Application of a Portable GPS/Desktop Mapping System for Fire Management Support

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ABSTRACT

The objective of this project was to demonstrate the feasibility of implementing a user-friendly, portable, low-cost Global Positioning System (GPS) receiver, as well as a notebook-based desktop mapping system to facilitate rapid updating, inventory, and analysis of forest fires on a near real-time basis.

Field trials of the GPS/desktop mapping system were completed in the summer of 1992 at the Ranger Lake Fire Attack Base, with the support of the Ontario Ministry of Natural Resources (Aviation, Flood and Fire Management Branch; Sault Ste. Marie District Office) and the Canadian Forest Service–Sault Ste. Marie (Great Lakes Forestry Centre).

Trials consisted of using aerial GPS to determine fire perimeter, to locate hot spots and lightning strikes, and to identify values-at-risk. Ground GPS was used to survey logging roads, values-at-risk, and prescribed burn perimeters, and to access certain locations using helicopter-borne GPS. Traditional mapping methods were then compared with the GPS/desktop mapping system.

All GPS data were transferred to a desktop mapping system in near real time using ELINX, a GPS-desktop mapping linkage software. The GPS data were initially converted into a database structure containing pertinent satellite, locational, time, and accuracy information. The point data were then filtered using spatial and database queries and, if required, a polyline or polygon was produced.

Operational testing of the GPS/desktop mapping system was completed in the summer of 1993 by a fire crew based at the Ranger Lake Fire Attack Base, Sault Ste. Marie District.

Results of the project indicate that a portable GPS/desktop mapping system can be integrated into the day-to-day operations of a typical fire attack base. If necessary, it can be moved quickly to temporary field camps to assist with fire management. Fire crews and crew leaders can be trained in the use of GPS and desktop mapping within a week. Information on the fire area and perimeter is available immediately after the transfer of the GPS data; high quality maps showing the location of values-at-risk and the perimeter of the fire, along with drainage, topography, and transportation routes, can be produced within a few minutes on an inkjet printer using plotter emulation software.

RÉSUMÉ

Le projet vise à démontrer qu'il est possible d'utiliser un récepteur peu coûteux, portatif et convivial, pour le Système de positionnement global (SPG), ainsi qu'un système micro-informatique de cartographie fonctionnant sur notebook pour faciliter et accélérer la mise à jour, l'inventaire et l'analyse des incendies de forêt en temps quasi réel.

Les essais expérimentaux du système de cartographie sur notebook/SPG ont été achevés à l'été de 1992 à la Base de lutte contre les incendies de Ranger Lake, avec l'appui du ministère ontarien des Richesses naturelles (Direction de l'aviation et de la lutte contre les inondations et les incendies du Bureau de district de Sault Ste. Marie) et du Service canadien des forêts–Sault Ste. Marie (Centre de foresterie des Grands Lacs).

Lors des essais, on a utilisé le SPG aérien pour déterminer les périmètres des incendies, localiser les points menaçants et les coups de foudre et identifier les endroits à risque. Un SPG au sol a été utilisé pour observer les chemins forestiers, les endroits à risque et les périmètres de brûlages dirigés. Certains endroits ont été rejoints au moyen d'un SPG héliporté. Les méthodes classiques de cartographie ont ensuite été comparées au système de cartographie sur notebook/SPG.

Toutes les données de SPG ont été transférées à un système micro-informatique de cartographie en temps quasi réel au moyen de ELINX, un logiciel de liaison micro-informatique cartographie- SPG. Les données du SPG ont d'abord été converties en base de données comportant de l'information pertinente sur le satellite, l'emplacement, le moment et la précision. Les données ponctuelles ont ensuite été filtrées au moyen de questions spatiales et portant sur la base de données et, là où cela était nécessaire, une polyligne ou un polygone ont été produits.

Les essais de fonctionnement du système de cartographie sur notebook/SPG ont été achevés à l'été de 1993 par une équipe de lutte contre les incendies de la Base de lutte contre les incendies de Ranger Lake du district de Sault Ste. Marie.

Les résultats du projet montrent qu'un système de cartographie sur notebook/SPG portatif peut être intégré aux opérations quotidiennes des bases typiques de lutte contre les incendies. Lorsque cela est nécessaire, ce système peut être acheminé rapidement sur le terrain à des camps temporaires pour aider à la gestion des incendies. On peut former en moins d'une semaine à l'utilisation du SPG et du système de cartographie sur notebook les équipes et les responsables de la lutte contre les incendies. De l'information sur le périmètre et l'emplacement des incendies est disponible immédiatement après le transfert des données de SPG; on peut produire en quelques minutes, sur une imprimante à jet d'encre, au moyen d'un logiciel d'émulation pour traceur, des cartes haute qualité montrant l'emplacement des endroits à risque et le périmètre de l'incendie, ainsi que le réseau de drainage, la topographie et les voies de transport.

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DISCUSSION

INTRODUCTION

Manual techniques are currently used to locate and map forest fires and to perform spatial analysis of fire data to support suppression planning and decision making in the field.

In 1991, trials were conducted by the Ontario Ministry of Natural Resources (OMNR) in the Timmins District to demonstrate the feasibility of airborne Global Positioning System (GPS) and Geographic Information Systems (GIS) on the 1991 GOGAMA 4 Wildfire, using ARC/INFO[1] equipment. These tests indicated that helicopter-borne GPS provides a rapid and accurate delineation of the fire perimeter. Although supplementary aerial photography provided more accuracy, the time and expense required to analyze the photography limited its usefulness for final fire mapping. Trials to date have demonstrated the potential of GPS in identifying fire perimeters. This can be done with sufficient accuracy to map fires through their growing stage as often as required to support fire suppression planning.

The time, effort, and number of staff required to manually produce maps in fire camps also limit the number of mapping updates that can be done. The GIS technology used in previous trials was not easily transported into the field, required GIS specialists and support staff, and was costly. There is a need for a less sophisticated, portable mapping system that can be used for fire staff to support fire suppression operations.

The objective of this project was to demonstrate the feasibility of implementing a user-friendly, portable, low-cost technology using a GPS receiver and a notebook-based desktop mapping system to support fire control operations both in the field and at fire operations headquarters.

The project was subdivided into three study phases:

PHASE 1. Requirements definition and database design
Portable GPS/desktop mapping system setup
Digital data preparation

PHASE 2. Portable GPS/desktop mapping system field trials
System implementation in a fire attack base

PHASE 3. Assessment of results and data analysis
GPS/desktop mapping system final prototype

To assess the detailed requirements for the GPS/desktop mapping system, the following people were consulted:

- Canadian Forest Service: Tim Lynham
  Doug McRae

- OMNR Aviation, Flood and Fire Management: Jim Caputo
  Paul McBay

- OMNR District Fire Office: Grahame Gordon

- OMNR Avionics: Pat Boudreau
  Paul Quinn

A block of land including and surrounding the Ranger Lake Fire Attack Base was designated on a 1:50 000 map as the detailed project area (Fig. 1). Values-at-risk information within this block was entered into the database.

Table 1 lists the hardware and software components for the portable GPS/desktop mapping system that were acquired in conjunction with the defined requirements and database design.

Because there is very limited coverage of Ontario Base Maps (OBMs) in a digital format for the study area, it was mutually agreed that four 1:250 000 digital National Topographic Series (NTS) base maps, covering the Sault Ste. Marie District and available through Natural Resources Canada (NRCan), would be used for the project.

Table 1. Equipment list for the GPS/desktop mapping system.

- GLOBAL POSITIONING SYSTEM
  Magellan NAV 5000 PRO GPS receiver
  External GPS antenna
  Vehicle mounting kit
  GPS fieldpack kit
  GARMIN SRVY II GPS receiver
  Magnetic mount external antenna

- COMPUTER HARDWARE
  Notebook 386-DX25 computer
  Super VGA color monitor
  Inkjet printer

- COMPUTER SOFTWARE
  QUIKMap software (desktop mapping/GIS)
  ELINX software (GPS-QUIKMap link)
  QUIKUtil software (database manager)
  Deskplotter software (HPGL plotter emulation)
  GPS/desktop mapping training manual and data

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[1]A product of ESRI (Environmental Science Research Institute), Redlands, CA.

Figure 1. National Topographic Series Digital Base Map 41J displaying the location of the Ranger Lake Fire Attack Base. Inset map of Ontario shows the base's location.

METHODS AND MATERIALS

Requirements Definition

The requirements definition is based in part on discussions with the Canadian Forest Service (CFS), the OMNR's Aviation, Flood and Fire Management Branch, and the Sault Ste. Marie District Fire Office, together with staff from ELIRIS Inc.

The CFS expressed interest in the use of a GPS/desktop mapping system to survey fire fronts and to determine rates of spread of forest fires. Such a system would also be useful in establishing a computerized fire history archive. Of particular interest to the CFS was the opportunity to gain knowledge of the technical setup and implementation of such a system prior to their undertaking GPS surveys of grass fires in South Africa as part of the Global Climate Change Project.

The OMNR's' Aviation, Flood and Fire Management Branch, together with the Sault Ste. Marie District Fire Office, expressed interest in the GPS/desktop mapping

system to survey fire perimeters and rates of spread. In addition, they noted the importance of ground applications for GPS by fire crews, and the value of the system as a decision support tool at the attack base.

Interest was also expressed in using forest stand information from obtainable SPOT satellite imagery, to estimate lost resource values-at-risk. General requirements of the system included its capacity to:

- map fire fronts
- determine fire rates of spread
- create a computerized fire history archive
- be used for ground applications of GPS by fire crews
- be used for fire intelligence and decision support
- update trail and road locations
- record the position of infrared detected hot spots
- compare values-at-risk information between GPS and maps
- use digital map outputs with fire reports
- be used for prescribed burn planning and identifying fire ignition patterns

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Based on discussions with cooperators and field personnel at Ranger Lake, and a review of the available information and operations at the Ranger Lake Attack Base, the following refinements to the proposed methodology were made:

1. Selection of a 1:50 000 map-size area around the Ranger Lake Attack Base to supply values-at-risk information for the database.

2. Construction of a database in which to transfer GPS locational and other data, both as points and polygon/polyline data. Point data provide specific information on the quality of GPS data and also have a time stamp; polygon data represent the edited or filtered outline of the fire or fire front.

3. Comparison of the use of GPS versus manual or traditional fire fighting methods through test trials of two situations: a) follow-up to a lightning strike or located spot fire, and b) an infrared scanned smouldering hot spot.

4. Assessment of the GPS/desktop mapping system in analyzing fire intelligence functions, such as:

   - area and circumference of a fire
   - rate of fire advance
   - determination of values-at-risk
   - fire impact on forest resources
   - accuracy of values-at-risk information
   - accuracy of manual- versus GPS-derived mapping
   - speed of production and quality of final maps

5. Assessment of the operational and training requirements of the attack base in terms of technical support for the GPS/desktop mapping system. To this end the Sault Ste. Marie District Fire Office dedicated one fire crew at Ranger Lake to support the field requirements of the project.

Database Design

Fire values-at-risk information

The following seven separate database files were set up to capture and display the OMNR area values-at-risk information:

Campgrnd	- campgrounds, Crown land access points
Cottage	- cottage subdivisions
Dwellings	- hunting camps, etc.
Lodge	- lodges
Logcamps	- logging camps
Towers	- fire and communication towers
Special	- special interest value

Under the 1988 OMNR Values-at-risk Mapping Project, a test database and screen format was developed by the department using the Oracle database to capture textual values-at-risk information. At that time, fire information had not been entered into this database for the Sault Ste. Marie District. Copies of the area values, which have been filled out by hand since 1988, and the Oracle database screen format were studied. Structures for seven database files were created. For all seven files, only necessary fields are present. If only one database file had been used it would have resulted in unused fields, depending on the type of value. For example, a lake-name field is appropriate for a cottage subdivision, but not for a tower. Separate files for each type of value were also used to provide maximum flexibility when viewing and analyzing the data.

All of the QUIKMap[2] fields required to display point information were added to each database file. The QUIKMap fields necessary to represent polyline and polygon information were added to the cottage and special database files. A field called GPScheck, which is a logical field (yes/no), was included in each database file to indicate if the coordinate for a value was corrected using GPS.

Database screen formats were set up for each database file to match the OMNR area values-at-risk input screen format (Table 2). The screen format was customized for each of the seven database files to reflect the differing fields present. QUIKMap display attribute fields were also included in the bottom portion of the screen format.

Symbols, including symbol type, color, and size, were chosen for each of the seven database files. Selected symbols were as pictorially representative of the object as possible. All symbols used were included with the QUIKMap symbol library. The size of the symbol used corresponds to the importance of the value. For example, lodges and campgrounds were given larger symbol sizes than were towers.

Point and polygon/polyline information

All fire-related forms, including the Fire Situation Report, Fire Assessment Report, Fire Log Reporting Form, and Fire Information Report, were examined. A database structure was developed for the Fire Log Reporting Form to represent forest fire activity in the district (fire archive) during the summer of 1992. Data were transferred from the Provincial Fire Log Database, which is maintained by the Aviation, Flood and Fire Management Branch in Sault Ste. Marie. It was decided that none of the above fire report forms or the Provincial Fire Log Database could be suitably modified; instead, a new database structure was

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[2] Desktop geographic information system software.

Table 2. Database records displaying structure for GPS point data, structure for GPS polyline/polygon data, and structure for fire values data (left to right).

DWELLING.DBF [37/178]

Field	Value	Field	Value	Field	Value
RECORD_NO	524	DATE	07/14/92	*Values Information*	
TIME	15:31:19.8	FLY_TIME	15:31:21		
ALTITUDE	427	CONDITION	out	Value	DWELLING
MODE	2	DATA_TYPE	P	Detail	L.U.P. HUNTCAMP
SATELLITES	02 15 28 00	KEY	PBSUB	Map Number	37
SQ	9 9 9 0	MN_LAT_DEG	46.00000	Township	HUGHES
PDOP	1.41	MN_LAT_MIN	52.00000	Owner	ROSS G. HOLLEY
DATE	07/14/92	MN_LAT_SEC	30.62518	Address	79 CREERY AVENUE,
DATUM	NAD27	MN_LON_DEG	83.00000	Contact	
DATA_TYPE	S	MN_LON_MIN	48.00000	Phone	(705) 942-2650
KEY	524	MN_LON_SEC	12.74716	Dollars	
MN_LAT_DEG	46.00000	MX_LAT_DEG	46.00000	Zone	17
MN_LAT_MIN	53.00000	MX_LAT_MIN	54.00000	Easting	290750
MN_LAT_SEC	21.31378	MX_LAT_SEC	20.29184	Northing	5186250
MN_LON_DEG	83.00000	MX_LON_DEG	83.00000	GPS Checked	
MN_LON_MIN	49.00000	MX_LON_MIN	50.00000	UTM Basemap	29518
MN_LON_SEC	3.51423	MX_LON_SEC	5.80598	UTM Block	6
MX_LAT_DEG	0.00000	SYM_LN_TYP	1	UTM Sub-block	0
MX_LAT_MIN	0.00000	SIZE_THICK	1	Information	Memo
MX_LAT_SEC	0.00000	DATA_COLOR	4	Access	Memo
MX_LON_DEG	0.00000	HATCH_PATT	2	Remarks	Memo
MX_LON_MIN	0.00000	LBL_TEXT	PB SUB-BURN		
MX_LON_SEC	0.00000	LBL_FONT			
SYM_LN_TYP	1	LBL_SIZE	15		
SIZE_THICK	15	LBL_COLOR	4	*Display Attributes*	
DATA_COLOR	4	LBL_ANGLE	0.0		
HATCH_PATT	1	LN_PLY	MEMO	Key	D37
LBL_TEXT	524	PLY_AREA	2.73	Symbol Type	18
LBL_SIZE	15	LN_PLY_LEN	762.80	Symbol Size	15
LBL_COLOR	4	OPERATION		Symbol Color	10
LN_PLY		FILE_NAME	PBSUB.CDF	Hatch Pattern	1
PLY_AREA	0.0			Label	37
LN_PLY_LEN	0.0			Label Size	15
OPERATION				Label Color	10
FILE_NAME				Operation	T

designed to capture polyline and polygon fire boundary information.

The polyline/polygon fire boundary database is a standard database file for QUIKMap, with the addition of three fields: DATE, FLY_TIME, and CONDITION (Table 2). Each record in the file represents GPS-derived boundary information for one flight around a fire.

For point information (i.e., points defining a fire boundary), a standard database file for QUIKMap is all that is required to capture the necessary information (Table 2). Individual files containing points are created for each flight around a fire. Each point in the file will contain GPS-derived locational, as well as date, time, and satellite information.

The following procedure was used to capture a fire boundary:

1. After a fire boundary was flown, the GPS data was downloaded and translated to a point file using ELINX.

2. The boundaries of the fire were then viewed as points. Points that represent low-quality GPS readings (e.g., bad Position Dilution of Precision or PDOP), as well as any points that may occur as a result of difficulties encountered in tracing the fire boundary, may be marked for deletion. These unwanted points may then be deleted using the *Delete Marked Records* option on the ELINX utilities menu.

3. If necessary to organize the point file, the fire boundary information may be transferred to the polyline/polygon fire boundary database. It is preferable to first view the fire boundary information as points in order to produce an accurate polygon with no overlaps. As soon as the fire boundary information is captured as a polygon it may be printed on a plotter for a fire report. The time, date, condition, and fire size information may be copied from the computer screen to the Fire Log or other fire reports.

Digital Data Preparation

Base maps

OMNR owns a set of the EMR NTS 1:250 000 maps for provincial coverage (Fig. 1) in an unstructured, Standard Interchange Format (SIF). Four NTS maps (41J, 41K, 41N, and 41O), acquired from EMR in an Intergraph Design File Format (DGN), were translated to QUIKMap format. Each NTS area map was divided into four separate digital base maps to show specific features:

- drainage
- topography
- transportation
- miscellaneous features

Digital base map files, with corresponding size in megabytes, were as follows:

| 41JWATER	1.03	41KWATER	0.15
41NWATER	0.54	41OWATER	1.00
41JCONT	2.29	41KCONT	0.44
41NCONT	1.39	41OCONT	1.65
41JTRAN	0.18	41KTRAN	0.10
41NTRAN	0.05	41OTRAN	0.05
41JMISC	0.19	41KMISC	0.05
41NMISC	0.02	41OMISC	0.02

Databases

Values-at-risk information, compiled for a rectangular area of 2 800 km^2 (64 km x 45 km) in the Ranger Lake area of the OMNR Sault Ste. Marie District, covered all or part of 35 townships.

Values-at-risk locations (UTM[3] coordinates) were obtained from OMNR values-at-risk maps — 1:50 000 topographic maps on which the values-at-risk are marked in stencil or as a colored symbol.

Information on values-at-risk was obtained from hand written OMNR Values Map Program printout sheets.

Values-at-risk database	Number of records
Campgrnd	14
Cottae	13
Dwelling	178
Lodge	7
Logcamp	1
Towers	3
Special1	9

All values-at-risk database information occurs as point data. Customized menus listing all base maps and database files were prepared and the symbols to identify the fire values-at-risk were completed (Fig. 2).
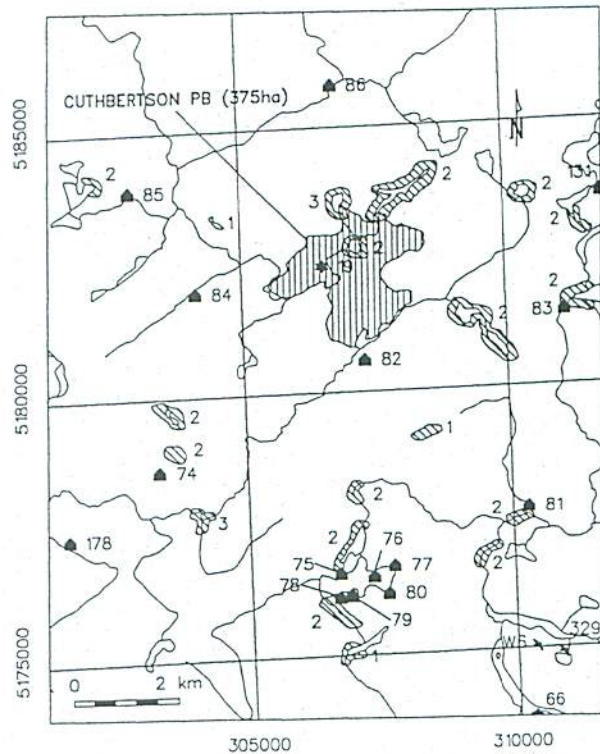
Figure 2. Example of values-at-risk and natural resource information for Cuthbertson Township, and of a prescribed-burn mapping using a Garmin SRVY II GPS receiver. Values-at-risk information is overlaid on a 1:250 000 scale NTS digital base map.

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[3]UTM = Universal Transverse Mercator.

Portable GPS/Desktop Mapping System Setup

Two brands of GPS equipment were used during the project: a Magellan NAV 5000 PRO 5-channel GPS receiver, and a Garmin SRVY II 8-channel GPS receiver. The Magellan was used during the initial field trials and the Garmin was used during the operational phase of the project.

Global positioning system (GPS) receivers

The Magellan NAV 5000 PRO receiver, with an external antenna kit and a magnetic vehicle mounting kit, gives GPS capability on land, water, and in the air. The NAV 5000 PRO is an intermediate-level receiver that met the initial requirements of the project, and is capable of submeter accuracy.

The Magellan GPS fieldpack kit consists of a backpack; a 12-volt Gelcell portable battery; connectors for the antenna suitable for mounting on a backpack, boat, or helicopter; electrical connectors; a cigarette lighter adapter; and a 12-volt battery charger. The GPS fieldpack kit forms part of the portable GPS and provides hands-free operation while traversing difficult terrain. It also renders the GPS independent of other external power sources for extended data logging (more than 1 500 records) either in land vehicles or in a helicopter.

The Garmin SRVY II unit consists of an 8-channel receiver with a large memory storage capacity (200 000 point locations), as well as attribute and descriptive data logging capabilities. The GPS antenna may be detached, thereby making it versatile for aircraft or ground applications. An external magnetic-mount antenna is optional and was used on vehicles. The Garmin SRVY II is an intermediate-level receiver that can be used in differential mode to achieve 1- to 3-m accuracy.

Computer hardware

The system consists of a personal computer (notebook 386-SX25) with a 387 coprocessor, an 80 Mb hard drive, a generic mouse, and a super VGA monitor. It provides sufficient speed and memory capacity.

The inkjet printer has dual color and black/white capability. It is light, portable, and produces high quality color output for maps and GPS data produced by the mapping software.

Computer software

The following computer software packages were used:

- QUIKMap, a fast, easy to use, desktop mapping and GIS
- ELINX, a GPS data translation software package that links the receiver with QUIKMap

- InFOcus and QuikUTIL, database and map management software packages that are used with QUIKMap.

A GIS training software package consists of a manual with accompanying digital data that can be used in conjunction with QUIKMap software; HPGL (Plotter) emulation software allows the inkjet printer to emulate a plotter and thereby produce high quality maps.

Hardware/software setup and personnel training

The portable GPS/desktop mapping system was set up at the Ranger Lake Fire Attack Base. This provided access to any fire information, and direct communication with the fire supervisor and fire crew leader. QUIKMap, ELINX, Magellan, and Garmin software were loaded into the notebook computer and tested, as were all base maps and database files.

A three-person fire crew was designated for the project, and training was provided on the Magellan NAV 5000 PRO and Garmin SRVY II GPS receivers. The crew leader and an assistant were given additional training on the use of ELINX, the Magellan and Garmin postprocessing software, and QUIKMap. Part of the training involved the transfer of natural resource data obtained from the Sault Ste. Marie OMNR District Office into the QUIKMap environment. The crew leader and technical assistant were also given training in the basics of digitizing polygons using the desktop mapping system.

GPS antenna configuration

During the initial Magellan NAV 5000 PRO field trials, a critical step in configuring the system was the placement of the external GPS antenna on the helicopter. Improper placement of the antenna will result in large areas of satellite blockage by the helicopter fuselage. It should be emphasized that to conduct GPS mapping or tracking, it is necessary to receive continuous GPS positions. This is facilitated by selecting an optimum location on the aircraft.

For the field trials, the Magellan GPS antenna was bolted directly to the roof of the cockpit on a Hughes 204B helicopter. This resulted in a very secure connection on the airframe and produced strong signal reception.

During operational testing of the GPS/desktop mapping system, the Garmin SRVY II detachable antenna was mounted to the dashboard of the helicopter in a location that provided maximum satellite signal reception. The detachable GPS antenna also provided portability among different helicopters and rapid redeployment for ground applications. An external aircraft antenna was not required.

Satellite signal reception

GPS signal reception was found to be satisfactory using the antenna configurations described above. GPS signal reception quality suffered when the external GPS antenna was blocked by the helicopter fuselage while banking the aircraft (up to 30°) or when accelerating, which produced a forward tilt of the airframe of up to 30°.

Loss of the GPS signal is generally of short duration and it is regained when the helicopter changes position. In addition, if the GPS receiver is capable of accessing eight to ten GPS satellite channels, the helicopter orientation has a negligible effect on the ability of the GPS receiver to acquire a position fix (e.g., Garmin SRVY II).

System mobilization/demobilization

During the course of the field work, the GPS/desktop mapping system was transferred several times between the Ranger Lake Fire Attack Base and Sault Ste. Marie. The Magellan GPS antenna was not dismantled except when a different helicopter was used. The computer equipment and GPS receiver were simply packed in boxes when moved.

The dismantling and packaging of the GPS/desktop mapping system is done by two people within 1 hour. The entire system consists of a backpack (containing the GPS antenna and receiver), and carrying cases for the notebook computer, the printer, and the monitor. The equipment will easily fit into a GMC Suburban or a minivan.

For remote field operations, use of a separate tent erected on plywood flooring is recommended; a gasoline-powered electric generator is required to generate the 120-volt power supply to operate the printer and monitor. The system can be used on internal batteries for about 1.5 hours (excluding the printer and monitor) before recharging is required.

RESULTS

A number of tests were initiated to compare traditional and GPS-assisted mapping methods. The trials were subdivided into helicopter-borne and ground GPS techniques.

Helicopter-borne GPS Field Trials

Mapping fire perimeters

Aerial GPS surveys were completed for fires that occurred prior to the start of the project (FIRE 28 and FIRE 14). In addition, several surveys were made of a prescribed burn (PB) in Lamming Township.

Sault Fire 28

Trial 1

Sault Fire 28 was flown on 29 June 1992, in 3-D mode at an altitude of 50–100 feet above the tree tops (Fig. 3). The flight path followed the topography. The prevailing wind was strong and from the west, requiring airspeeds of 50–100 kph for safety reasons, and steep banking to follow the topography.

The flight characteristics resulted in satellite reception problems, and only a few GPS points were recorded. The GPS sample rate was one per second.

Trial 2

Sault Fire 28 was flown 13 July 1992, in 3-D mode at a constant elevation of 1 600 feet (Fig. 4). This gave 100 feet of altitude above the highest point of land. The helicopter flew into the wind at all times at a speed of 15–20 kph, and no banking was required in the light wind conditions.

This trial provided very good results. The GPS receiver acquired a sufficient number of points to give good resolution to the fire boundary. Some data gaps did occur when a satellite was blocked by the engine or rotor assembly of the helicopter.

Sault Fire 14

Sault Fire 14 was flown on 13 July 1992, in 3-D mode at a constant elevation of 1 600 feet. This gave an altitude of 100 feet above the highest point of land. The helicopter flew into light winds at 15 kph, and no banking was required.

Data gaps occurred when flying in a westerly direction because of signal blockage of one satellite by the engine or rotor assembly. Nevertheless, the resulting GPS data provided a good representation of the fire boundary.

Lamming Township Prescribed Burn

The Lamming PB boundary was flown three times: (1) prior to the burn, following a skidder road that defined the PB perimeter; (2) during a preliminary burn; and (3) during a complete burn.

Trial 1

The first flight occurred on 14 July 1992, in 2-D mode at a constant elevation of 1 800 feet, or at a 500-foot altitude. The helicopter flew at 15 kph in light winds. No banking was required and the helicopter flew into the wind at all times.
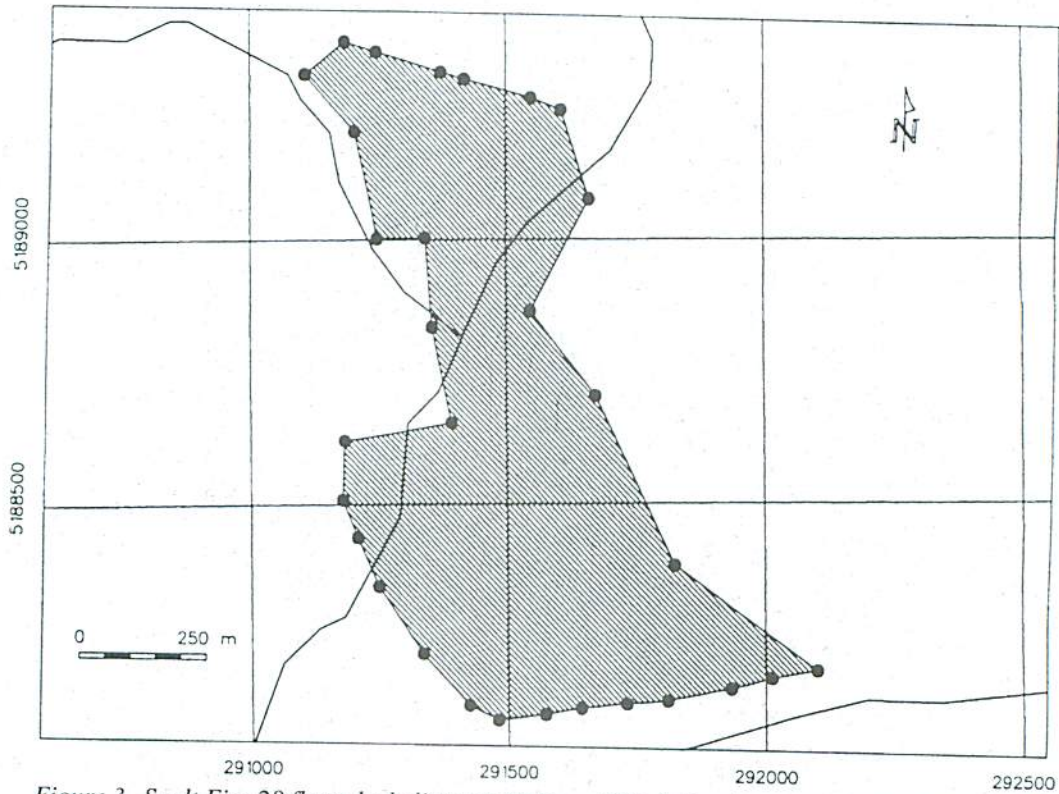
Figure 3. Sault Fire 28 flown by helicopter 29 June 1992, following topography at 50–100 kph and banking on tight turns. Points indicate a GPS satellite fix.
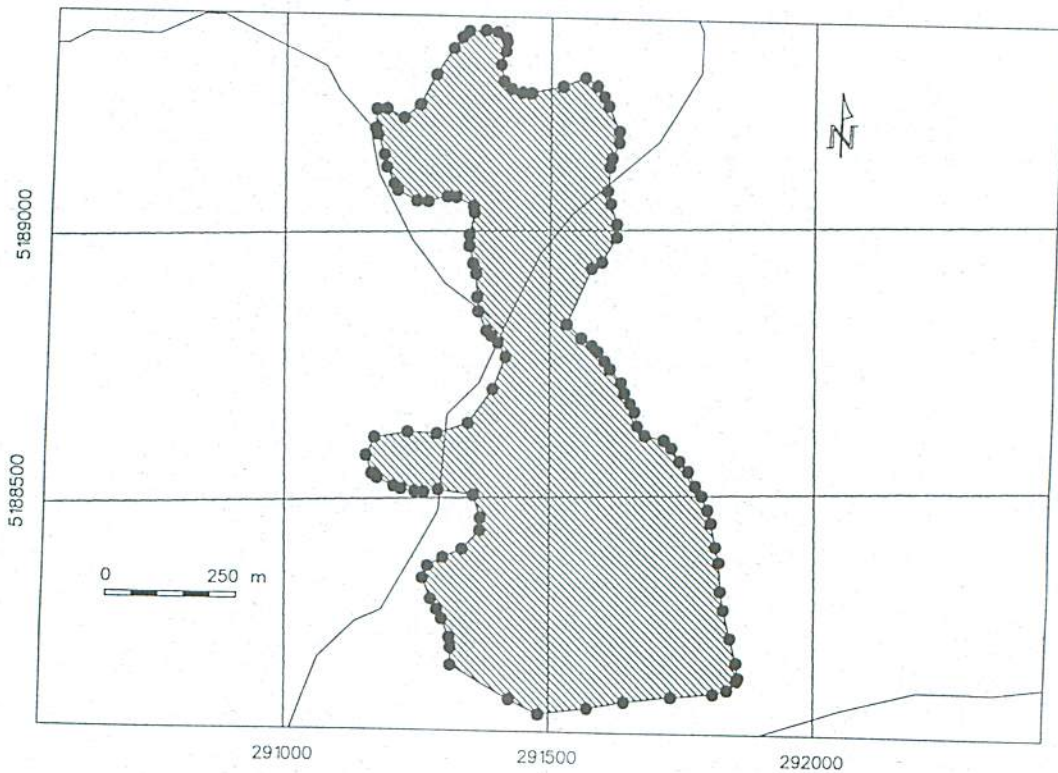

Figure 4. Sault 28 Fire flown by helicopter 13 July 1992, at a flying level at 1 600 feet, 15–20 kph in light wind, with no banking on the turns.

At times the helicopter pilot had some difficulty seeing the skidder trail from the flight altitude. This led to a navigation error and resulted in an inaccurate survey of the northwestern section. However, GPS data was sufficient to provide a good representation of the PB perimeter at a GPS sample rate of one position per second.

Trial 2

The second trial took place on 14 July 1992, in 2-D at a constant elevation of 1 600 feet, or at a 300-foot altitude above the highest point of land covered by the PB (Fig. 5). The helicopter flew at 15 kph and winds were light. No banking was required and the helicopter faced the wind at all times.

The GPS data was sufficient to provide a good representation of the PB perimeter at a GPS sample rate of one reading per second. The lower flight altitude allowed the pilot to easily follow the skidder trail.

Trial 3

The third trial was carried out 14 July 1992, in 2-D mode at a constant elevation of 1 400 feet, or at an altitude of 100 feet above the highest point of land covered by the PB area (Fig. 5). The helicopter flew into the wind at 15 kph and no banking was required.

The helicopter pilot was able to follow the skidder trail very precisely, although some minor problems occurred when side trails branched off the main trail. At this low altitude it was difficult to differentiate the main skidder trail from side trails. Whenever satellite blockage occurred it was possible to rotate the helicopter slightly, yet still follow the skidder trail. The GPS data recorded at a 1 400-foot elevation provided the best representation of the PB boundary at a sample rate of one GPS reading per second.

All three surveys of the PB boundary agree closely, with the exception of the surveying/navigation error that
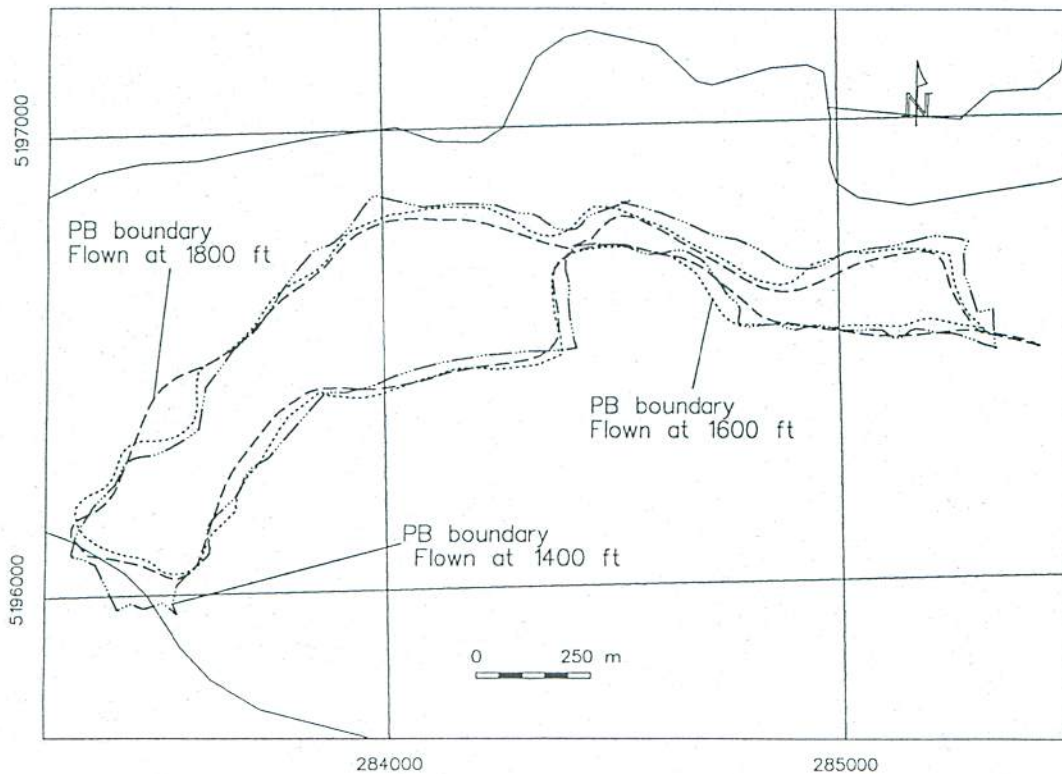

Figure 5. Lamming Township prescribed burn boundary flown 14 July 1992, prior to the burn. The prescribed burn was flown by helicopter at altitutes of 1 800, 1 600, and 1 400 feet at 15 kph in light winds with no banking required.

occurred when flying at 1 800 feet. The 1 400-foot elevation survey appears to be the most accurate, followed by those done at 1 600 feet and 1 800 feet. Flying at a low, constant elevation generally gave better results under the terrain conditions encountered.

Preliminary Burn (Eastern Section)

The eastern section of the Lamming PB was flown on 28 July 1992, after a preliminary burn (Fig. 6). The burned area was flown at an elevation of 1 400 feet in 2-D mode, at an altitude of 100 feet. The helicopter flew at 15 kph into a light wind and required no banking.

The GPS data provide a very good representation of the fire boundary, and match the information from the previous three GPS surveys.

Full Burn

The prescribed burn was flown when the fire-ignition helicopter left for refueling. Generally, it was possible to fly along the upwind side of the fire boundary; however, it was impossible to survey the downwind side of the fire because of smoke. As such, the edge of the fire boundary

was estimated (Fig. 7). A prescribed burn, unlike a naturally occurring fire, is back burned, i.e., ignited on the downwind side and burned upwind.

The upwind position of the progressing fire was estimated, because the heat and rising air currents did not allow the helicopter pilot to accurately trace the fire edge. The helicopter pilot could not closely approach the downwind side of the fire because of the lack of visibility caused by the smoke plume. This resulted in a map with an oval-shaped fire contour. The PB area was not reflown after the fire because the contract for the helicopter was canceled.

Prescribed burn (PB) ignition pattern

There is no traditional method for tracking the ignition pattern of prescribed burns other than by visual approximations on a map or aerial photo, but this is not usually done. With a GPS- equipped helicopter, it should be possible to accurately track the fire ignition pattern.

During the trial it was not possible to install the GPS antenna on the helicopter that initiated the ignition pattern, because the aircraft was not available before the prescribed
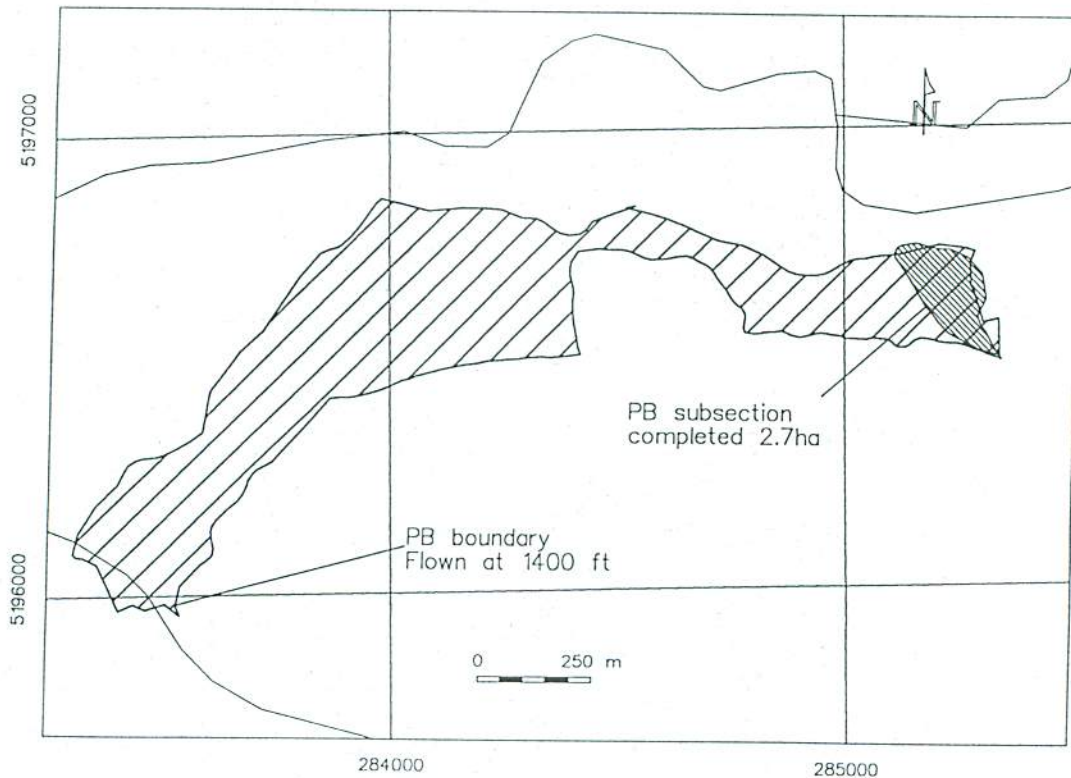

Figure 6. Lamming Township PB boundary flown at 1 600 feet, overlaid by PB subsection burn boundary flown at 100 feet above ground (1 400 feet).
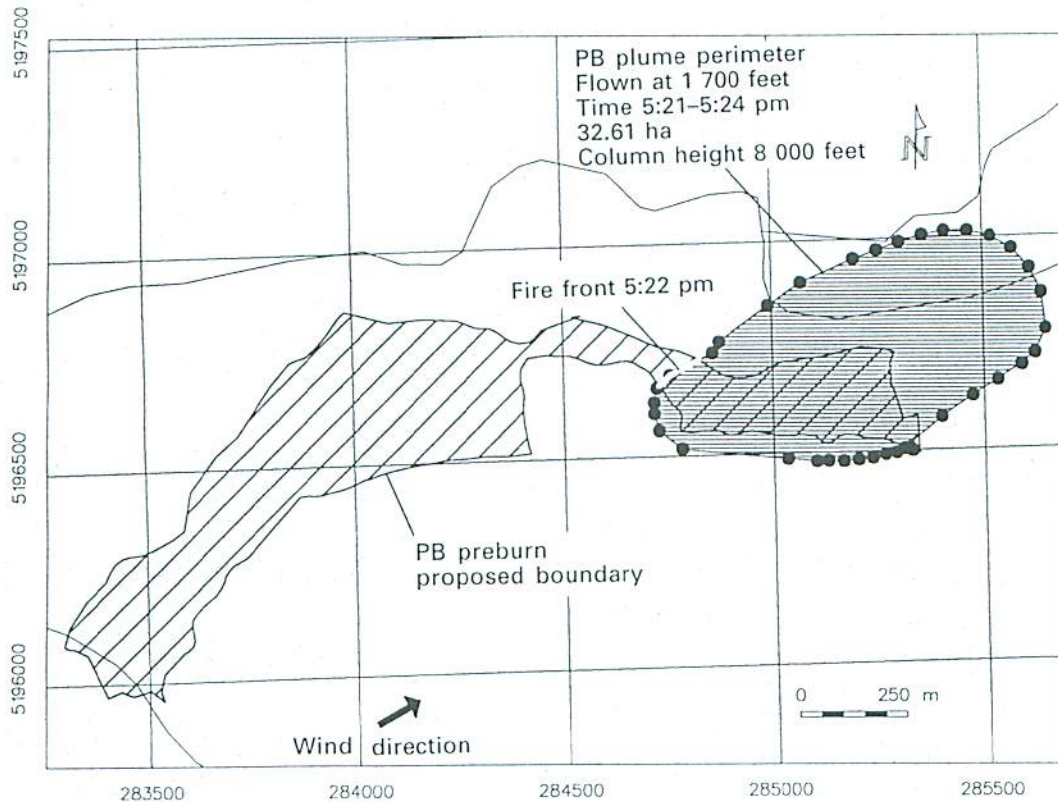
Figure 7. Lamming Township PB boundary (preburn) flown at 1 600 feet, overlaid by the burn smoke plume perimeter and fire front.

burn was carried out. The helicopter with the GPS antenna was not allowed to enter the prescribed burn area because it was on call for fire fighting support. This resulted in limited access to the fire and made it impossible to complete a survey of the ignition pattern.

Road mapping

A section of the Ranger Lake Road was mapped using aerial GPS. The high air speed of the helicopter necessitated sharp banking to follow the road and this caused a loss of satellite signal while turning, because of signal blockage by the helicopter airframe. The resulting GPS data is plotted in Figure 8. The helicopter GPS road survey compares favorably with the ground GPS survey and the location of the road on the 1:250 000 scale digital base map.

Values-at-risk mapping

The traditional method for representing resource values-at-risk information is to estimate the location or visual approximation of a value-at-risk (e.g., hunting cabins) from a map or from file information. Using aerial GPS, an absolute coordinate was obtained by hovering directly

over the value-at-risk until the GPS acquired a reading (Fig. 9). An average of ten readings were usually taken at each location.

Ground GPS Field Trials

Hot spot locating

Traditionally, hot spot fires have been located by helicopter, marked on a map or aerial photo, and identified on the ground using white "ticker tape", which is dropped from the helicopter. The estimated location is passed on to the ground crew, who take a bearing and attempt to find the hot spot. Accuracy in describing the hot spot location is dependent on the geographic features present and the capability of the person mapping. If a helicopter is available, it may hover over the hot spot while the ground crew takes a direct bearing.

For this trial, the helicopter hovered over the hot spot and recorded its location using GPS. An average of ten GPS readings provided a good approximation of the location (± 30 m), which was then relayed to the ground crew. The GPS coordinate was then entered as a "WAYPOINT" into
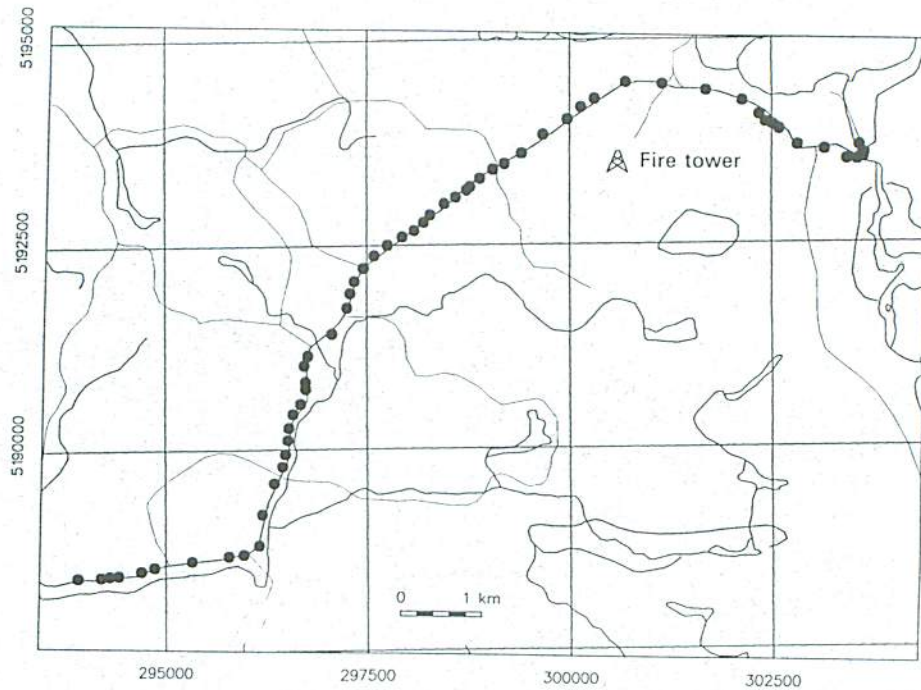
11

Figure 8. GPS aerial mapping of the Ranger Lake Road by helicopter flying at 50–100 kph with steep banking on the corners. GPS readings are displayed as solid circles; the Ranger Lake Road is represented as a solid line (1:250 000 Digital Base Map 41J).
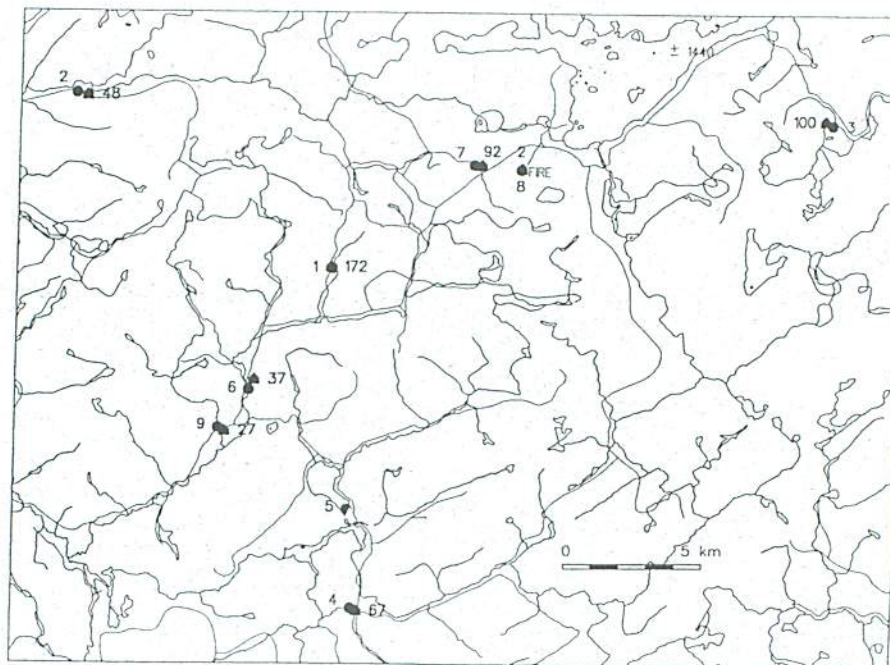

Figure 9. Comparison of GPS-derived locations and original file locations for fire values-at-risk, Ranger Lake Test Block (see Table 3).

the GPS ground receiver, which provided the ground crew with distance and bearing information. With this information, the fire crew leader can go to the nearest body of water, estimate the length of hose required, and traverse directly to the hot spot. A comparison of the two methods is shown in Table 3.

Trial 1

Ticker tape was dropped near the Sault Fire 28 and close to an access road. The ground crew used the estimated location of the ticker tape from a 1:50 000 topographic map and a starting point that was 260 m from the ticker tape location. The fire crew used the traditional method of pace and compass, but they had not identified the location of the hot spot after 45 minutes. According to the fire crew leader, several additional hours of searching would likely have been required to locate the ticker tape. Using GPS, the hot spot was located in 17 minutes.

Trial 2

Ticker tape was dropped near an access road and the ground crew used the helicopter to obtain a compass bearing. The traditional pace and compass search started 110 m from the ticker tape. It took 15 minutes to access and locate the hot spot. No attempt was made to use GPS, since the tape had been found.

Trial 3

Ticker tape was dropped about 500 m from an access road. GPS navigation started at an access road 460 m from the ticker tape location, and 22 minutes were required to locate the tape. Using GPS, the fire crew was directed to within 25 m of the tape, which was then sighted.

Poor satellite linkage occurred while traversing the forest using the Magellan NAV 5000 PRO receiver, and it was necessary to stop for 1 minute every 100 m to establish GPS readings. While stationary, the GPS receiver had no problem acquiring readings and providing new distances and bearings.

It is not necessary to use the GPS ground receiver continuously to locate a hot spot; stopping and reading the GPS every few minutes provides information on the distance and bearing to the waypoint (hot spot). This provides the fire crew with midcourse corrections that can be used to redirect the compass bearing.

In thickly forested areas the NAV 5000 PRO GPS receiver had difficulty locking-in on the satellite signal while in mobile, continuous mode. The GPS satellite signals were interrupted by foliage and this resulted in a loss of signal quality (SQ). An SQ above 6, over a period of several seconds, is required on each of three or four channels in order to acquire a location. This was difficult to achieve while walking through dense stands.

Acquiring a GPS-derived distance and bearing to a hot spot at the start of the search would make it possible for a competent compass person to get within 100 m of the hot spot for traverses of up to 1 000 m. Acquiring one to three additional GPS readings along the traverse route and updating the distance and bearing to the hot spot would place the fire crew within 20–30 m of the target.

Road mapping

Traditional mapping of logging and access roads is conducted using supplementary aerial photos, and new road locations are transcribed onto 1:15 640 FRI or 1:50 000 topographic map sheets. Recent logging roads may get roughly sketched onto 1:50 000 maps until the FRI maps are updated.

Several primary and secondary roads were surveyed using ground GPS in a vehicle equipped with an external antenna, which was attached to the roof with a magnetic platform. The results of the survey were plotted on the available 1:250 000 digital base map of the area. No problems were encountered in surveying major roads, such as Highway 129. This highway follows the Mississaugi River through an area of low relief, and the forest cover is cleared for 100 m on either side of the road. This permits good GPS satellite signal reception. The survey was done while traveling at 80 km/hr and recording the location at 1-second intervals (Fig. 10).

The terrain along the Ranger Lake Road is typical of the Canadian Shield. Satellite signals are frequently blocked by rock cuts and hills immediately adjacent to the road (Fig. 10). Two methods were employed to survey a portion of the Ranger Lake Road using the NAV 5000 PRO: automatic satellite selection and manual satellite selection.

Table 3. Locating hot spots using traditional and GPS-assisted methods.

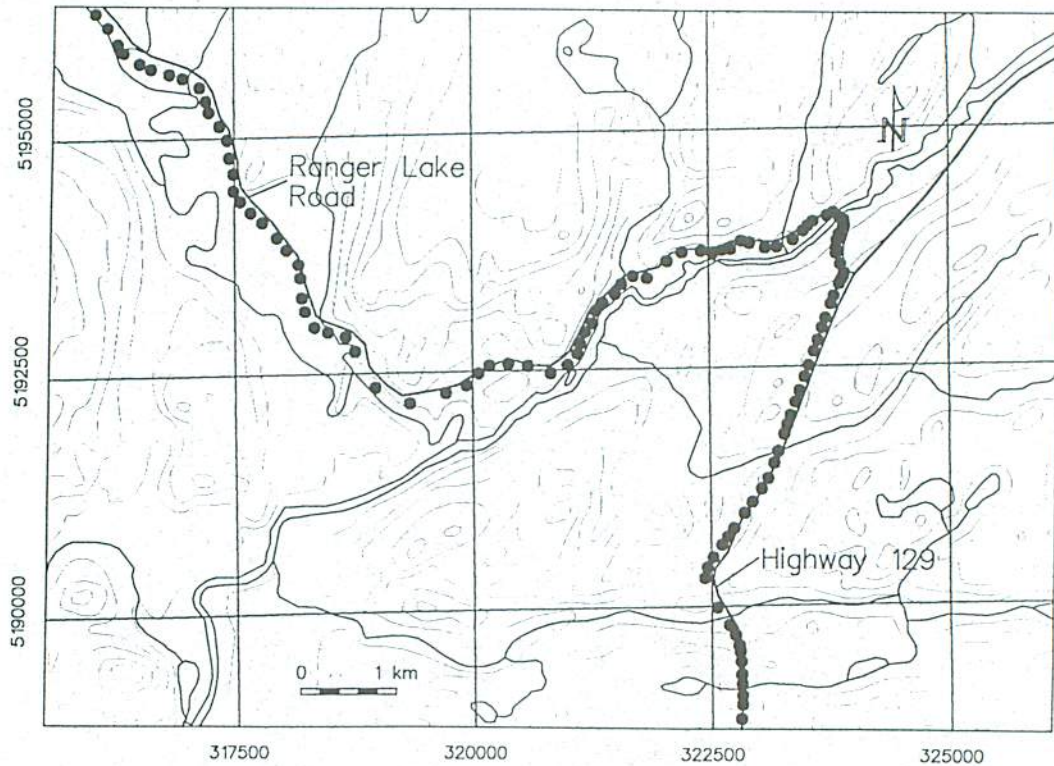| Trial	Distance	Method used		Comments
		GPS	Traditional	
Fire 28	260 m	Yes	No	Edge of burn, high relief
Ranger 1	110 m	n/a	Yes	Open, forested, moderate relief
Ranger 2	460 m	Yes	n/a	Forested, low relief

Figure 10. GPS road survey of the Ranger Lake Road. Some of the data gaps are due to satellite blockage by adjacent hills.

Automatic satellite selection

Using this method, the GPS receiver determines which satellite(s) can provide the most accurate location. This is done through an internal intelligence defined by the firmware.[4] The firmware computes the best satellite configuration from an almanac of satellite positions, based on the terrain setting and the current GPS location. The difficulty in using this approach when working on the Canadian Shield is that the GPS receiver is not designed to operate in broken terrain; it cannot readjust quickly to changes and therefore loses satellite contact. This results in temporary, rapid switching among satellite configurations. Automatic switching from one set of satellites to another requires time to lock onto the signal. During this time, GPS readings are not generated and this results in gaps in the road survey.

Manual satellite selection

To limit the loss of GPS signals from satellites, and the automatic switching to different sets of satellites, only the most accessible satellite signals were selected. The remaining available satellite signals were manually

switched off. This resulted in more continuous access to the signals and fewer gaps in the road survey, but at the cost of having lower precision due to a higher PDOP error.

A survey of the road was carried out in different directions so as to fill any gaps. This proved to be useful, but some locations with deep road cuts or adjacent hills proved difficult to survey. The recommended speed for the vehicle is from 15–25 km/hr, acquiring one GPS reading per second. Depending on the area, the road survey quality can vary from very good to fair using a mobile GPS unit.

Values-at-risk mapping

The location of a selected number of fire values-at-risk was determined using ground GPS. A number of sites (e.g., hunting cabins) were visited and ten GPS readings were taken and averaged at each site. In addition, the location of assets from the fire values' maps for a selected area around the Ranger Lake Fire Attack Base was added to the desktop mapping system, along with any related text (Fig. 8). The fire values-at-risk information included campgrounds, cottage subdivisions, dwellings, lodges, logging camps, items of special interest, and towers.

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[4] Firmware software that is saved on a memory chip.

Fire Operations

During the 1993 fire season the GPS/desktop mapping system was installed at the Ranger Lake Fire Attack Base to assist with fire operations. The following exercises were completed by the fire crew for fire applications and related natural resource inventories (Serrati 1993):

• Cuthbertson Township prescribed burn mapping (Fig. 2)
• Ranger Lake Attack Base response radius (Fig. 21)
• Creation of a fire intelligence support database (Fig. 22)
• Updating of the digital fire values-at-risk database
• Raptor survey
• Wlasy Township prescribed burn
• Forest stand mapping (Fig. 13)
• Sudbury Fire 4 perimeter map
• Perimeter and fire values-at-risk using Garmin SRVY II; Sudbury Fire 23, Sudbury OMNR District (Fig. 11)
• Sudbury Fire 12 perimeter map
• Little Garden Creek prescribed burn mapping

Fire crew staff members concluded that they became well versed in the use of the GPS/desktop mapping system with a minimum of technical support. The OMNR fire staff gave presentations and demonstrations to a number of groups, including:

• Russian fire managers delegation
• Chinese fire managers delegation
• Regional fire center staff (Sudbury)
• Area supervisors (Central Region)
• Fire analyst (Central Region)
• Fire crews (Ranger Lake Fire Attack Base)

DISCUSSION

Data Analysis and Assessment of Results

Accuracy and precision using GPS

The full capabilities of the Global Positioning System are limited to 100-m root mean square (RMS), referred to as "selective availability"[5] (S/A). The effects of selective availability can be removed by using differential GPS to provide higher accuracy. Differential GPS was not used for the current study, because a ± 50-m precision provided sufficient detail at the scale required for forest fires. In addition, the 1:250 000 digital base maps have an inherent inaccuracy of ± 100 m. Accuracy limits for a 1:20 000 OBM are about ± 10 m.
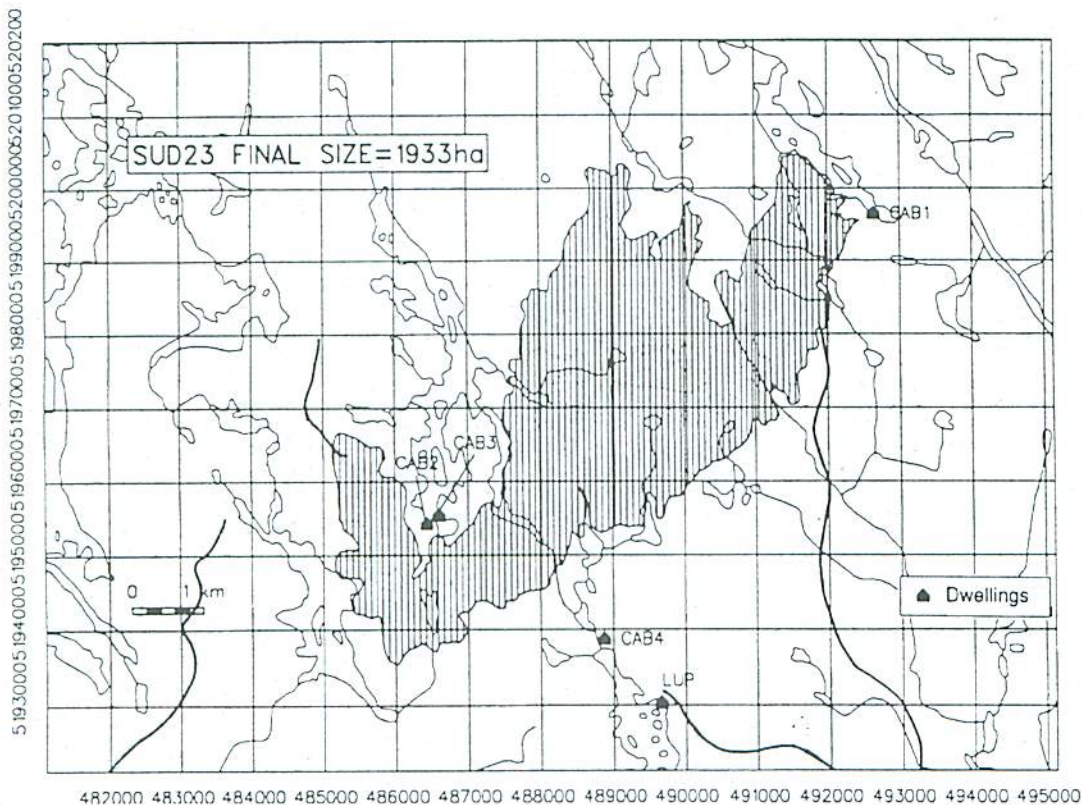

Figure 11. Perimeter and fire values-at-risk using Garmin SRVY II; Sudbury Fire 23, Sudbury OMNR District.

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[5] Selective availability refers to the fact that only certain users, such as the United States Defence Department, can have access to the highest available signal accuracy.

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For locating fire values-at-risk, such as dwellings and outpost camps, an average of ten GPS readings were taken; however, a minimum of 200 readings is recommended. The averaging of GPS data at a single location eliminates some of the error brought about by selective availability. Averaging GPS readings against a known benchmark provides a good measure of the accuracy and precision of a single GPS receiver (Fig. 12).

The PDOP is an important measure of the accuracy of the GPS position fix, and is dependent on the satellite configuration. Variations in the PDOP values can range from one to greater than 50 (PDOP "spike"), given an incomplete constellation of satellites during initial field testing. If PDOP values are in the acceptable range of one to six, then errors will fall within the selective availability limit of 100-m root mean square.
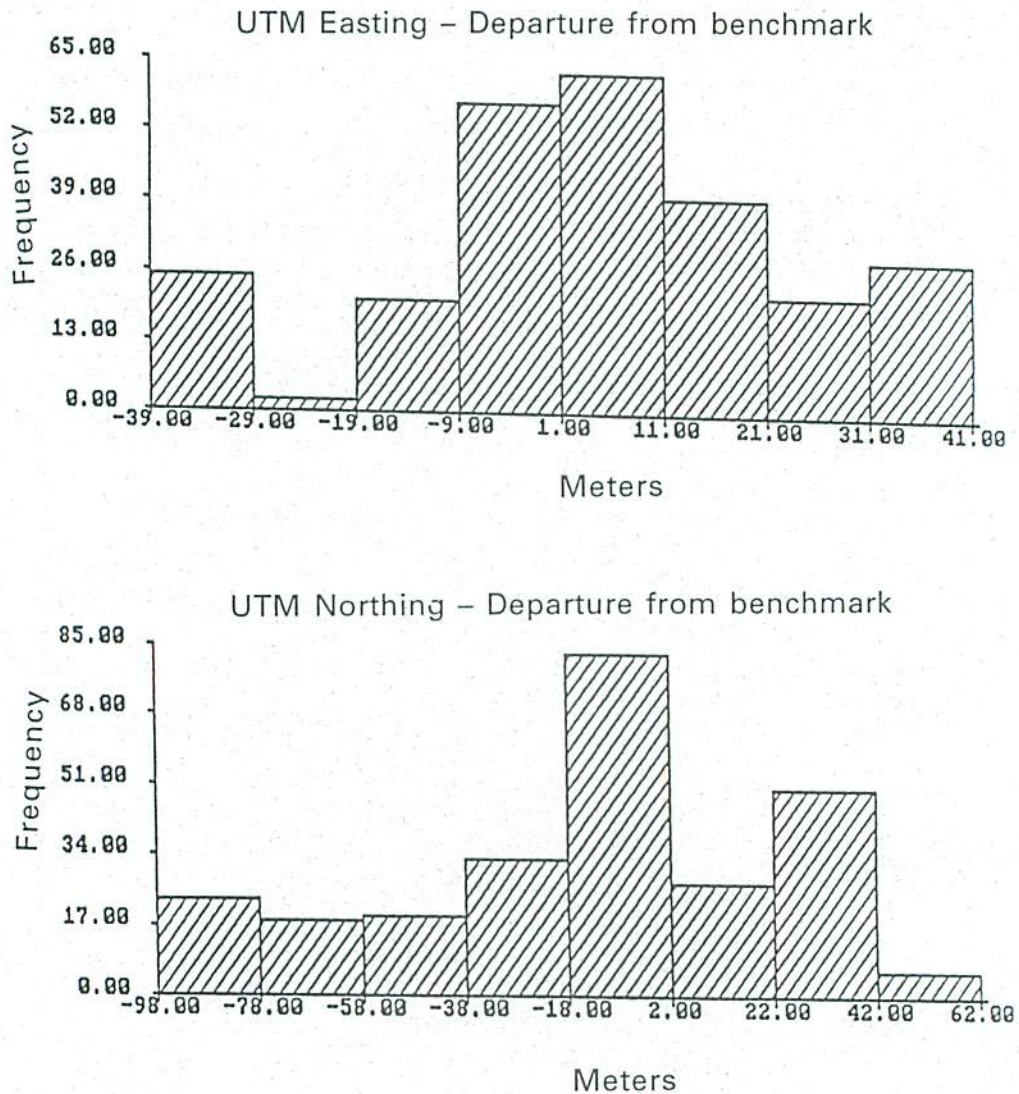
Satistics for Histograms:

Number of Recordings= 259

FIELD	N	MEAN	STD	MIN	MAX
NORTH_DEP	259	-13.85	38.22	-98.00	43.00
EAST_DEP	259	4.34	18.65	-39.00	41.00

Figure 12. Histograms displaying departure of GPS readings from a known benchmark. Note the similarity to a normal distribution.

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To assess the accuracy of the Garmin SRVY II GPS receiver, a series of tests were made using a control point as a known location. For each test, several hundred position fixes were taken and the radial distance from the control point was calculated (error vector). The results of five separate tests over a 2-day period were averaged and a cumulative frequency distribution was constructed (Fig. 13). The results indicated that about 80 percent of the position fixes fell within a 30-m radius of the control point. Since the requirements for fire mapping are ±50 m, then the standard (nondifferential) accuracy and precision of the Garmin SRVY II was sufficient to meet fire mapping requirements.

As of January 1993, the available constellation consisted of 21 active satellites, which provide full 3-D coverage when all are broadcasting. Additional spare satellites to be placed in orbit in the future will provide for a greater selection and result in fewer signal blockage problems and lower PDOPs.

Mapping fire boundaries

Hand-sketched outlines of the fire boundaries compare well with the GPS-derived fire boundaries (Fig. 14), except that hand-sketched maps show a less detailed boundary. In areas where there are few geographic controls, such as streams and lakes, the hand sketches lack detail; the GPS-derived outlines display the same level of information in all cases.

The hand sketch of Fire 28 differs substantially from the GPS-derived outline in the north section of the fire. This is because the hand-sketched map includes several small spot fires north of Fire 28; the GPS mapping did not include these.

For both Fire 14 and Fire 28, the area represented by the hand-sketched fire boundary is larger than that determined by GPS mapping. This is partly due to the inclusion of spot fires and the less precise nature of the hand-sketched boundary.

Both fires were small enough to be sketched while the helicopter hovered at an altitude from which the entire fire was visible. For large fires this "birds-eye-view" approach is not feasible. In contrast, GPS is not affected by the size of a fire — the level of resolution for the fire boundary is dependent on the speed at which it is mapped.

Mapping timber roads and trails

GPS is an effective and rapid means of mapping timber roads and trails if supplementary or recent aerial photos are unavailable. The current manual methods used by timber companies and the OMNR are approximations of road or trail locations. During the field trials, the GPS road mapping exercise was hampered by an incomplete satellite constellation. Rugged topography can also block the satellite signal and result in data gaps. However, the GPS-mapped roads are within the accuracy of the 1:250 000 NTS maps, and are a useful approximation on OBM 1:20 000 digital base maps. For greater detail and more precise road location, differential GPS is recommended.
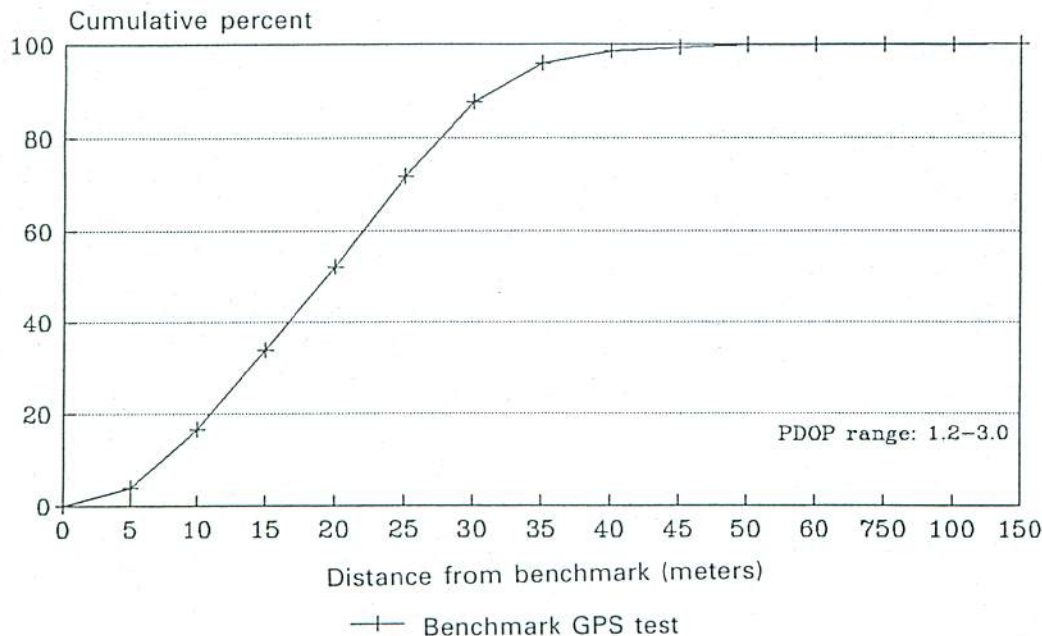

Figure 13. Cumulative frequency distribution of GPS positions, showing distance from a control point (benchmark); 80 percent of the GPS positions fall within 30 m of the control point.
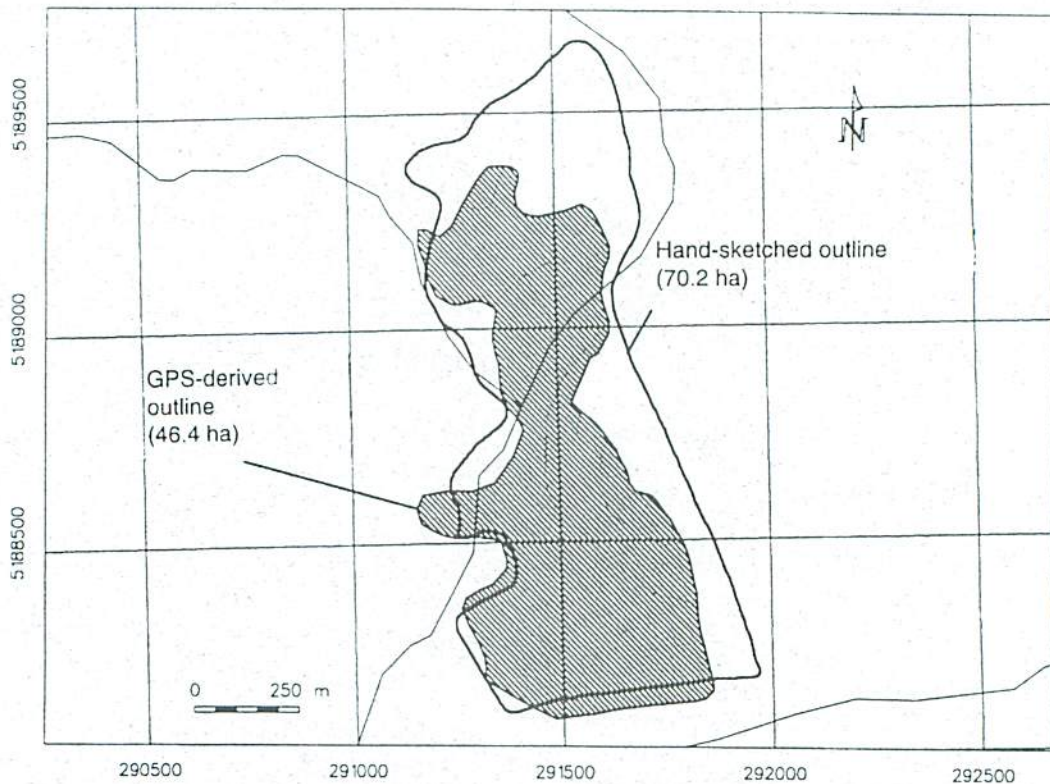
17

Figure 14. GPS-determined fire boundary overlaid by a hand-sketched boundary of Fire 28, Ranger Lake Fire Attack Base, Sault Ste. Marie District.

Mapping fire values-at-risk

The current manual mapping methods involve estimating the location of fire values-at-risk primarily from archive files and maps, and transferring these locations onto 1:50 000 topographic maps. No geographic coordinate correlation exists between the archive files containing the attribute information and the maps. With GPS, the location of fire values-at-risk can be estimated to within ± 50 m. The fire values-at-risk database contains both geographic coordinates and attribute information that can be easily manipulated on the digital base map or in the database. Using the GPS locations as a benchmark, it is possible to estimate the level of accuracy in the original fire values-at-risk data (Fig. 8, Table 4). With continued use of GPS to georeference fire values-at-risk, the overall quality of the database will improve. It is also important to note that on smaller scale maps (e.g., 1:250 000 versus 1:50 000) there is less visual difference between GPS- and nonGPS-determined positions because the symbol covers a larger area.

Table 4. Comparison of GPS-derived locations and original file locations for fire values-at-risk, Ranger Lake Test Block.

| Value	Detail	Values-at-risk maps		GPS		Departures	
		Easting	Northing	Easting	Northing	Easting	Northing
D172	Huntcamp	293575	5190200	293607	293607	32	-58
D48	Huntcamp	284850	5196750	284447	284447	-403	74
D100	Huntcamp	311675	5195050	311939	311939	264	-167
D67	Huntcamp	294275	5177775	294059	294059	-216	83
Camp4	Access Pt	294125	5181275	293991	293991	-134	166
D37	Huntcamp	290750	5186250	290553	290553	-197	-372
D92	Huntcamp	299150	5193750	298885	298885	-265	16
T2	Tower	300600	5193575	300579	300579	-21	-39
D27	Dwelling	289650	5184425	289421	289421	-229	113

18
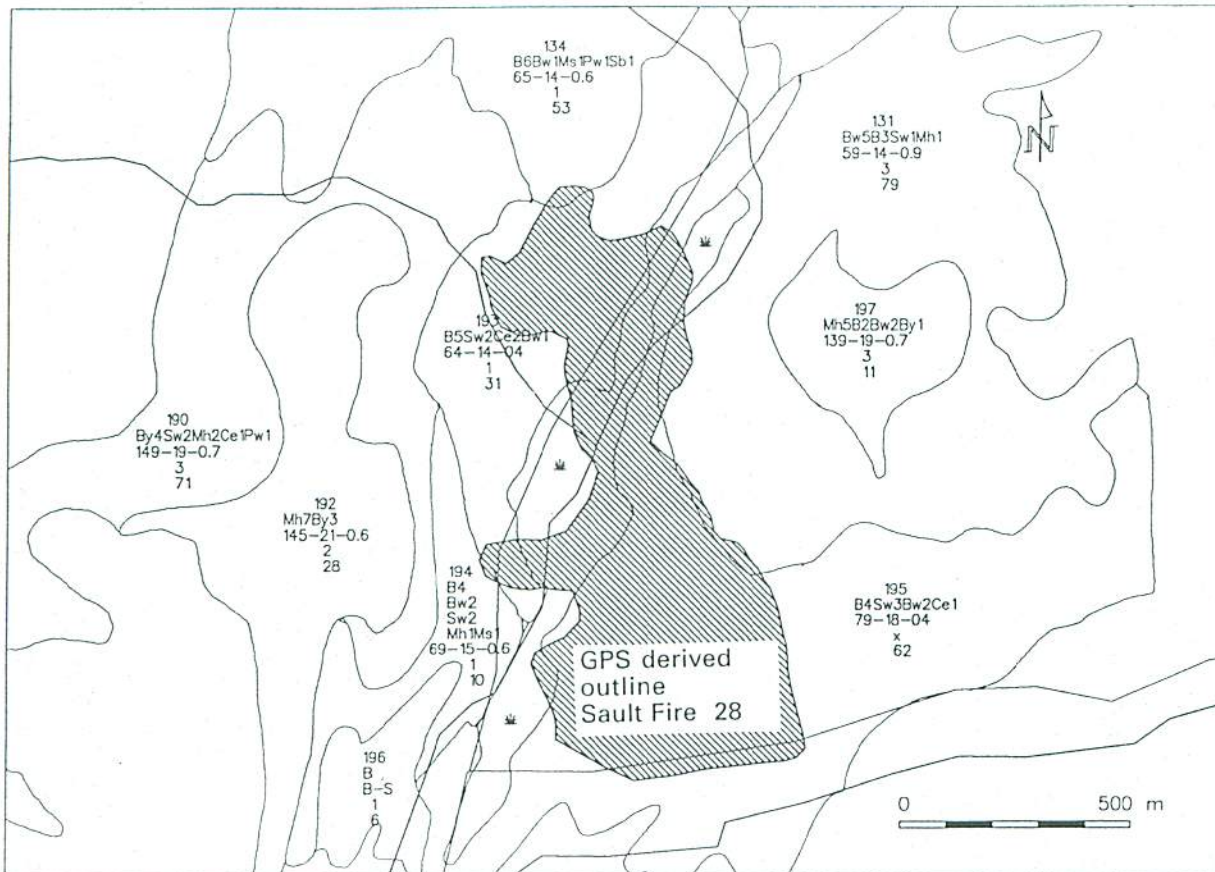
Figure 15. Forest stand polygons overlaid by a GPS-derived polygon of the burn area (see Table 5 for details).

Fire impact on forest values-at-risk

The impact of a fire on forest stands can be quickly calculated by overlaying the fire boundary polygon (derived from GPS mapping) on the forest stand polygons for the area (derived from the Forest Resource Inventory) (Fig. 15, Table 5). Current limitations on the use of this method within the study area are the lack of digital OBMs and digitized Forest Resource Inventory maps. An alternative would be to transfer reclassified LANDSAT imagery as polygons to the desktop mapping system.

Rate of fire advance

Because of the low fire hazard during the field portion of the project, no tests could be made on active forest fires in the area. To assess the capabilities of the portable GPS/ desktop mapping system in an active fire situation, it was used by the CFS to map the progress of grass fires in South Africa. Since the GPS receiver provides both geographic coordinates as well as the time, it is possible to calculate the rate of advance along the fire front and the rate of fuel consumption for a given area (GPS data courtesy of Doug McRae, Canadian Forest Service–Sault Ste. Marie).

Figures 16 and 17 show the fire front boundaries with labels that indicate the start and end times of each flight

that defined the fire front. The average flight time was about 10 minutes, the length of the fire front ranged from 6 to 10 km, and the helicopter ground speed ranged from 28 to 65 km/hr. In some cases, one flight started immediately after the previous one ended, i.e., the fire front was flown from west to east and the next flight flew the same front from east to west, starting at the point where the previous flight had ended. This method leads to a wedging effect, in which the fire front will not have advanced far at one end (starting end of the second flight), but will have advanced farther at the opposite end, other conditions being equal. The wedging effect was compounded by the fact that this was a rapidly spreading grass fire. For most fires in northern Ontario this problem would not be as significant, at least with respect to rate of spread.

Figure 18 shows four polygons that represent four fuel consumption rates, as defined by four flights over the fire front. The rate of fuel consumption was calculated as the area between fire fronts divided by the time differential between fronts. The time differential between fronts was determined by averaging the start and end times for a flight, and subtracting the average time for both flights. The shape and area, as well as the rate of fuel consumption, for each of these four polygons are likely distorted to some extent due to the wedging effect described previously.
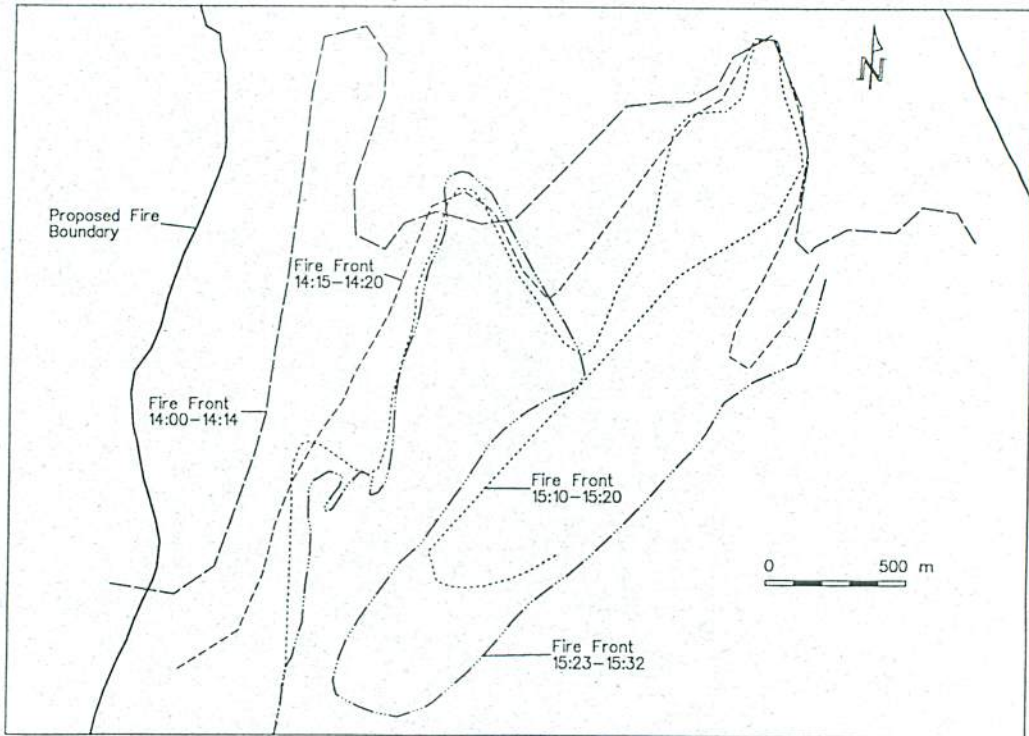
19

Figure 16. GPS-determined fire fronts of a grass fire in South Africa. Four fire fronts are represented showing flight time. (GPS data courtesy of Doug McRae, Canadian Forest Service–Sault Ste. Marie.)
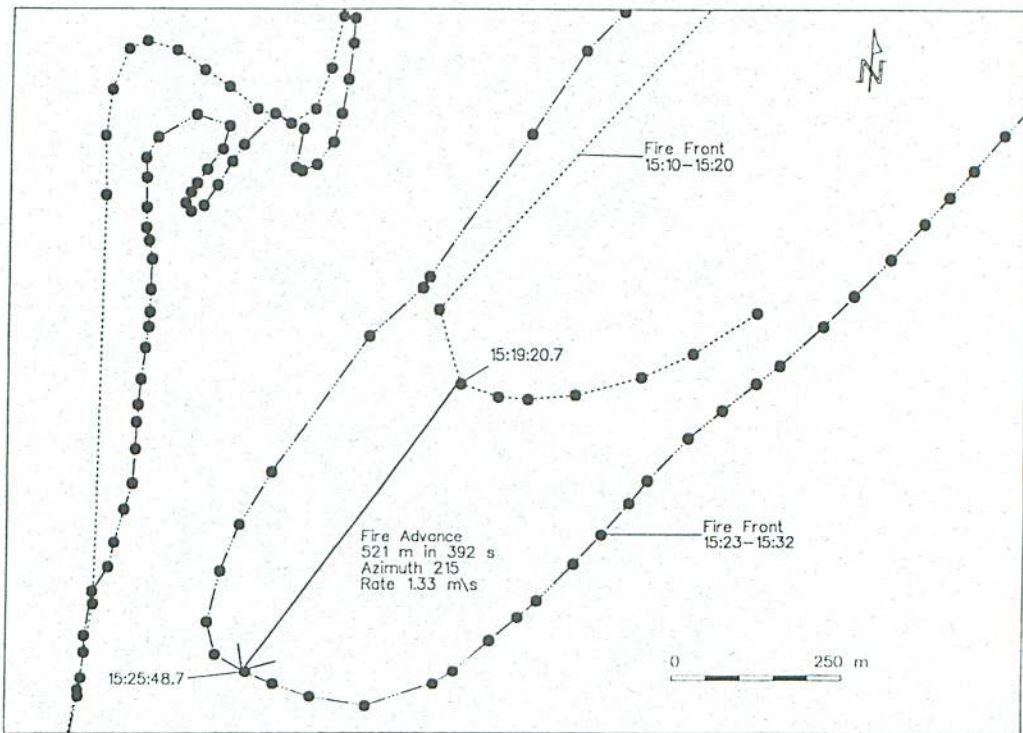

Figure 17. Magnified portion of Figure 8 showing the rate of advance of a fire "tongue". GPS derived positions are displayed as filled circles.
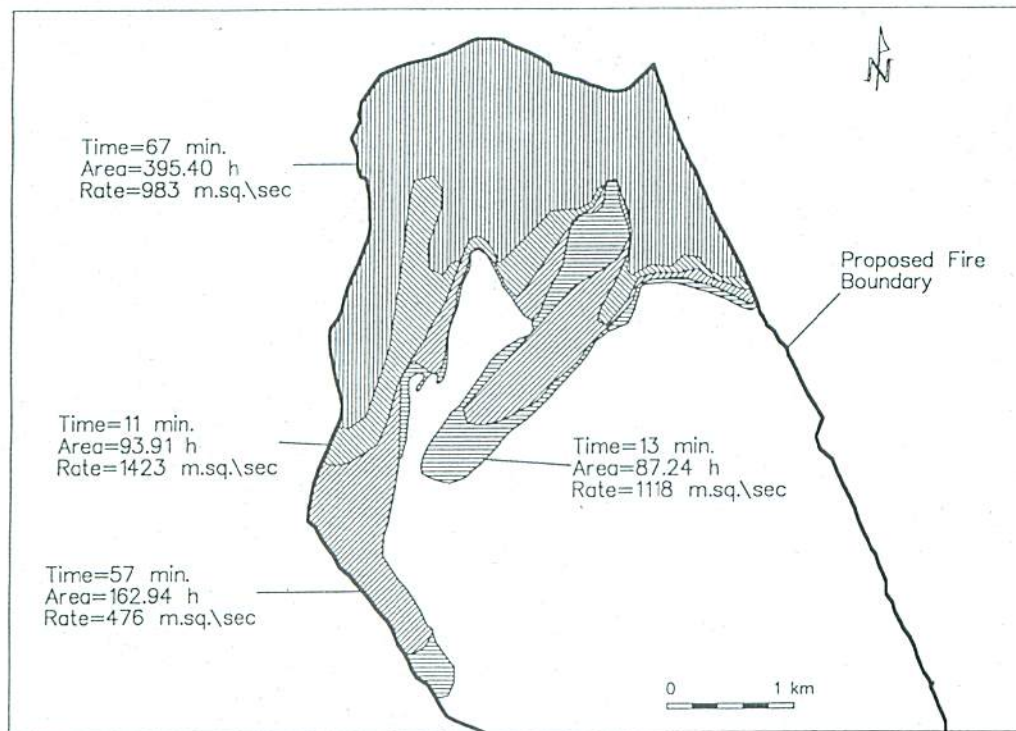
Time=67 min.
Area=395.40 h
Rate=983 m.sq.\sec

Time=11 min.
Area=93.91 h
Rate=1423 m.sq.\sec

Time=13 min.
Area=87.24 h
Rate=1118 m.sq.\sec

Time=57 min.
Area=162.94 h
Rate=476 m.sq.\sec

Proposed Fire
Boundary

0   1 km

Figure 18. Polygons representing rate of fire area growth as defined by four different flights of the fire front.

Two methods that could lessen the wedging effect would be to fly the fire fronts as quickly as possible while still maintaining resolution, and/or delay the second flight for as long as possible. In Figure 19 only two of the fire fronts were used (first and fourth flights) in calculating the rate of fuel consumption. The time lapse between the two flights was 70 minutes.

Data Transfer

Vector-based GIS (ARC/INFO)

GPS data for Sault Fire 28 was transferred to an ARC/INFO system through a cooperative effort with personnel from the Aviation, Flood and Fire Management Branch of the OMNR.

GPS and base map data may be transferred to ARC/INFO from a number of different stages in the GPS-ELINX-QUIKMap data transfer process:

1. GPS data can be exported directly from the Magellan postprocessing software by selecting *To ARC/INFO* from the *Convert* command of the pulldown menu. This produces an ASCII file with the format:

    record_no, longitude, latitude.

With the ARC/INFO *Generate* command it is possible to produce an ARC/INFO point file that can be converted into line coverage format.

2. A small utility was written that takes Magellan GPS data and produces two different ASCII files. The first file has the format:

    record_no, longitude, latitude.

The second file contains all of the satellite information and has the format:

    record_no, time, altitude, mode, satellites, signal quality, pdop.

The first file can be imported into ARC/INFO with the *Generate* command. The file containing the satellite information can then be linked to the first file using the *ARC/INFO Relate* command, because each file contains a common field (record_no). The reason for transferring satellite information is for quality control of the GPS data. This utility was written because the Magellan ARC/INFO transfer function that was described in (1) above does not transfer this satellite information.
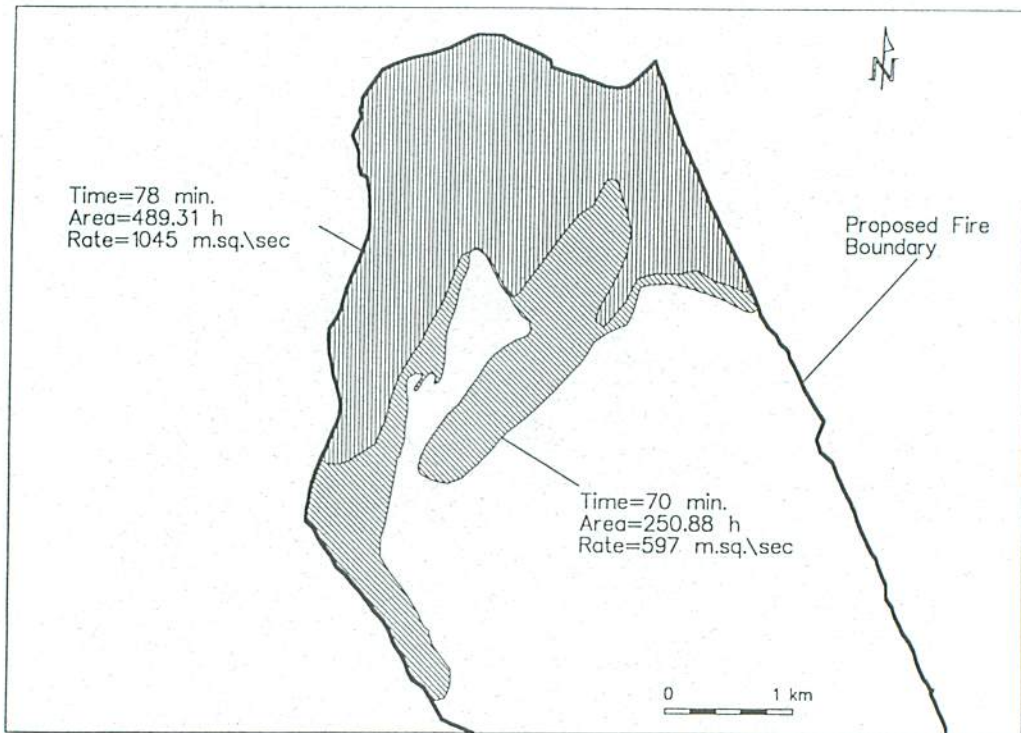
Figure 19. Polygons representing fuel consumption rates for the two main fire fronts. Time lapse between the two flights was 70 minutes.

3. QUIKMap memo information (polyline, polygon database information) can be imported into ARC/INFO using QUIKMap's DBT2ASC translation module. The DBT2ASC output can be altered to a format that the *Generate* command in ARC/INFO will accept to produce a line coverage format.

4. QUIKMap point data information can be imported into ARC/INFO by creating an ASCII output of the point database information, and then altering it to a format that the *Generate* and *Relate* commands will accept to produce ARC/INFO point data.

5. QUIKMap basemap information can be exported to ARC/INFO as a DXF file through the *Export to DXF* option on the QUIKMap output menu.

6. Methods (3) to (5) above, which involve QUIKMap itself, will also work in the reverse direction, i.e., from ARC/INFO to QUIKmap.

Raster-based GIS (SURFER-IDRISI)

To demonstrate the transferability of both the desktop mapping (QUIKMap) vector information and GPS-derived data into a raster-based GIS,[6] the following steps were taken:

1. Elevation contours for the area surrounding Sault Fire 28 were digitized using QUIKMap's *Trace* command. This resulted in a database containing latitude/longitude coordinates for each elevation contour. Using the QUIKMap translator DBT2ASC, the database records were converted into an ASCII file with the format:

longitude, latitude, elevation (i.e., x, y, z)

2. The longitude, latitude, and elevation data file was then read into SURFER, a contouring and 3-D rendering software package that created a "gridded" file, also referred to as a DEM (Digital Elevation Model). Using SURFER, the topography of the area containing Fire 28 can be viewed in 3-D perspective (Fig. 20).

3. The GPS database, translated by ELINX, was exported as an ASCII file that contained longitude and latitude coordinates. The coordinates were then imported into SURFER as a boundary line file (.BLN), and draped on the 3-D perspective of the topography.

4. The DEM was reformatted for import into IDRISI, a raster-based GIS, and reclassified to reflect 15 elevation classes. GPS longitude and latitude coordinates for the Fire 28 fire boundary were imported as a vector file and

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[6] Information is represented by pixels on the screen, than as point, line, or polygon information as is the case in vector-based systems.
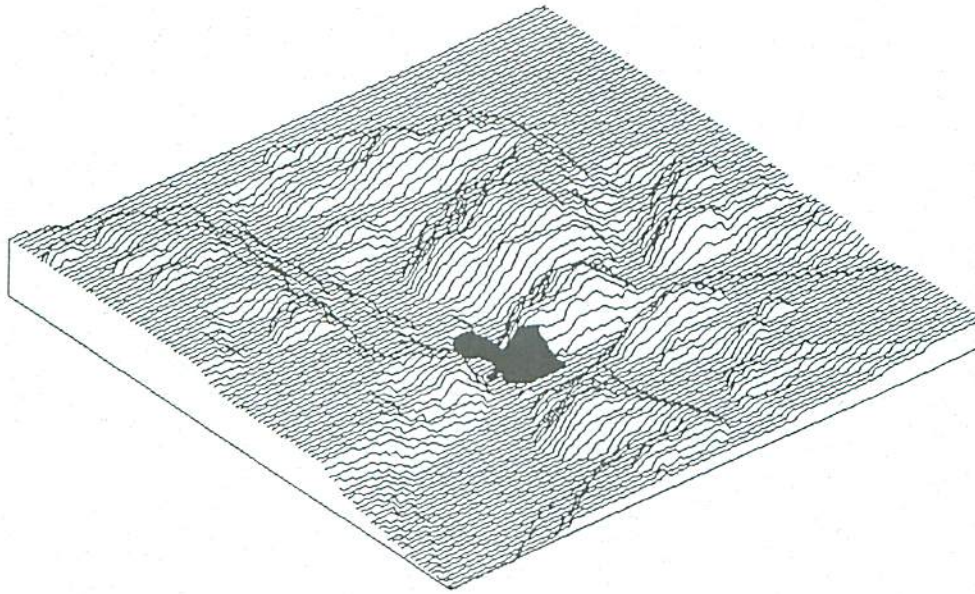
Figure 20. Digital elevation model (DEM) for the Fire 28 area looking NNE at an inclination of 60° with the GPS-derived fire boundary overlaid on the topography (DEM).

overlaid on the elevation image. The GPS vector data was also converted into a raster polygon. The GPS-derived polygon representing the area of the burn was then draped over the DEM (topographic contours) to provide a 3-D perspective of the fire boundary.

5. Forest stand polygons in QUIKMap format were converted into ASCII files and imported as vectors into IDRISI. These were then converted into raster polygons. The forest stand polygons were then draped over the DEM to display their location, relative to topography.

Other types of spatial analysis and modeling are possible once data has been transferred into IDRISI; however, the intent of this study was only to demonstrate the upward transferability of the GPS/desktop mapping system information.

Decision Support

A fire attack base equipped with a portable GPS/desktop mapping system has at its disposal a computer system that contains fire and natural resource values-at-risk. These can be accessed to quickly and accurately map the progress of a forest fire and to locate hot spots and fire values-at-risk. Confidence can be placed in the level of accuracy of the data. Simple spatial or database queries can quickly provide the fire supervisor with information on which to base decisions on how fire fighting resources should be allocated, and to determine the values-at-risk concerned and their level of priority.

Example A: Radial Search

Figure 21 demonstrates the use of a radial search to determine all fire values-at-risk falling within a radius of 4 km of Fire 28. An example of the information available for these values is summarized in Table 4 and is immediately available on screen to the fire supervisor.

Example B: Fire Attack Base Response Radius

In this example, the fire archive digital data from 1982–1992 for the Sault Ste. Marie District were transferred into the QUIKMap environment. This information was plotted on a 1:250 000 EMR digital base map to illustrate the pattern of fire occurrence, and to assist the fire manager in identifying the most suitable location at which to base a helicopter within the Sault Ste. Marie District. The procedure involved tagging and counting the number of fires within a 90-km radius of Ranger Lake, Sault Ste. Marie, and Blind River. The result of this query indicated that Ranger Lake was the most appropriate location (Fig. 22).

Example C: Fire Intelligence and Operations Support

Members of several provincial fire teams participated in the design of a database that would support their particular operations. Two data files were created: CREWINFO, a point file containing information such as crew name, home base, last days off, and regular working hours; and HOSELINE, a polyline/polygon/point file, which contained fields such as number of lengths of hose available, number of pumps available, and other fire equipment data.
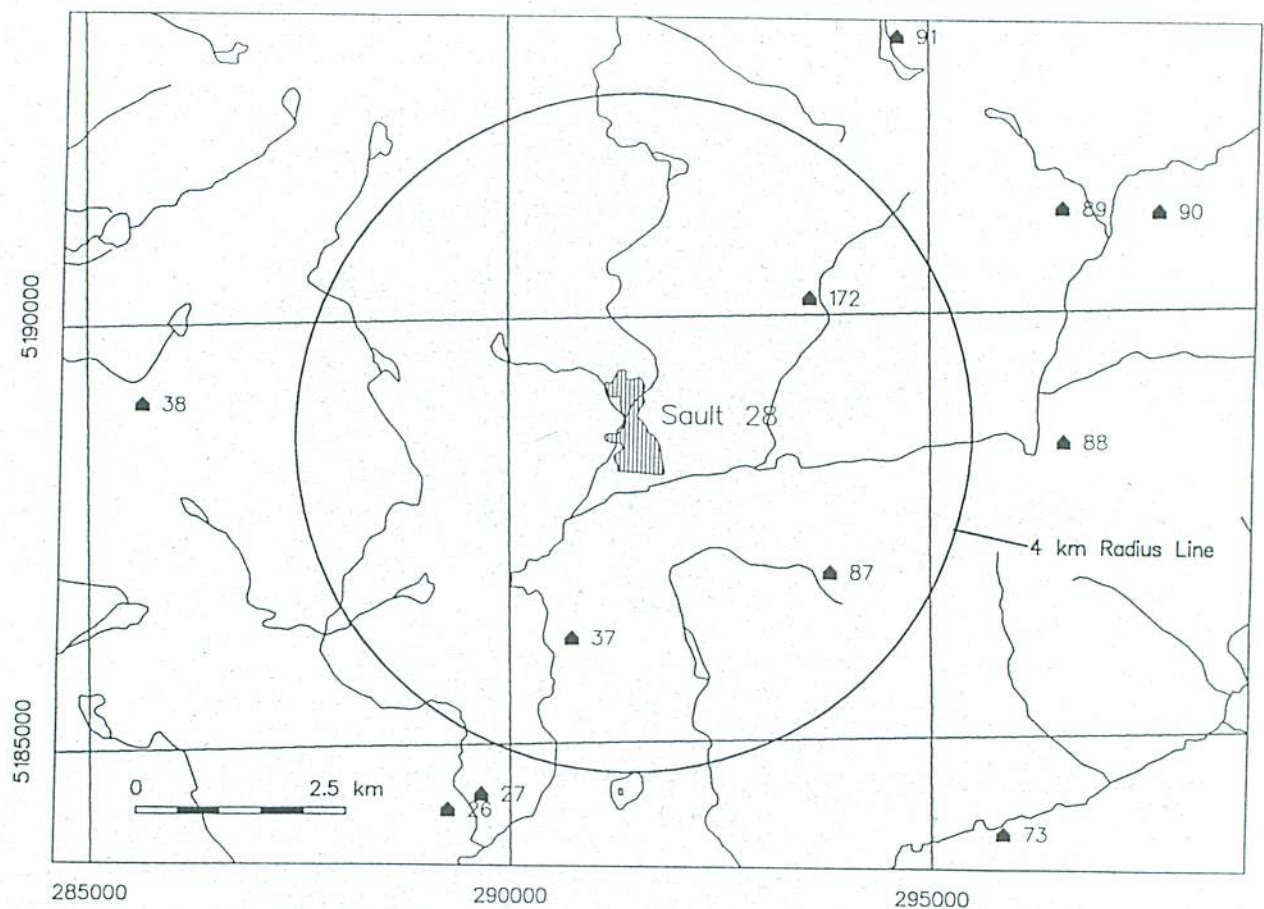
Figure 21. GPS-derived fire boundary for Fire 28. The circle represents a spatial query of the fire values-at-risk database (dwellings) for all records falling within a 4-km radius.

Table 5. Stand type, species, and number of hectares burned–Sault Fire 28.

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STAND_NUM	SPECIES	AGE	HEIGHT	STOCKING	SITE	MODIFIER	BURN_AREA
134	B6Bw1Ms1Pw1Sb1	65	14.0	0.6	1	53	1.80
131	Bw5B3Sw1Mh1	59	14.0	0.9	3	79	1.47
195	B4Sw3Bw2Ce1	79	18.0	0.4	x	62	28.01
193	B5Sw2Ce2Bw1	64	14.0	0.4	1	31	9.42
194	B4Bw2Sw2Mh1Ms1	69	15.0	0.6	1	10	0.08
0	swamp	0	0.0	0.0			7.25

Geographic coordinates can be derived using the GPS receiver and basic attribute and descriptive information that can be entered into the computer in the field. The GPS data can then be transferred and appended to the data files to update the fire intelligence and operations map (Fig. 23).

Training Requirements

During the fire season (1992 and 1993), the crew leader and fire crew personnel were trained in the use of GPS. This included background reading and approximately 2 days of hands-on training in the field.

The crew leader and a technical assistant were also trained in the use of desktop mapping. One full day was spent reviewing the QUIKMap educational package, one-half day learning advanced digitizing functions, and one-half day training in the use of ELINX (GPS to desktop GIS translation software). The crew leader and technical assistant had received some limited computer experience prior to this training.

Major contributing factors to this successful training program were strong interest and enthusiasm on the part of the crew, adequate commitment and allotment of time for
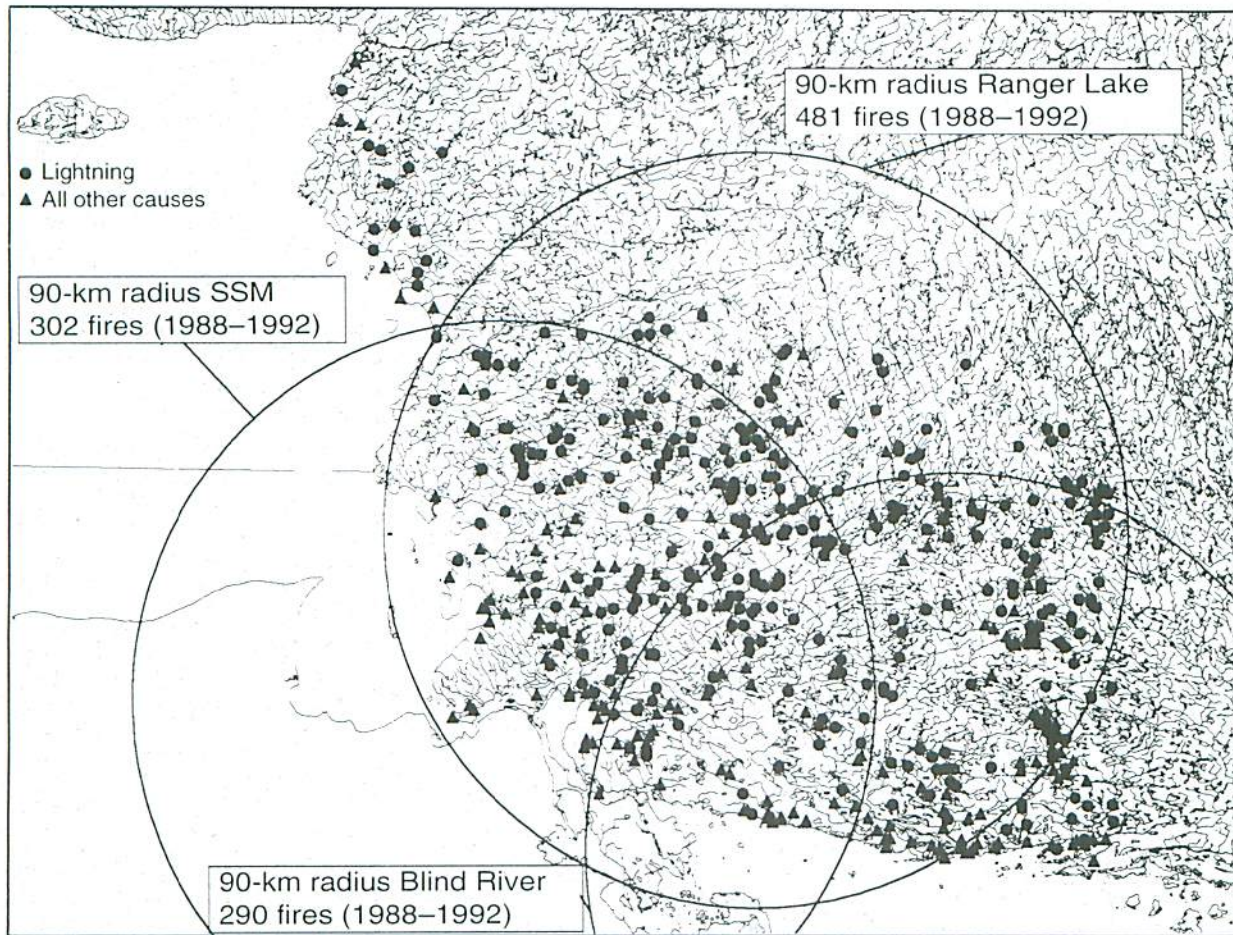
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Figure 22. Fire attack base response radius. Filled circles represent fire archive digital data from 1983–1992; large open circles from left to right represent 90-km radii for Sault Ste. Marie, Ranger Lake, and Blind River.

training by supervisory staff, and the fact that the individuals had some computer experience.

Ideally, each crew leader, fire boss, and communications officer should be trained in the use of GPS and desktop mapping. Each member of the fire crew should receive training in GPS.

A time estimate for training staff follows:

Crew leader, fire boss, and communications officer:

GPS	2 days
QUIKMap	1 day
Advanced QUIKMap	1 day
ELINX	1/2 day
GPS/GIS concepts	1/2 day

Other fire crew personnel:

GPS	2 days

As a prerequisite for training, fire crew personnel should have adequate experience in traditional compass navigating and map reading. It would be more difficult and less productive to train personnel in these advanced skills if they are weak in traditional methods. Crew leaders and the fire boss should have some background in computer applications, such as database management, mapping, CAD, or other graphics software.

CONCLUSIONS AND RECOMMENDATIONS

The results indicate that a portable GPS/desktop-mapping system can be integrated into the daily operations of a typical fire attack base and can be quickly moved into a temporary field camp to support fire control operations. Fire crew personnel can be trained in the use of GPS and desktop mapping within 1 week. Information on the area and perimeter of a fire is available immediately after the
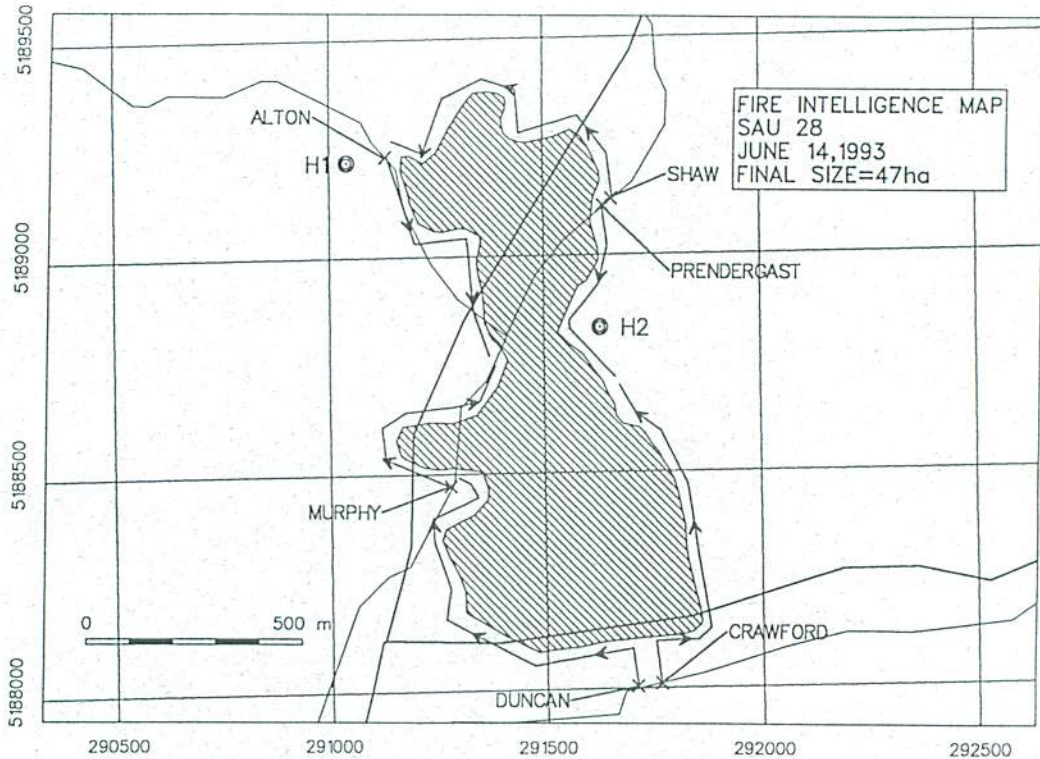
Figure 23. Fire intelligence and operations support; GPS-derived fire perimeter with CREWINFO (names) and HOSELINE (arrows) databases.

transfer of the GPS data. High quality maps showing values-at-risk, the perimeter of the fire, drainage, topography, and transportation routes can be produced in a few minutes on an inkjet printer.

The results of this project should be used in the design of future phases of the Fire Management Information System currently being developed by the Ontario Ministry of Natural Resources.

One person should be selected to be the district expert user. This person would maintain and oversee the GPS/ desktop mapping system.

One possible training problem is that crew leaders and other fire crew personnel are seasonal employees and may not return the following year. Employees who do return may need some refresher training. In addition, consideration will have to be given to the scheduling of fire personnel to ensure that an expert user is available at all times and that sufficient crews have been trained in the use of GPS.

GPS receivers that are designed for high accuracies (i.e., submeter) have difficulty in operating over broken terrain and under a stand canopy. During the initial field trials, the Magellan NAV 5000 PRO had difficulty in acquiring a

satellite signal through a forest canopy in typical Canadian Shield relief while in a mobile, continuous mode of operation. This is primarily because the submeter design of the instrument requires a high quality satellite signal from four satellites before it can calculate a position fix.

The GARMIN SRVY II, used during the operational phase of the project, was not hampered by a forest canopy under similar relief conditions while in a mobile, continuous mode of operation. The SRVY II is not designed for submeter capability, yet it will provide a 1- to 3-m level of accuracy.

Consideration should be given to adapting the desktop mapping software and GPS linkage software for the OMNR GPS/Loran systems that are planned for the OMNR's fleet of aircraft.

Consideration should also be given to assessing the limits and capabilities of differential GPS to achieve higher accuracies. Many OMNR applications require at least 10-m accuracies in either real-time or postprocessing modes. Various options are available to achieve this, but information and research is lacking. Telecommunications (telemetry) will play an important role in any application that requires real-time accuracies, and will simplify the process of acquiring subdecameter capability.

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ACKNOWLEDGMENTS

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