend
Harvester Trails
Cut Boundary
GPS Stream
GIS Stream
N
garnet
strong
lab
forest management
research & training
Prepared by Mike Wolfe, P.Eng.
in Cooperation with
The Network of Centres of Excellence
Sustainable Forest Management
The Fundy Model Forest
and
J.D. Irving Ltd.
Sussex, New Brunswick
50 0 50 100 150 200 250 300 350 400 Meters
1:5000


Alberta Site
Cut Block Layout
and
Harvest Trails
Legend
Cut Trails
Cut Boundary
N
garnet
strong
lab
forest management
research & training
Prepared by Mike Wolfe
In Cooperation with
The Network of Centres of Excellence
Sustainable Forest Management
and
Weldwood of Canada Ltd.
Hinton, Alberta
Data Collected 96/11/21 to 96/12/02
50 0 50 100 150 200 250 300 350 Meters
1:2000


Total Stand Density
vs
Satellite Reception
Legend
0
1
2
3
4
Blocked Satellites
Cut Boundary
Stand Density (stems/ha)
1250
2000
2750
3500
4250
5000
5750
6500
7250
8000
8750
9500
N
garnet
strong
lab
forest management
research & training
Prepared by Mike Wolfe, P.Eng.
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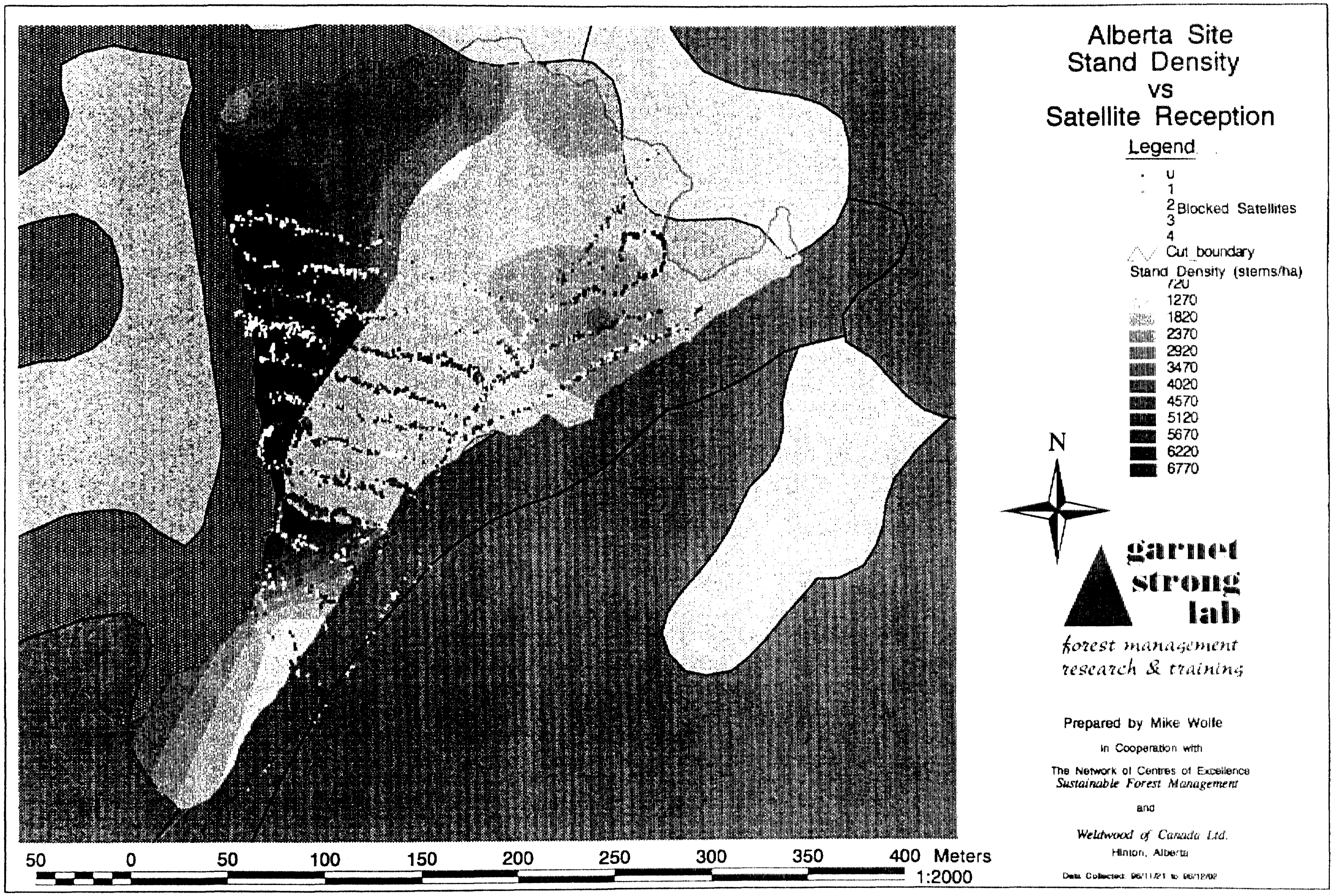
Sustainable Forest Management
The Fundy Model Forest
and
J.D. Irving Ltd.
Sussex, New Brunswick
Data Collected:
50 0 50 100 150 200 250 300 350 400 Meters
1:5000



Alberta Site
Stand Density
vs
Satellite Reception
Legend
0
1
2 Blocked Satellites
3
4
Cut boundary
Stand Density (stems/ha)
720
1270
1820
2370
2920
3470
4020
4570
5120
5670
6220
6770
N
garnet
strong
lab
forest management
research & training
Prepared by Mike Wolfe
in Cooperation with
The Network of Centres of Excellence
Sustainable Forest Management
and
Weldwood of Canada Ltd.
Hinton, Alberta
Data Collected: 96/11/21 to 96/12/02
50
0
50
100
150
200
250
300
350
400 Meters
1:2000

VITA

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