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A New Digital Elevation Model of Ontario

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ABSTRACT

A Digital Elevation Model (DEM) is a computer-based representation of the topography of a landscape. DEMs are a fundamental data layer in Geographic Information Systems. A large number of primary and secondary terrain attributes, useful for environmental modeling, can be generated from a DEM. This report describes the methods and results involved in the development of a new DEM for Ontario. Source data for this DEM were derived from the National Topographic Series (NTS) 1:250,000 digital maps of Canada.

The role of topography in ecosystem processes, environmental modeling, and forest management are discussed. Details are given of the steps involved in generating a DEM from the source data using the ANUDEM procedure. Advantages of this procedure over other methods are suggested. The source data, following the required preprocessing, can be used to generate DEMs at a range of user-specified resolutions (above a minimum grid spacing supported by the data). Preliminary analysis suggests that the NTS data will support a resolution of about 100 m in rugged terrain, but only coarser resolutions in areas of extensive, low relief such as Ontario's far north. The utility of a DEM is only realized when the resolution of the grid, and the scale of the source data, match the landscape processes being studied.

RÉSUMÉ

Les modèles numériques d'altitude (MNA) sont des représentations informatiques de la topographie du paysage. Les MNA constituent une couche de données fondamentale des Systèmes d'information géographique. On peut obtenir, au moyen d'un MNA, un grand nombre d'attributs de terrains primaires et secondaires, utiles à la modélisation environnementale. Le présent rapport décrit les méthodes utilisées pour l'élaboration d'un nouveau MNA pour l'Ontario, ainsi que les résultats obtenus. Les données d'entrée ont été tirées des cartes numériques au 1:250 000 de la Série nationale de référence cartographique (SNRC) du Canada.

On traite du rôle de la topographie dans les processus écosystémiques, la modélisation environnementale et la gestion des forêts. On précise les étapes utilisées pour la production d'un MNA à partir des données d'entrée au moyen de la technique ANUDEM. Les avantages de cette technique par rapport à d'autres méthodes sont soulignés. Les données d'entrée, une fois prétraitées, peuvent être utilisées pour produire des MNA pour toute une gamme de résolutions précisées par l'utilisatuer (supérieures à un espacement minimum du quadrillage, en fonction des données). L'analyse préliminaire semble indiquer que les données de la SNRC permettent d'obtenir une résolution d'environ 100 m en terrain accidenté, mais des résolutions moins précises dans les vastes régions peu élevées, telles que le Grand Nord ontarien. L'utilité d'un MNA n'apparaît que lorsque la résolution du quadrillage et l'échelle des données d'entrée correspondent aux processus du paysage étudiés.

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INTRODUCTION

A Digital Elevation Model (DEM) can be defined as an ordered array of numbers that represents the spatial distribution of elevations above some arbitrary datum in a landscape (Moore et al. 1991). Typically, elevations are recorded as meters above sea level. These are related spatially in terms of either latitude and longitude intersections or via Universal Transverse Mercator (UTM) grid locations. As discussed here, the elevation data are stored at each corner point on a regularly spaced grid.

A new DEM of Ontario has been created under the auspices of the Bio-environmental Indices Project (BIP). The BIP is a major collaborative initiative of the Canadian Forest Service (Mackey and McKenney 1994). Partners include the Ontario Ministry of Natural Resources (OMNR), the Australian National University, the Ontario Geological Survey, and the Canadian Wildlife Service. The overall project aims to develop reliable spatial estimates of selected wood and non-wood values for Ontario forests which can be used for various planning problems and trade-off analyses. A major component of the BIP has been the development of primary databases upon which to build these spatial models. The major elements of the primary data that have been examined to date, include:

- climate
- extant vegetation cover
- soil/parent material
- various forest plot data (e.g., ecological surveys, wildlife surveys, and insect and disease surveys)
- topography

This report describes the methodology and some results involved in the creation of a new DEM of Ontario. The role of topography in forest ecosystems followed by the methods used in developing the Ontario DEM is discussed. The method used for building this DEM has several advantages over alternative interpolation procedures and these are briefly reviewed. The results section illustrates several outputs including a generalized version of the provincewide DEM and some finer-scale DEMs of selected parts of the province developed using the same procedures, but with different source data. Some potential applications of DEMs in forest ecology and management are also described.

THE ROLE OF TOPOGRAPHY IN FOREST ECOSYSTEMS

General Background

The composition, structure, and functioning of forests is a product of complex interactions between the biota and (1) the primary physical resources needed for plant growth (water, light, heat, and mineral nutrients), (2) natural disturbance regimes (e.g., wild fires, insects, and disease), and (3) human management.

The spatial and temporal distribution of water, light, heat, and nutrients has been found to strongly influence regional landscapes and local patterns of forest ecosystems (Hills 1961, Sims et al. 1989). It can be argued that data about the physical environment is as important as data about the biological resource itself. New methods for the inventory of forest ecological resources draw upon this knowledge in using plant–environmental relations to spatially extend survey plot data. Sophisticated forest simulation models (Shugart 1984) require estimates of these environmental variables for the key input parameters. Our ability to analyze the forest in terms of both description and prediction is therefore limited by the accuracy with which the primary physical resources used by plants can be predicted. Topographic data have proven to be essential in developing reliable spatial estimates of these resources.

Topography may be linked directly or indirectly to virtually every major ecosystem function across a landbase, from the local stand or site (ecosite, ecoelement) to the smaller-scaled ecological mapping units (ecoregion, ecodistrict) (Figure 1, Table 1).

Topography exerts a fundamental control on the distribution and availability of water, radiation, heat, and more indirectly, mineral nutrients. Elevation-lapse rates affect temperature and precipitation at a meso-scale. The quantity of solar radiation received at a site is influenced by slope, aspect, and horizon shading. The distribution of soil water is a function of, among other things, slope angle and the upslope contributing area. Because available nutrients must be in solution, topography (through its influence on leaching, erosion, and deposition) also affects the nutrient status of landscapes.

A meso-scaled DEM can be used to generate reliable spatial estimates of long-term mean monthly climatic

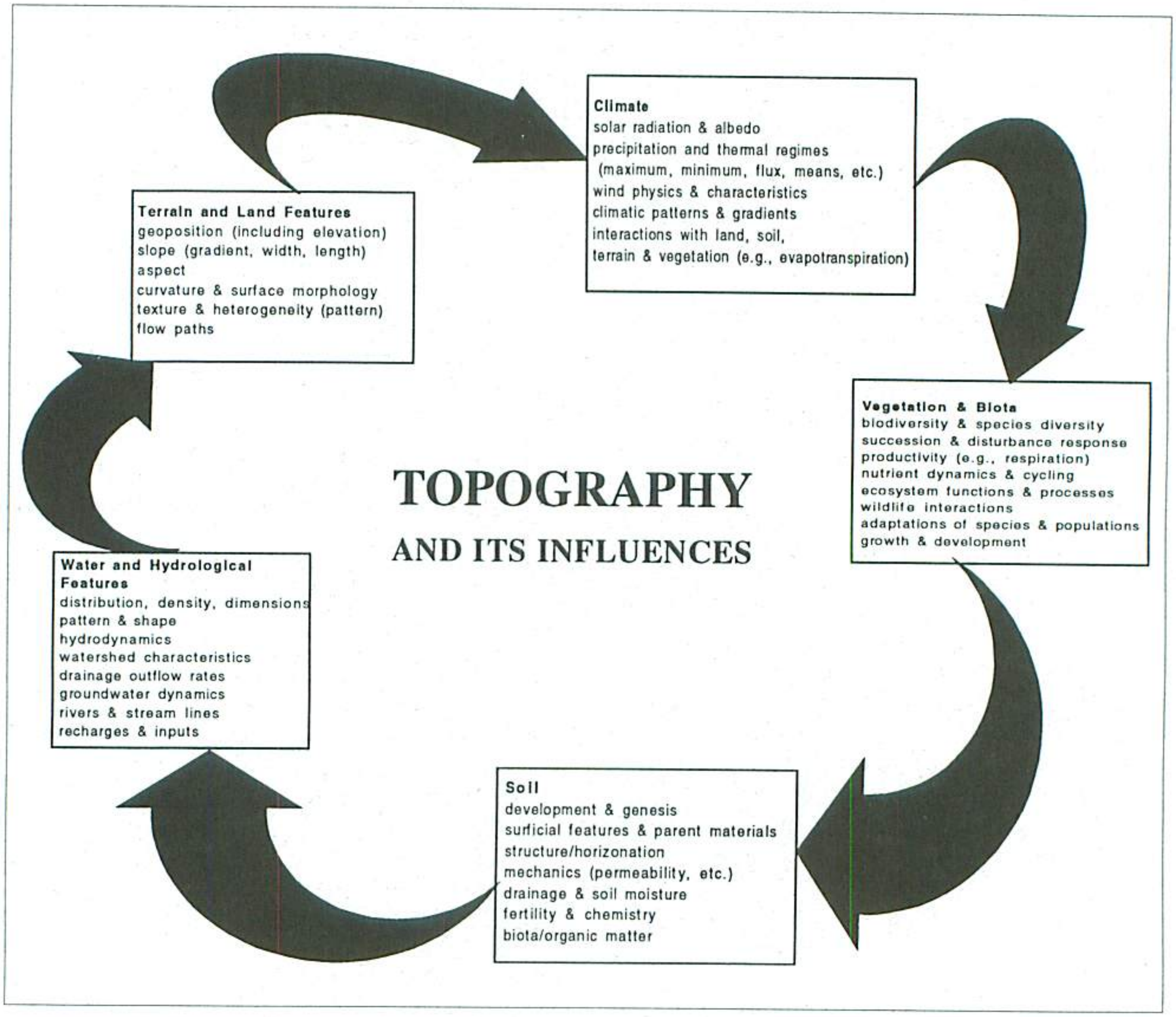

Figure 1. A stylized representation of the interactions of topography and environment. In addition, such factors must be considered across gradients of SPATIAL SCALE and TIME and in relation to a range of other possible PROCESSES and DISTURBANCE REGIMES.

Table 1. The Canadian Committee for Ecological Land Classification (CCELC) system for the hierarchical description and mapping of ecosystems in Canada (modified from Wickware and Rubec 1989). This system shows that, at every level, topography is influential in controlling the definition of ecosystem units.

General level of resolution	CCELC unit	Range of spatial scales	Primary controlling features
Macro-scale	ecozones ecoregions	1:3M+ 1:1M – 1:3M	zonal climate, broad geology, physiography, etc.
Meso-scale	ecodistricts ecosections	1:125K – 1:500K 1:50K – 1:250K	landform patterns, physiography, etc.
Micro-scale	ecosites ecoelements	1:10K – 1:50K 1:2.5K – 1:10K	local relief, soil type, vegetation, elevation, etc.

variables using the method developed by Hutchinson and Bischof (1984) and as applied by Nix (1986), (*see also* Mackey and Sims 1993). Thus the new DEM of Ontario described here is being used to generate gridded estimates of a suite of climatic variables for the entire province.[1] These climatic data are being used, for a range of purposes including, to help redefine seed zones for forest regeneration planning.[2] At a finer scale, DEMs can be input to knowledge based modeling software to generate a range of terrain attributes. Table 2 lists some of the secondary attributes generated by the TAPES suite of software (Moore et al. 1993). Band (1993) Mackey (1993), give examples of the use of DEMs for ecological analyses.

The Role of Topography at a Regional Level

Topography plays an instrumental role in controlling the regional patterns of climate (i.e., at scales of 1:250,000 – 1:1,000,000). Regional climatic patterns are largely a function of the interactions between the geography of prevailing weather systems and topography. Elevation-induced lapse rates modify latitudinal thermal gradients. Similarly, regional precipitation gradients are influenced by topographically-driven lapse rates and rain shadow effects. Channeling, in association with prevailing wind directions during the wet season, also has an effect. Winter prevailing wind patterns can be used to help interpret the patterns of snow depth and snow persistence, and in the spring, patterns of snowmelt and runoff associated with major and minor watersheds. Glaciation features and low-to-moderate elevations over much of Ontario have tended to mark and conform the landscapes in general directions. Many of these corrugations and lineations act to modify wind speeds and patterns over broad areas.

Topographic features such as the surface shape, relative relief, and dimensions/size of elements provide important information about the types or complexes of surficial deposits and soil features that occur regionally (Hall and Olson 1991). Regional landform patterns are predominantly the result of glacial events over the past 200,000 years. At least four major glaciations, the last of which retreated less than 12,000–14,000 years before present (BP) moved over much of Ontario (Zoltai 1961, 1965, 1967) (*see* Figure 2). With the exception of a zone of strongly broken topography along the Lake Superior coast, much of the Shield portion that dominates the central third of Ontario is characterized by an undulating, bedrock-dominated terrain. Current surficial deposits are predominantly shallow tills over bedrock, glaciofluvial deposits of sands and coarse materials, and finer-textured glaciolacustrine materials (Sado and Carswell 1987). Small, confined deposits of peatland occur frequently throughout the Shield wherever drainage is restricted or seasonally raised. To the north, overlying the Paleozoic sediments of the Hudson Bay Lowland, extensive, unconfined wetlands occur. These open fens, treed swamps, and open bogs (*cf.* Jeglum et al. 1974) cover most of the northern third of Ontario. Moreover, this part of the province continues to undergo active isostatic rebound. Therefore, relatively minor topographic influences in an area that has an average slope of about 65 cm per km can have profound effects upon the vegetational cover. Impounded or redirected surface water flows can, over the course of a number of years, cause some significant changes to surface vegetation patterns and wetland type. Because of the lack of topographic relief, the landscape is waterlogged. In addition, the area is frequented by precipitation, fog cover, and high humidity in summer.

Topographic features control the distribution of drainage and hydrological patterns over broad areas. For example, much of Ontario's Shield terrain is characterized by dense distributions of small lakes and well-defined streams and water channels that closely follow terrain slopes and are strongly constrained by the shallow-to-bedrock conditions. Lakes tend to form in poorly drained pools and depressions sitting upon bedrock dishes and within cavities and chasms overlying a relatively impermeable rock basement. Consequently, topography can be used to predict a great deal of information about hydrological flow patterns and quantities over an area, particularly where local watersheds within an area can be clearly recognized and mapped (Jenson and Dominque 1988).

Moreover, hydrological patterns, as interpreted from regional patterns of topography, can in turn provide a great deal of information about the conditions and extents of lake and stream water fisheries; the quality and quantity of water flow as it relates to hydroelectric energy potential; the suitability of waterbodies and watercourses for wildlife habitat requirements, recreation, or parks use; or to address questions related to representativeness, biodiversity conservation, and ecological sustainability.

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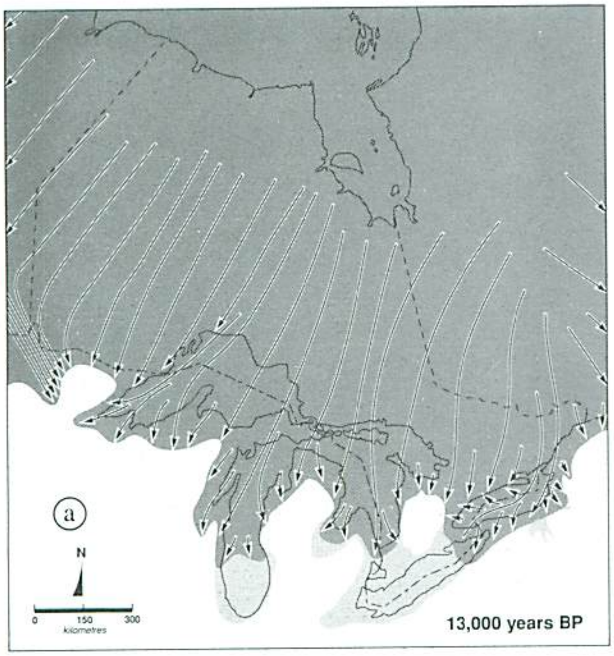
[1]Mackey, B.G.; Yang, Yun-quin; McKenney, D.W.; McMahon, J.P.; Hutchinson, M.F. 1994. An evaluation of Hill's site regions using a new bioclimatic model for Ontario (in prep).

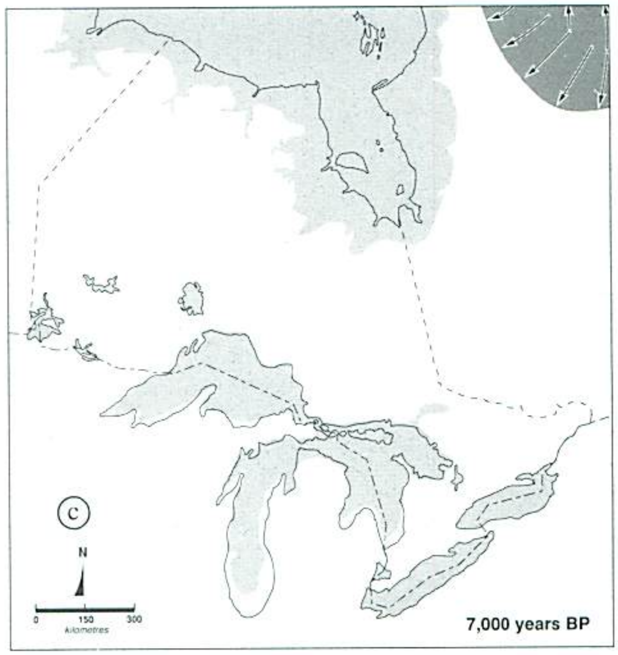
[2]McKenney, D.W.; Mackey, B.G.; Ali, I.; Szcyrek, N. 1994. Seedwhere: a decision support tool for seed transfer. NODA Information Report (in prep.).

Table 2. Some topographic attributes that can be derived from a DEM (from Moore et al. 1991).

Attribute	Definition	Hydrologic significance
Altitude	elevation	climate, vegetation type, potential energy
Upslope height	mean height of upslope area	potential energy
Aspect	slope azimuth	solar irradiation
Slope	gradient	overland and subsurface flow velocity and runoff rate
Upslope slope	mean slope of upslope area	runoff velocity
Dispersal slope	mean slope of dispersal area	rate of soil drainage
Catchment slope[a]	average slope over the catchment	time of concentration
Upslope area	catchment area above a short length of contour	runoff volume, steady-state runoff rate
Dispersal area	area downslope from a short length of contour	soil drainage rate
Catchment area[a]	area draining to catchment outlet	runoff volume
Specific catchment area	upslope area per unit width of contour	runoff volume, steady-state runoff rate
Flow path length	maximum distance of water flow to a point in the catchment	erosion rates, sediment yield, time of concentration
Upslope length	mean length of flow paths to a point in the catchment	flow acceleration, erosion rates
Dispersal length	distance from a point in the catchment to the outlet	impedance of soil drainage
Catchment length[a]	distance from highest point to outlet	overland flow attenuation
Profile curvature	slope profile curvature	flow acceleration, erosion/deposition rate
Plan curvature	contour curvature	converging/diverging flow, soil water content

[a]All attributes except these are defined at points within the catchment.





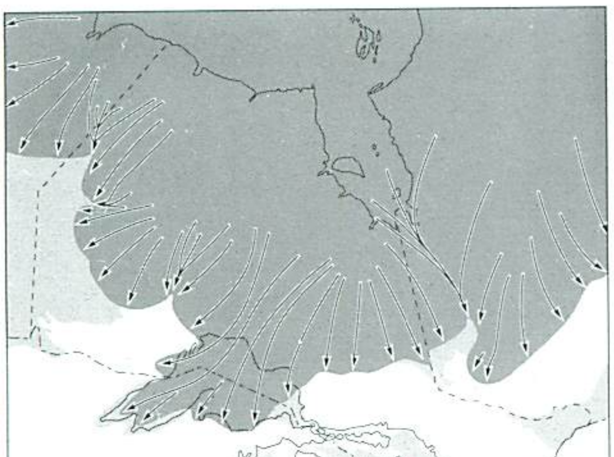


Figure 2. Major patterns of glaciation over Ontario associated with the last Ice Age: a) 13,000 years before the present (BP), b) 10,000 years BP, and c) 7,000 years BP. Major flow patterns and movements have affected the distribution of current topographic features throughout the province.

Regional topographic features may be key determinants of vegetational patterns, influenced indirectly through their effect upon climate and association with soils/ surficial materials, but also by acting as natural surfaces (e.g., barriers, corridors) across which plants and animals must migrate and disperse over time. For example, many plants have mechanisms for pollination and seed dispersal that are wind or water-controlled. Topographic breaks and lineations may act as natural small-scale barriers to the movement of certain species or populations of organisms.

The Role of Topography at a Local Level

At the meso-scale and micro-scale levels (e.g., scales of 1:10,000 – 1:250,000), landform features frequently play an important role in the definition of ecological units. Typically, there are recurring patterns and topographic/geographic complexes across which one can predict the characteristics of landform and soil features (Table 3, Baldwin et al. 1990). In addition, most landform/surficial patterns (i.e., either individual landforms or complexes of two or three landform conditions) have a standard set of vegetation communities that can be described along toposequences (Figures 3 and 4).

Local patterns of topographic features, the local aggregations of landform(s), and various soil and vegetation conditions are associated with different areas of Ontario. By their nature (i.e., processes related to their formation), certain landform and landform complexes exhibit similar soil characteristics regardless of geographic location (Paton 1978, Jenny 1980). In

Table 3. General relationships of main surficial features to topography, as well as to general soil material types and erosion/drainage potential (adapted from Sims and Baldwin 1991).

Landform Unit[a]	Topography	Material	Drainage/Erosion
Ground moraine (Subglacial till)	flat to gently undulating, often expansive; usually without abrupt or steep slopes; the landscape is often patterned with drumlins, fluting features or small, irregular mounds	the till varies depending on the origin of the rock material; coarse fragments occur in a wide range of volumes and sizes	disordered or random drainage patterns are most common
Drumlins	low, narrow, oval to elongated hills, often occurring in irregularly patterned, oriented drumlin fields; groups of drumlins and/or drumlinoid ridges have a characteristic streamlined appearance and are oriented in the same direction	the till material of drumlins varies considerably; often tills are bouldery and sandy; calcareous tills are often silty and stony	poor internal drainage; typically good surface runoff; erosion potential is generally low hazard
Ablation till (Supraglacial till)	irregular and variable relief, often with knob-and-kettle appearance; frequently associated with collapse features such as crevasse fillings and kames, and ice-contact sediments such as end moraines and eskers	a mixture of ice-contact, till, and fluvial materials; there are abrupt and usually unpredictable changes in material composition	disordered drainage, usually with stagnant kettle pools; erosion potential from nil to high hazard
Shallow drift Overlying bedrock	relief is strongly controlled by the surface configuration of the bedrock, ranging from gently rolling to rugged and broken; small wetland and water pools may develop	variable materials, but usually composed of coarse till deposits; organic terrain is common in depressions on raised bedrock features	areas are often poorly or imperfectly drained because of the shallow soils;erosion potential is generally low
End moraines	variable relief, but typically hummocky to irregular; sometimes major landscape features such as large, steep-sided ridges; subparallel ridges 1 – 10 km wide and 5 – 100 km long; abrupt elevation changes	mainly composed of glacial till, with pockets of granular glaciofluvial materials; more variable than ground moraine, but sometimes strongly compacted	disordered drainage, with local ponds and poorly developed drainage networks; erosion potential is often high, depending on soil texture and degree of slope
Eskers	visible from the air as sinuous, low ridges occurring alone or in complexes; sometimes widening into fan or delta shapes; discontinuous to continuous features	typically water-sorted sands and gravels; typically tilted and, in profile, faulted; often with abrupt variations in soil materials	excellent internal drainage; often flanked by swamps or kettle-hole features; erosion potential is generally low
Kames and crevasse fillings	individual kames are conical to irregularly shaped; kame terraces or kame moraines may occur; crevasse fillings are short, ridge-like features	stratified but poorly-sorted sands and gravels; strata are often tilted and faulted; abrupt variations in materials and stratification are common	excellent internal drainage; erosion potential is generally low

....(cont'd)

Landform Unit[a]	Topography	Material	Drainage/Erosion
Outwash deposits	usually level or gently sloping; the landscape is sometimes pitted or covered with kettle holes; fossil channel scars may occasionally be apparent	clean, stratified sands and/or gravels; horizontal strata, often very well defined	good internal drainage, high soil infiltration; erosion potential is variable
Glaciolacustrine and glaciomarine deposits	smooth and level or gently undulating; often overlain by organic deposits (e.g., Hudson Bay Lowlands); wind erosion may occur on sand plains creating blowout areas and sand dunes; raised beaches or minor ridges may occur	well-stratified silts, with either clays or sands; beach ridges are usually sorted, stratified sands, gravels, and cobbles; silt/clay plains are often varied	silt/clay plains have poor internal drainage; sand plains have good internal drainage; erosion potential varies from low to high
Alluvial deposits	typically associated with clearly visible streams or rivers; often develop as long, linear features with level to gently undulating terrain; scars of abandoned channels are often evident; terraces may be evident along valley walls; wetland may develop in low lying areas	well-stratified silts, sands, gravels; cobbles and boulders are deposited where underlying material is till, and where water transported down large materials; channel segments may become filled with silt and organic materials	characterized by a high water table and often subject to flooding; erosion of stream banks, redirecting stream channels
Colluvial deposits	typically associated with steep slopes, cliffs, or riverbanks; fragmented talus material deposited by rock falls from cliffs is a common colluvial deposit	unsorted and unstratified, angular, fragmental rocks; coarse materials of varying sizes (in talus deposits) and silts, clays, fine-to-medium sands (in valley deposits); often unconsolidated and unstable slopes	low water-retention capability for talus; may be subject to periodic downslope creep; soils may be susceptible to erosion by running water
Aeolian deposits	distinct formations and shapes, including parabolic, transverse, and blow-out dunes; dunes typically occur in oriented clusters and surrounding topography is often level or depressed	fine and/or medium sands (in sand dunes); silt, with some clay and very fine sand (in loose deposits); usually well sorted and weakly stratified; strata are often tilted, faulted, with abrupt variations	good internal drainage; susceptible to wind erosion, especially where there is little surface cover by stabilizing vegetation
Organic terrain	flat and low-lying; confined to small pockets and depressions in bedrock terrain; treed to open, sometimes with surface patterns, including hummocks, water tracks, or ribbed features	organic material in varying states of decomposition; composed of mostly *Sphagnum* spp. and other mosses, woody materials, and sedges; variable rates of decomposition and accumulation, sometimes over short distances	stagnant to slow drainage; water table is at or near the ground surface, at least for part of the year; erosion potential is low

[a]Common surficial units are further defined and described in Sims and Baldwin (1991).

After Deglaciation

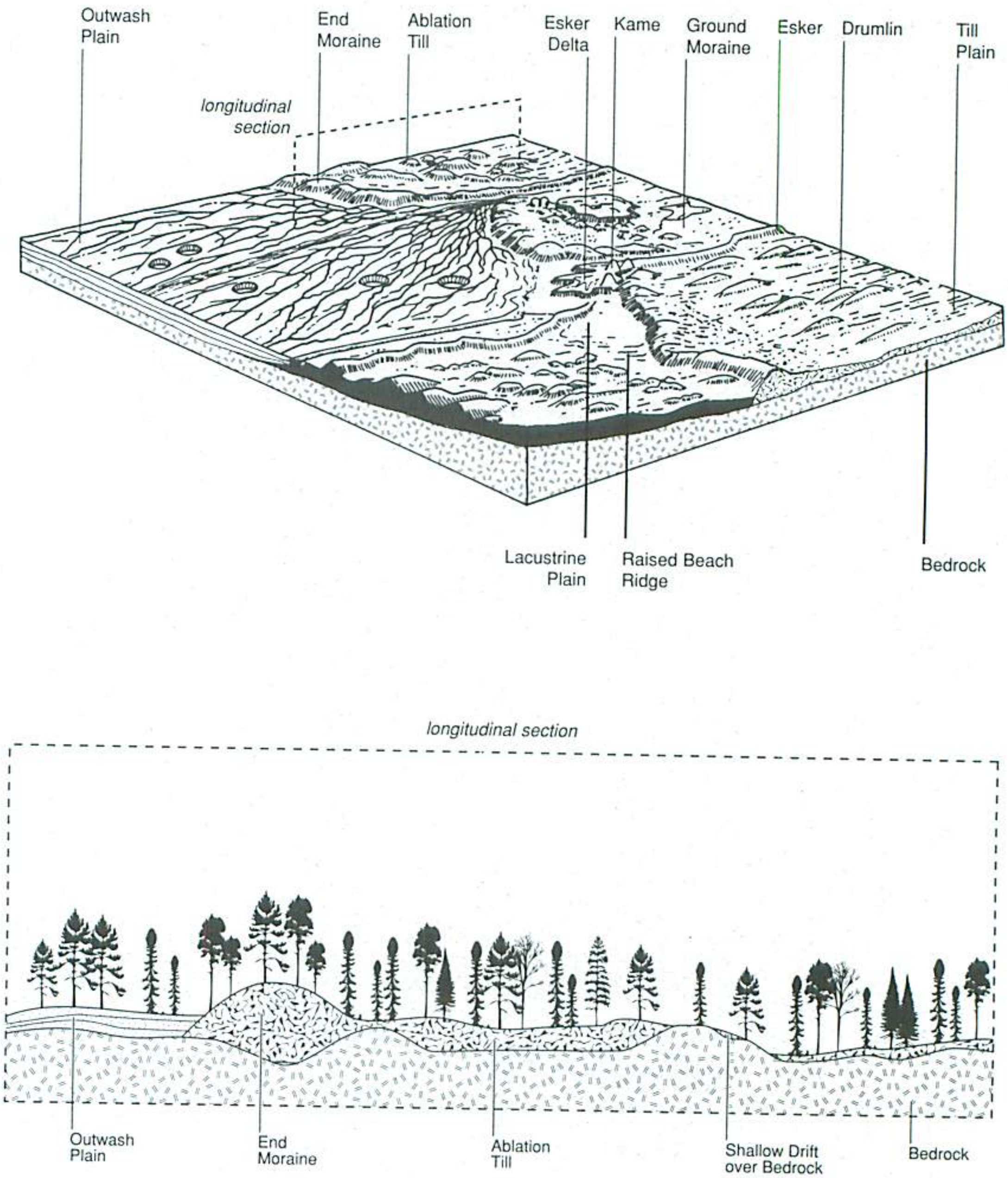


Figure 3. 3D diagram showing the effects of glaciation on a typical Shield landscape in Ontario — the direction and movement of ice fronts can be interpreted, in part, by examining current topographic features.

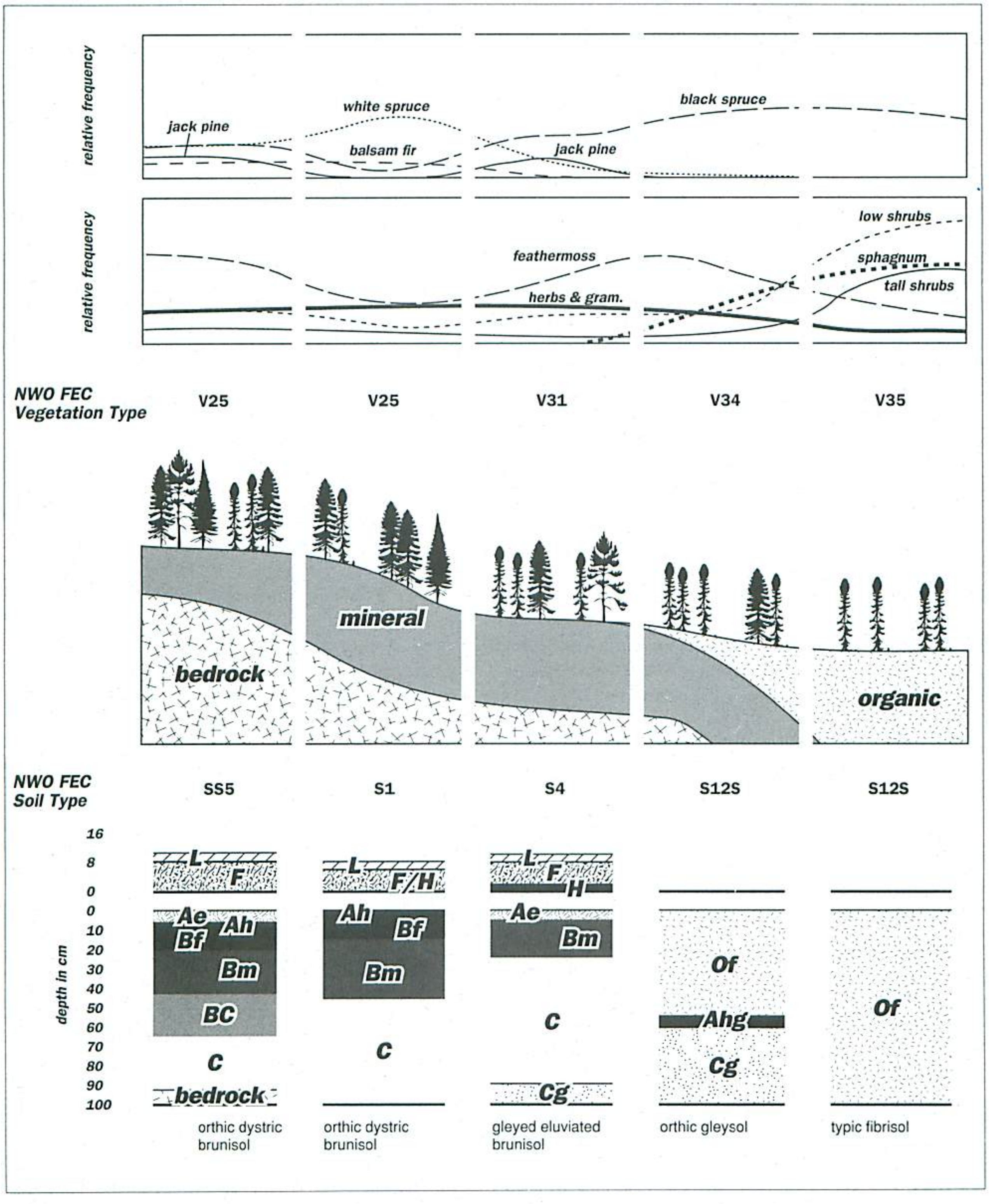


Figure 4. An example of a toposequence gradient for a northern Ontario forest occurring on a deep coarse-loamy ground moraine landform. The diagram schematically shows common vegetation types, soil types and other landscape features associated with slope positions. Nomenclature follows Sims et al. (1989) and Baldwin et al. (1990).

addition, the distribution of vegetation communities is often closely related to soil/site features (Daubenmire 1968, 1974; Jones et al. 1983; Klinka et al. 1989). When these relationships are well understood within a local or specific area, it is possible to predict trends in certain soil and vegetation characteristics through the recognition of topographic features (Van Cleve and Yarie 1986).

Characterizing the expression of specific site-related factors is not always easy. Often it requires complex and elaborate procedures. However, many important site conditions can be assessed, either directly or indirectly, from simple ground and aerial observations of the topography. Since local topography influences the expression of numerous additional site factors, its description provides a convenient basis by which these factors can be predicted. If a preliminary impression of a site's ecological character can be developed through such inference in the management planning process, the results of forest management practices can be postulated.

There are several site factors which can be predicted from topography, including slope position and slope angle. Within a local area, air and soil temperatures tend to decrease with lower topographic position, an effect especially pronounced on steeper, north and east facing slopes (Brady 1984, van Groenewoud 1986) (This cold air drainage at a local scale contrasts with temperature lapse rate effects at a regional scale.) Soil drainage and soil aeration are generally greater at higher topographic positions (Brady 1984, van Groenewoud 1986). Lateral movement of water (seepage and surface runoff) increases with a larger slope angle within local watersheds. This becomes more predictable if topography has also been used to help understand local surficial materials and their predominant textural and transmissivity characteristics. Due mainly to lateral water movement, higher concentrations of soil moisture and many nutrients tend to be found at lower slope positions (Klinka et al. 1980, Brady 1984, Hausenbuiller 1985, Roberts 1986). Formalization of the topographic controls on the movement of water through a catchment have led to the development of knowledge-based computer models, based on DEMs, for predicting various soil attributes across the landscape (Moore et al. 1993).

Site factors which act independently of (but, as already stated, which often may be inferred from) topographic influences are also important (Brady 1984, Hausenbuiller 1985). These factors may alter the expression of a site's ecological character from that which would be predicted based solely on its topographic position. Soil texture, soil depth, coarse fragment content, organic matter form and thickness, vegetation cover, and microtopography are such considerations. Hence, these are often the result of complex interactions between topography and the soil parent material. Within a specific geographic area, many of these properties can be broadly anticipated from knowledge of landform characteristics alone and their mitigating effects along a slope gradient predicted.

The various interrelations between topography and key landscape processes mean that DEMs are a fundamental input into spatially distributed models of forest productivity. When coupled to other biophysical data within a Geographic Information System (GIS), they form the basis for the prediction of biomass production, chemical cycles, growth and yield for timber production, ecosystem cycles, and atmosphere–soil exchanges.

Development of toposequence models across selected landform types (*see* Figure 4) provide one method to better understand the relationships of topography in relation to local expression of vegetation pattern and soil features. Their construction requires familiarity with basic characteristics of each landform type as well as an understanding of the relationships among topographic position, degree of slope, and topographically dependent site factors. Once developed, however, toposequence models can help to better appreciate and understand recurring slope patterns within a local landscape. In turn, a series of schematic toposequences encompassing common landform/soil/vegetation conditions may be formulated and used to develop more accurate ecosystem maps for an area, or to formulate more detailed and knowledgeable resource management plans.

It is important to recognize that, although landform development processes were similar throughout most of Ontario, local geographic conditions have created a degree of variability in some site factors. Consequently, landform/soil/vegetation relationships will differ somewhat from one locality to another. For example, vegetation development and certain soil characteristics (e.g., soil moisture regime or drainage) observed on an end moraine constructed from sandy, bouldery till might be different from those exhibited by an end moraine constructed from a fine-textured till. Topography, therefore, influences local site conditions in similar ways but the degrees of influence will vary depending upon other factors such as regional climate, the textures and mineralogy of local landform deposits, and the types of vegetation that are associated with an area.

METHODS

The ANUDEM Procedures

The National Topographic Series (NTS) 1:250,000 digital topographic data were digitized by, and obtained from, the Canadian Centre for Mapping and were the source data for the development of the Ontario DEM. These data are well suited to provincewide and regional DEM development and are useful for a wide range of strategic and operational planning purposes. They also compliment applications that can be developed from DEMs based on finer-scaled source data such as the NTS 1:50,000 digital topographic series and the Ontario Base Map 1:20,000 digital topographic series.[3]

There are three basic formats a DEM can take: (1) triangulated irregular networks, (2) contour-based networks and, (3) regular grid networks (Moore et al. 1991). The third approach, regular grid networks, is computationally more efficient than the others and generally matches the structure of other commonly available spatial data, such as satellite imagery. A basic problem with standard digital topographic data (e.g., contours, spot heights, and stream lines) is that they provide an irregular network of elevation data points. These data therefore need to be interpolated to produce a regular grid of elevations. The ANUDEM computer program was used to interpolate the NTS digital data.

The ANUDEM computer program is actually part of the ANUDEM software package. The package includes other programs that facilitate generation of the final product:

GRDCON - produces contour strings from a regular grid of values, i.e., elevation contours from a DEM

INTGRD - a general purpose grid manipulation program that enables grids to be resampled at user specified resolutions

POLGRD - interfaces a regular grid of values with a network of polygons enabling special values to be assigned to grid cells that fall within the polygons

The ability of ANUDEM to produce reliable DEMs stems from several features (Hutchinson 1989, Hutchinson and Dowling 1991):

1. The process is computationally efficient; hence, DEMs with over a million points can be easily interpolated using a computer workstation.

2. The roughness penalty (one of the interpolation parameters) can be modified to allow the fitted DEM to follow the sharp changes in terrain associated with ridges and sometimes with streams and other land features.

3. The program uses a drainage enforcement algorithm that attempts to remove all sinks in the fitted DEM which have not been identified by the user. The approach attempts to maintain a connected surface drainage pattern.

4. Drainage enforcement is further enhanced by incorporating user-supplied, stream line data in the interpolation process. Use of these data leads to more accurate placement of stream lines and removal of additional sinks. Each stream acts as a breakline for the interpolation conditions (so that stream lines lie at the bottom of associated valleys). Also, in data scarce areas, the stream lines provide a source of additional topographic information.

5. As noted above, the program can recognize and preserve sinks in the landscape (i.e., local minima) in addition to automatic drainage enforcement. Hence, the interconnected structure of surface drainage (including streams and lakes) can be maintained. These have potential in their own right as layers in a Geographic Information System.

6. The grid spacing of the output DEM is user-controlled (subject to the quality of the source data as discussed below).

ANUDEM has many features that are not found in other interpolation programs. The ability to sensibly deal with stream lines and lakes make it particularly well suited to Ontario landscapes. It has been applied in many parts of the world including Australia, New Zealand, the Caribbean, and Africa and is currently being used to generate a DEM of the globe by the EROS World Data Centre, United States Geological Survey (S. Jenson, pers. comm.).

Building the Ontario DEM

ANUDEM is a Fortran program which has been used on VAX minicomputers and SUN ® UNIX

[3]Mackey, B.G.; Sims, R.A.; Baldwin, K.A.; Moore, I.D. 1994. (in press). Spatial analysis of boreal forest ecosystems: results from the Rinker Lake case study. *in* Proceedings, Internat. Conf. on Integrating GIS and Environmental Modelling, Sept. 26-30, 1993, Breckenridge, Colo., U.S.A. (in press).

workstations. The ANUDEM program has now been incorporated into the most recent version of the ARC/INFO ® GIS software package. Workstations are needed when handling large data sets. Software is also needed for editing, processing, and converting the vector data for utilization by ANUDEM. The Geographic Information System (GIS) package ARC/INFO ® proved useful for these additional tasks. A SUN ® workstation and clone running the GRASS ® GIS package, and an IBM compatible 486 personal computer running the IDRISI ® GIS package, were used for subsequent analysis of the DEMs.

Figure 5 summarizes the steps in implementing ANUDEM. Development was completed over an 18 month period using approximately two person-years solely devoted to the project (i.e., one GIS technician full time for 18 months and one computer programmer for 6 months at the beginning of the project). Additional support was provided to address various problems (e.g., creating a separate coverage for islands, edge matching and joining lake arcs between mapsheets to create an entire lake coverage for Ontario). The 18 month period included synthesis and error checking phases. The major steps are summarized below; however, Appendix 1 provides more detail.

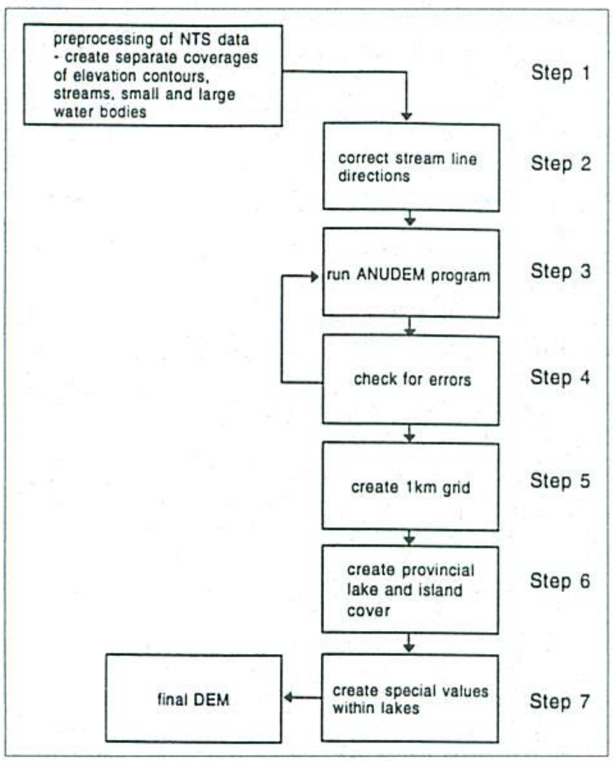


Figure 5. Flow chart of the ANUDEM procedure used to generate the new digital elevation model of Ontario.

Step 1- Preprocessing

The NTS data were received in a standard interchange format (SIF). The data were converted to ARC/INFO format, using the ARC/INFO conversion called ARCSIF, to allow preliminary work on the vector data. This conversion was used to extract pertinent data to create separate coverages for the four file types required by ANUDEM:

1. Elevation contours - these were the primary elevation data provided by the digital NTS.

2. Stream lines - this coverage included lakes and streams to indicate the connected surface drainage flow. These data assist in the interpolation of elevation contour data (note that elevations are densely sampled along contours but absent in-between).

3. Lakes - a separate coverage of lake polygons was constructed so that special 'no data' values could be assigned to grid cells that fell within them.

4. Polygon boundary - many of the map sheets had a substantial part of their area comprising a very large water body such as Hudson Bay or one of the Great Lakes. In these cases, a polygon boundary was used to identify these areas so they could be excluded from analyses.

Step 2 - Creating the lakes and stream coverages

The lake and stream coverages were amalgamated to allow for continuity of the drainage network. Some lakes or parts of lakes and drainage networks had been left out of the original NTS digital data and were digitized manually. The stream lines were then checked to ensure they were pointing downslope.

When the NTS data were originally digitized, maps were scanned in one direction. Some streams have their coordinate pairs stored from upstream to downstream; however, this was not always the case. A procedure was developed using both C (a programming language) and the ARC/INFO AML language. The user is required to display the stream data on the monitor screen and then 'click-on' at the bottom of a drainage network (e.g., the mouth of a river) and ensure that this arc is flowing in the correct direction. The program, using the top node of the selected arc, then searches back to the connecting arc in the upstream drainage network and verifies that the node connecting to the downstream node is the same. If these nodes are not the same, the program flags the arc with a unique identification. Upon reentry into ARC/EDIT (an ARC/INFO routine) these uniquely identified arcs are, with the use of an AML, SELECTed and FLIPped to the proper flow direction. The program works its way upstream through the entire catchment until some discontinuity between nodes (e.g., a break in the drainage pattern) occurs. Due to the discontinuity of the drainage data, this process was repeated many times.

Step 3 - ANUDEM processing

The NTS source data were processed through ANUDEM on a mapsheet-by-mapsheet basis. There are ninety-three, 1:250,000 NTS mapsheets covering the province of Ontario.

DEMs were generated for selected mapsheets at a range of grid spacings from 50–500 m. These data were compared in two ways; first, by generating elevation contours and plotting these with the original vector data (contours and streams) and second, by overlaying the original contours on a raster image of the DEM. The test sheet for the far north of Ontario produced spurious topographic features at a 100 m grid spacing. Rugged landscapes around the north shore of Lake Superior easily supported a DEM of 100 m resolution. It was decided that for development purposes a uniform grid spacing of 200 m would be used to validate the DEM on a provincial basis. This grid spacing yielded 900 x 1300 grid points per map sheet.

A DEM was produced for each mapsheet using data from a 25% overlap of the surrounding mapsheets. This was necessary as errors can be generated along the mapsheet edges. The elevation grid produced in the overlap section was subsequently discarded to ensure a seamless fit between mapsheets.

The output of each ANUDEM run is a DEM plus diagnostic files. The latter are designed to facilitate interpretation of the drainage clearance decisions made by the program.

Step 4 - Error checking

The DEMs for each mapsheet were verified in two ways. New elevation contours were produced using GRDCON. Using ARC/INFO, these new contours were overlaid on the original NTS contours together with the original streams, lakes, and output diagnostics. Visual inspections revealed major errors (e.g., spurious heights and sinks usually associated with mislabeled contours in the original data or streams that were missed in the flipping process).

Mapsheet DEMs were also plotted in raster (grid) format in ARC/INFO, with the original vector data again overlaid. Errors were corrected and Steps 3 and 4 repeated as necessary for each mapsheet.

Step 5 - Creating an initial provincewide grid

While ANUDEM allows a user-defined grid spacing there is, as noted above, a minimum resolution that will be supported by a given source data set. Preliminary sensitivity analyses, such as those detailed in Step 3, were undertaken to determine the optimum grid spacing supported by the source data. In the far north, within the Hudson Bay Lowlands, a minimum grid spacing of 200–500 meters appears reasonable. In the more rugged terrain around Thunder Bay, a 100 m grid spacing was appropriate.

As an initial step, a provincewide DEM was generated at a 1-km grid spacing (0.01388888 decimal degrees). This resolution is sufficient to support meso-scaled climate modeling and matches landcover data available from the AVHRR satellite. Input files were fed into ANUDEM from all 93 NTS map sheets and a 1-km grid spacing specified. (Note that at 200 meters a provincewide DEM would contain approximately 105 x 10^6 grid points.) Hardware limitations prohibited generating the 1-km provincewide DEM in one run. Hence, the province was divided into three parts (i.e., NE - 43 series, NW - 53 series, and the Southern series NTS data). The three grid files were later joined together to generate a single grid with 756,104 points for the entire province.

Step 6 - Provincewide lake coverage

Major lakes needed to be masked out of the grid for two reasons; first, there were no elevation data for lake bottoms and second, to enhance visual interpretation. This was done by assigning the cells within the lake boundaries a special 'no data' value. Since the lake polygons were digitized on a mapsheet-by-mapsheet basis, the segmented lake polygons were assembled into whole polygons in a provincial lake coverage. The lake polygons between mapsheets were edge matched. Any dangles (i.e., lake or island polygon vectors that were not completely closed) needed to be joined. Following this, the islands were deleted from the lake coverage and put in their own provincial island coverage. This posed a problem because the original digital NTS data were not always consistent in distinguishing island attribute codes from lakes.

Using ARC/INFO, a batch file was set up to utilize the BUILD command in ARC, which rebuilt the coverage and created a world polygon. World polygon refers to the area not enclosed by the lake polygon arcs. Use of the BUILD command automatically labels the world polygon with a code of 1. The interior of the lake polygon would be left with a code of 0. The batch file then used ARC/EDIT software to select all the exterior polygon vectors (i.e., lake arcs) and put them into a new coverage. The problem with this method was that only 10,000 arcs could be converted at a time (an ARC/INFO limitation) thereby restricting the process to a mapsheet basis. Some mapsheets, which contained over 10,000 arcs, were split into smaller sections.

Step 7 - Creating the final DEM

The DEM was then run through POLGRD to allocate a special value (i.e., arbitrary values such as 0 or -999) to the grid points that fell within lakes and complete the process of DEM construction.

RESULTS

The Ontario DEM

Figure 6 shows the 1-km DEM of Ontario. Elevations of the 1-km grid range from a minimum elevation of sea level, around Hudson Bay, to a maximum elevation of about 610 meters, west of Thunder Bay. The figure illustrates the low relief of the Hudson Bay Lowlands and various areas of higher elevation (e.g., the Niagara Escarpment, Algonquin Park, and the north shore of Lake Superior).

Figure 7 illustrates, from a bird's-eye view, the DEM of the Thunder Bay – Nipigon area. To obtain this image, the DEM was processed at a resolution of approximately 100 meters (0.001111111 decimal degrees) from NTS map sheets 52H and 52A, in northwestern Ontario. The image was classified to 20-m intervals and displayed in a Lambert conformal projection. Major water bodies were then overlayed for better distinction.

Figures 8, 9, and 10 capture the ability to zoom in on the DEM once the data have been processed. These three images are successively closer views of an area encompassed by the same boundaries as Figure 7. The above classified DEM was draped over the raw DEM. The view angle is from the northeast over lake Nipigon and faces toward Thunder Bay. Each of the images has a vertical exaggeration applied to help show the relief of the surrounding area. Figure 8 shows every tenth line of data, Figure 9 every fourth line, and Figure 10 shows every line. The color scheme for Figures 8, 9, and 10 is the same as that of Figure 7.

Figure 11 illustrates how DEMs can be used to examine secondary terrain attributes. A 400 m DEM was produced for northwestern Ontario and used to define aspect shading. The region encompasses the area between latitudes 48 and 52 degrees North, and longitudes 96 and 88 degrees West. The 400 m spacing was selected as an appropriate scale for broad, regional analysis. The northwestern region was selected for testing due to the authors' familiarity with its landscape and ecology. Source data were the 16 NTS map sheets for the region. The selected spacing generated a computationally manageable grid of 1,042,568 points. The GRASS GIS software package was used to analyze and display the DEM.

An important terrain attribute that can be derived from DEMs is the topographic wetness index (TWI) (*see* Moore et al., 1991, Mackey 1994, and Mackey et al., 1994). This terrain index can be used to predict soil moisture status. Soil moisture has implications for ecological relations, road building, and timber harvesting. Figures 12 and 13 illustrate the topographic wetness index at two scales. Figure 12 was generated from a 100-m grid of NTS mapsheet 52H, northwest of Thunder Bay, Ontario. Major drainage patterns are shown. Figure 13 shows the topographic wetness index generated from finer-scaled source data provided by the Ontario Base Map Series (OBM). The OBM's have a scale of 1:20,000 with contour intervals of 10 meters. To help validate the provincewide DEM, and for further ecological and economic applications, a 20-m grid resolution DEM was completed of the Rinker Lake study area near Thunder Bay, Ontario. This area is embedded within the 52H area shown in Figure 12. Ongoing research is aimed at quantifying what the topographic wetness index values mean, both hydrologically and ecologically, at different scales.

The steps for developing a DEM from OBM data were similar to that of the NTS data. However the OBM data were already in ARC/EXPORT format and therefore did not have to be converted (as outlined in Step 1), only IMPORTED. Unlike the NTS digital data, OBM mapsheets were already edge-matched and all vectors were coded accordingly. Swamps and beaver dams were excluded from the drainage coverage.

As part of an on-going validation of the accuracy of the ANUDEM program, comparisons are being made with DEM's created by other interpolation methods and from other data sources.

OBTAINING THE DEM

The DEM was developed in close collaboration with the Ontario Ministry of Natural Resources (OMNR). Current plans are for the DEM to be distributed within the OMNR and to OMNR partners by the Integrated Natural Resource Information System (INRIS) project. INRIS will be responsible for the distribution of the DEM to its clients. Other researchers or agencies interested in the DEM should contact D.W. McKenney at the Canadian Forest Service – Ontario.

CONCLUDING COMMENTS

DEMs are a critical component of an environmental GIS for forest planning and management. A range of terrain attributes can be derived that have climatic, hydrological, and hence, ecological and wood production applications. The provincewide DEM described here is now being used to map watershed boundaries across the province of Ontario and to support meso-scale climate modeling. Building upon these activities are a range of applications including the refinement of soils and geology maps, the definition of wildlife habitat, and the refinement of seed zones for forest regeneration planning. All these applications are being developed in the context of Decision Support Modules using analytical GIS approaches.

ACKNOWLEDGMENTS

This work has been supported by the Canadian Forest Service – Ontario and by the Ontario Ministry of Natural Resources, Genetic Resource Management Program and the Integrated Natural Resource Information System project. Funding was provided by the Northern Ontario Development Agreement and the Ontario Sustainable Forestry Initiative. Additional thanks for ongoing advice is owed to Dr. M.F. Hutchinson of the Centre for Resource and Environmental Studies, The Australian National University, Canberra, A.C.T., Australia.

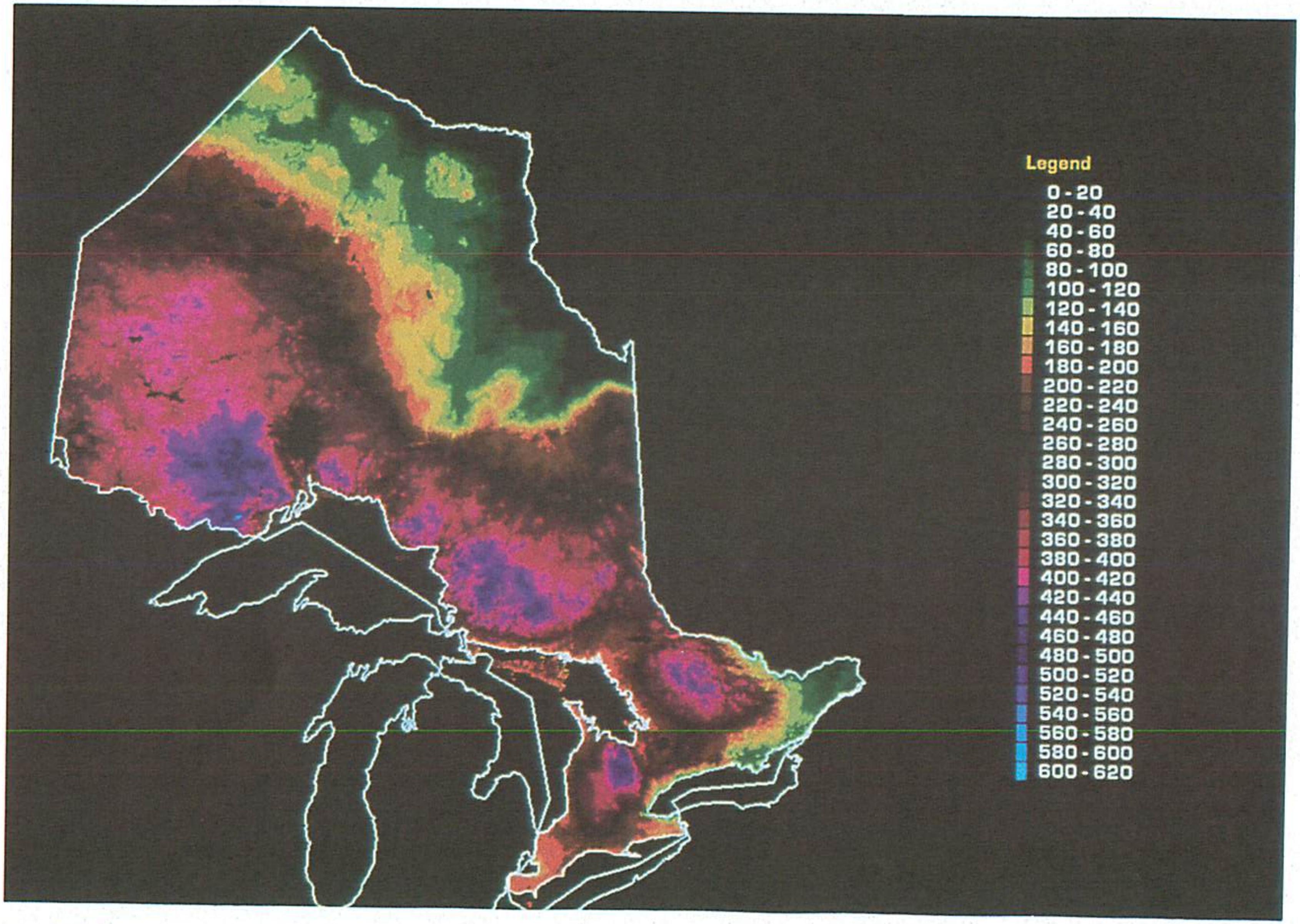


Figure 6. Ontario provincial DEM prepared at a 1 km grid spacing and with major lakes masked out; elevations are shown as 20–m contour intervals (approximate scale 1:11 M).

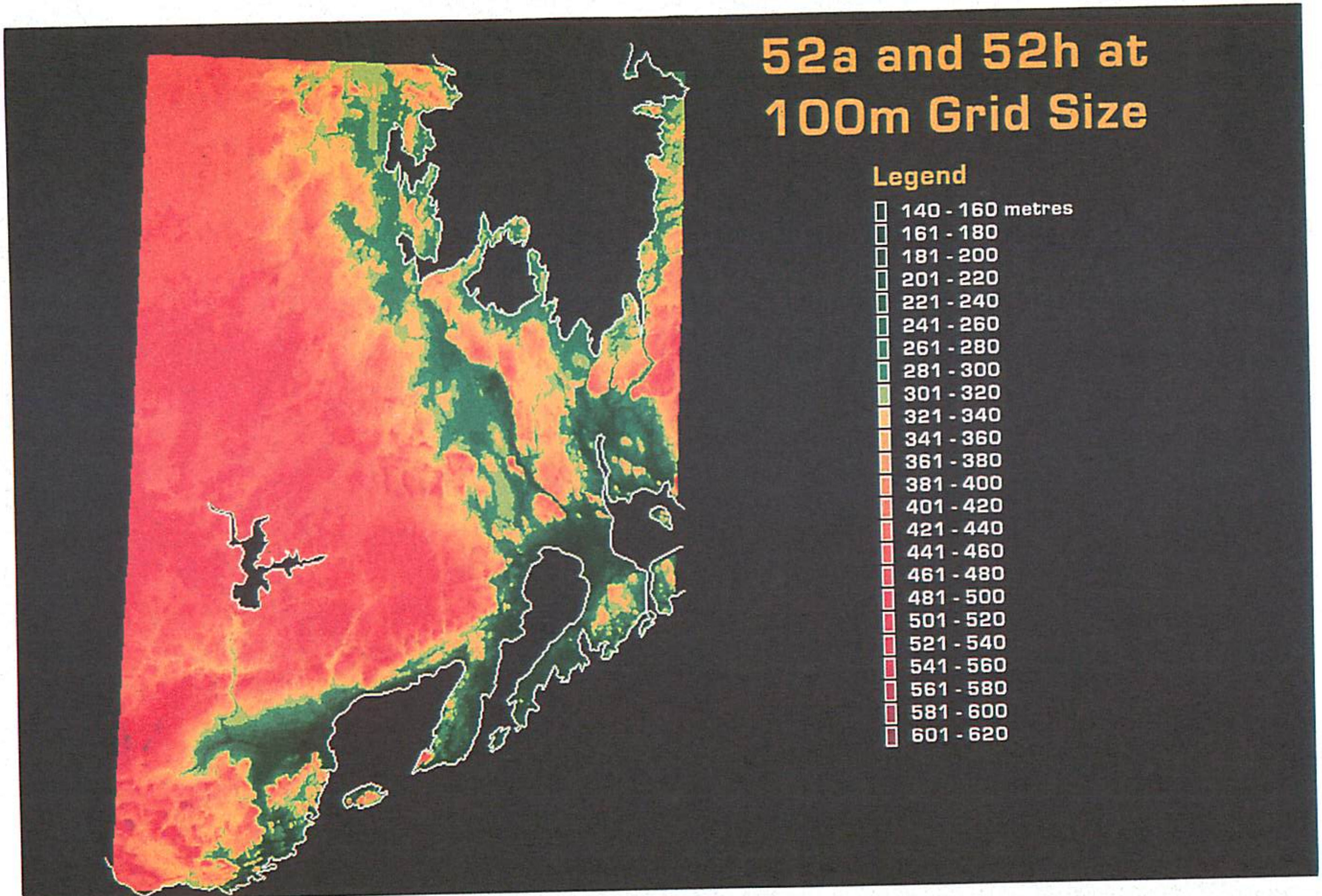


Figure 7. Bird's-eye view of the DEM of Thunder Bay – Nipigon area for National Topographic Series Mapsheets 52a and 52h; elevations are shown as 20–m contour intervals (approximate scale 1:1.5 M).

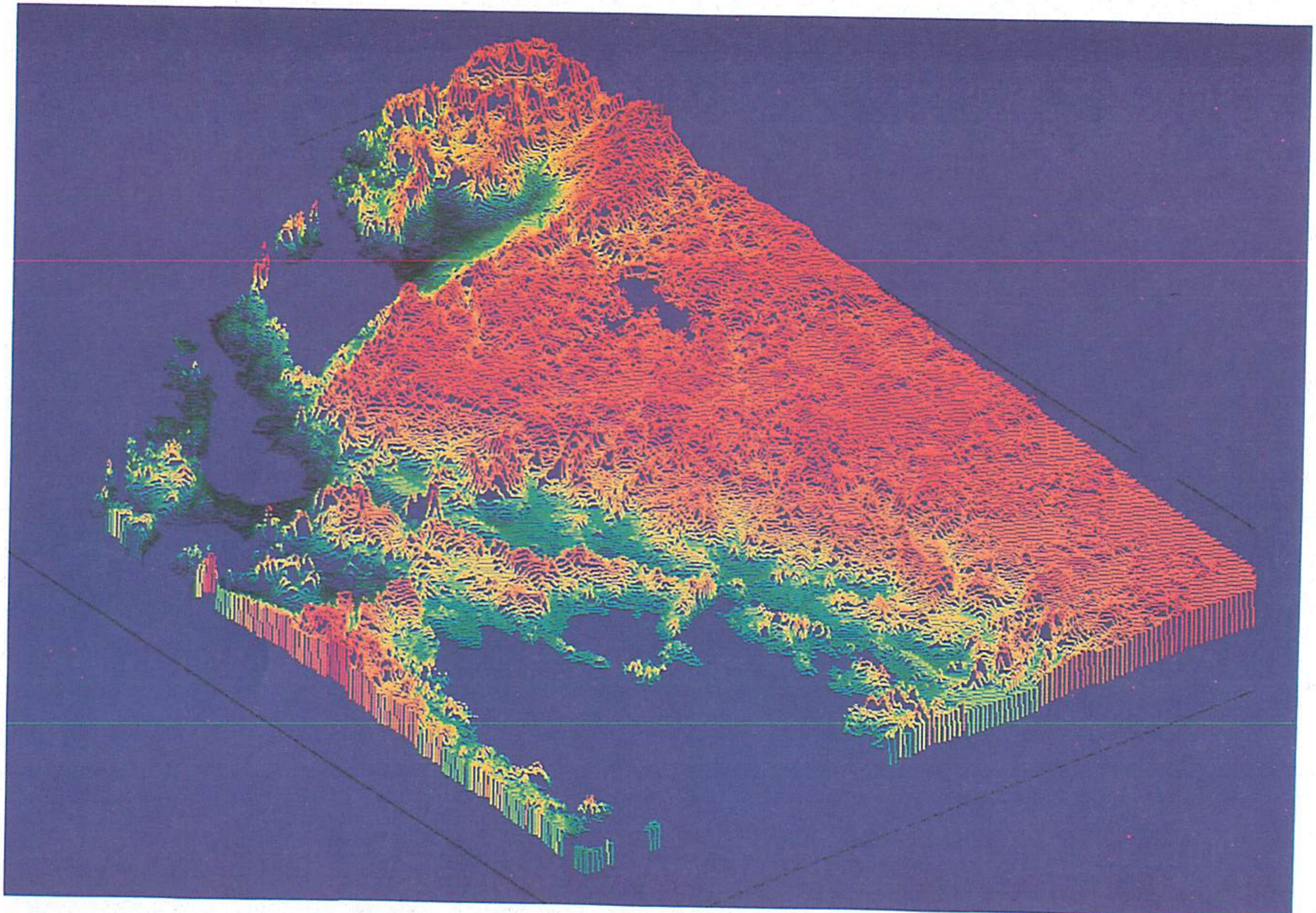


Figure 8. A three dimensional view of Thunder Bay, looking from the northeast over Lake Nipigon. The grid was created using every tenth line of data.

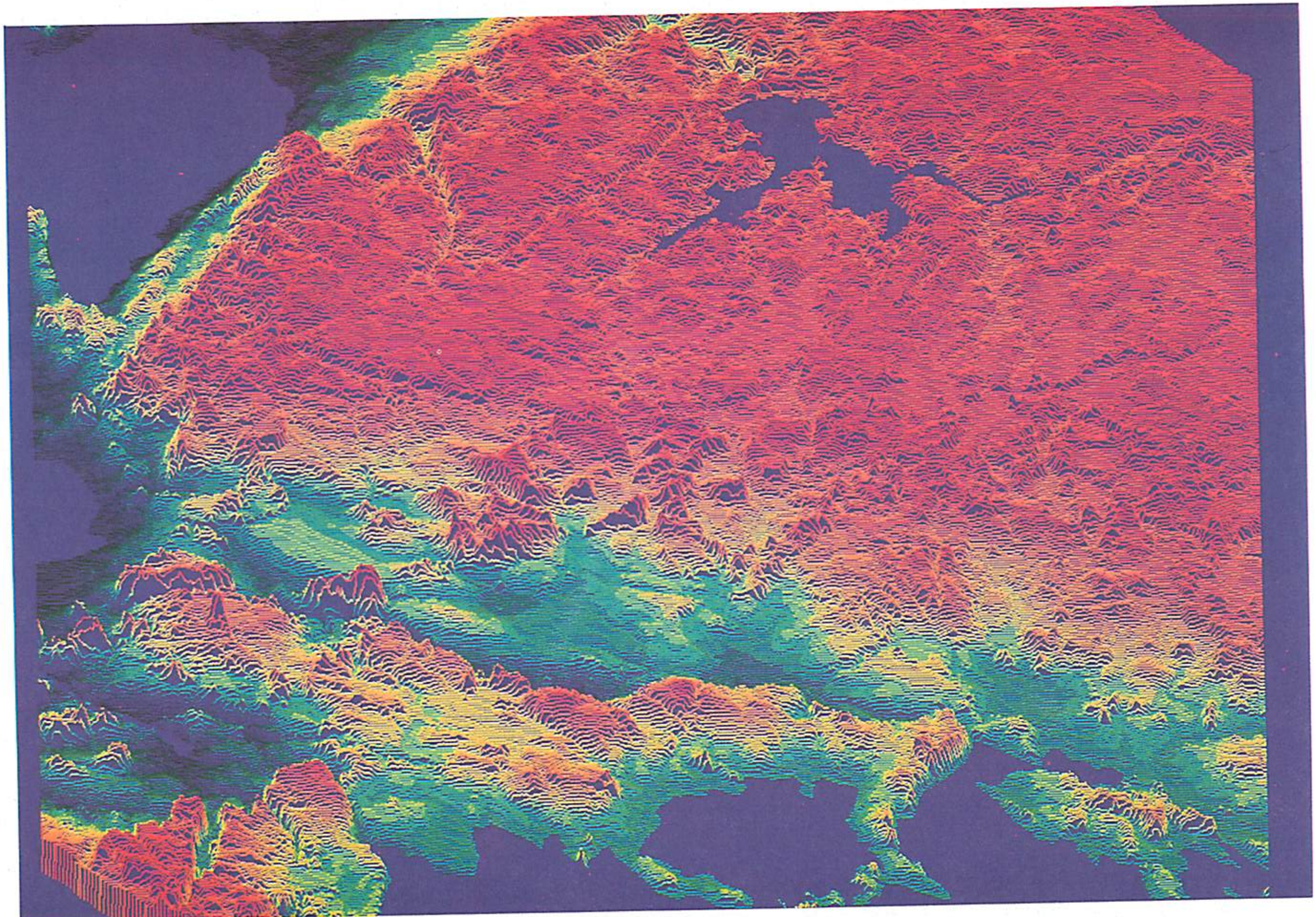


Figure 9. A magnified view of part of the area shown in Figure 8. This time every fourth line of data was used to create the grid.

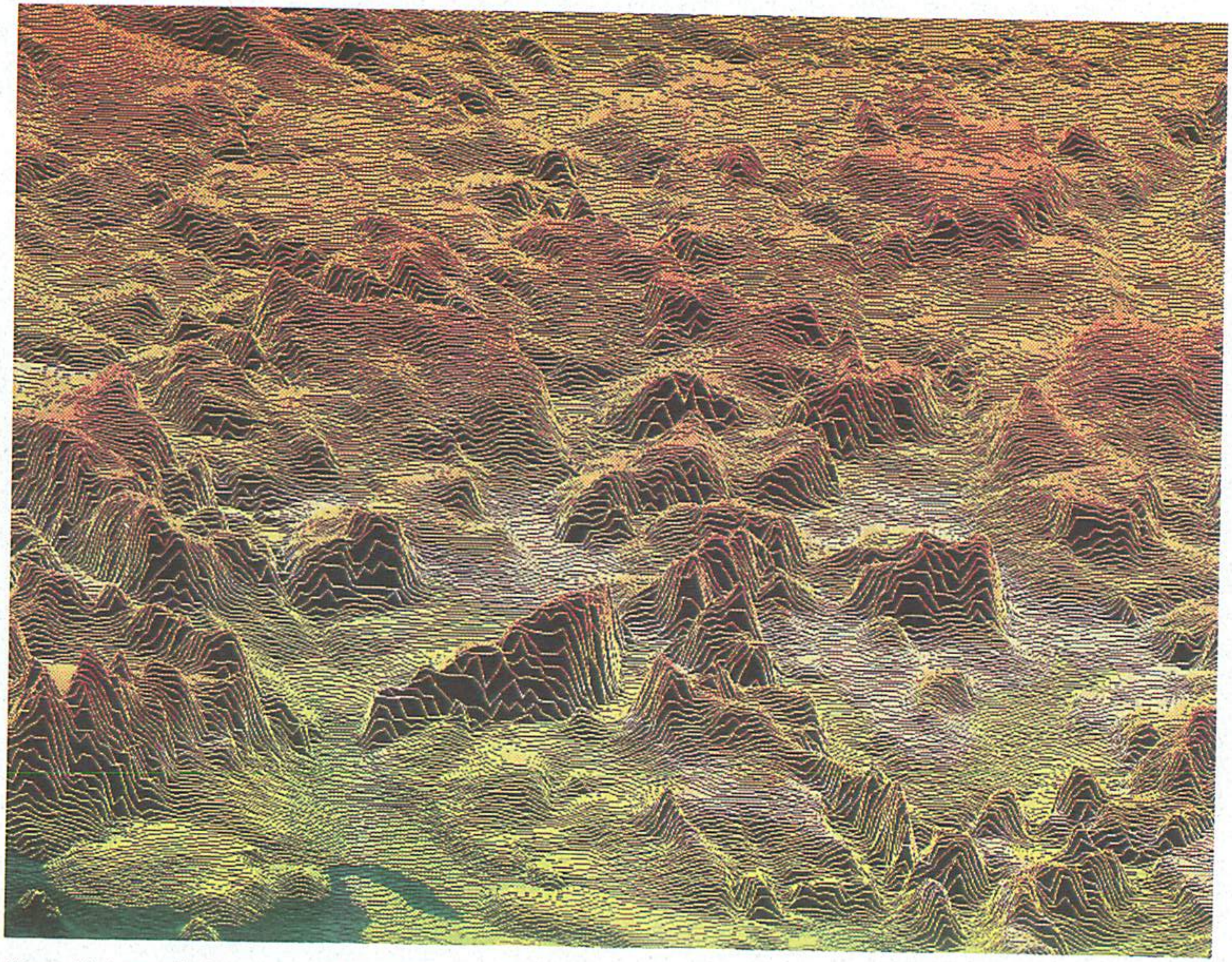


Figure 10. A magnified view of part of the area shown in Figure 9. Every line of data was used to create the grid.

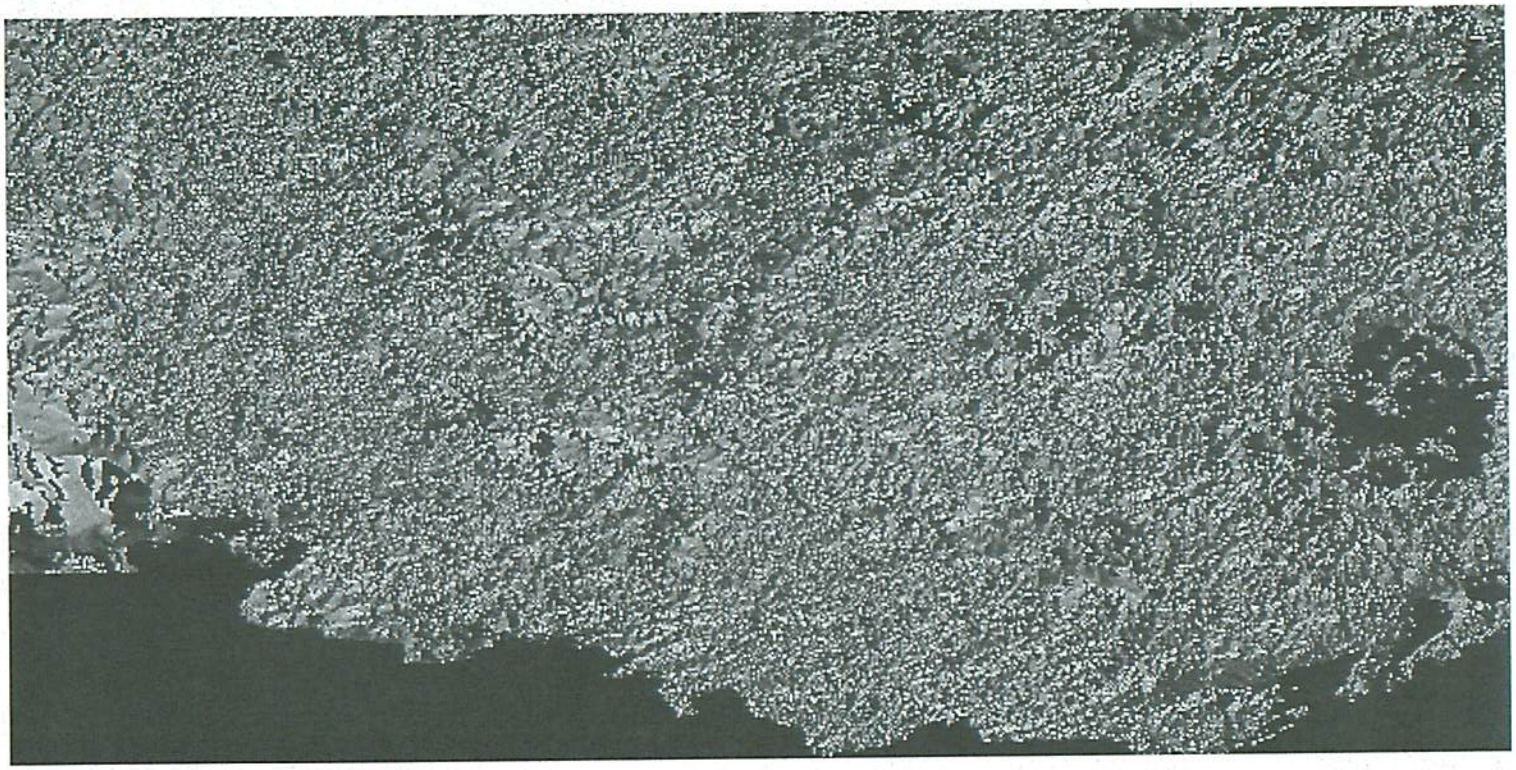


Figure 11. A grid of northwestern Ontario, at a 400 m grid spacing defining aspect shading; area shown is a map segment that spreads 4 degrees of latitude [48° N to 52°] and 8 degrees of longitude [-88° W to -96° W]; north direction is towards the top of the map.

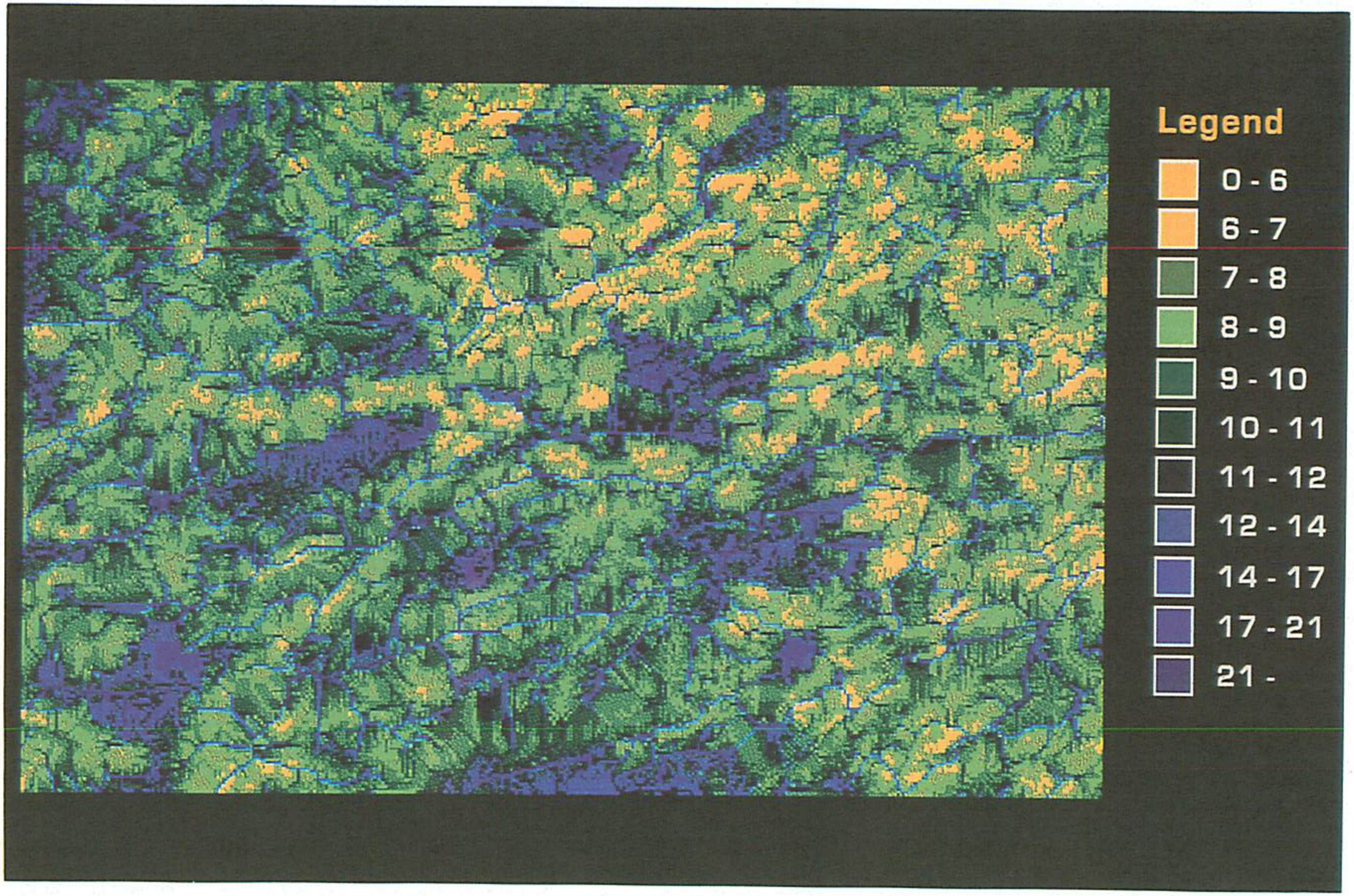


Figure 12. Topographic Wetness Index for the Rinker Lake study area near Thunder Bay, Ontario. Local dendritic drainage patterns are evident where lighter tones are water shedding, darker tones are water collecting; lakes are shown in navy blue (after Mackey et al. 1994, see Footnote 3). Grid was created at a 100 m grid spacing. (Area shown is a map segment from 49° 00' N to 49° 27' N latitude and -89° 19' W to 89° 61' W longitude.)

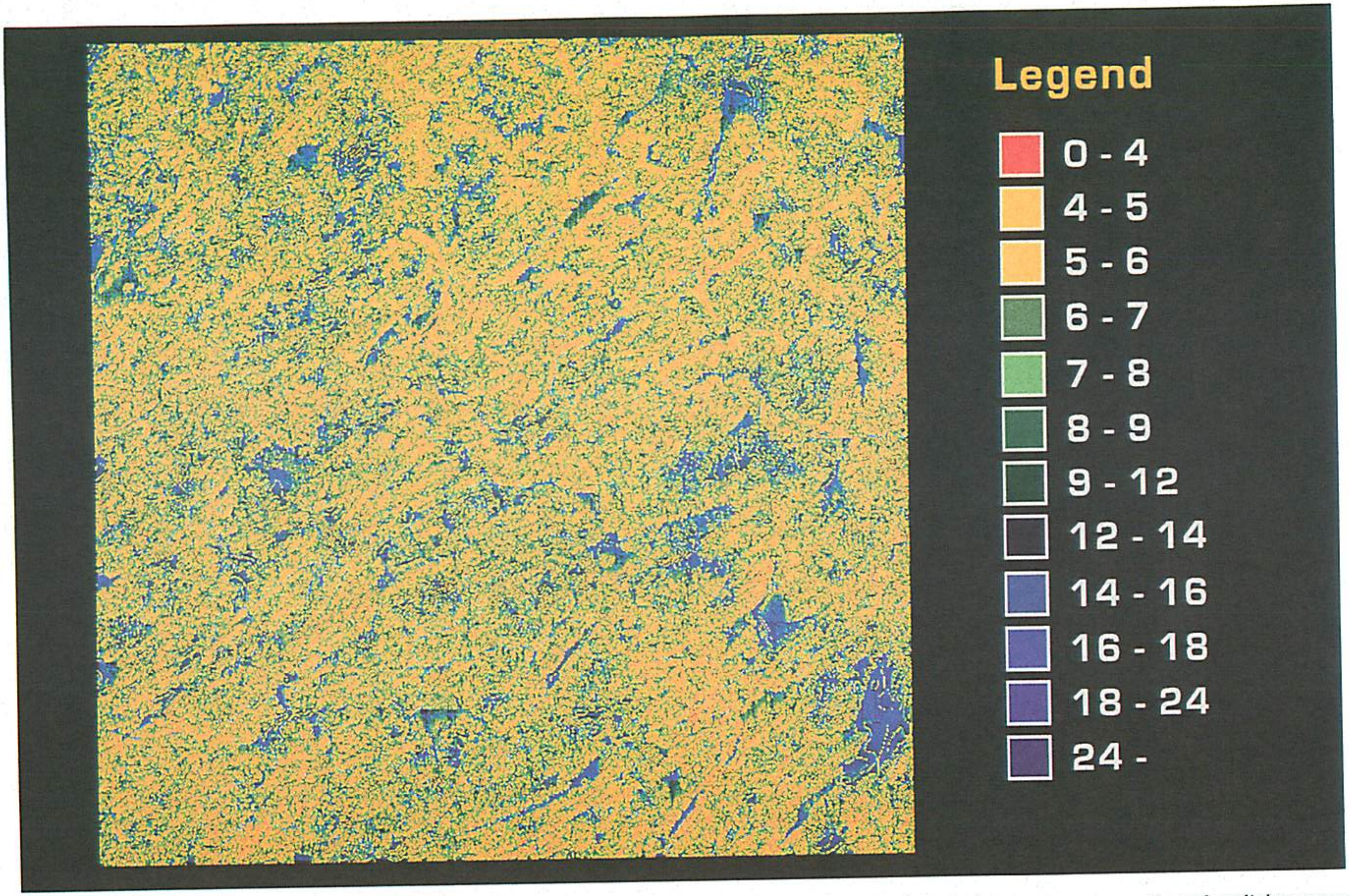


Figure 13. Topographic Wetness Index for the Rinker Lake study area near Thunder Bay, Ontario. Local dendritic drainage patterns are evident where lighter tones are water shedding, darker tones are water collecting; lakes are shown in navy blue (after Mackey et al. 1994, see Footnote 3). This grid was created at a 20 m grid spacing using the TAPES software package (approximate scale 1:214,000).

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Appendix 1 - Additional details on ANUDEM and the creation of the Ontario DEM.

Optimization of the ANUDEM Input Parameters

The ANUDEM procedure is scale free in that the resolution of the DEM is dependent upon the resolution and quality of the source data. However, the ANUDEM program has a number of parameters that can be fine-tuned to optimize the interpolation of a given data set.

The values for: (1) root mean square residual, (2) roughness minimum curvature, (3) elevation tolerances, and (4) minimum residuals were determined by iteratively testing their effects on data from two test areas (*see* Figure A1):

1. Kapuskasing, NTS:42G in the area bounded by 49.0 to 49.5 degrees latitude and -83.0 to -83.5 degrees longitude, and
2. Nipigon, NTS:52H in the area bounded by 49.1 to 49.35 degrees latitude and -89.45 to -89.7 degrees longitude.

These areas were selected for their contrasting topographies. Kapuskasing has undulating medium-to-low relief while the Nipigon area is more rugged.

Values for roughness minimum curvature, elevation tolerances, and minimum residuals are listed, for reference, in an ANUDEM command file, Example A1. Their selection was also guided by previous experience with the ANUDEM program. The NTS data proved relatively insensitive to the range of values normally used.

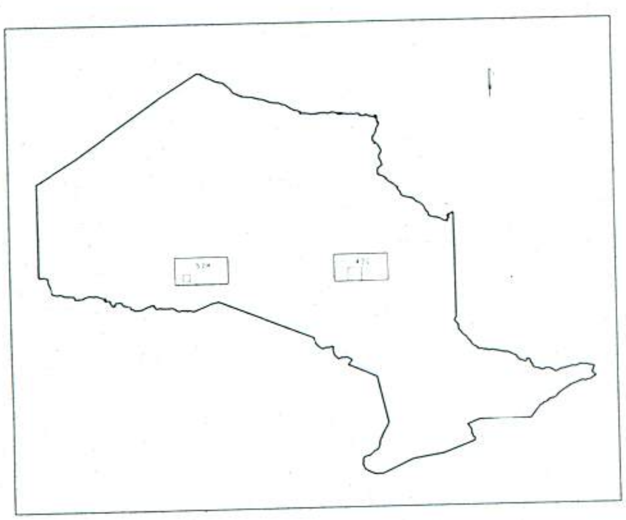

Figure A1. Map of Ontario showing sites used for this study.

Assessment of Optimum Grid Spacing

Grid spacing is the most crucial parameter. Because the data are being processed digitally it is possible to produce a grid of any resolution. However, there is always a minimum resolution that the data will support. Also, a trade-off must be made between grid resolution and data storage capabilities, as doubling the grid spacing increases the volume of data by a factor of four.

In selecting the optimum grid spacing, it was desirable to separate the relative effects of elevation data, stream lines, and the drainage enforcement in the interpolation process. ANUDEM was run to create several different interpolations of the same area. Five DEMS were produced for Kapuskasing and three for Nipigon using differing combinations of grid spacing, input data, and drainage enforcement. The various combinations are shown in Table A1. Elevation contours were produced from each DEM using the program GRDCON. The range of sensitivity analyses demonstrated the effort invested in stream line correction and the use of the ANUDEM procedures provided extra topographic detail. The grid with the drainage enforcement algorithm turned on had more definition of contours than the grid with drainage enforcement turned off. In flatter areas the drainage supplies more data. These data are especially beneficial when contours are far apart.

Preparation Steps to Run ANUDEM

1. The exact process taken to prepare data for editing on a UNIX station will depend on the form in which the data is received. Data will first need to be transformed to an ANUDEM format (i.e., an ascii file with known extents, and compatible grid spacing).

   : **import cover <exported file> <new cover file>**
   : **sif2arc** **
   : **project cover** **

   We received data in two different ways; the OBM data was received in an ARC **export** format and the NTS data was received in a Standard Interchange Format (SIF). The data was then **import**ed or changed from **sif** to **arc** format using the **sif2arc** command in ARC/INFO and, if necessary, **project**ed from UTM to Geographical format (i.e., lat. and long.).

2. ANUDEM requires streams to be flowing in the correct direction (i.e., downhill). This can be achieved with the ARC/EDIT tool of the ARC/INFO package.

Table A1. Assessment of optimum grid spacing.

Area and test parameters	Drainage enforcement turned on	Grid space in decimal degrees	Contours included in ANUDEM run	Stream lines included in ANUDEM run	Lakes included in ANUDEM run
Kapuskasing area					
Generated contours, streams and lakes at 100 m	yes	0.001111111	yes	yes	yes
Generated contours, only, at 200 m	yes	0.00187265917	yes	no	no
Generated contours plus streams at 200 m	yes	0.00187265917	yes	yes	no
Generated contours, streams and lakes at 200 m	yes	0.00187265917	yes	yes	yes
200 m grid	no	0.00187265917	yes	no	no
Nipigon area					
Generated contours, streams and lakes at 100 m	yes	0.001111111	yes	yes	yes
Generated contours, streams and lakes at 200 m	yes	0.00187265917	yes	yes	yes
200 m grid	no	0.00187265917	yes	no	no

: **cd /work/<tile>**
: **arc**
arc: **arcedit**
arcedit: **disp 9999**
arcedit: **editcover stream**
arcedit: **drawenvironment arc arrows**
arcedit: **editfeature arc**

The above commands could be put into an AML for quick and easy entry and reentry into ARC/EDIT.

3. As mentioned previously, the stream arcs were flowing in random directions. Therefore, an interactive program was set up to select the main or root arc of a drainage network. The selected arc had to flow in the proper direction and then be flagged with a unique identifier. The STREAMALIGN program would then recognize the unique identifier and, based on how the nodes matched, would flag any connecting arcs upstream with nodes that did not match. Upon reentry into ARC/EDIT an AML was created to **select** the flagged arcs and **flip** them. The Rinker Lake OBM data had an AML named RINKEDIT, which was set up in the work directory.

   : **cd /work**

   : **arc**
   arc: **&run rinkedit <tile>**

   At this point, the AML would have **flip**ped the **select**ed arcs and put the user in a position to assess AML results and start the process over again if necessary. This may be the case in areas not affected by the AML. This would happen in areas of arcs where nodes did not connect or where drainage discontinuity occurred. Arcs, from that point of discontinuity on, would be ignored. The RINKEDIT AML was set up so that, upon reentry into ARC/EDIT, any arcs affected by the above processes would be drawn to the screen in a different color. This allowed the user better capability to identify where drainage discontinuity might have occurred.

4. When streams had been edited satisfactorily, the coverage was then ungenerated in ARC and changed to ANUDEM format.

   : **cd /work/<tile>**
   : **arc**
   arc: **ungenerate cover <cover name>**
   <ungenerate file name>
   : **/work/programs/ungen2anudem**

   The program UNGEN2ANUDEM was written to take the ungenerated file and put that file into an ANUDEM format. The coverage is then ready to be used by ANUDEM. The same process must be performed on all coverages to be used by ANUDEM. For example any contour, spot, and polygon or land coverages.

5. Edit ANUDEM command file (*see* Example A1) and execute ANUDEM program.

   : **/home/anudem/anudem < /work/anucom/<ANUDEM command file> > /work/demout/ANUDEMgrid.log &**

   A directional command file will execute the ANUDEM program and record progress in a directional output log file. To execute the ANUDEM program, the < sign indicates that the ANUDEM command file, in the work/anucom subdirectory, will be utilized for input parameters into the ANUDEM program. The > sign indicates that the visual process for ANUDEM execution will be sent to a log file in the /work/demout subdirectory. The & sign allows the program to run in the background. Output for ANUDEM will be found in the subdirectory specified in the ANUDEM command file.

   : **/work/demout/ <grid name>**

6. To view the grid and check for errors, two methods were taken.

a) When using ARC/INFO version 5.0 (no grid viewing capabilities), GRDCON was used to generate contours from the new grid which could be overlaid on top of the original contours and visually compared. To create a hard copy of the contours, an AML consisting of a series of moves and draws would plot the contour data. The data were then plotted out on a pen or mylar plotter.

   : **/work/demout**
   : **/home/grdcon/grdcon**
   : **/work/programs/makeplot**
   (to create an aml of the newly generated contour data to be used in ARC/INFO)

   : **arc**
   arc: **&run mylarplot**
   (aml set up to create a series of moves and draws from the above created AML)

   arc: **quit**
   : **/work/plots**
   : **plot <contour file> <plotting device>**

b) Using version 6.1 of ARC/INFO, on a UNIX workstation, the ARCPLOT commands **gridpaint** and **cellvalue** were used as additional methods of checking the newly generated grid. However, before these commands could be used, the grid had to be i) inverted (using program IDRID) and ii) changed to an grid format (using the ARC command **asciigrid**).

i) : **/work/programs/idrid**

This program would invert and change the format of the grid to be viewed in ARC/INFO ARC/PLOT. Before running **asciigrid**, the inverted grid needs a header stating: the number of columns and rows, lower left x corner, the lower left y corner, and the cell size.

NCOLS ****
NROWS ****
XLLCORNER ****
YLLCORNER ****
CELLSIZE ****

Once this header has been added to the top of the inverted grid, the grid should then be saved. The grid is now ready to be imported via the arc asciigrid command.

ii) : **/work/demout**
: **arc**
arc: **asciigrid <name of inverted ascii file with header> <name of output grid>**

To view the grid in ARC/INFO, use ARCPLOT.

arc: **arcplot**
arcplot: **display 9999**
arcplot: **mapextent <ascii grid>**
arcplot: **gridpaint <ascii grid> # equal area # gray**
arcplot: **cellvalue <ascii grid> ***

Any irregular black or white spots, inferring elevation sinks or spikes, should then be examined and corrected, if necessary. The ARCPLOT command **cellvalue** with the '*' option allows the user to query the grid interactively to assess cell values. To correct digital errors, Steps 2-6 were repeated.

Post ANUDEM Programs

1. Ontario has many small lakes spanning its topography. Because no elevations were given in the digital data for lakes, POLGRD was used to 'cut' the lake areas out of the DEM created by ANUDEM. However, the islands do have elevation data and, therefore, need to remain. To accomplish this task, POLGRD was also used on the island coverage to retain island polygons. A lake cover (containing all lakes, no islands) plus an island cover (containing all islands and no lakes) were needed. These two covers were kept in two separate command files, each having different options of 0 or 1 for extracting lakes or retaining islands. Each command file was then used in executing POLGRD. Output files of POLGRD were specified to be in an xyz format. This was done so that after the two command files were executed, the two new grids could be concatenated together, using the concatenate command in UNIX.

: **/work/<tile>**
: **/home/polgrid/polgrd < <polgrid lake command file>**
: **/home/polgrid/polgrd < <polgrid island command file>**
: **cat <island grid> <lake grid> > <islandlake grid>**

2. The data, now listed as a number of points in xyz format, needs to be reorganized into row format. To do this, use the program INTGRD. A command file can be set up to run the parameters for INTGRD.

: **/home/intgrid/intgrd < <intgrd command file>**

To view the new grid in ARC/PLOT, *see* section entitled Preparation Steps to Run ANUDEM, (6b)

Example A1. Example of input parameters for ANUDEM run (listing of command file needed to produce DEM for Kapuskasing test area).

```
ANUDEM
0                              drainage enforcement off
1                              mainly contour data
150000                         Max ridge length
0.6096                         RMS residual 2%
0                              local maxima not constrained
0.0                            roughness minimum curvature
5.0 30.48 125.0                elevation tolerances
35                             number of iterations
0.0 700.0                      height limits
/work/demout/resid.dat         output residuals
0.2                            minimum residuals
-83.75 -82.75
49.0 49.5
0.001872659126 0.001872659126
2
/work/42g/cont.con
5
(I5,f6.0)
(8f10.6)
/work/42g/stream.str
3
(I5,2f5.1)
(8f10.6)
/work/demout/kapnd.grd
0
(16f5.1)
/work/demout/knd.pnt
/work/demout/knd.str
```