Enhancing the Forest Soils Mapping Database for Northern Ontario: Development of a Prototype GIS-based Approach

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ABSTRACT

Using existing mapped and remotely sensed data for a 400-km² test area near Ignace, Ontario, three complementary methodologies were developed and tested to discriminate forest soil conditions important to operational (i.e., 1:15 840 to 1:20 000 scale) forest management planning. All three approaches use Geographic Information System (GIS) technology in concert with expert systems to define soil polygons. The methodologies appear to be especially suited to geographic areas where appropriate forest soil mapping is either currently unavailable, is of unknown quality, or is available only at smaller (e.g., 1:100 000) than required scales.

The methodology integrates digital spatial data from the following five sources: (1) National Topographic System (1:50 000) base maps; (2) Ontario Land Inventory (1:250 000) soils theme maps; (3) Northern Ontario Engineering and Geological Terrain Survey (1:100 000) surficial landform maps; (4) provincial Forest Resources Inventory (1:15 840 and 1:20 000) timber inventory maps; and (5) satellite (SPOT, ERS-1, and Landsat [TM]) imagery.

Office and field examination of the resulting map sheets confirm that the methodology provides reliable, spatially based soils information. Potential modifications that could be implemented in the future are also discussed, and additional operational testing, incorporating these improvements, is recommended.

RÉSUMÉ

À l'aide de données de cartographie et de télédétection existantes pour une zone d'essai de 400 km² près d'Ignace (Ontario), 3 méthodes complémentaires de repérage des sols forestiers importants pour la planification opérationnelle de l'aménagement forestier (échelle de 1:15 840 à 1:20 000) ont été mises au point et testées. Les trois approches utilisent la technologie des systèmes d'information géographique pour définir des polygones de sol. Elles semblent particulièrement convenir aux endroits où la cartographie des sols forestiers est insuffisante, inadéquate, de qualité inconnue ou d'échelle trop réduite (par exemple 1:100 000).

Les données spatiales numériques des cinq sources suivantes sont utilisées : (1) cartes de base (1:50 000) du Système national de référence cartographique; (2) cartes thématiques sur les sols (1:250 000) de l'inventaire des terres de l'Ontario; (3) cartes du relief (1:100 000) du Northern Ontario Engineering and Geological Terrain Survey; (4) cartes d'inventaire forestier (1:15 840 et 1:20 000) de l'inventaire provincial des ressources forestières; (5) imagerie de satellites (SPOT, ERS-1 et Landsat [TM]).

Les examens au bureau et sur le terrain des cartes produites ont confirmé que l'on pouvait ainsi obtenir de l'information fiable, à référence spatiale, sur les sols. Des possibilités d'amélioration sont examinées, et des recommandations sont formulées en vue de la réalisation d'essais opérationnels supplémentaires lorsque ces améliorations auront été apportées.

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ENHANCING THE FOREST SOILS MAPPING DATABASE FOR NORTHERN ONTARIO: DEVELOPMENT OF A PROTOTYPE GIS-BASED APPROACH

1.0 INTRODUCTION

Practising foresters in Ontario must be increasingly stringent and rigorous in their operational management and planning processes. Furthermore, to remain globally competitive it is imperative that the forest industry in the Province of Ontario clearly demonstrate its ability to practise sustainable forest management. Given the current shift toward "ecosystem-based management", there is an increasing awareness that better spatially based soils information is urgently required.

For many key components of forest planning and operations—road planning and construction, equipment operability, erosion/compaction hazard prediction, harvesting and silvicultural planning, growth and yield prediction—reliable soils information is urgently needed at operational levels (e.g., approximately a 1:20 000 scale) of forest management.

Throughout much of northern Ontario forest soils mapping is widely acknowledged as inadequate for addressing these issues. Most soils mapping associated with commercial forest land in Ontario is either local (e.g., derived directly from agricultural soil surveys near townsites) or was completed at a very broad scale (e.g., the Ontario Land Inventory at the 1:250 000 scale). As such, it is of limited use. Despite this, operational planning requires many key decisions that would be greatly served by reliable soils information for a given geographic area.

A principal impediment to undertaking conventional soil survey approaches in remote forest lands is that it is prohibitively time-consuming and expensive. Although there is an acknowledged need for such mapped data, mapping forest soils in this manner is not a feasible alternative given the vast forested land areas that exist across northern Ontario. As well, terrain features of much of northern Ontario are very heterogeneous, because they are a product of a complex glacial history; an abundance of shallow-soil, landform-controlled surface features; and mainly immature, dissected drainage patterns.

Recent advances in Geographic Information Systems (GIS) and the availability of high quality satellite digital imagery allows the integration of a variety of existing and new data sets that may be particularly useful in addressing this shortfall of reliable, spatially based soils information. The current report describes three test methodologies that were applied to a representative 400-km² study area near

the town of Ignace in northwestern Ontario. The primary purpose of this work was to provide practical, cost-efficient, operational-scale soil information as required by foresters using new approaches and technologies. A GIS-based approach is integrative, and also provides the important additional capability of providing products that are readily useable, updateable, and interpretable for a wide range of applications.

1.1 Soil and Landform Maps Currently Available for Northern Ontario

Most forest land in southern Ontario is covered by existing soils maps that were prepared at scales of 1:50 000 or 1:63 360 by Agriculture Canada. Similar soils mapping for the geographic areas currently included in the Northwestern and Northeastern regions of Ontario is available for only a few small areas.

Other than some very broad provincial-level coverages produced by the Ontario Geological Survey, the only universal landform and surficial deposits mapping for these two regions is the Northern Ontario Engineering Geological and Terrain Survey (NOEGTS) maps. NOEGTS mapping, at a scale of 1:100 000, commenced in 1977 under the auspices of the Ontario Engineering Geology Terrain Study (Gartner et al. 1981). NOEGTS mapping, consisting of a photointerpretive evaluation of the near-surface geological formations, was designed primarily for engineering interpretation and the identification of sources of aggregate, and of difficult and problem terrains.

Also available is the more generalized and physiographically oriented Ontario Land Inventory (OLI) Land Classification mapping, prepared at a scale of 1:250 000. OLI Land Classification maps identify different landscapes units and/or land units; an associated database provides a breakdown of each land unit by its percent coverage of soil texture, petrography, depth, and moisture regime classes of the parent material of each component (Richards et al. 1979).

1.2 The Prime Land Inventory Program

Between 1985 and 1992, the Ontario Ministry of Natural Resources (OMNR) undertook a Prime Land Inventory Program. This program attempted to identify regional patterns of soil features that could help generally to categorize northern Ontario forest lands into "prime",

"intermediate", or "non-prime" for the growth of important tree species. The approach, which varied between the western and eastern parts of northern Ontario, incorporated some limited but critical soils information into a decision-tree system. This was then applied to broad landscapes at the 1:250 000 scale.

The Prime Land Inventory Program was intended to help forest planners develop more effective ways of scheduling, at a synoptic level, various harvest and silvicultural treatments based on the inherent productivity of different geographical areas of forest lands (Greenwood 1987, Towill and Sims 1989).

The Prime Lands Inventory Program was first undertaken within the OMNR's Northern (now Northwestern) Region in 1985. The purpose of this initiative was to delineate relatively homogeneous areas for classification using a Prime Land Key developed by the OMNR (Jones 1986). The Prime Land Key required the input of parameters related to soil depth, depth of organic material, soil texture, and drainage characteristics to determine an area's Prime Land Class and Subclass (Greenwood 1987, Robinson, Merritt and deVries Limited, 1987).

In 1987, Robinson, Merritt and deVries Limited evaluated the suitability of utilizing NOEGTS and OLI Land Classification mapping for the prediction of Prime Land Class and Subclass for creation of a Prime Land Inventory for use within the Northwestern Region. A comprehensive study integrated these map bases along with data collected from 532 field sampling sites within ARC/INFO GIS (Robinson, Merritt and deVries Limited 1987). The investigation indicated that the OLI Land Classification attribute data appeared to be generally more consistent when compared to the NOEGTS attribute data. It was also capable of providing an appropriate expression of Prime Land distribution at the regional, district, and broad management unit levels (Robinson, Merritt and deVries Limited 1987).

Based on these findings, the OMNR proceeded to develop algorithms that related independently derived species/site productivity information and OLI Land Classification land unit attribute data to produce an inventory of Northwestern Ontario's land base on the basis of Prime Land Class and Subclass. Algorithm development and 'finetuning' was completed during the late 1980s.

During 1990/91, the OMNR's Northwestern Region Science and Technology Unit (NWRS&T) completed a project to identify and map Prime Lands across northwestern Ontario using an integrated GIS mapping and Prime Land modeling approach (Bill Towill, OMNR, pers. comm.). The map base used was the 1:250 000 Ontario Land Inventory, along with its associated attribute

data, made available in digital format through Environment Canada. These attributes, together with regional growth and yield data and the OLI graphics database, were integrated into a Prime Land classification productivity model. Twenty-two 1:250 000 OLI map sheets and associated polygons were interpreted, classified, and mapped for species productivity (Bill Towill, OMNR, pers. comm.).

Although this information base proved useful for initial landscape stratification, because of the relatively small scale of the maps the spatial resolution was low and the polygon size was large. For example, the average land unit size across three National Topographic System map sheets (NTS 52 F, 52 J, and 52K) was approximately 7 000 ha. While this integrated database allowed for planning at a regional level, a wide range of soil and topographic conditions is known to occur within these large polygon areas. In order for the NWRS&T approach to be useful at the operational forest level, there was a need to refine these large, relatively heterogeneous land units into smaller, more homogeneous soil units.

Recent developments in forest research and forest management policy and practices, as well as technological innovations, provide a basis for significantly advancing the "Prime Land" concept at finer levels of resolution. The current project represents a further step in the development of more effective forest management and forest planning tools particularly suited to northern Ontario.

2.0 PROJECT RATIONALE AND OBJECTIVES

Recent research relating to improved forest management practices and forest soil/site productivity has repeatedly highlighted the need for developing a better spatial understanding of the physical land base, including spatially defined soil and landform information. Until recently it was generally acknowledged that the time and resources necessary to acquire data and develop this spatial product would be prohibitive. However, recent technological advances in GIS-based analyses combined with the integration of remotely sensed data, and the judicious use of field data verification procedures, together provide a promising new alternative.

The main purpose of the current study is to integrate, using GIS technology, existing maps and satellite imagery to refine, redefine, and subdivide OLI-base Prime Land productivity map polygons into more homogeneous soil units. The approach described in this report was developed in cooperation with the Canadian Forestry Service (CFS), the OMNR, and the forest industry (AVENOR Inc., Thunder Bay, Ontario).

The primary objective of this work is to develop a costeffective means to utilize readily available soil, landform, and landscape data to generate new maps that will assist foresters in undertaking operational, ecosystem-based forest management.

3.0 STUDY AREA

To conduct the data integration, a satisfactory study area needed to be chosen. The following criteria were used to select an area:

- large size (at least 400-km² contiguous area);
- representative of the general terrain; a dominance of shallow soil and a variety of typical surficial conditions, surface drainages, and soils;
- under active forest management by AVENOR, with an up-to-date and digitized Forest Resources Inventory (FRI) coverage;
- digital coverages of National Topographic System (NTS) and OLI base maps were available;
- coverage by SPOT, Landsat, and ERS-1 satellite imagery with recent scenes of good quality; and
- · generally accessible by road for field checking.

The area, selected in consultation with the CFS, OMNR, and AVENOR, lies within two 1:250 000-scale OLI maps (52F [Dryden] and 52G [Ignace]). Its centroid is located approximately 18 km west of Ignace, in northwestern Ontario (Fig. 1). The study area covers $400 \, \mathrm{km}^2$ (20 km by 20 km) and lies within AVENOR Inc.'s Dryden Division holdings (Wabigoon Management Unit). The landscape within the study area is dominated by rolling and knobby rock-buttressed landforms with numerous small lakes and wetlands (Mollard and Mollard 1980, Roed 1980).

The digital FRI data for the study area showed that jack pine (*Pinus banksiana* Lamb.) and black spruce (*Picea mariana* [Mill.] B.S.P.) working groups ¹ are almost equally represented on a spatial basis and, together, they account for the majority of the forest cover. Large areas between Crocker Bay and Revell Lake were harvested in the early 1970s. Recent (1992 and 1993) timber harvesting operations have focused on areas approximately 5 km east of Kinmoapiku Lake, 3 km south southeast of Revell Lake, and 7 km south of Revell Lake (Map 1).

4.0 MATERIALS

Several data sets were integrated in various ways to improve the spatial homogeneity of OLI polygons. Those digital data sets acquired or created during the course of the study included:

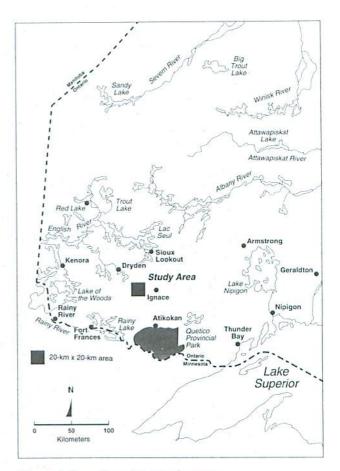
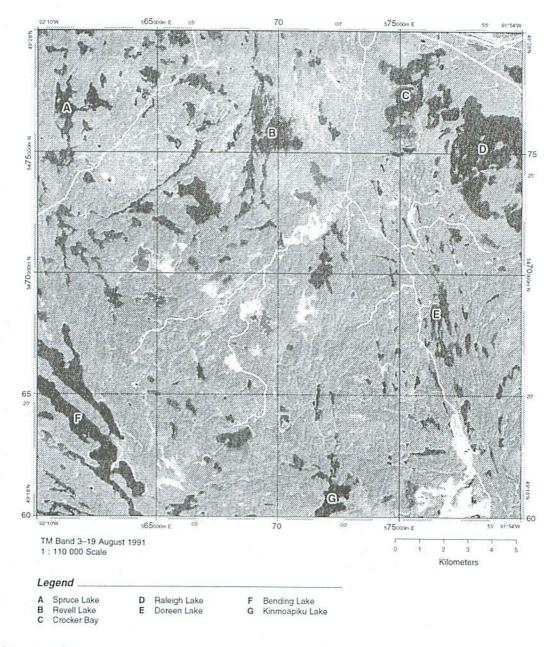


Figure 1. Location of the study area.

- 1:250 000 scale OLI Land Classification maps—52F (Dryden) and 52G (Ignace);
- eight 1:100 000 NOEGTS map sheets (Table 1);
- portions of five 1:50 000 NTS map sheets used to provide ground control points and contour information for georeferencing and to create a digital elevation model (DEM);
- a SPOT Panchromatic satellite image (10-m ground resolution) (Table 2);
- digital FRI data for the entire area at a scale of 1:15 840;
- a Landsat Thematic Mapper (TM) satellite image (30-m ground resolution) (Table 2);
- a ERS-1 satellite radar image (25-m ground resolution) (Table 2); and
- limited ground-truth information obtained from a field survey conducted during the early fall of 1993 (see Section 5.4).

¹ A 'working group' represents a collection of forest stands in which one tree species occurs alone or as the predominant one in a mixture of species.



Map 1. Ignace study area.

Table 1. Northern Ontario Engineering Geology Terrain Study (NOEGTS) database maps digitized for this investigation.

NOEGTS database		NOEGTS	
map number	NTS sheet	study number	NOEGTS study area
5058	52 F/NW	21	Blue Lake area
5059	52 F/NE	22	Wabigoon Lake area
5060	52 F/SW	37	Rowan Lake area
5061	52 F/SE	38	Gold Rock area
5062	52 G/NW	23	Press Lake area
5063	52 G/NE	24	Metionga Lake area
5064	52 G/SW	39	Gulliver River area
5065	52 G/SE	40	Pakashkan Lake area

Each of the data sets utilized in the investigation exhibits different characteristics in terms of scope, purpose, and precision. These characteristics are briefly described for each data set in Appendix A.

Analyses of these data sets were undertaken using ARC/INFO GIS software (distributed by Environmental Systems Research Institute, Inc. (ESRI), Redlands, CA) and EASI/PACE image analysis software (distributed by PCI Inc., Richmond Hill, ON). ARC/INFO Version 5.0 was installed on a SUN Sparc Station 2, while EASI/PACE Version 5.1 was installed on an IBM RISC 6000. It was possible to readily transfer all data types used in this study between these software packages.

Table 2. Satellite data used in this investigation.

Data description	Acquisition date	Ground resolution
SPOT Panchromatic	27 July 1987	10 meters
Landsat TM	19 August 1991	30 meters
ERS-1 (Radar)	12 July 1992	25 meters

5.0 METHODOLOGY

The data sets were integrated in varying ways to enhance spatial differentiation beyond that provided by the OLI polygons. Three distinct methods were employed and the results of each were evaluated, in part, using field data to determine the success in predicting soil unit characteristics (e.g., soil texture, soil depth).

These methods were developed to both test the capabilities provided by differing data combinations as well as to recognize that certain combinations may provide specific tools for different levels of planning and/or analyses. For example, the level of soil unit resolution achieved using one method may be acceptable at the forest management planning level, but another method may be more desirable for township-level planning. Further, limitations in availability of digital data for any given management unit will preclude the use of one or more method(s) and, hence, the capabilities of each need to be fully demonstrated.

The data sets and integration procedures employed for each of the three methods are illustrated in Figure 2. Essentially, Methods 1 and 2 focus primarily on the use of existing map data along with SPOT imagery. The primary difference is the use of FRI data in Method 2. Method 3 represents a supervised classification of Landsat TM imagery—supervised using empirical data derived from field studies and the FRI. The steps followed in each method are described in the following sections.

5.1 Method 1. Soil Classification Using OLI, NOEGTS, and SPOT Panchromatic Data

1. Using ARC/INFO GIS import the following data sets in digital format:

OLI polygons (1:250 000 scale);

NOEGTS polygons (1:100 000 scale);

Elevational data from 1:50 000 NTS map sheets; and Transport and water covers from 1:50 000 NTS map sheets.

Each data set must be imported and georeferenced (tied to known geographic coordinates on the Earth's surface) to a common projection (Universal Transverse Mercator Projection [UTM]). The integrity of each data set must be confirmed and data layers cleaned and debugged, as required. Quality control procedures include connecting features between adjacent map sheets (edge-matching), identifying and recapturing any missing features, and locating empty or miscoded database fields.

- Develop the necessary equivalencies between the NOEGTS and OLI map annotations. The NOEGTS polygons were relabeled utilizing a look-up table to make them compatible with OLI-based Prime Lands typology. (Relabeling procedures and conventions are outlined in Appendix B.)
- 3. Create a georeferenced image database using PCI's EASI/PACE software applied to SPOT Panchromatic data. This is accomplished by collecting, from 1:50 000 NTS map sheets, the coordinates of features that are clearly defined and common to both the satellite image and the map sheet (e.g., road crossings, shoreline features, etc.).
- Import the contour line vectors from ARC/INFO to EASI/PACE to create a Digital Elevation Model (DEM) using EASI/PACE's GRDVEC and GRDINT processes.
- Prepare a hardcopy plot of the SPOT Panchromatic image at a scale of 1:25 000 overlaid with color-coded NOEGTS and OLI polygons for initial visual checking. Correlations among line placements of the two overlays in relation to the SPOT image were closely examined.
- 6. Subdivide the NOEGTS polygons using the SPOT Panchromatic data. This is accomplished using PCI Inc.'s stand-alone "FLY!" program and the hardcopy image. In this procedure the SPOT image and NOEGTS polygons are draped over the DEM. A three-dimensional perspective scene is generated to allow the analyst to "fly" through and visually examine and interpret soil

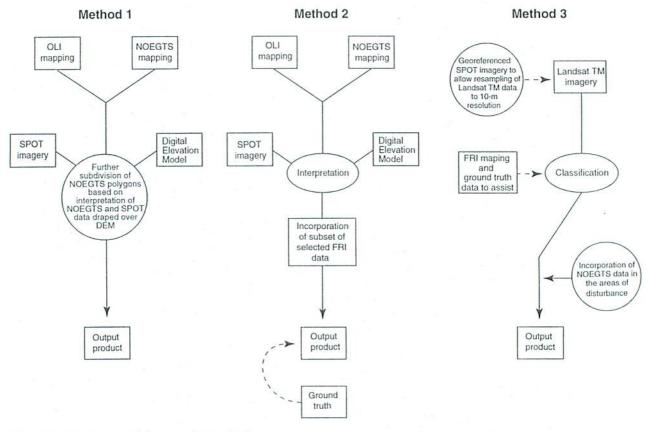


Figure 2. Integration of data sets by method.

conditions using an elevation component. Air photo interpretation skills are helpful in this procedure because the fly-through effect is similar to viewing oblique stereoscopic aerial photographs. Familiarity with forest site, slope, and species relationships and the 'scale effect' involved in photo interpretation are also an asset. Identified polygons are drawn on the 1:25 000 hardcopy image.

- Digitize the polygons drawn on the 1:25 000 hardcopy image as identified from the visual interpretation of SPOT data.
- 8. Prepare a map showing soil units by primary soil texture.

5.2 Method 2. Soil Classification using OLI, NOEGTS, SPOT Panchromatic, and FRI Data

- 1. Repeat Steps 1-8 from Method 1.
- Import digital FRI stand boundaries and stand attribute data into ARC/INFO.
- Prepare procedures in ARC/INFO using Arc Macro Language (AML) that selects specific forest stand

polygons from the FRI database on the basis of stand attribute data. Assumptions (as shown in Table 3) are made to filter the FRI stand data to identify stands that fulfil certain classification, species composition, and site class parameters. These stand polygons are then assigned a corresponding soil texture descriptor and integrated with the final data set created by Method 1. Preexisting NOEGTS polygon boundaries, as well as those interpreted through analysis of the integrated SPOT/DEM data, are retained in the new database.

 Prepare a map showing soil units by primary soil texture.

5.3 Method 3. Soil Classification Using Landsat TM Data

- Delineate the geographic extent of the study area from the SPOT Panchromatic image and create a georeferenced database; this was done using EASI/PACE software. Ground control points are collected from 1:50 000 NTS topographic maps (see Section 5.1, Step 3).
- 2. Register the Landsat TM image to the SPOT image and resample the Landsat TM data to 10-m resolution. This

procedure is accomplished by cubic convolution resampling² in EASI/PACE.

- 3. Prepare a soil classification image by using TM Bands 1, 6, and 7 as input for an unsupervised classification.³ Classes were aggregated or grouped using soil texture categories and polygon labeling conventions similar to those employed in Method 2. Some type of ground truth information must be available and used as an essential part of class aggregation. In this project FRI mapping and ground truth data were used to guide the classification process.
- Prepare a map showing soil units by primary soil textures.

In this procedure, TM Bands 1 (blue), 6 (thermal infrared), and 7 (mid-infrared) were selected and input to an unsupervised isoclustering algorithm⁴ requesting 60 spectral classes. These bands were chosen because they are known to be particularly sensitive to soil reflective characteristics (Lillesand and Kiefer 1987). Spectral signatures of all pixels within the image area were compared across the three TM bands. Pixels with numerically similar spectral signatures were clustered together into a single spectral class.⁵ This iterative process is continued until each pixel within the image has been assigned to one of the 60 spectral classes.

Each of the 60 spectral classes was regrouped into soil texture classes utilizing the FRI coverage and field survey

Table 3. Soil-vegetation relationship assumptions used in the creation of AMLs for the preparation of primary soil texture mapping.

Assumption	Polygon label*
FRI polygons classed as 90 percent jack pine (Pj), on all site classes, were considered to represent deep, sandy, dry soil conditions	20D2
FRI polygons classed as 100 percent black spruce (Sb), Site Classes 3 or 4, were considered to represent productive organic sites	70W1
FRI polygons classed as treed muskeg (9?0), open muskeg (9?1), or brush and alder (9?2) were considered to represent nonproductive organic sites	80W2
FRI polygons classed as rock (9?3) were considered to represent areas of exposed bedrock	9a0D1xs

^{*}Polygon label linked to FRI-based soil texture polygon in ARC/INFO database.

² In order for SPOT Panchromatic and Landsat TM data to be used in concurrent image analyses, the Landsat TM data must be geographically overlaid on the SPOT data and the ground resolution of the TM data increased to 10 m. To achieve this, the TM data is 'resampled' using the cubic convolution method. This method involves two processes: namely, (1) the extraction of DNs from pixel locations in the original image and their relocation to the appropriate pixel location in the 'corrected' image, and (2) the interpolation of DN values for pixels created by the reduction of ground resolution from 30 m to 10 m. The cubic convolution method uses the weighted average of 16 surrounding pixels to derive the DN value of the new pixel space in the corrected image.

³ Use of TM Bands 1, 6, and 7 was based on their suitability as described in Lillesand and Kiefer (1987).

⁴ An unsupervised isodata clustering algorithm accepts, from the user, the number of classes into which an digital image is to be divided (60 in this study). The algorithm then proceeds to examine the spectral reflectance values of each pixel within the image, grouping those with the closest values into the same or adjacent classes. This iterative process continues until the image is represented by only the number of classes specified by the user. The user/analyst then assigns each class to a category, in this study a primary soil texture type.

⁵ The ISOCLUS algorithm statistically examines each cluster and the following three criteria are applied:

^{1.} Clusters having too large a standard deviation in spectral signatures are split to form two smaller clusters.

^{2.} Clusters that are statistically too close to one another in the multidimensional measurement space are merged into a single cluster.

^{3.} Clusters with too few pixel members are discarded.

information as ground truth data. The final soil unit boundaries were created by converting the classified raster image to a vector image (in EASI/PACE), and then exporting the vector data to ARC/INFO. Primary soil texture labels were assigned to each soil unit in ARC/INFO using assumptions similar to those listed in Table 3.

5.4 Field Program

A field program, aimed at collecting accurate soil condition information, was conducted from 15–27 September 1993. A total of 15 transects was selected according to accessibility (i.e., proximity to roads) and the distribution of soil units. The map created as a result of Method 2 analysis (NOEGTS/SPOT/FRI) was used as the basemap for selecting transects. Transects were designed to cross as many soil unit boundaries as possible so as to maximize the expected variations in soil type. To evaluate the spatial accuracy in upland–lowland boundary delineation, transects were generally located along topographic gradients.

Vegetation types and soil types (V-types and S-types, respectively), as defined by the Northwest Ontario Forest Ecosystem Classification (NWO FEC) (Sims et al. 1989), were collected at the point where a soil polygon boundary was encountered along each transect. A Global Positioning System (GPS) unit was used to accurately geoposition transect startpoints and to collect positional data on the ground where soil polygon boundaries were indicated.

For each field transect, graphical profiles were created to visually compare the results of the ground truth data with the results of Method 1 (NOEGTS/SPOT/FRI) and Method 2 (Landsat TM). This permitted a direct visual assessment and comparison of the results of the field studies with the classification methods. Procedures used to create these comparison profiles are described as follows:

- Create a gridded DEM using the TIN software procedure in ARC/INFO and the digital NTS contour data.
- Differentially correct the GPS data by individual transect (PFINDER Software, Trimble Navigation, Ltd., Sunnyvale, CA) and import the transects into ARC/INFO. Drape the transects over the TIN DEM. Resolve elevation data along the length of each transect based on the DEM and generate individual surface profiles for each transect.
- 3. Within ARC/INFO, assign primary soil texture values to the corresponding segments of each transect for each of the ground truth data, Method 2, and Method 3 databases. The method used to convert S-types to equivalent OLI-based Prime Land Classification soil descriptor codes is shown in Appendix C.

4. Import all of these data to a Lotus 1-2-3 spreadsheet and create graphical plots of each transect showing primary soil texture plotted according to distance and elevation for each of ground truth, Method 2, and Method 3.

The comparison profiles are presented in Appendix D.

6.0 RESULTS

6.1 Method 1. Integration of OLI, NOEGTS, and SPOT Panchromatic Data

The incorporation of NOEGTS polygons with the previously classified OLI polygons resulted in extensive subdivision of the OLI polygons (Map 2). These subdivisions represent a significant reduction in average polygon size, as shown in Table 4. In addition, the inherent variability in soil/terrain conditions within the large OLI polygons were more clearly delineated. As noted previously, OLI polygons are classified on the basis of their dominant soil condition, but up to 45 percent of any map unit may consist of other materials. Hence, the greater resolution provided by NOEGTS allowed a much finer resolution of the variability described, but not mapped, within the OLI system.

The boundaries of NOEGTS polygons generally did not correspond nor 'nest' within those of the OLI. This situation was also encountered and described by Robinson, Merritt and deVries Limited (1987), and is to be expected given the differing objectives and interpretation techniques of the two studies.

Further subdivision of the NOEGTS/OLI polygons was achieved by incorporating the SPOT data (*see* Table 4). This primarily resulted in the delineation of large, relatively homogeneous polygons, particularly those areas of

Table 4. Results of inclusion of NOEGTS and SPOT data with OLI polygons.

OLI polygons	
Number of polygons	14
Average polygon size (ha)	2 857
Range (ha)	3-16 239
OLI and NOEGTS polygons	
Number of polygons	83
Average polygon size (ha)	482
Range (ha)	0.006-10 062
OLI, NOEGTS, and SPOT polygor	ns
Number of polygons	111
Average polygon size (ha)	360
Range (ha)	0.006-10 026

organic material. Numerous smaller areas, although apparent, were not delineated because further discrimination of soil units was considered to be beyond the resolution limits established for this method.

6.2 Method 2. Integration of FRI Data Into Method 1

While the NOEGTS/SPOT-enhanced database provided a far greater level of detail than did the OLI database alone, it was necessary to further subdivide the polygons in order to ensure the resultant classification was useful at an operational level (i.e., at the 1:20 000 scale used for preharvest assessment and operational-level, on-site decisions). This is evident, for example, by the large undifferentiated class mapped as "Rock (with shallow surficial deposits)" in Map 2. At the very least, in this type of Canadian Shield terrain one would expect a much greater occurrence of organics and localized, deep glacial deposits within this bedrock complex.

To achieve a higher degree of polygon subdivision and accuracy, FRI digital data were integrated with the NOEGTS/SPOT database. In this method, FRI polygons that fulfilled certain parameters (see Table 3) were extracted from the FRI dataset and overlaid onto the results of the NOEGTS/SPOT interpretation. Each selected FRI polygon was then interpreted as to its likely soil type using the AMLs listed in Table 3. As a result, subdivision of NOEGTS/SPOT polygons was extensive, resulting in the formation of approximately 2 223 individual polygons.

Map 3 shows the result of the integration of FRI data and, clearly, there a is much greater delineation and interpretation of organics throughout the study area. To a lesser degree, this is true also for localized glacial materials. In comparing Map 3 with Map 2, one can readily see the improved resolution and accuracy of areas mapped as productive and nonproductive organic soils.

The abilities of this method to accurately delineate soil textures are presented numerically in Table 5. This table is based on a cross-correlation matrix that identifies map classes with actual field data. The numerical values presented in the table represent the outcome of direct comparisons between mapped and field soil textures using the comparison profiles presented in Appendix D. Where the mapped soil texture line segment in the comparison profile matched the field soil texture line segment, a '1' was entered in the shaded contingency table cell. Where they did not match, a '1' was entered in the column corresponding to the mapped soil texture and the row corresponding to the field soil texture.

Examination of Table 5 and the contingency tables suggest that the ability of NOEGTS/SPOT/FRI data integration

to accurately map soil texture is relatively low (*i.e.*, soils found to be coarse loamy are predicted only to be coarse loamy). However, wider groupings of soil textures, such as those combining the "exposed bedrock" class with the "shallow surficial deposits over bedrock" class (Table 5), result in a much improved correlation.

The effect of grouping soil textures is illustrated in Table 6. The combination of the two classes noted above resulted in a correspondence between mapped and field interpretations of 82 percent (55 of 67 cases).

6.3 Method 3. Landsat TM Image Classification

The results of the satellite image classification undertaken with Landsat TM data georeferenced to the SPOT imagery are provided as Map 4. The correlation between spectral class boundaries and the FRI polygon boundaries for wet organic soils ("Organic Non-productive") is very strong as a result of the ability of the infrared band to discriminate wet areas. Discrimination of soil textures associated with better drained upland soils was more difficult and required direct input by forest ecologists into the interpretation. By supervising the classification in this way, it was possible to classify the following five broadly defined soil and terrain conditions:

- · deep to moderately deep coarse loamy;
- predominantly coarse loamy with peaty phase organic material;
- organic (nonproductive);
- · exposed bedrock; and
- bedrock with very shallow coarse loamy surficial deposits.

The Landsat TM classification was particularly difficult in areas of disturbance (e.g., recent timber harvesting and road rights-of-way). In these areas, the NOEGTS attribute data were used to determine primary soil texture.

Contingency tables showing the correlation between Landsat interpreted soil classes and those derived from the field survey data are presented in Table 7. The comparison profiles from which these tables were constructed are presented in Appendix D.

The Landsat classification contingency tables indicate a situation similar to that encountered with the NOEGTS/SPOT/FRI classification; namely, the correlation of interpreted soil class to that determined in the field appears to be relatively low. If soil textures are combined into larger groups within the study area (Table 8), the following correlations are achieved:

- 57 percent when sandy, coarse loamy, and coarse loamy/peaty phase soil types are grouped; and
- 39 percent when exposed bedrock/shallow surficial deposits over bedrock are grouped.

Table 5. NOEGTS/SPOT/FRI classification vs. field survey data contingency table.

	Soi	l texture	es and nu	ımber	of occurrence	es as observed dur	ring the fiel	d survey	Ö	
Soil textures as predicted by NOEGTS/FRI	Very gravelly	Sandy	Coarse loamy	Silty	Organic (productive)	Organic (nonproductive)	Exposed bedrock	Shallow surficial deposits (range of textures)	Unclassed	Total number predicted by NOEGTS/ FRI
Very gravelly		4	10			6		7	1	28
Sandy		4	1			4	1	1		11
Coarse loamy				6		1				7
Silty										
Organic (productive	e)	3		1-	3			3		10
Organic (nonproductive)		1	1		2	1				5
Exposed bedrock										
Bedrock with very shallow surficial		45	8		9	11	6	49		128
deposits Unclassed		43	2							2
Total occurrences as observed during the field survey		57	22	7	14	23	7	60	1	191

Cells where NOEGTS/SPOT/FRI interpreted the same soil texture as observed during the field survey.

Table 6. Aggregated soil types—NOEGTS/SPOT/FRI classification vs. field survey data contingency table.

	Soil textures a	and number of occu	irrences as	observed during the field su	irvey	
Soil textures as predicted by NOEGTS/FRI	Deep, coarse- textured material	Deep, fine- textured material	Organic material	Shallow surficial deposits (range of textures)/ exposed bedrock	Unclassed	Total number predicted by NOEGTS/FRI
Deep, coarse-textured material	19	6	11	9	1	46
Deep, fine-textured material						
Organic material	5	1	6	3		15
Shallow surficial deposits (range of textures)/exposed						
bedrock	53		20	55		128
Unclassed	2					2
Total occurrences as observed during the field survey	79	7	37	67	1	191

Cells where NOEGTS/SPOT/FRI interpreted the same grouping of soil textures as observed during the field survey.

Table 7. Landsat TM classification vs. field survey data contingency table.

	Soil to	extures	and num	iber of	occurrences	as observed durin	g the field	survey		
Soil textures as predicted by NOEGTS/FRI	Very gravelly	Sandy	Coarse loamy	Silty	Organic (productive)	Organic (nonproductive)	Exposed bedrock	Shallow surficial deposits (range of textures)	Unclassed	Total number predicted by NOEGTS/ FRI
Very gravelly		1	4			2		1	1	9
Sandy		2								2
Coarse loamy		19	2	2	4	7		36		70
Coarse loamy/ peaty phase Organic (productive)		11:	6	1	7	6	4			35
Organic (nonproductive)		2								2
Exposed bedrock Bedrock with very shallow surficial deposits		22	9	4	3	8	2			
Unclassed			1		3	o	3	23		72
Total occurrences as observed during			1 0							1
the field survey		57	22	7	14	23	7	60	1	191

Cells where interpretation of Landsat TM predicted the same or virtually the same soil texture as observed during the field survey.

Table 8. Aggregated soil types—Landsat TM classification vs. field survey data contingency table.

	Soil textures	and number of occu	irrences as	observed during the field su	irvey	
Soil textures as predicted by NOEGTS/FRI	Deep, coarse- textured material	Deep, fine- textured material	Organic material	Shallow surficial deposits (range of textures)/ exposed bedrock	Unclassed	Total number predicted by NOEGTS/FRI
Deep, coarse-textured material		3	26	41	1	116
Organic material	2					2
Very shallow surficial deposits (range of textures)/exposed						
bedrock	31	4	11	26		72
Unclassed	1					1
Total occurrences as observed during the						5.€3
field survey	79	7	37	67	1	191

Cells where interpretation of Landsat TM predicted the same grouping of soil textures as observed during the field survey.

Using this method alone, it was not possible to determine differences in soil moisture regime and soil depth with any degree of confidence. For the classified TM image to be useful as a data source for input to the Prime Land algorithm, however, soil moisture and depth information is required. In the absence of more accurate moisture and depth data, the existing NOEGTS database was used. The TM-classified polygon boundaries were brought into ARC/ INFO GIS, and associated soil texture code attributes were merged with the 'underlying' NOEGTS polygon soil moisture and depth code attributes. This process resulted in the creation of a database containing individually numbered, unique polygons whose boundaries were based on TM classification, and a descriptor code containing attribute fields consisting of the TM-interpreted soil texture and NOEGTS soil moisture and depth data.

7.0 DISCUSSION

7.1 Enhanced Prime Land Soils Mapping

When compared to the OLI maps and attribute data, all three methods developed in this study, using existing and available data, resulted in increased precision and accuracy with regard to delineating soil/site conditions in forested ecosystems. Precision in boundary definition increased progressively from Method 1 (OLI/NOEGTS) through Method 2 (NOEGTS/SPOT DEM/FRI) to Method 3 (partially supervised Landsat TM/SPOT). In the case of Method 3, as illustrated by comparing Maps 2, 3, and 4, this boundary definition increased significantly. Overall, the integration of SPOT DEM and NOEGTS with the OLI (Method 2) resulted in a reduction in average polygon size from 2 857 ha to 360 ha within the study area.

It is clear from the most detailed data sources available for the study area (field checking and FRI) that the accuracy of interpretation also increased, particularly with regard to the non-forested wetland soils, exposed bedrock, and bedrock with shallow soils classes. The interpretation of wetland features was particularly enhanced due to the incorporation of FRI data. These data are based upon a standardized aerial photo interpretation procedure using 1:15 840 scale stereo photos. The incorporation of SPOT/DEM data was particularly valuable in separating out larger, more homogenous areas of shallow-to-bedrock conditions and organic deposits.

The interpretation of loamy, sandy, and gravelly types, however, is much more questionable other than the enhanced capability to differentiate them from the organic

and bedrock types. Clearly, more work on these methodologies is needed to improve their accuracy of interpretation.

The Landsat TM classification (Method 3) provides a very high degree of boundary precision (Map 4). Because these polygon boundaries are based on spectral characteristics, there is no question as to the precision of boundary definition. However the accuracy of interpretation may be questioned, as shown in part by low to moderate correlations with ground truth data (Table 7). Map 4 defines differences in soils, water, and vegetative cover as expressed through spectral reflectance values. Hence, the interpretation of soil/site conditions for any given area using this methodology must be based on sound local knowledge of vegetation/site conditions as well as the disturbance history.

This is not unreasonable because the purpose of this project was to increase the spatial interpretation of management areas for operational forestry. Invariably, those foresters utilizing the information will also be intimately familiar with forest soil/site conditions in their area and thus should be involved in the interpretation when this methodology is chosen. Such interpretations can also be dramatically improved when incorporating data from Forest Ecosystem Classification manuals that are now available for much of Canada's boreal forest (Sims et al. 1989, Zoladeski et al. 1995, Zoladeski and Cowell⁶).

The primary function of Ontario's FRI data is to provide information to aid in forest management planning; however, species composition data contained within the FRI database may also be used to help identify the extent, location, and tree species components of vegetation communities. One of the key assumptions of the current investigation was that, although there are occasions where vegetation communities/associations occupy atypical soil/ terrain units in any given area, the vegetation is usually associated with predictable underlying soil conditions. On this basis a limited number of conservative assumptions was developed by the study team by linking specific FRI classifications and tree species occurrences to underlying soil conditions (Table 3). Although some field verification and testing of these assumptions for the study area was undertaken (Appendix D), it is clear from the field-map correlation matrices (Tables 5-8) that either the assumptions were not fully validated and/or the field study design was not adequate (see Section 7.2).

Even without the SPOT/DEM component of the analysis, which is somewhat time-consuming to undertake and

⁶Zoladeski, C.A.; Cowell, D.W. Yukon ecosystem classification: Field guide and management interpretations. Indian and Northern Affairs, Whitehorse, Yukon. (In prep.)

involves significant computer processing time, the databases developed in conjunction with these methodologies were considered to be valuable for use in forest management planning. The integration of NOEGTS, DEM, NTS, and FRI data with or without Landsat TM classification offers a much highTer degree of spatial resolution than either OLI or NOEGTS data alone. Even by itself, the DEM would be useful to help generate terrain indices that predict critical soil/landscape features such as soil moisture regime and downslope runoff (see Gessler et al. 1995). The component databases, once assembled within a GIS, provide a basis for generating useful and pertinent information at the operational level of forest management.

7.2 Database and Field Design Considerations

This section discusses some of the key technical issues encountered during the course of the project, and is intended to provide guidance for researchers interested in employing or enhancing the methodologies. It also highlights some of the potential problems that may have limited the accuracy of interpretation.

The 1:250 000 OLI Land classification coverages for the study area were extracted from the database previously created as part of the NWRS&T's Prime Land mapping project. These coverages included a 'transport cover' (roads, rail lines, hydro corridors etc.), 'water cover' (major lakes [with a dimension greater than 304.8 m (Department of Energy, Mines and Resources 1978)] and watercourses), and OLI polygon boundaries and attributes. The OLI maps were sufficient to depict OLI polygon boundaries, but were considered inadequate for further mapping as only major roads and water bodies were shown. During the course of the study, satisfactory transport and water covers were obtained for the study area via digital FRI and Landsat TM data. In future applications, either 1:50 000 NTS or Landsat TM data should be chosen as the source for water and transport covers.

Problems were encountered when integrating the FRI base maps from the AVENOR corporate database with the existing 1:50 000 NTS-based NOEGTS/SPOT database. The FRI base maps were originally produced in Imperial units (feet/chains), and then converted to SI (metric) equivalents. This conversion resulted in the introduction of a significant level of spatial error. In addition, the AVENOR database utilizes the Lambert Conformal Projection and not the Transverse Mercator Projection used for NTS maps. As a result, the FRI data were not properly aligned with known topographic features (control points) when overlaid on the NTS-based NOEGTS/SPOT base map created for the study area. Using the NTS map sheets as a base, the spatial component of the FRI data was adjusted slightly to conform with known control points.

Assumptions developed by the study team that linked certain types of FRI classifications and tree species occurrences to underlying soil conditions (Table 3) are conservative. Although no efforts were made to assess the influence on the accuracy of soil texture mapping by including further assumptions or by modifying assumptions, future investigations should further refine the effects of other factors (e.g., cut-off limits for species percentages [90 percent for jack pine, 100 percent for black spruce], the appropriate site classes to be used, and mixtures of 'indicator species' and what these mixtures indicate with respect to soil texture or other soil/landform features).

It should also be noted that forest tree species/communities and their association with soil of various textures must be verified further within a GIS at an individual (FRI) stand level. Mapping of soil conditions based on working group will often be inaccurate, given that a working group is determined based on which tree species contributes the largest proportion of the total volume of the forest stand. For example, a mixedwood stand containing 40 percent jack pine may fall within the jack pine working group, but the stand may not necessarily occupy sandy soils.

Method 3 (Landsat TM classification) offers the opportunity to classify primary soil textures for extensive areas in the absence of a digital FRI database. It is important to note, however, that this method requires that ground-truth data be available prior to classification. In the current project, NOEGTS, FRI, and field sampling were used to assist in the classification of the image. If this methodology is chosen for operational forest management, then either ground-truth data should be collected and/or direct supervision of the classification should be undertaken by a forester knowledgable about local soil/site conditions. Furthermore, the use of hardcopy maps, including NOEGTS and FRI, along with Forest Ecosystem Classification guides, could improve the classification without the need for digital products.

Satellite imagery offers advantages over traditional mapping systems (i.e., NOEGTS, FRI), and provides cost-effective, recent, and updatable coverage of extensive areas of land. One significant drawback is the fact that areas of disturbance (e.g., clear-cuts, roads, and fire) cannot be classified in the same manner as undisturbed areas.

The contingency tables (Tables 5–8) and comparison profiles (Appendix D) were prepared in an attempt to provide some measure of data interpretation accuracy to test the project's three methodologies. Although it is important to ensure the highest level of map accuracy, it must be noted that the methodologies employed in this study involve the use of a variety of existing databases,

several of which are the products of previous studies and programs. Each of these was designed for specific purposes employing project-specific techniques for data capture, field sampling, and data presentation. Furthermore, the final map products cover a wide range of scales (1:15 840 through 1:250 000).

The creation of new map products from these sources should not be undertaken without an intimate knowledge of local soil/site/landscape characteristics to best interpret the results. Decisions regarding which lines to keep and where to place them across such a wide range of scales means that field verification, if required, must be very carefully designed. Time and budget did not permit sufficient coverage of the study area to ensure that sampling of mapped units was statistically representative. Also, the field design involved sampling at or near map unit boundaries. Given the wide range of data types and map scales employed when creating the map, which was field checked, it would have been more accurate to sample polygon interiors representing a full range of polygon sizes with statistically significant representation (25 percent to 50 percent of units mapped).

8.0 CONCLUSIONS

This report describes three separate methodologies that delineate and classify soil textures at a scale of 1:50 000 within areas where conventional soil survey data are currently unavailable. These methodologies integrate existing map-based information, such as the National Topographic System (NTS), Ontario Land Inventory Land Classification (OLI), Northern Ontario Engineering Geology Terrain Survey database (NOEGTS), and Forest Resources Inventory (FRI), with digital satellite imagery (SPOT Panchromatic, Landsat TM). These methods are intended to allow forest managers to develop operationally useful soil/site productivity thematic maps, including identification of the most productive forest sites. The results of this investigation may be useful for integration with the OMNR's NWRS&T Prime Land classification productivity model.

Although more fine-tuning and testing of these methods are required, they provide a basis for forest industries and the OMNR to dramatically increase, at a reasonable cost, the development of operationally useful soil/site productivity thematic maps, or other soils-based spatial coverages. The main advantage of these approaches is that they strive to integrate all available information, and to provide a basis for update and revision (because the data resides in a GIS) following field investigations to ground-truth and verify map units.

When used in conjunction with existing FRI data, the resulting soils maps will enable the classification, mapping,

and inventory of soils-based forest units. These units, in turn, can be used in timber supply analyses, updates, and enhancements of periodic inventories and in the identification of potential forest allocations, annual allowable cuts, silvicultural schedules, and annual work schedules. Any of the three approaches will enable forest managers to adopt, at an operational level, a soil/site productivitybased spatial model that uses existing soil/site information enhanced with remote sensing or FRI data. These approaches are cost-effective alternatives for the allocation of increasingly scarce harvesting and silvicultural (regeneration) human and capital resources. Their refinement and application are of critical importance if Ontario's forest industry is to demonstrate its ability to practice sustainable forest management and thus remain globally competitive.

9.0 PROJECT TECHNICAL AND DATA REQUIREMENTS

The methodological design, implementation, and testing of interim results for this project involved a significant effort. Knowledge was gained through exploring, expanding, and integrating the capabilities of existing databases. To assist in the further development of these methodologies, as well as the eventual operationalization of the techniques for forest management, it is important to detail the various technical and resource requirements. This section summarizes the GIS and remote sensing hardware/software and costs and data availability issues as a guide for interested practitioners.

9.1 Hardware/Software Requirements

Although each of the methods developed during the project resulted in a greater subdivision of the OLI and NOEGTS polygons, software and hardware requirements to complete each method were the same (i.e., hardware/software costs are fixed). The recommended hardware and software products are briefly described below. (Note: prices and configurations as of January 1996.)

Hardware requirements

Unix-based workstation:

- Sun SPARC 2 minimum (Sun SPARC 10 for upgradability and speed)
- 64 MB RAM minimum, 2 GB disk storage minimum, 8-mm 2.3 GB tape drive, 2 serial ports
- 8-bit graphic card minimum (24 bit for improved onscreen analysis)
- · 19" color monitor
- 24" x 36" digitizing table compatible with ARC/INFO and EASI/PACE
- 36" x 48" color raster plotter

Software requirements

- ARC/INFO GIS software Modules: Basic
- · EASI/PACE image analysis software

Modules: Kernal, Classification, Plotting, Geometric Correction, Modeling, Vector package, Tape I/O, Fly!

Estimated hardware/software costs

SPARC 2 with 8-bit graphics card	\$6,000.00
24" x 36" digitizing table	2,000.00
36" x 48" color raster plotter	
(e.g., HP Design 2550C)	15,000.00
ARC/INFO GIS software	30,000.00
EASI/PACE image analysis software	_24,500.00

Total estimated hardware/software cost ~\$ 77,500.00

Materials costs

When a project of a scale similar to this is to be undertaken by a federal, provincial, or industrial organization (e.g., Canadian Forest Service, OMNR, AVENOR), it is assumed that some of the required materials will be available 'in-house', or that they can be obtained at a nominal cost via interagency agreements. These types of materials include hardcopy 1:250 000 OLI Land Classification map sheets, digital 1:250 000 Prime Land mapping data (NWRS&T), hardcopy or digital NOEGTS map sheets, hardcopy or digital FRI data, etc. The following are additional basic material costs that may be incurred during the course of a similar project:

Individual hardcopy 1:100 000 scale NOEGTS map sheet	\$ 8.00
Individual hardcopy 1:50 000 scale NTS map sheet	9.95
All digital covers for a single 1:50 000 NTS sheet, including contours, where available	545.00
Digital elevation model only of a single 1:50 000 NTS sheet (no additional covers), where available	270.00
Individual SPOT Panchromatic full scene (60 km x 60 km)	2,700.00
Individual Landsat TM full scene (185 km x 185 km)	5,000.00
Individual Landsat TM subscene (90 km x 90 km)	2,400.00

Level of effort required

The level of effort required to produce a hardcopy map indicating soil textures within a given area is a function of both the method(s) chosen and the size of the area being considered. Availability of data in digital format also affects the level of effort and costs. In this study, the level of effort expended in Method 1 also constituted work toward completion of the other methods. A series of tables have been developed outlining the level of effort required, by task, to complete each of the three methods for a 40-km² area, based on different scenarios (Appendix E). Levels of effort have been estimated assuming: (1) the area being examined has a relatively heterogeneous landscape, (2) databases used are reasonably 'clean', and (3) staff are well-trained and familiar with the necessary software packages and hardware configurations.

Table 9 summarizes the personnel and effort requirements by scenario and method. These estimates do not include the cost or effort involved in field checking the results as these will vary widely depending on many factors, including the duration and intensity of the field survey, the experience of field staff, the location of the study area relative to where the GIS and remote sensing work is being conducted (e.g., travel and subsistence costs), and the degree of access within the study area.

9.2 Availability of Data/Databases

The availability within Ontario of the data sources utilized during the course of this study is briefly summarized in Table 10. Tables 10 and 11 have been developed based on current knowledge of work previously completed, or to be completed, and should not be considered comprehensive. Direct contact with the sources of hardcopy mapping and/ or the digital data/database is recommended.

10.0 ACKNOWLEDGMENTS

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Table 9. Summary of level of effort estimates by scenario (in person-days).

Scenario/method	GIS technician	GIS analyst	RS* technician	RS analyst	Total person-days
No digital map-based data available:					
Method 1	4.75	6.75	1.0	3.0	15.5
Method 2	14.75	11.75	1.0	3.0	30.5
Method 3	4.75	7.0	1.0	10.0	22.75
Digital OLI and NTS covers					
(including contours) available:					
Method 1	2.5	7.0	1.0	3.0	13.5
Method 2	12.5	12.0	1.0	3.0	28.5
Method 3	2.0	7.25	1.0	10.0	20.25
Digital OLI, NTS covers (including					
contours) and FRI stand maps availabl	e:				
Method 1	2.5	7.0	1.0	3.0	13.5
Method 2	2.5	11.0	1.0	3.0	17.5
Method 3	2.0	7.25	1.0	10.0	20.25

^{*} RS = Remote sensing.

Table 10. Availability of data/databases.

	Fori	mat		
Data/database	Hardcopy	rdcopy Digital Coverage		Source
NTS (1:25 000)	X	х	Provincewide	Energy, Mines and Resources, Ottawa, ON.
NTS (1:50 000)	X		Provincewide	Energy, Mines and Resources, Ottawa, ON.
NTS (1:50 000)		X	Select areas only	Energy, Mines and Resources, Ottawa, ON.
OLI	x		Provincewide	OMNR, Provincial Remote Sensing Office, Toronto, ON.
OLI		X	Majority of NW Ontario (see Table 11); other select areas	Table 11: OMNR, Northwest Region Science and Technology, Thunder Bay, ON.
NOEGTS	х		Majority of northern Ontario	Ministry of Northern Development and Mines, Public Information Centre, Toronto, ON.
NOEGTS		X	Select areas only (see Tables 12A to 12D)	Table 12A: OMNR, Northwest Region Science and Technology, Thunder Bay, ON. Table 12B: OMNR, Centre for Northern Forest Ecosystems Research, Thunder Bay, ON
				Table 12C: Ontario Geological Survey, Toronto, ON. Table 12D: CFS, Great Lakes Forestry Centre, Sault Ste. Marie, ON.
FRI	x		Provincewide	OMNR, Natural Resource Inventories Section, Sault Ste. Marie, ON.
FRI		X	Select areas only	OMNR, Natural Resource Inventories Section, Sault Ste. Marie, ON.
SPOT		Х	Provincewide	Radarsat International Inc., Richmond, BC.
Landsat TM		X	Provincewide	Radarsat International Inc., Richmond, BC.

Table 11. OLI map sheets digitized and classified by the OMNR's Northwest Region Science and Technology Unit's Prime Land mapping program.⁷

42 C	White River	52 F	Dryden
42 D	Schreiber	52 G	Ignace
42 E	Longlac	52 H	Nipigon
42 F	Hornpayne	52 I	Armstrong
42 K	Kenogami River	52 J	Sioux Lookout
42 L	Nakina	52 K	Lac Seul
52 A	Thunder Bay	52 L	Pointe Du Bois
52 B	Quetico	52 M	Carroll Lake
52 C	International Falls	52 N	Trout Lake
52 D	Roseau	52 O	Lake St. Joseph
52 E	Kenora	52 P	Miminiska Lake

OLI polygons and associated databases were only completed for map sheets covering the Ontario landbase occurring south of 52° N (Richards et al. 1979)

Table 12A. NOEGTS database maps provided to Robinson, Merritt and de Vries Limited (1987) by Northway Map Technologies Ltd. in ARC/INFO format.

NOEGTS database map number	NTS sheet	NOEGTS study number	NOEGTS study area name
5107	52 K/NW	3	Pagwash Lake
5051	52 H/SW	41	Heaven Lake
5059	52 F/NE	22	Wabigoon Lake
5070	52 C/NE	54	Seine River
5073	52 B/NW	55	Marmion Lake
5079	42 E/SW	43	Roslyn Lake

Table 12B. NOEGTS database maps provided to the OMNR Centre for Northern Forest Ecosystem Research, by Geomatics International in SPANS GIS format (1993).

NOEGTS database map number	NTS sheet	NOEGTS study number	NOEGTS study area name
5058	52 F/NW	21	Blue Lake
5059	52 F/NE	22	Wabigoon Lake
5060	52 F/SW	37	Rowan Lake
5061	52 F/SE	38	Gold Rock
5069	52 C/NW	53	Rainy Lake
5070	52 C/NE	54	Seine River

Table 12C. NOEGTS database maps provided to the Ontario Geological Survey by Geomatics International in ARC/INFO format (1994).

NOEGTS database map number	NTS sheet	NOEGTS study number	NOEGTS study area name
5003	41 I/SE	100	Sudbury
5041	31 L/SW	101	North Bay
5042	31 L/SE	102	Mattawa
5043	31 K/SW	103	Deep River

Table 12D. NOEGTS database maps available in ARC/INFO format from CFS, Great Lakes Forestry Centre.

NOEGTS database map number	NTS sheet	NOEGTS study number	NOEGTS study area name
5049	52 H/NW	25	Gull River
5050	52 H/NE	26	Mt. Royal
5051	52 H/SW	41	Heaven Lake
5052	52 H/SE	42	Frazer Lake

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APPENDIX A. Descriptions of map and satellite data.

Ontario Land Inventory—Land Classification

Between the mid-1960s and 1970s, the Ontario Land Inventory (OLI) Program, under the auspices of ARDA (Agricultural Rehabilitation and Development Act), undertook 1:250 000 scale mapping of the Ontario landbase occurring south of 52° N latitude. The basic purpose of the OLI Program was to provide information for broad or regional levels of resource planning and management, whereas the purpose of the Land Classification component was to delineate broad areas having a recurring pattern of certain physical features (Richards et al. 1979). The Land Classification system was based upon the degree of brokenness of the land, the depth of soil over bedrock, petrography (basically a measure that indicated the depth to free calcium carbonate), and the soil moisture regime. Hardcopy color maps identifying different landscape units and/or land units were produced. In addition to a classification scheme that allowed rapid determination of the basic attributes of a landscape/land unit (through use of the map legend), an associated database was developed which provided a breakdown of each land unit by its components; percentage of the land unit occupied by each component (usually to the nearest 5 percent); and the texture, petrography, depth, and moisture regime classes of the parent material of each component (Richards et al. 1979). As the size of the smallest land unit usually discerned was approximately 10 km² (Richards et al. 1979), mapped products provided only a regional or provincial perspective of an area.

Northern Ontario Engineering Geology Terrain Study

Initiated in 1977 by the Ontario Geological Survey, the purpose of the Ontario Engineering Geology Terrain Study was to evaluate near-surface geological conditions for the purposes of determining the engineering significance of the terrain. Between 1977 and 1980, the Northern Ontario Engineering Geology Terrain Study (NOEGTS) mapped a total of 370 000 km² of northern Ontario at a scale of 1:100 000. The coverage of NOEGTS extended from 46° N latitude to 50° N in northeastern Ontario and to 51° N in northwestern Ontario. (Areas to the south of 46° N latitude were mapped under the Southern Ontario Engineering Geology Terrain Study [SOEGTS].) The principal technique used for obtaining terrain information was stereoscopic airphoto interpretation. Terrain units were initially delineated on contact prints of vertical aerial photographs ranging in scale from 1:38 000 to 1:70 000. Interpreted terrain unit boundaries were subsequently transferred to a base map at a scale of 1:100 000. Field surveys were undertaken to verify the airphoto interpretation. Field checking took the form of a "windshield" survey—examination of natural and man-made cuts, recording of geological observations along most accessible roads and highways, photographs, helicopter survey of inaccessible areas, etc. The resulting color hardcopy data base maps provide a reconnaissance classification of an area's terrain based on identification of the origin, materials, topography, and drainage of geological landforms.

National Topographic System

The National Topographic System (NTS) provides the reference data for all information found on Canadian maps. In Ontario, NTS mapping is available at scales ranging from 1:25 000 to 1:1 000 000. Mapping at scales of 1:250 000 and 1:50 000 are most commonly used at the regional and local levels, respectively. By recording topographic data with contours, and the relative distance between readily observable objects on the ground, these maps provide an accurate source of locational and physiographic information.

Digital Elevation Model

A digital elevation model (DEM) is a digital representation of the continuous variation of topography over space. In this study, the DEM was created by table-digitizing contour lines from the relevant 1:50 000 NTS sheets in ARC/INFO. The contour vectors were exported from ARC/INFO to EASI/PACE. In EASI/PACE the contour vectors were converted to a raster 'contour' digital image. A digital image is a two-dimensional matrix wherein each cell (referred to as a pixel) of the matrix contains a digital number (DN) value. The creation of the raster contour image was a two-step process. In the first step, the vector lines (contour lines) were encoded or "burned into" an image channel with pixels located beneath the contour vector assuming the DN of the contour's elevation. An algorithm then interpolated the DN values (elevations) of pixels between the encoded pixels representing the contours. The algorithm determined an elevationless pixel's DN value by searching the image in eight directions (up, down, left, right, and the four diagonals) for the location of the two nearest encoded contour lines. Each pixel was subsequently classified as residing on a slope, a depression, or a peak.

Utilizing PCI's Inc.'s 'FLY!' program, an analyst was able to 'fly' through a virtual three-dimensional representation of the DEM over which the NOEGTS mapping and SPOT satellite imagery were draped.

Forest Resources Inventory

The OMNR's Forest Resources Inventory (FRI) provides descriptive information about the timber resources occurring on roughly 61.6 million hectares, or about 58 percent of the total area of the Province of Ontario. In the FRI, estimates of the timber resources in individual forest stands are described on forest stand maps and associated statistical analyses and reports. The FRI relies heavily on interpretation of aerial photography, supplemented with field sampling. The key features of the forest stand data are: tree species composition, age, height, stocking, site class, and area. The first inventory of Ontario's forest resources was conducted between 1946 and 1958 by the Department of Lands and Forests (now the OMNR). In 1958 an Inventory Maintenance Program was initiated, the goal of which was to update the initial survey on a 20-year basis. The third FRI cycle began in 1977 and is scheduled for completion in 1997.

Historically, FRI information was presented on hardcopy maps or summary reports (ledgers) compiled on a geographical township or base map (7.5 minutes longitude by 15 minutes latitude) basis at a scale of 1:15 840. Stand attribute data and associated compilation reports were stored on magnetic tape. More recently, FRI updates have been prepared in ARC/INFO format using the Ontario Base Mapping (OBM) base, which is prepared at a 1:10 000 scale (southern Ontario) or a 1:20 0000 scale (northern Ontario).

SPOT

The French-developed SPOT (Systeme Probatoire pour l'Observation de la Terre) satellite was first launched in 1986 (SPOT-1). SPOT-1 orbits at a mean altitude of 830 km, circling the earth just over 14 times a day. SPOT-1 passes vertically above a given point on the earth's surface once every 369 revolutions (i.e., once every 26 days). SPOT-2 (launched in 1990) and SPOT-3 satellites have been placed in the same orbit as SPOT-1. SPOT satellites have pointable optics that allow the capture of nadir (directly overhead) and off-nadir (oblique) images. Because of the pointable optics and the number of satellites, it is possible to acquire images of the same point on the earth's surface as frequently as every 2 days (although these images will include a combination of nadir and off-nadir images). SPOT-1 was phased out in 1990.

SPOT satellites are fitted with two identical highresolution-visible (HRV) imaging systems. Each HRV is designed to operate in either of two sensing modes: (1) a 10-m resolution "panchromatic" (black and white) mode (single spectral band), or (2) a 20-m resolution multispectral (color infrared [IR]) mode (three spectral bands—green, red, near-IR). Spectral reflectance values are encoded over a 256-digital number (DN) range. A single SPOT image covers an area of 60–80 km by 60–80 km on the ground. A SPOT panchromatic digital image or, scene, has a pixel size equivalent to 10 m² on the ground. (A pixel is the smallest recognizable unit within a digital raster image.) This means that any object larger than 10 meters will be represented within the raster image or, alternatively, the object dominating a 10-m pixel will be represented.

Landsat

Developed by NASA, with the cooperation of the United States Department of the Interior, the first Landsat satellite was launched in 1972 (Landsat-1). The first three satellites (Landsat-1, -2, and -3), launched between 1972 and 1978, orbited at a nominal altitude of 900 km. They circled the earth once every 103 minutes, resulting in 14 orbits per day and an 18-day orbital cycle. These three satellites carried two remote sensing systems: (1) a return beam vidicon (RBV) camera system, and (2) a fourchannel multispectral scanner (MSS) system. The RBV system consisted of television-like cameras. In Landsat-1 and -2, each of three RBV cameras recorded a single spectral band (green, red, near-IR), with a ground resolution of about 80 m. A two-camera side-by-side configuration was employed on Landsat-3. The Landsat-3 RBV system recorded a single spectral band (green to near-IR) with a nominal ground resolution of 30 m. The MSS system flown on Landsat-1 was the first global monitoring system capable of producing multispectral data in digital format. The MSS on board Landsat-1, -2, and -3 covered a 185-km swath width in four wavelength bands: two in the visible spectrum (green [Band 4] and red [Band 5]) and two in the near-infrared [Bands 6 and 7]. The DNs available for initial assignation within each band ranged from 0 to 63. DNs were resampled to 128 grey levels for Bands 4 to 6 and remained at 64 for Band 7. The MSS on Landsat-3 also incorporated a thermal band (Band 8), but this channel failed shortly after launch. Each Landsat-1, -2, and -3 MSS scene covers an area of about 185 km x 185 km with a ground resolution of approximately 79 m. Landsat-1, -2, and -3 were decommissioned in 1978, 1982, and 1983, respectively.

Landsat-4 and -5, launched in 1982 and 1984, respectively, orbit the earth at an altitude of 705 km. Both satellites circle the earth once every 99 minutes, completing just over 14.5 orbits per day. This orbit correlates to a 16-day repeat cycle for each satellite. The orbits of Landsat-4 and -5 were established 8 days out of phase and, as such, it is possible to obtain coverage of the same point on the earth's surface every 8 days (with alternating satellite coverage). Landsat-4 and -5 carry a MSS system essentially identical to those on earlier Landsat satellites

and produce 185-km x 185-km scenes with a ground resolution of approximately 79 m. In place of the RBV system, Landsat-4 and -5 carry the Thematic Mapper (TM) sensor. The TM sensor incorporated a series of advancements over the MSS: including, several spectral bands (blue, green, red, near-IR, thermal-IR, and two mid-IR), improved color sensitivity (256 DNs versus 64 DNs), and better spatial resolution (30 m versus 80 m).

ERS-1

The European Space Agency's first European Remote Sensing Satellite (ERS-1) was launched in 1991. This satellite orbits at an altitude of approximately 785 km. Although it has been operated on 3-day repeat cycles, the majority of ERS-1's mission was performed in a 35-day repeat cycle. A 35-day cycle was planned for ERS-2's entire mission. Using advanced microwave and radar techniques, the ERS satellites measure many parameters not provided by either SPOT or Landsat: including, sea state, sea-surface winds, ocean circulation, sea/ice levels, and other valuable geodetic information. The ERS-1 satellite payload includes an Active Microwave Instrument (AMI) containing Synthetic Aperture Radar (SAR). Utilizing a 10-m-long antenna, a narrow radar beam is directed onto the Earth's surface along an 80-100 km-wide swath. High-resolution imagery is built up from the time delay and strength of the return signals, which depend primarily on the roughness and dielectric properties of the surface and its range from the satellite. Because of the nature of radar, the SAR sensor is capable of collecting data regardless of weather, season, or light conditions. ERS-1 SAR images provide a ground resolution of 25 m. As ERS SAR is very sensitive to surface roughness and soil and plant moisture content, and the data can be used for crop identification, land use mapping, and soil moisture monitoring. When SAR data and optical sensor data such as MSS and TM are combined, the reliability of object classification can be greatly increased.

APPENDIX B. Procedure for developing equivalencies between NOEGTS and OLI labeling conventions.

Key soil attributes, such as texture, moisture, and depth, together with independently derived species/site productivity information developed from regional growth and yields initiatives, have recently been integrated into a Prime Land classification productivity model by NWRS&T. Soil attribute information for OLI Land Classification map polygons, available from 1:250 000 maps, was used to predictively map species productivity.

In order for NOEGTS information to be used in an OLIbased Prime Land mapping system, NOEGTS polygon descriptors had to be relabeled to allow for possible input into the NWRS&T's Prime Land algorithms. Steps used in the relabeling process are described below.

The Prime Land algorithm requires three main variables: namely, (1) texture, (2) moisture, and (3) depth. The polygon labels appearing on the maps or in the associated map database were defined in such a manner as to reflect the parameters contained in NWRS&T's productivity tables (see Table B-1). The codes associated with the three variables are provided below:

1) Texture codes

- 0 No texture information
- 1 Very gravelly
- 2 Sandy
- 3 Coarse loamy
- 4 Silty
- 5 Fine loamy
- 6 Clayey
- 7 Organic
- 8 Organic nonproductive
- 9a Exposed bedrock
- 9b Rock with shallow

2) Moisture codes

- D Dry
- F Fresh
- M Moist
- W Wet
- U Unknown

3) Depth Codes

- 1xs Extremely shallow (<20 cm)
- 1s Shallow (20–100 cm)
- 2 Deep (>1 m) surficial deposits

Polygons are labeled with up to seven characters, ordered as follows:

Primary texture, secondary texture, moisture regime, depth

Examples: 7 2 W 2 (organic material, sand, wet, >1 m).

9b 3 F 1s (rock with shallow coarse loamy material, fresh, 20–100 cm).

Table B-1. Identification of codes used for redefining NOEGTS polygon labels based on NWRS&T's "Productivity Data for Northwestern Ontario Soil Conditions - Poplar" (rev. 05 June 1991).

	Assigned texture class	1	2	3	4	5	6	7	.8	
Assigned depth class	Moisture Regime	VGR - very gravelly:All textures with > 50 percent particles >2mn	SDY - Sandy: vcS, cS, mS, fS, LvcS, LcS, LmS, LfS	C.LMY - Coarse Loamy: SiS, SL, LvfS, L, vfS	SLY - Silty: SiL, Si SCL, SiCL	FLY - Fine Loamy: CL,	CYY - Clayey: C, SC, SiC, HC		Feathermoss Organic	Sphagnum Organic
Depth > 1	meter									
2	Dry (0,0)	n/a n/a	19.34±1.82 4.65±1.31	n/a n/a	n/a n/a	n/a n/a	n/a n/a			ñ
	Fresh (1,2,3)	n/a n/a	19.82±1.92 4.52±1.88	17.95±2.44 6.63±0.90	19.10±2.75 4.61±1.44	20.37±2.67 5.28±2.33	25.78±0.87 6.55±2.33			
	Moist (4,5,6)		n/a n/a	1.80±2.80 4.66±1.98	n/a n/a	n/a n/a	22.84±2.80 4.66±1.98	Nonproductive		
	Wet (7,8,9)		n/a n/a	n/a n/a	n/a n/a	n/a n/a	n/a n/a		Nonproductive	Nonproductive
Depth < 1	meter		iā.						= -	
1xs	Extremely									
	shallow (<20 cm)	n/a n/a	n/a n/a	n/a n/a	n/a n/a					
1s	Shallow 20–100 cm)	n/a	21.47±0.43 2.99±1.91	n/a n/a	n/a n/a	n/a n/a	n/a n/a	Nonproductive	Nonproductive	Nonproductive
1pd	Shallow - poorly									
	drained (20-100 cm)		n/a n/a	n/a n/a	n/a n/a	n/a n/a	n/a n/a	Nonproductive	Nonproductive	Nonproductive

Assignment of NOEGTS Descriptors to Reflect OLI-based Prime Land Classification Codes:

1. Soil texture codes:

In the NOEGTS map legend, textural information is provided under the heading "Material" and labels are coded as follows:

b	boulders, bouldery	г	rubble	
C	clay, clayey	S	sand, sandy	
g	gravel, gravelly	m	silt, silty	
p	peat, muck	t	till	

These codes and their combinations were assigned to OLI-based texture classes as follows:

NOEGTS texture code	Assigned texture class*
No texture given	0
b, g, gb, gs, r, sg	1 -
S	2
ms, sm, t, ts	3
m	4
c, cm, cs, mc, sc	6
Na ulka kawala	7

^{*} OLI-based Texture Classes 5, 8, 9a, and 9b do not have corresponding textures/soil types in the NOEGTS classification system.

2. Moisture Codes:

The assigned moisture regime was dependent upon the soil texture. OLI-based moisture codes were assigned to the NOEGTS texture codes as follows:

Assigned NOEGTS texture code(s)	Assigned moisture code
8 1	D
2, 3, 4	F
5, 6	M
7	W

3. Depth Codes:

NOEGTS "Bedrock" codes were assigned to the OLIbased soil depth codes as follows:

N	NOEGTS code	, z	Assigned depth code
RL	Bedrock plateau	1s	Shallow soil (20–100 cm)
RN	Bedrock knob	1s	Shallow soil (20-100 cm)
RP	Bedrock plain	1s	Shallow soil (20-100 cm)
RR	Bedrock ridge	1xs	Extremely shallow soil (< 20 cm)
/R	Bedrock below a drift veneer.	2	Deep soil (> 1 meter)
	All other cases; wherever no bed- rock code is given.	2	Deep soil (> 1 meter)

APPENDIX C. Conversion of northwestern Ontario Forest Ecosystem Classification S-types to OLI-based Prime Land classification codes.

Depth category		Soil type, moisture regime	Assigned soil code
Deep mineral	S1	Coarse Sandy, Dry	20D2
	S2	Fine Sandy, Fresh	20F2
	S3	Coarse Loamy, Fresh	30F2
	S4	Silty - Silt Loamy, Fresh	40F2
	S5	Fine Loamy, Fresh	50F2
	S6	Clayey, Fresh	60F2
	S7	Sandy, Moist	20M2
	S8	Coarse Loamy, Moist	30M2
	S9	Silty - Silt Loamy, Moist	40M2
	S10	Fine Loamy - Clayey, Moist	50M2
	S11	Moist / Peaty Phase	70M2
Deep organic	S12F	Organic (Feathermoss), Wet	80W2
	S12S	Organic (Sphagnum), Wet	80W2
Very shallow	SS1	Discontinuous Organic Mat on Bedrock	9a0U1xs
	SS2	Extremely Shallow Soil on Bedrock	9b0U1xs
	SS3	Very Shallow Soil on Bedrock	9b0U1s
	SS4	Very Shallow Soil on Boulder Pavement	9b0U1s
Shallow to moderately deep	SS5	Shallow - Moderately Deep / Sandy	20U1s
(E)	SS6	Shallow - Moderately Deep / Coarse Loamy	30U1s
	SS7	Shallow - Moderately Deep / Silty - Fine Loamy - Clayey	not encountered
	SS8	Shallow - Moderately Deep / Mottles - Gley	not encountered
	SS9	Shallow - Moderately Deep / Organic - Peaty Phase	70U1s

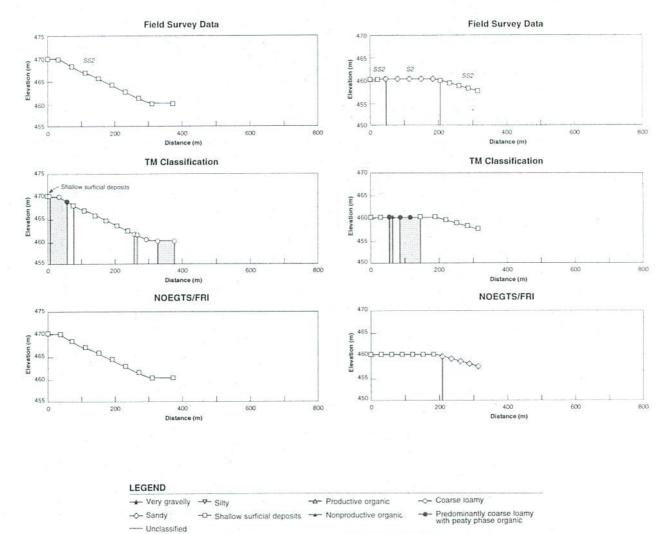
Note: Table is based on that developed by Sims et al. (1989).

APPENDIX D. Comparison profiles.

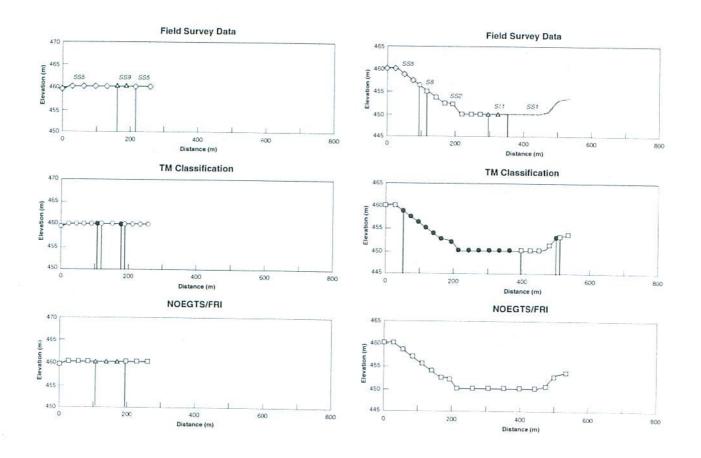
A series of comparison profiles were prepared to graphically illustrate the soil textures found during the field survey versus the soil textures 'predicted' to occur based on the NOEGTS/FRI and Landsat TM classification methods. The location of the transects completed in the study area are shown on Maps 3 and 4. The SW prefix refers to how the study area was referenced during the early phases of the study.

Comparison Profile: SW-1

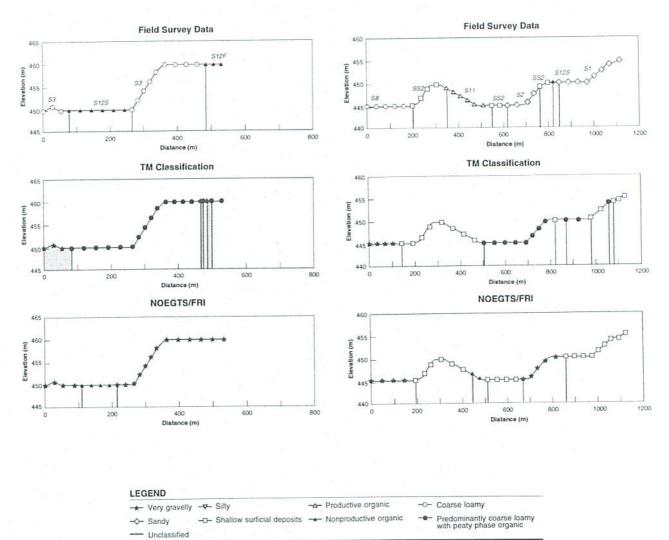
Comparison Profile: SW-2



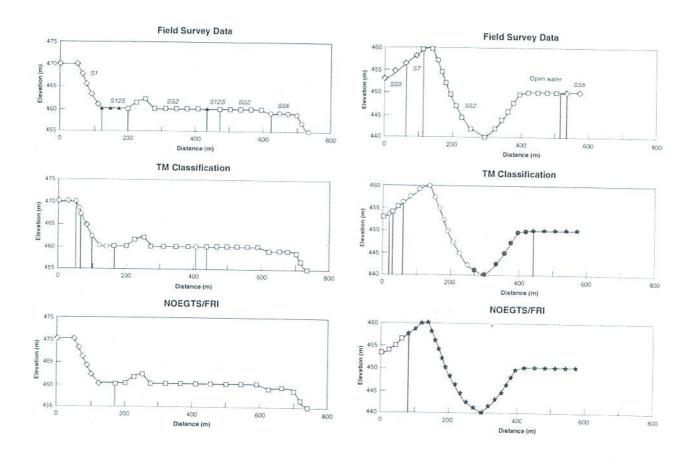
Comparison Profile: SW-4



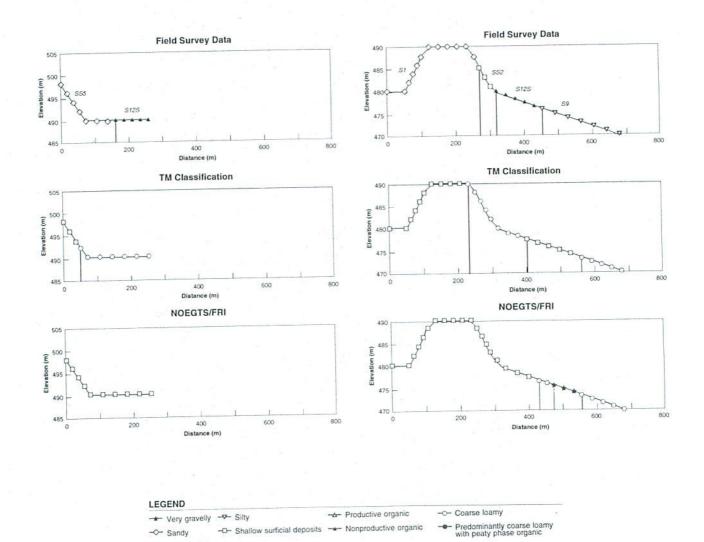
LEGEND					
→ Very gravelly	-▼- Silty	-4-	Productive organic		Coarse loamy
→ Sandy	-C- Shallow surficial deposits	-	Nonproductive organic	-0-	Predominantly coarse loamy
Unclassified					with peaty phase organic



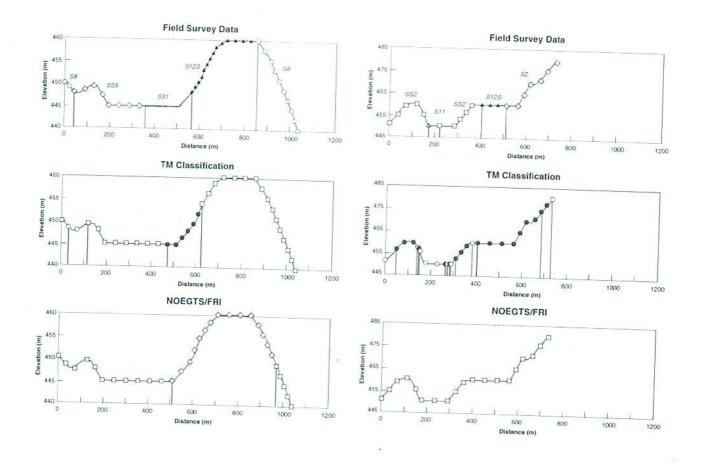
Comparison Profile: SW-8



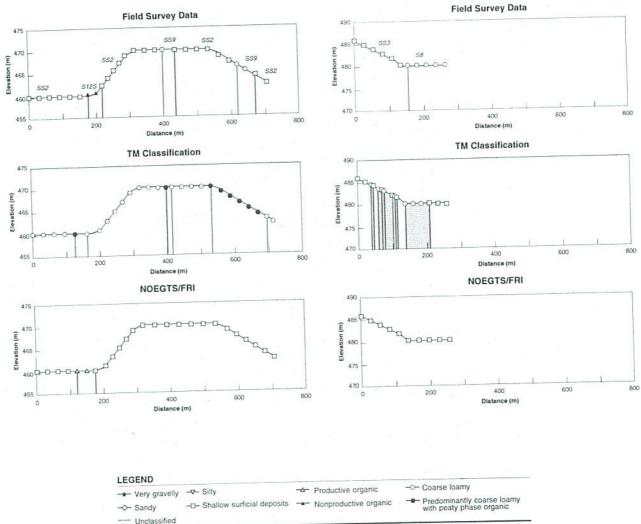
LEC	END					
*	Very gravelly	-♥- Silty	-4-	Productive organic	-0-	Coarse loamy
→	Sandy	-O- Shallow surficial deposits		Nonproductive organic		Predominantly coarse loam
	Unclassified			Ri Ri		with peaty phase organic

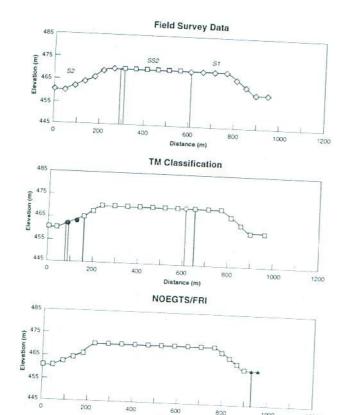


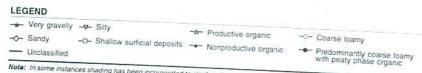
Comparison Profile: SW-12



LEGEND					
★ Very gravelly	-▼- Silty	-	Productive organic	-	
			r roductive organic	-0-	Coarse loamy
V Gandy	-D- Shallow surficial deposits		Nonproductive organic	-0-	Predominantly coarse loam
Unclassified			**************************************		with peaty phase organic







APPENDIX E. Level of effort scenarios.

An Enhanced Forest Soils Mapping Database for Northern Ontario Using a GIS-based Approach: Scenario 1

Assumptions: Study area of 40 km², no digital map-based data available.

		GIS technician	GIS analyst	RS technician	RS analyst	Total person-days
Method		11				
Metho	od 1	0.25	0.25			0.5
	igitize OLI polygons igitize NOEGTS polygons	0.25	0.25			0.75
3. D	rigitize transport and water covers from 1:50 000 ITS map sheet	1.0	0.25			1.25 3.25
· D	Digitize contour cover from 1:50 000 NTS map sheet	3.0	0.25			1.0
	Create database structure in GIS environment		1.0			2.0
5. C	Recode OLI and NOEGTS polygons		2.0			2.0
7. (Georeference SPOT Panchromatic image and output			1.0		1.0
h	nardcopy image				1.0	1.0
8. (Create digital elevation model Subdivide NOEGTS polygons using "FLY!" in EASI/PA	CE			2.0	2.0
9.	Subdivide NOEGTS polygons using TET. In Establishment Subdivide NOEGTS polygons using TET. In Establishment Subdivide NOEGTS polygons using TET.	0.5	0.25			0.75
10.	Digitize polygons identified during "FLY!" session		2.5			2.5
	Prepare map depicting primary soil textures	5.25	6.75	1.0	3.0	16.0
1	Total person-days - Method 1					
	hod 2	10.0	1.0			11.0
1.	Digitize FRI stand polygon boundaries	10.0	1.5			1.5
2.	Import digital FRI stand attribute data		1.5			
3.	Develop AMI s to select FRI stands exhibiting strong		1.0)		1.0
	species/soils relationships from FRI database		1.5	5		1.5
4.	Integrate FRI database with Method 1 database		2.5	5		2.5
5.	Prepare map depicting primary soil textures	15.25	5 11.	75 1.0	3.0	31.0
	Total person-days - Method 2*	13.2.	, 11.	5,55		
Me	ethod 3			1.0		1.0
1.	Georeference Landsat TM image			1.0		
2.	Classify Landsat TM image using NOEGTS/FRI				5.	.0 5.0
3.	Intersect soil polygons identified during classification				5	.0 5.0
	process with Method 1 database		- 3	6.0		3.0
4.	Prepare map depicting primary soil textures Total person-days - Method 3**	4.7		7.0 1.0	0 10	0.0 22.

^{*} Includes Method 1, Steps 1 through 10.
** Includes Method 1, Steps 1 through 6; excludes all Method 2 steps.

An Enhanced Forest Soils Mapping Database for Northern Ontario Using a GIS-based Approach: Scenario 2

Assumptions: Study area of 40 km², digital OLI and NTS covers (including contours) available.

Method/step		GIS technicia		GIS	ırs) availab RS		Total
Method 1	ethod 1	techn	ncian	analyst	technician	analyst	Total person-days
 Digitize NOI 	EGTS polygons						15511
	igital OLI and NTS data	0	5	0.25			0.75
Create databa	se structure in GIS environment	1.:	5	1.0			2.5
4. Recode OLI a	nd NOEGTS polygons			1.0			1.0
5. Georeference hardcopy imag	SPOT Panchromatic :			2.0			2.0
6. Create digital of	elevation model				1.0		1.0
	EGTS polygons using "FLY!" in EASI/P					1.0	1.0
8. Digitize polygo	ons identified during "FLY!" session	ACE				2.0	2.0
9. Prepare map de	picting primary soil textures	0.5	(0.25			0.75
Total person-d	avs - Method 1			2.5			2.5
Method 2	-ys method 1	2.5	7	7.0	1.0	3.0	13.5
1. Digitize FRI star	nd polygon boundaries						15.5
2. Import digital Fr	RI stand attribute data	1.0	1	.0			11.0
B. Develop AMI s	a stand attribute data		1	.5			
species/soils rela	o select FRI stands exhibiting strong tionships from FRI database						1.5
. Integrate FRI dat	abase with Method 1 database		1.	0			1.0
. Prepare map depi	cting primary soil textures		1	5			1.5
Total person-day	's - Method 2*		2.5	5			2.5
lethod 3		12.5	12.	0 1	.0 3.)	28.5
Georeference Land	dsat TM image						
	M image using NOEGTS/FRI as			1	.0		1.0
	ons identified during classification od 1 database				5.0		5.0
	ing primary soil textures				5.0		5.0
Total person-days			3.0			3	3.0
ncludes Method 1, S		2.0	7.25	1.0	0 10.0	20	0.25

Includes Method 1, Steps 1 through 8.
Includes Method 1, Steps 1 through 4; excludes all Method 2 steps.

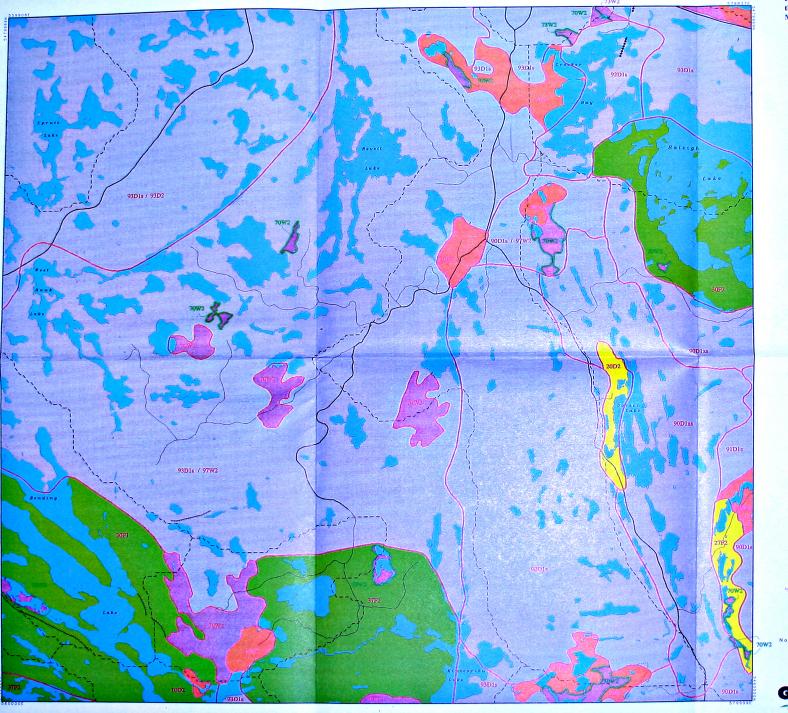
An Enhanced Forest Soils Mapping Database for Northern Ontario Using a GIS-based Approach:

Assumptions: Study area of 40 km², digital OLI, NTS covers (including contours) and digital FRI stand data available. Scenario 3

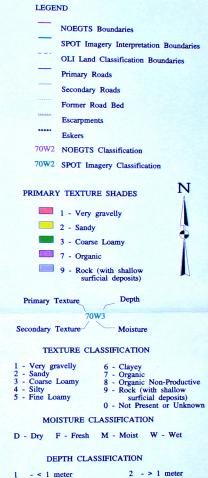
Assumptions: Study area of 40 km ² , digital OLI, NTS covers	GIS technician	100000000000000000000000000000000000000	RS technician	RS analyst pe	Total erson-days
Method/step	7				
Method 1	0.5	0.25			0.75
 Digitize NOEGTS polygons 	1.5	1.0			2.5
Incorporate digital OLI and NTS data	1.5	1.0			1.0
Create database structure in GIS environment		2.0			2.0
A Recode OLI and NOEGTS polygons		2.0			
 Georeference SPOT Panchromatic image and outp 	ut		1.0		1.0
hardcopy image				1.0	1.0
6. Create digital elevation model				2.0	2.0
7 Subdivide NOEGTS polygons using "FLY!" in EA	ASI/PACE	0.25			0.75
8. Digitize polygons identified during "FLY!" session	on 0.5	0.25			2.5
depicting primary soil textures		2.5	1.0	3.0	13.5
9. Prepare map depicting printing Total person-days - Method 1	2.5	7.0	1.0	3.0	13.5
					1.5
Method 2 1. Incorporate digital FRI stand boundaries and attri	ibutes	1.5			1.3
Incorporate digital FRI stands exhibiting st Develop AMLs to select FRI stands exhibiting st	trong				1.0
2. Develop AMLs to select FRI stands of species/soils relationships from FRI database		1.0			1.5
CDL database with Method 1 database		1.5			2.5
- depicting primary soil textures		2.5			
4. Prepare map depicting printery Total person-days - Method 2*	2.5	5 11	.0 1.0	3.0	17.3
Method 3			1.0	C	1.0
Georeference Landsat TM image	OI ac				
 Classify Landsat TM image using NOEGTS/FF ground truth 				5.0	0 5.0
 Intersect soil polygons identified during classif 	fication			5.	0 5.0
process with Method 1 database			3.0		3.0
4. Prepare map depicting primary soil textures				.0 10	0.0 20.2
Total person-days - Method 3**	2	1		100	

^{*} Includes Method 1, Steps 1 through 8.

** Includes Method 1, Steps 1 through 4; excludes all Method 2 steps.



Development of a Prototype GIS-Based Approach: Enhancing the Forest Soils Mapping Database for Northern Ontario Map 2: Integration of OLI and NOEGTS Databases with Interpreted SPOT/DEM Data



1xs - extremely shallow

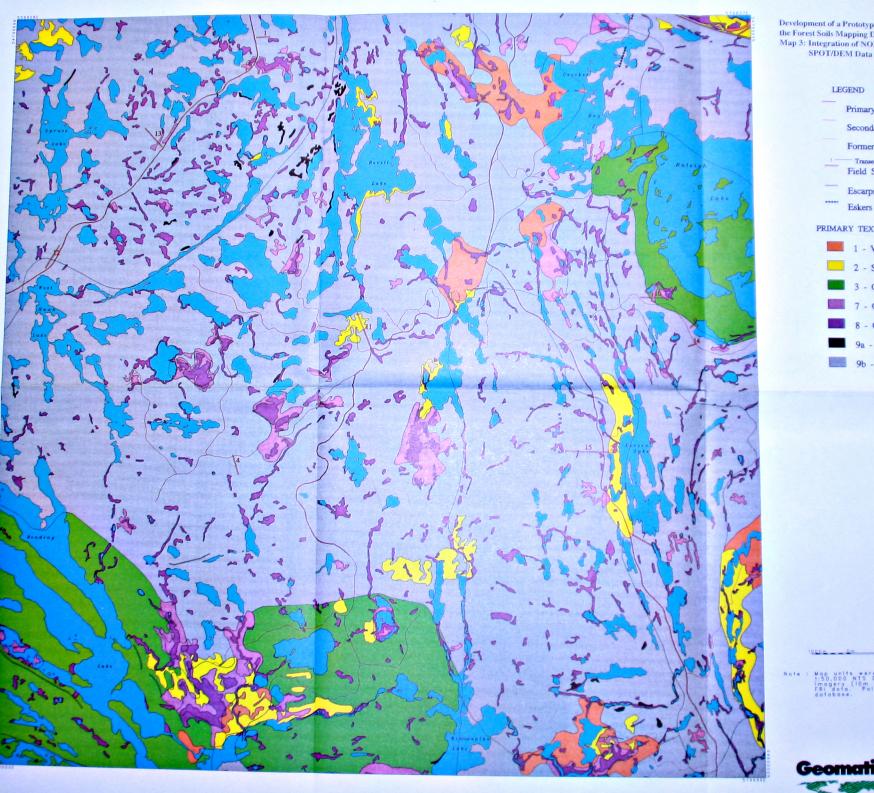
< 20 cm. 1s - shallow 20 - 100 cm.

Scale 1 : 50 000

Map Units and attributes were developed using 1:250,000 OLL; 1:100,000 NOEGTS; 1:50,000 NTS DEM; and the interpretation of Panchromatic SPOT (IUm x 10m spatial resolution) imagery.

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Development of a Prototype GIS-Based Approach: Enhancing the Forest Soils Mapping Database for Northern Ontario Map 3: Integration of NOEGTS Database, Interpreted SPOT/DEM Data and FRI Database

Primary Roads

Secondary Roads

Former Road Bed

Transect Number

Field Survey Transect

Escarpments

PRIMARY TEXTURE SHADES

1 - Very Gravelly

2 - Sandy

3 - Coarse Loamy

7 - Organic

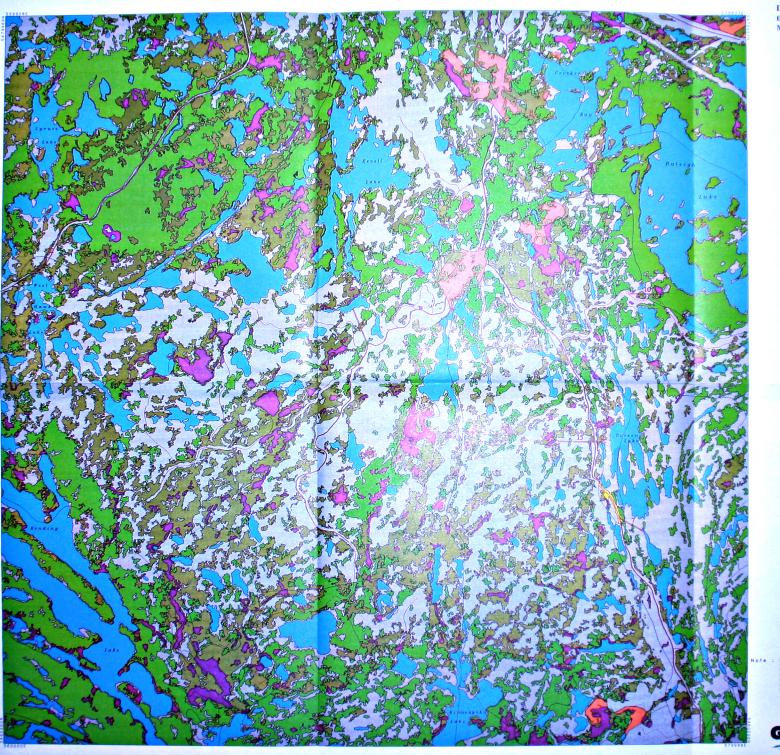
8 - Organic Non-Productive

9a - Exposed Bedrock

9b - Bedrock with Shallow Surficial Deposits

N

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Development of a Prototype GIS-Based Approach: Enhancing the Forest Soils Mapping Database for Northern Ontario Map 4: LANDSAT TM Soil Classification (Supplemented by NOEGTS)

LEGEND

Primary Roads

Secondary Roads

Former Road Bed

Transect Number Field Survey Transect

PRIMARY TEXTURE SHADES

1 - Very Gravelly

2 - Sandy

3a - Deep to Moderately Deep Coarse Loamy

3b - Shallow Sandy/Coarse Loamy/ Peaty Phase Organic

8 - Organic Non-Productive

9a - Exposed Bedrock

9b - Bedrock with Very Shallow Coarse Loamy Surficial Deposits

Scale 1 : 50 000

Map units were developed through interpretation of LANDSAT TM Imagery (Bands 1,6.7; 10m x 10m spatial resolution) supported by it: 50,000 NTS and 115,840 FM as ground truth. In areas of disturbance (i.e., clerified roads), NOCOTS doto was incorporated to great a support of the company of texture intermetion. Palygon attributes retained in a digital delicace.

