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THE DERIVATION OF SPATIALLY REFERENCED ECOLOGICAL DATABASES FOR ECOSYSTEM MAPPING AND MODELING IN THE RINKER LAKE RESEARCH AREA, NORTHWESTERN ONTARIO

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INTRODUCTION

Implementation of an ecological approach to sustainable forest management requires that attention be paid to ecological information outside the traditionally narrow focus of conventional operational concerns. It is critical that ecological entities that exist on the landscape be properly identified, and that their relative values be carefully weighed for purposes of both resource extraction and conservation. Development of a total inventory of ecological resources and processes within an area of operational interest is essential, in principle necessitating an interdisciplinary approach.

Ecosystems are complex entities of multiple ecological dimensions that come in various sizes and shapes. They may overlap on the ground, depending upon the scale of investigation and the manner in which they are described. Consequently, ecological inventories should be capable of distinguishing various properties of ecosystems and defining their relationships at various spatial scales. Issues of scale are particularly important when spatially referenced ecological information is being compiled. Local, fine-scale inventories should be nested within the context of broader-scale, regional ecological units as defined within ecologically based land classification systems.

Spatially referenced, ecological information will increasingly be used to construct or calibrate predictive, dynamic ecosystem models at a variety of scales, for management purposes. As they are developed and tested, such models will be seeking to derive spatial information on critical ecosystem characteristics that are not directly interpretable from primary data sources. Examples of ecological parameters that may be modelled in this manner include the spatial distribution of primary environmental regimes such as radiation, ground water, and nutrients; potential ecological ranges for various biological communities and species populations; temporal, successional responses of vegetation communities to natural or anthropogenic disturbances; indices of biodiversity; specific regional effects of climate change and pollution; and dynamic linkages between local-level ecological conditions and responses to resource management activities at various scales. The accuracy of any modeling effort depends upon the input of spatially reliable estimates of environmental attributes.

For northwestern Ontario, spatially referenced ecological data are limited in both thematic coverage and the scales at which they are available. Often, the data are outdated and do not accurately represent current landscape features, particularly vegetation conditions. In their standard forms, existing spatial databases, such as the Ontario Land Inventory (OLI), Northern Ontario Engineering Geology and Terrain Survey (NOEGTS), and Forest Resource Inventory (FRI), are useful for some, but not all, land management applications. For operational forest management, both the OLI and NOEGTS databases lack sufficiently detailed data to support local management planning. While FRI data are provided at an operational scale (i.e., 1:15 000 to 1:20 000 scale), these products lack ecological scope by detailing, for a moment in time, only the mensurational characteristics that are interpretable from the forest canopy (e.g., tree species composition, stand

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age, and site productivity). To achieve ecologically based forest management, existing databases may need to be modified and/or new databases may have to be created, at appropriate scales, to represent the spatial distribution of all types of ecological parameters (soil, understory vegetation, etc.). Fortunately, new technology for collecting, analysing, and presenting spatial data is rapidly becoming available to the land manager. As well, a broad-based sense of social and political urgency about sustainable approaches to resource management is driving managers to incorporate scientific knowledge of ecological relationships into their management planning processes.

The Rinker Lake Project

In the spring of 1992, a multidisciplinary and multiagency research project was initiated at the Rinker Lake Research Area in northwestern Ontario. A principal goal of this collection of studies was to assimilate and integrate the findings of various researchers into prototypes of spatially based ecosystem models, or sets of models (initially, static and descriptive; ultimately, dynamic and predictive) that could be applied in the context of resource management planning. Another goal was the identification and description of ecosystem components and processes at scales of 1:15 000 to 1:20 000 (the current scale of operational forest management planning in northwestern Ontario).

The project served as a demonstration of the practical application of a geographic information system (GIS) for the purposes of resource inventory, ecosystem process modeling, and management planning. An analytical GIS approach was employed throughout the project to 1) integrate various digital, spatially referenced, ecological databases (e.g., FRI, land cover, soil, terrain); 2) construct and test ecosystem models; and, 3) develop several "case study" resource management applications that demonstrate the utility and application of the work.

To carry out the modeling work, data were required that provided spatial representation of both primary and derived ecological attributes. Primary spatial data used throughout the project included nine digital topographic mapsheets from the Ontario Base Map (OBM) Series (1:20 000 scale), black and white aerial photographs (1:15 840 scale) acquired during the summer of 1985, color infrared aerial photographs (1:10 000 scale) acquired in September, 1992 and September, 1994, and 2 Landsat Thematic Mapper (TM) images (bands 1–7) acquired June 20, 1992 and September 11, 1993. Additionally, various ecological ground survey data were collected at approximately 550 georeferenced points across the Research Area.

Spatial databases describing fundamental ecological characteristics of the Rinker Lake Research Area were subsequently derived from these primary spatial and ground survey data. A digital elevation model was constructed from the OBM topographic contour data. Features of Quaternary geology within the Research Area were mapped using aerial photo interpretation and ground truth observations at some 250 survey points throughout the Research Area. Soil texture coverages were derived by reclassifying the Quaternary landform polygons according to ground observations of soil texture at approximately 200 points across the Research Area. Land cover classifications were derived from the 1992 and 1993 TM images. As well, coverages of roads and cutovers were updated as forest management activities proceeded during the study period.

The techniques for deriving these spatial databases constitute the focus of this note. More detailed descriptions of the database development work carried out in the Research Area are presented elsewhere (*see* NODA File Report 33). The primary databases described in this note (terrain, soils, and land cover) are currently being used in ongoing modeling efforts to predict the spatial distribution of primary environmental regimes and of species biological responses to physical and temporal phenomena within the Rinker Lake Research Area. The database development and modeling work carried out for the Rinker Lake Research Area, at an operational scale of 1:20 000, parallels and complements similar modeling work for the province of Ontario at a landscape scale of approximately 1:250 000 (Mackey and McKenney 1994; McKenney et al. 1996a).

The Ontario Ministry of Natural Resources (OMNR) is currently updating the provincial silviculture guidelines (e.g., Ontario Ministry of Natural Resources 1997), in part to address a requirement dictated by the recent Timber Environmental Assessment for Crown Lands to employ standard, mappable site types and ecosite terminologies in the forest management planning process. Databases for the Rinker Lake Research Area have provided important background information for the development of these new guidelines. The techniques that have been tested in the Rinker Lake Research Area, as well as techniques from several other prototype ecosite mapping locations in northwestern Ontario, are helping to shape the future of Ontario's forest management planning process.

Overview of the Rinker Lake Research Area

Located about 110 km north of Thunder Bay, Ontario, the 900 km^2 (i.e., 30 km x 30 km) Rinker Lake Research Area (Fig. 1) encompasses nine Ontario Base Map (OBM) mapsheets (1:20 000 scale). Latitude / longitude coordinates of the approximate center of the Research Area are 49° 10' N; 89° 20' W. The Research Area is bounded by Lac des Iles in the northwest, Poshkokagan Lake in the northeast, and Eaglehead Lake in the southeast. It is accessible from Thunder Bay via provincial Highway 527, a drive of approximately 1.5 hours. It lies wholly within the Lake Nipigon Ecoregion of the Boreal Shield Ecozone (Ecological Stratification Working Group 1995). The humid to perhumid, moderately cool, boreal climate of this ecozone is generally characterized by warm, rainy summers and cold, snowy winters. Specifically, the Research Area receives in the order of 75 cm of total precipitation annually, approximately 50 cm of which occurs as rainfall (Environment Canada 1982b; Mackey et al. 1996). Annual

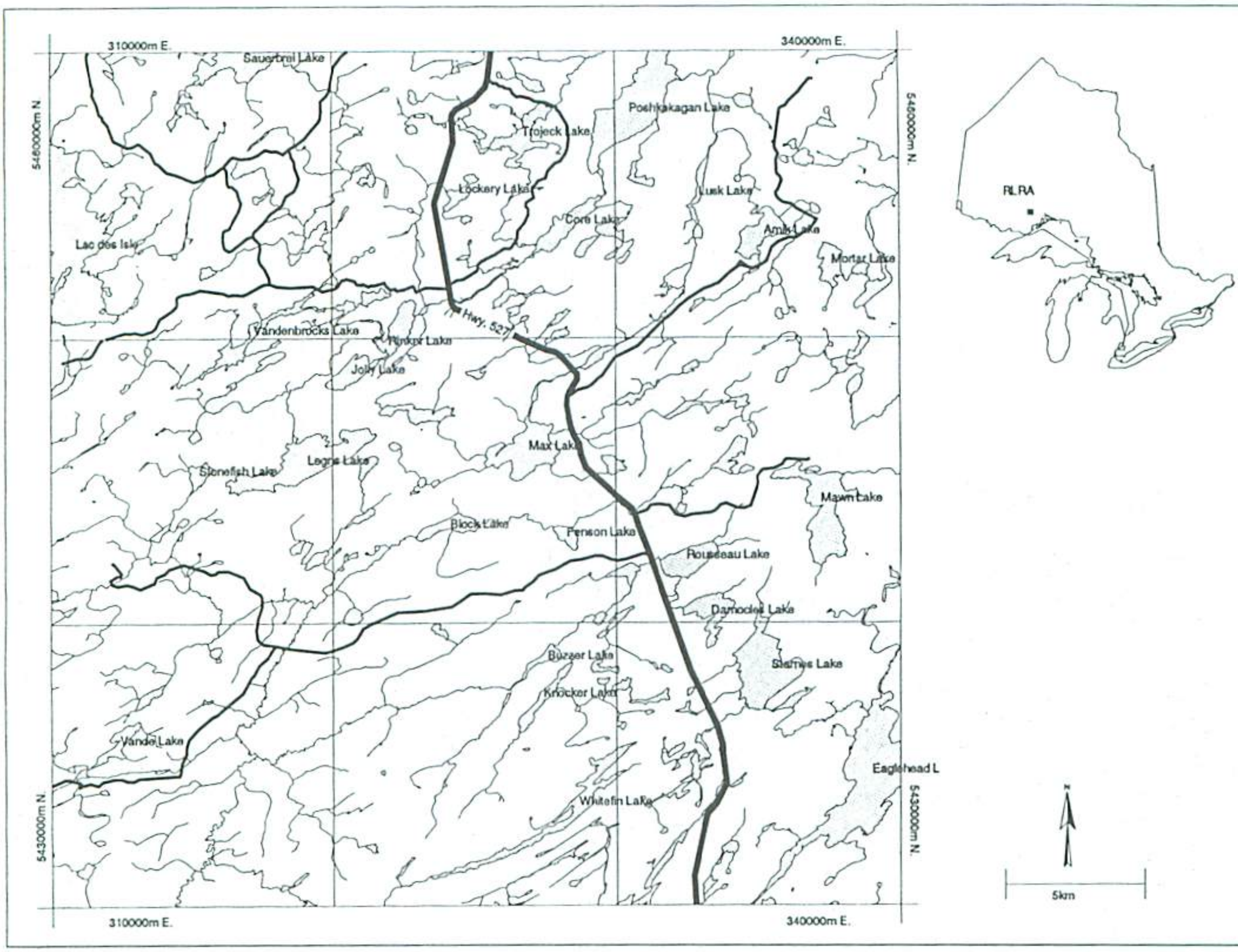


Figure 1. Map of the Rinker Lake Research Area (RLRA) showing lakes, streams, and main roads.

snowfall averages over 250 cm (Environment Canada 1982b), but the average snow depth rarely exceeds 75 cm throughout the course of the winter. The mean annual daily temperature for the area is about 0°C; mean annual daily minimum temperature is approximately -6°C, and mean annual daily maximum is around 6.5°C (Environment Canada 1982a).

Landscape features of the Rinker Lake Research Area constitute a heterogeneous mosaic of both surface and subsurface conditions. Hundreds of water bodies and rivers cover some 103.4 km^2 (11.5 percent) of the Research Area. The physiography of the Research Area is primarily bedrock-controlled, characterized by undulating hills of low or moderate relief, and by low parallel ridges oriented in a northeast to southwest direction. Elevations range between 360 m and 560 m above sea level (asl), with the majority of the relief (over 80 percent of the area) occurring between 440 m and 500 m asl. Highest elevations occur in the northwest and southeast sectors of the Research Area (Fig. 2). The underlying bedrock includes Archean "greenstones" and granites, as well as diabase and unmetamorphosed shales and limestones from the Proterozoic Era.

The Rinker Lake Research Area is located within the Boreal Forest Region of Canada (Rowe 1972). This region is characterized by extensive conifer forests of black spruce (*Picea mariana* [Mill.] BSP.) and white spruce (*Picea glauca* [Moench] A. Voss), jack pine (*Pinus banksiana* Lamb.), and balsam fir (*Abies balsamea* [L.] Mill.), as well as mixed stands of conifer and northern hardwood species such as trembling aspen (*Populus tremuloides* Michx.) and white birch (*Betula papyrifera* Marsh.). Lowlying, wetland forests are dominated by eastern white cedar (*Thuja occidentalis* L.), tamarack (*Larix laricina* [Du Roi] K. Koch), and black spruce. In overview, the mature forests of the Rinker Lake Research Area are a diverse combination of pure and mixed stands comprising all of the major tree species listed above.

The Research Area lies within the bounds of Abitibi-Consolidated Inc.'s Spruce River Sustainable Forest Licence. Although timber harvesting has been conducted within the Research Area over the past 40 years, the majority of industrial activity has occurred since 1985. As a consequence, a range of stand age classes is represented within the area, from recently harvested, regenerating stands (aged 0–10 years) to intact, mature forest (aged >100 years).

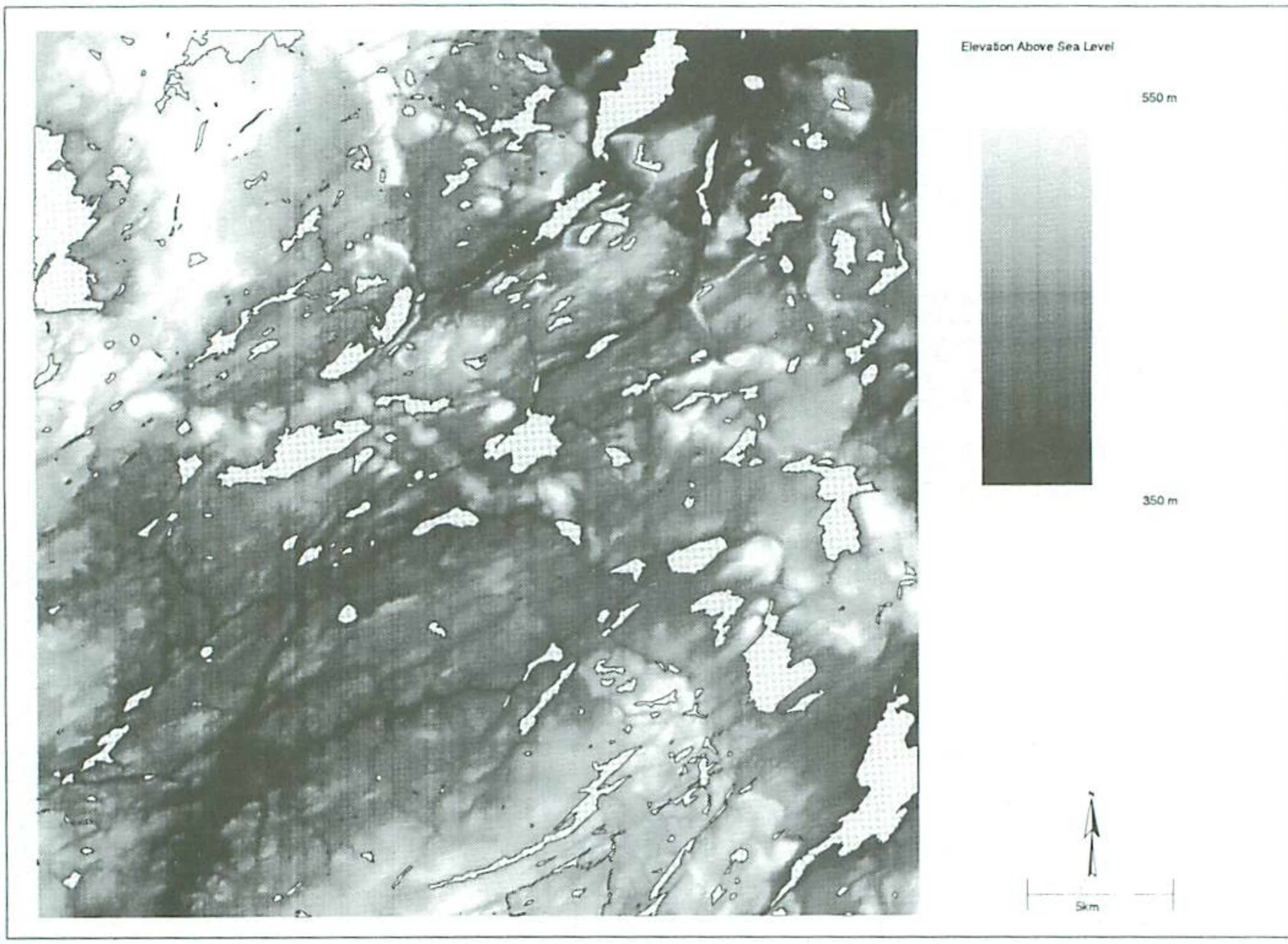


Figure 2. Digital elevation model for the Rinker Lake Research Area, constructed at a 20 m grid spacing from Ontario Base Map elevation data. Major water bodies are also shown.

The Ontario Ministry of Natural Resources maintains a fire-fighting base at the northeastern end of Rinker Lake, near the center of the Research Area. The camp provided an excellent base of operations for research staff, and its use was an important factor in the success of field work.

DEVELOPMENT OF A DIGITAL ELEVATION MODEL FOR THE RINKER LAKE RESEARCH AREA

A digital elevation model (DEM) is an ordered array of numbers that represents the spatial distribution of elevations above some base datum (e.g., mean sea level) in the landscape (Moore et al. 1991). Spatial referencing typically uses coordinates defined by latitude and longitude or Universal Transverse Mercator (UTM) grid intersections. A good DEM contains accurate, digital, topographic data that can then be used as the basis for reliable, spatially referenced estimates of local and regional climatic regimes, and numerous terrain-related ecological attributes of the landscape (Mackey et al. 1994).

A DEM for the Rinker Lake Research Area was developed at a 20 m grid resolution (Fig. 2) using the ANUDEM procedure (Hutchinson 1989) and digital input data from the OBM topographic series. OBM digital topographic data are available for a significant portion of the commercially important forested land area in northwestern Ontario. These data comprise lake polygons, stream vectors, spot heights, and 10-m interval elevation contours. Base maps encompassing the Research Area include the following nine mapsheets: 16 3100 54300 to 54500, 16 3200 54300 to 54500, and 16 3300 54300 to 54500. Contour, lake, and stream data were interpolated using the ANUSPLIN procedure (Hutchinson 1987), following computational procedures as described by Mackey et al. (1994).

The DEM provides a digital representation of the topography of the landscape within the Research Area. Figure 2 shows the northeast–southwest orientation of the bedrock ridges underlying the central portion of the Area. The heights of land associated with outcrops of the Nipigon diabase formation in the northwestern and southeastern portions of the Research Area are also clearly illustrated.

The DEM also constitutes a database upon which interpretive climatic and terrain analyses can be conducted. By fitting climatic surfaces to the DEM (Mackey et al. 1996), values for a range of climatic and bioclimatic variables were estimated at point locations in the Research Area where field data were collected, thereby enhancing the ecological descriptions of these sample plots. A radiation model (Wilson and Gallant 1998) has been calibrated for the Research Area to provide estimates of parameters associated with solar radiation for the same sample plots. Statistical terrain analyses also make use of the DEM and other spatial data to establish empirical relationships between topographic landscape attributes and primary environmental regimes within the Research Area.

QUATERNARY GEOLOGY AND SOILS OF THE RINKER LAKE RESEARCH AREA

Detailed spatial data on the distribution of soil attributes within the Rinker Lake Research Area were considered to be an essential component for the development of integrated ecosystem models. In conjunction with the DEM, these data would provide a comprehensive description of the physical landscape of the Research Area. At the outset of the project, existing spatial data for substrate characteristics of the Area consisted mainly of incomplete mapped coverages of features of bedrock and Quaternary geology, at scales no finer than 1:100 000 (e.g., Mollard and Mollard 1981). Some interpreted coverage of soil attributes was available for the entire Research Area in the Ontario Land Inventory series, at a scale of 1:250 000. Consequently, to have spatially referenced soil data for the Research Area at a nominal scale of 1:20 000, a database had to be constructed using primary sources.

Initially, a map of the Quaternary landforms of the Research Area was developed using conventional photo interpretation of black and white aerial photographs (1:15 840 scale), supplemented by color infrared aerial photography (1:10 000 scale). This was augmented by field observations of both bedrock and Quaternary landform characteristics, collected at approximately 250 georeferenced ground points. Twenty-two Quaternary landform classes were identified (Table 1). The resulting map layer was line digitized.

Quaternary materials in the Research Area are predominantly of glacial origin, although some post-glacial deposits of recent origin also occur. These deposits range in thickness from a thin veneer (<1 m) to more than 30 m, but on average are less than 5 m thick. According to the Quaternary landform database developed for the Research Area, glacial till is the most common surface sediment, covering 68 percent of the terrestrial portion of the Research Area. Approximately 17 percent of the land area is covered by glaciofluvial deposits, comprising flat outwash plains and positive relief, ice-contact features, such as eskers and kames. There are also limited expanses of fine-grained, mostly silt-sized, glaciolacustrine sediments, which were deposited in local glacial lakes. Recent materials include organic deposits, covering about 12 percent of the land area; sandy alluvium; and coarse, angular talus.

Reclassification of Quaternary Landform Classes to Soil Texture Classes

Within a landscape, soils constitute an integral, enduring ecosystem component that influences many biological and hydrological processes. The distribution of two primary environmental regimes, moisture and nutrients, is largely affected by characteristics of the soil resource. Matrix texture is the most useful single attribute for predicting moisture and nutrient retention characteristics of a soil. In conjunction with spatial information on local terrain conditions and the chemical attributes of soil parent

Table 1. Listing of the 22 Quaternary landform classes recognized for the Rinker Lake Research Area. A thematic map of the Quaternary geology of the Research Area is presented in NODA File Report 33. The areal extent within the Research Area for each class is given in square kilometers.

1	Colluvium/talus (0.3 km^2)	
2	Organic deposits	: peat, muck (79.1 km^2)
3	Alluvial deposits (1.1 km^2)	
4	Glaciolacustrine deposits	: general
5	"	: silt, clayey silt, silty sand (5.4 km^2)
6	"	: as in classes 4 and 5, with up to 1 m organic overlay (1.0 km^2)
7	Glaciofluvial outwash	: general (19.4 km^2)
8	"	: sand, gravelly sand (14.8 km^2)
9	"	: gravel, sandy gravel (8.9 km^2)
10	"	: boulder deposits (0.5 km^2)
11	Glaciofluvial ice contact stratified drift	: general (35.7 km^2)
12	"	: sand, gravelly sand (19.9 km^2)
13	"	: gravel, sandy gravel (8.0 km^2)
14	"	: esker (2.2 km^2)
15	Glacial till deposits	: general (82.8 km^2)
16	"	: silty sand to silt till, up to 10% coarse fragments (93.0 km^2)
17	"	: stony sand to silty sand till (14.0 km^2)
18	Bedrock-drift complex	: general (33.9 km^2)
19	"	: mainly till cover (122.6 km^2)
20	"	: mainly glaciofluvial sand and gravel cover (9.1 km^2)
21	"	: organic cover (1.6 km^2)
22	Precambrian bedrock (74.9 km^2)	

Table 2. Definitions of the seven classes of soil texture employed in the development of a thematic map of C horizon soil texture for the Rinker Lake Research Area. The areal extent within the Research Area for each class is given in square kilometers. Percentages indicate the proportion of soil matrix composition represented by the indicated texture class(es).

Class	Definition
1	≤20 cm soil/bedrock (78.5 km^2)
2	Coarse sandy (≥70% medium and/or coarse sand) (114.9 km^2)
3	Fine sandy (≥70% fine sand) (15.2 km^2)
4	Silty sand/sandy silt (clay <20% and 30% < all sand classes <70%; or very fine sand ≥70%) (332.4 km^2)
5	Silt (clay <20% and silt ≥70%) (5.4 km^2)
6	Fine loamy/clayey (clay ≥20%) (0 km^2)
7	Organic (≥40 cm Of, Om, Oh) (81.8 km^2)

Table 3. Reclassification matrix for conversion of Quaternary landform classes to C horizon soil texture classes.

Soil Texture Class (*see* Table 2)	Quaternary Classes (*see* Table 1)
1	1, 10, 22
2	9, 14
3	3
4	7, 8, 11–13, 15–20
5	4, 5
6	4, 5
7	2, 6, 21

materials, knowledge of soil texture can offer predictive insight into the distribution of soil moisture and nutrients across a selected landscape.

For the Rinker Lake Research Area, spatial estimates of the C horizon soil texture were obtained by reclassifying landform classes from the Quaternary geology map (Table 1) into soil texture groupings (Table 2). A reclassification matrix (Table 3) was developed, in which relationships between Quaternary landform classes and soil texture characteristics were incorporated. These relationships were elucidated from field observations[1] and laboratory texture analyses[2] of samples collected at over 300 ground survey points throughout the Research Area. Once the reclassification matrix was finalized, it was used to reclassify polygons on the Quaternary geology map to generate a soil texture map and spatial data layer (Fig. 3).

An independent dataset, containing soil texture information from approximately 144 georeferenced ground survey points, was used to verify the texture reclassification. Soil texture data were collected for both surface (0–25 cm) and deep (C horizon) soil strata at ground survey points that were selected to represent the range of Quaternary landform classes across the Research Area. Predicted (reclassified) soil textures were compared with observed (actual) soil textures for each of the goereferenced plot locations in the verification dataset. An error matrix was constructed by cross-tabulating predicted versus observed C horizon texture classes. Within this verification sample, C horizon soil texture was accurately predicted 73 percent of the time.

The soil texture classes employed in this reclassification were customized to address the textural characteristics of the soils within the Rinker Lake Research Area. Upland mineral soils, which constitute approximately 85 percent of the soil cover in the Research Area, were typically found to contain very little (<5 percent) clay; matrix texture essentially comprised a mixture of silt and sand. The majority of the tills (covering approximately 68 percent of the land portion of the Research Area) comprised between 30 and 70 percent sand – often very close to a 50:50 mixture. The conventional Canadian soil texture classification (Working Group on Soil Survey Data 1978; Ontario Institute of Pedology 1985) splits these soils between silty sand and silt loam classes, segregated at the point of 50 percent sand content. For the Rinker Lake Research Area, due to the high silt content in the soils it was deemed desirable to define a texture class that encompassed the silty sand/sandy silt characteristics of the upland till (and some glaciofluvial) deposits, thus recognizing textural similarities within map polygons of similar genetic origin. Consequently, seven texture classes

[1] Field soil textures were determined according to procedures described in Ontario Institute of Pedology (1985) and Sims et al. (1989).

[2] Laboratory soil textures were determined using the hydrometer method, as described in Kalra and Maynard (1991).

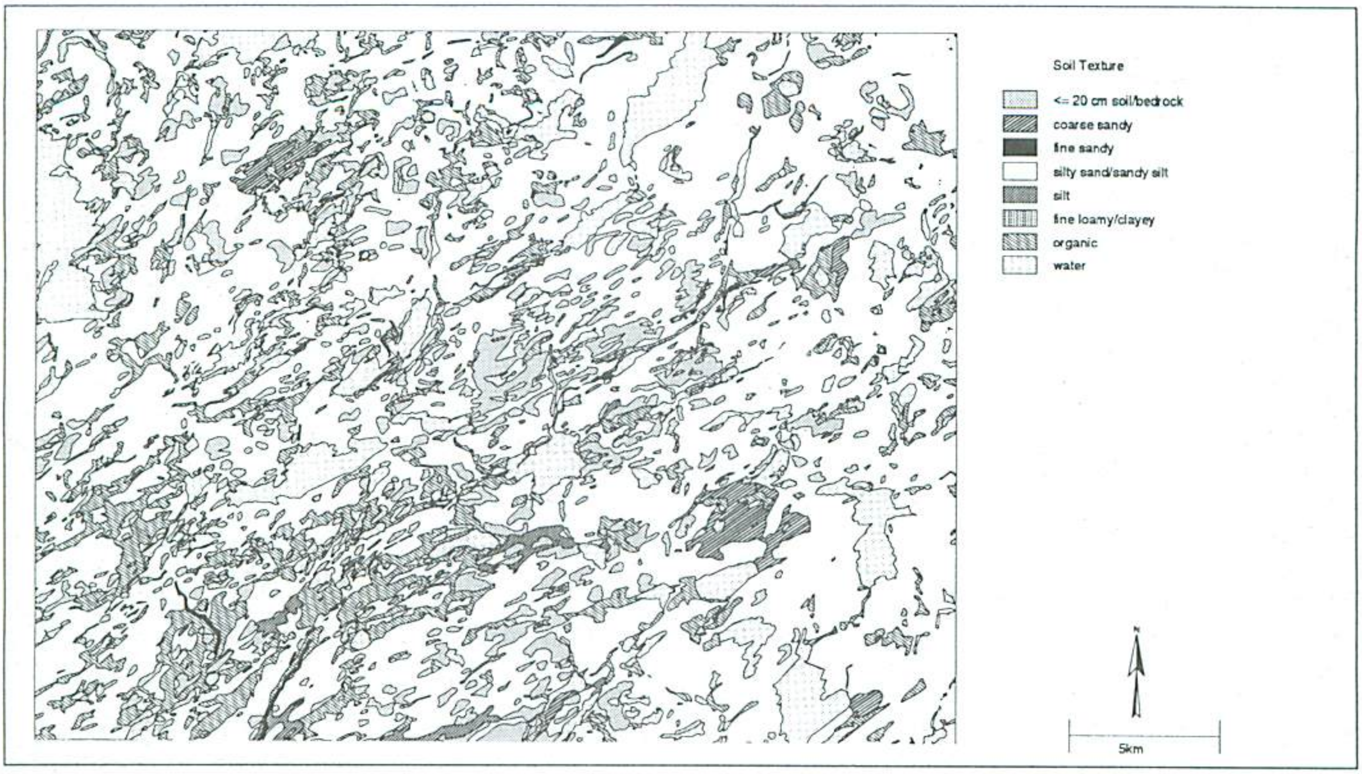


Figure 3. Thematic map of C horizon soil texture for the Rinker Lake Research Area, reclassified from Quaternary landforms as interpreted from aerial photos of the Research Area and validated by ground survey observations. Definitions of the texture classes are presented in Table 2. (Class 6, "fine loamy/clayey", is not represented in the Research Area).

were defined (Table 2): a shallow soil class, two classes of sands (coarse and fine), a silty sand/sandy silt class, a silt class, a clay/fine loam class, and an organic soil class. The textural definitions of these classes differed somewhat from the conventional thresholds represented on the soil texture triangle (Ontario Institute of Pedology 1985), however, they were intended to reflect the distribution of particle sizes as observed in the soils of the Research Area and hopefully, to distinguish among textural entities that actually occur on the local landscape.

Glaciofluvial sediments found in the Research Area were generally classed as gravelly sands. Most of the glaciofluvial deposits throughout the Research Area contained high fractions of fine and very fine sand, although many of the eskers in the southwestern part of the Area were composed mainly of open framework gravel with very poor water retention capacity. The fine-grained glaciolacustrine deposits were classed as either silt loams or silty clay loams. Regardless of depositional origin, soil profiles throughout the Research Area were commonly characterized by a cap of silty sediment overlying the genetic parent material.

LAND COVER OF THE RINKER LAKE RESEARCH AREA

Forest Resource Inventory

The Ontario Forest Resource Inventory (FRI) provides mapped coverage of most of the commercially forested areas of the province, derived from photo interpretation of black and white aerial photographs. FRI map coverages, at either 1:15 840 or 1:20 000 scale, provide some detailed information on forest cover types, species mixes, and estimated wood volumes. Additional spatial data typically linked to FRI coverages include current and historic road networks, harvesting schedules, historical forest practices, and lake/stream coverages. These maps are a primary database used by foresters throughout northwestern Ontario for forest management planning activities. FRI coverage and the associated spatial files for the Rinker Lake Research Area were made available to the project as digital databases by Abitibi-Consolidated Inc.

Satellite-Derived Land Cover Classification of the Rinker Lake Research Area

Imagery (seasonal, multitemporal) from satellites (mainly Landsat and SPOT) is readily available, but not widely used for forestry-related operational activities or planning, despite many studies that show the widespread utility of these products for such purposes (Treitz and Howarth 1996). Researchers from University of Waterloo and the Institute for Space and Terrestrial Studies, working at the Rinker Lake Research Area, investigated the potential for mapping forest ecosystems from remotely sensed images at various scales (Kalnins et al. 1993; Treitz et al. 1997). Within the Research Area, satellite imagery was used to develop a digital database describing land cover conditions.

Land cover information and descriptive summaries were derived from two classified Landsat Thematic Mapper (TM) satellite images dated June 20, 1992 and September 11, 1993. The land cover classification was developed in conjunction with personnel from the Institute for Space and Terrestrial Studies, University of Waterloo, and Geomatics International, Inc. Additional data that encompassed the Research Area and were employed in development of the classification included nine digital OBM topographic mapsheets (1:20 000 scale); nine digital FRI mapsheets, photo interpreted from 1985 black and white aerial photographs (1:15 840 scale); ground survey ecological plot data; and color infrared aerial photographs acquired in September 1992 (1:10 000 scale).

Unsupervised clustering of spectral bands 2, 3, and 4 from the TM data was conducted using the ISODATA clustering algorithm from the EASI/PACE image analysis software package (PCI 1993). Ultimately, 16 land cover classes were defined using results from the spectral analysis, in conjunction with information derived from ground survey data and interpretation of the infrared aerial photographs (Table 4). To refine the image classification, 1) polygons representing roads and cutovers were manually outlined using a graphic overlay constructed from aerial photographs and the unclassified spectral data; 2) polygon distributions for alder thickets and other wetland classes were transferred directly from digital FRI wetland coverages; and 3) road and water vectors were extracted from FRI and OBM databases. Mature, closed canopy forest was spectrally discriminated into five broad canopy classes, ranging from pure conifer to pure hardwood. Two classes of cutover, as well as three classes of open canopy forest and non-forest, were distinguished on the basis of spectral signatures. Classification results were filtered using a 3 x 3 mode filter and then sieved with a connectiveness criterion of eight to effectively remove any polygons less than two hectares in size.

Spatial accuracy of the spectral classification was tested on a systematically sampled grid using photo interpreted land cover from the 1:10 000 color infrared aerial photographs as validation data. An error matrix was constructed for the spectrally defined forest classes (classes 3–7, 13, 14, 16; Table 4) in each of the 1992 and 1993 satellite images. Road, cutover, and wetland classes, which were derived from FRI and OBM data or aerial photos (classes 2, 8–12; Table 4), were checked by visual inspection of the classified images and by re-registration against the FRI and OBM digital data. Spectrally derived water polygons (class 1; Table 4) were assessed against OBM water coverages and found to be 100 percent accurate. For the 1992 and 1993 images, class-to-class matching accuracies were 69.7 and 65.2 percent, respectively. Accuracy within a one class range of association (i.e., accepting assignment to adjacent classes) jumped to 90.9 and 81.8 percent, respectively. For this classification, the latter accuracy rating was probably acceptable, given the general nature of the forest cover classes and the intrinsic, fine-scaled spatial and compositional heterogeneity of forests in the Research Area. At the landscape scale of 1:20 000, this classification was only intended to map broadly differentiated classes of forest cover.

Overview of Land Cover in the Rinker Lake Research Area

About 97 percent of the landbase within the Research Area is covered by natural forest vegetation, although human activities have extensively modified both the physiognomy and species composition of the forest cover. Mature forests in the Research Area consist, most commonly, of a mixture of black spruce, white spruce, balsam fir, white birch, and trembling aspen. According to interpreted land cover from the Landsat TM image dated June 20, 1992, mature, closed canopy forest covered about 82 percent (approximately 655.3 km^2) of the land portion of the Research Area. Of this total, conifer and conifer-dominated mature forests were estimated to cover about 48 percent (383.0 km^2) of

Table 4. Listing of the 16 land cover classes recognized for the Rinker Lake Research Area. A thematic map of the land cover of the Research Area is presented in NODA File Report 33. The areal extent within the Research Area for each class is given in square kilometers.

Land Cover Class	Legend
1	Water (103.4 km^2)
2	Roads (19.2 km^2)
3	Closed Canopy Mature Forest - Conifer (290.2 km^2)
4	Closed Canopy Mature Forest - Conifer Dominated Mixedwood (93.0 km^2)
5	Closed Canopy Mature Forest - Approximately 50/50 Mixedwood (38.7 km^2)
6	Closed Canopy Mature Forest - Hardwood Dominated Mixedwood (156.3 km^2)
7	Closed Canopy Mature Forest - Hardwood (77.5 km^2)
8	Alder-Dominated Thicket Swamp (15.3 km^2)
9	Recent Cutover (<10 yr.) (47.2 km^2)
10	Older Cutover (≥10 yr.) (18.9 km^2)
11	Non-Treed Wetland (9.8 km^2)
12	Treed Wetland (14.2 km^2)
13	Miscellaneous Open Non-Forested Sites (e.g., gravel pits, roadside clearings) (7.7 km^2)
14	Open Canopy Forest - Hardwood (5.0 km^2)
15	Shadow (0.2 km^2)
16	Open (Sparse) Canopy Forest - Conifer (2.1 km^2)

the land portion of the Research Area, while hardwood and hardwood-dominated mixedwoods covered about 34 percent (272.3 km^2) of the landbase. Young (0–10 years) cutovers covered about 8 percent (approximately 66 km^2) of the land portion of the Research Area. The relative proportions of mature forest to young, regenerating forest are changing rapidly as timber harvesting operations proceed throughout the Area. An additional 7.5 percent of the land base was accounted for by wetlands, alder thickets, sparse vegetation cover (e.g., associated with shallow soils) and other minor vegetation features.

Only a small proportion (approximately 3 percent) of the land cover within the Research Area is defined by human-constructed features. Permanent human structures include cottages on Max Lake, Mawn Lake, and Starnes Lake; a mining camp on the southeast shore of Lac des Iles; a fire-fighting base camp at the northeastern end of Rinker Lake; and an extensive network of forest access roads. According to the June, 1992 satellite image, existing road networks accounted for19 km^2 (about 2.3 percent) of the land area.

GROUND SURVEY DATA

Ground survey data were employed in both the development and verification of spatial databases and ecosystem models for the Rinker Lake Research Area. Table 5 outlines information contained in 3 ground survey databases that were constructed during field work in the Research Area between 1992 and 1995. All plots were georeferenced using a global positioning system (GPS), and differentially corrected to a set of fixed base station co-ordinates to obtain accuracy levels in the range of 2-5 m (x, y dimensions) and <15 m (z dimension).

Observations from 249 georeferenced field locations played an important role in the development of the Quaternary geology map by providing ground information for reference during aerial photo interpretation. These sampling locations were selected to represent the range of landform conditions occurring in the Research Area and to provide adequate geographic coverage of samples to support subsequent Quaternary geology map production. Soil texture data obtained during this survey were used to develop an understanding of relationships between Quaternary landforms in the Research Area and their characteristic soil matrix textures. Another database was developed by sampling at intervals along transect lines that were located along slope gradients across the range of landform classes in the Research Area. Summary vegetation and soil observations, including soil texture samples, were recorded at 237 georeferenced points. The data from this independent ground truth survey were used to check the accuracy of various proposed algorithms for predicting soil texture from the Quaternary landform classes.

Intensive ecological sampling was completed on 99 10 m x 10 m forest plots. Using sampling methodologies developed for the Northwestern Ontario Forest Ecosystem Classification program (Sims et al. 1989), detailed quantitative descriptions were compiled on vegetational

Table 5. Summary of the ecological attributes contained within three ground survey databases collected for the Rinker Lake Research Area.

	Ground Survey Database		
Data Attributes	Geological Field Survey	Ground Truth Survey	Forest Ecology Plots
Geoposition (GPS)	x	x	x
Landform feature	x	x	x
Slope	x	x	x
Aspect	x	x	x
Topographic position	x	x	x
Soil depth	x	x	x
Soil texture	x	x	x
Soil chemistry[1]	x	x	x
Soil moisture/drainage		x	x
Humus condition			x
Forest floor cover			x
Overstory vegetation description		x	x
Understory vegetation description		x	x
Tree growth (mensuration)[2]			x
Sub-catchment area			x
NWO FEC classification[3]		x	x

[1] Soil samples were analyzed for total and exchangeable cations, nitrogen, organic matter, iron, aluminum, and pH.

[2] Collected data included breast height diameter, height, age, and basal area.

[3] V-type and S-type were determined according to Sims et al. (1989).

composition and abundance, tree growth, forest floor cover and humus characteristics, physical and chemical soil attributes, local drainage patterns, and site moisture status, as well as other site/soil/stand features.

These detailed ecological plot descriptions provided critical reference data for the ecosystem mapping and modeling work in the Research Area. Soil texture data were pooled with those obtained in the geological ground survey to establish textural characteristics of the Quaternary landform classes. Vegetation descriptions from these plots assisted in developing the land cover classification for the Landsat TM images. Site data, such as percent slope, aspect, and topographic position were employed in checking the Research Area's DEM and are being used in ongoing terrain analyses. Forest mensuration data (tree heights, diameters, and ages) are an important component of site productivity modeling efforts. Additional ground data, collected by other project collaboraters, on the distribution and abundance of a variety of songbird, reptile, and amphibian species have been used in fine-scaled habitat mapping and to model species ranges in relation to climatic gradients in Ontario (e.g., McKenney et al. 1996b). Survey plots were distributed across a range of landform features and along major topographic gradients, making it possible to use the ecological plot descriptions to construct several toposequence models for the Research Area.

Common Toposequence Models within the Rinker Lake Research Area

Toposequence models are schematic representations of site relationships between landform, soil, and vegetation units along topographic gradients in a particular landscape (Corns and Annas 1986, Meades and Moores 1989, Baldwin et al. 1990, Zoladeski et al. 1994). Toposequence models may be constructed using ground survey data, collected along topographic gradients on representative examples of landform features within a geographic area. Relationships between soil or vegetation characteristics and topographic position are elucidated from the data and then generalized in the construction of these models. Because fundamental ecological processes within a defined geographic area are relatively constant (Tuttle 1970, Daubenmire 1968, 1974), toposequence models can be considered to be representative within that area wherever general climate, geomorphology, and vegetation potential remain within locally normal ranges (Van Cleve and Yarie 1986).

Toposequence models succinctly portray common vegetation and soil/site patterns in relation to landscape topography. Good toposequence models encapsulate information on basic vegetation conditions and their relationships with common soil/landform complexes within a geographic area. Once developed, toposequence models are useful tools for the recognition, interpretation, and prediction of site-specific, topographically influenced, soil and vegetation characteristics (Houseknecht et al. 1986). Because they illustrate the ecologically significant transitions across topographic features, toposequence models can be helpful in the development and refinement of aerial photo interpretation keys (Johnson and Walsh 1997). Such keys can be used to identify forest ecosystem attributes, assess site productivity or stand susceptibility to insect damage, and to develop timber harvesting and regeneration strategies.

Toposequence modeling can be applied to any land-based interpretive exercise requiring an understanding of site-related properties. Such diverse management activities as pre-harvest timber surveys, wildlife habitat assessment, and integrated management planning can benefit from the preparation of toposequence models. In mapping exercises, toposequence models can promote a much clearer understanding of the spatial distribution of soil and vegetation conditions.

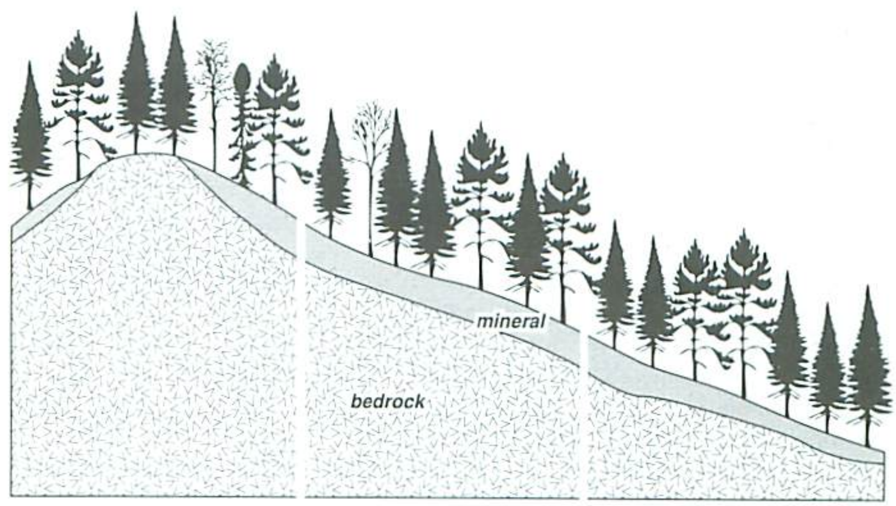
During intensive field sampling within the Research Area, forest ecology plots were situated along topographic gradients across a variety of landform classes. Site, soil, and vegetation data from these plot series were compiled, summarized, and graphically organized into toposequence illustrations to clearly describe the individual toposequences that were sampled. An example toposequence model is presented in Figure 4; a set of four such models, each representing a different landform complex, is presented in NODA File Report 33.

SUMMARY

The principles of ecosystem management necessitate a detailed awareness of ecological values that occur within a management unit. Knowledge is required, not only of what ecological attributes are present within the ecosystems to be managed, but also of where they are currently located within the management unit and what dynamic processes link them together. At the initiation of the Rinker Lake project, limited mapped coverage existed of the ecological attributes characterizing the Research Area at spatial scales suitable for operational considerations. The project sought to acquire or create digital spatial databases of primary ecological parameters, which could then be used in the development and testing of a range of ecosystem models. Ultimately, the Rinker Lake project intended to offer a model for ecosystem management at an operational scale in a selected landscape.

This report has summarized some key outputs of the first phase of the project, viz. the development of integrated, spatially referenced databases that serve as a baseline inventory of primary ecological parameters in the Rinker Lake Research Area. These databases were interpreted from a variety of primary sources, including aerial photographs, satellite images, topographic maps, and ground survey data. Each database has been digitized and registered to a common basemap scale and projection to facilitate manipulation and analysis within a geographic information system. The derived databases significantly augment existing spatially referenced inventory data available for the Research Area (e.g., the Ontario Forest Resource

Overstory	Bf 40 Pj 30 Pot 25 Sb 22	Bf 50 Pj 28 Bw 7	Bf 56 Pj 29
Shrubs	Bf 7 Dierlon 3	Bf 12 Bw 8 Acerspi 4 Dierlon 1	Bf 9 Acerspi 37 Dierlon 4
Herbs and Graminoids	Aralnud 8	Maiacan 2	Clinbor 5 Maiacan 2 Aralnud 1
Moss/Lichen	Fmoss 32	Fmoss 47	
Vegetation Type	V16	V16	V24



Slope Position	crest	upper	middle
% Slope	12	15	15
Humus Type	Mycelial fibrimor	Subhumic fibrimor	Subhumic fibrimor
% Coarse Fragments	< 5	< 5	< 5
Soil Type	SS1	SS6	SS6

Soil Horizon Summary

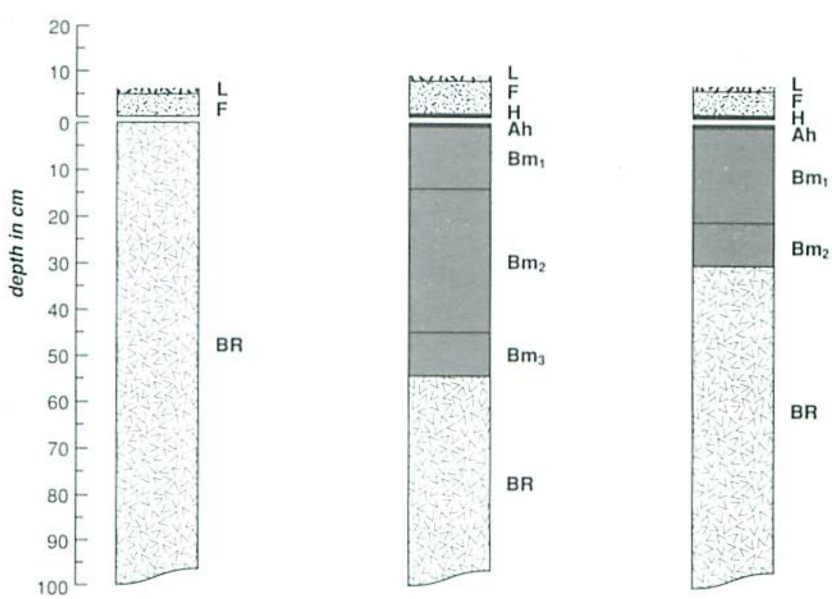


Figure 4. An example of a toposequence model for a common landform/forest type combination in the Rinker Lake Research Area. In this landscape condition, a balsam fir dominated mixed forest occurs on a thin veneer of glacial till overlying a long bedrock slope.

Inventory). The techniques described in this note are intended to be used in conjunction with local or regional tools for ecoregionalization (e.g., Hills 1961, Ecological Stratification Working Group 1995), ecosite mapping (e.g., Harris et al. 1996, Racey et al. 1996), and ground-based ecological site classification (e.g., Sims et al. 1989).

The second phase of the project should provide an improved understanding of spatially distributed ecological relationships in boreal forest areas, through the development of spatially predictive ecosystem models that utilize these ecological databases. Efforts are currently underway to develop spatial models that will facilitate the prediction of various derived ecological attributes from the primary databases described in this report. Ongoing work includes development of a spatially distributed model for soil moisture regime in the Research Area using soil texture data and terrain indices derived from the DEM. The biological response of vegetation communities to environmental regimes within the Research Area is being investigated using ecological domain analyses. The degree to which the current spatial distribution of recognizable vegetation types can be explained on the basis of the distribution of critical ecological attributes, such as topographic position, soil texture, and soil moisture will determine the likelihood of predicting future vegetation distribution across the landscape following disturbance. Succession models, encompassing temporal dynamics of various vegetation types, are being coupled to the domain analyses to further refine the capability for predicting potential vegetation distributions. Other work in progress involves the modeling of site productivity for several tree species using terrain and climate factors derived from the DEM and habitat analyses for a range of wildlife species.

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