ENVIRONMENTAL MONITORING AT A PROVINCIAL SCALE

Providing GIS Compatible Thematic Data
Through the Integration and Analysis of
Digital Elevation Models and Satellite Imagery

Malcolm Gray and Fern Schultz

British Columbia Ministry of Crown Lands
Surveys and Resource Mapping Branch
553 Superior Street
Victoria, British Columbia, CANADA, V8V IX5
Telephone: (604)387-1146 FAX: (604)387-3022

ABSTRACT

In order to be an effective tool for provincial resource management and environmental monitoring, Geographic Information Systems (GIS's) require access to information that is not only comprehensive, standardized, digital, and current, but is also available Province-wide. Much of the existing provincial resource mapping fails to meet one or more of these criteria.

In an attempt to overcome this lack of suitable data, a method is being prototyped that uses digital topography and satellite imagery to provide a geo-referenced resource database of ground cover, present land use and topographic features. This product is called a Baseline Thematic Map.

Technical obstacles which are being addressed include; registration issues (including relief displacement), classification schema definition, raster and vector format conversions, integrity of the input data and topographic segmentation of digital elevation models.

The application of this mapping methodology for a large area (170 000 sq. km., 1:250 000 map scale) is discussed. Application at a scale of 1:20 000 is also discussed. Results have shown that an economically valuable database can be produced that is reliable, up-to-date and suitable for supporting regional environmental decision making.

KEY WORDS: Satellite Imagery, Digital Topography, GIS, Resource Management, Thematic Mapping

1 INTRODUCTION

The management of British Columbia's natural resources is becoming an increasingly complex task. Reasons for this trend include: a shift from resource inventories to site specific management, integrated and coordinated management of multiple resources, and a requirement to more strictly monitor and regulate environmentally harmful substances and activities. Many of the issues must be addressed at a provincial level.

The economic potential of Geographic Information System (GIS) technology to support planning and decision making has been realized by the Government of British Columbia. GIS technology provides resource managers with a powerful tool which has the potential to efficiently meet the requirement for information analysis. For such a tool to be effective in a manager's ongoing activities, it requires access to resource information that is not only reliable, comprehensive, standardized, digital, and up-to-date, but is also available Province-wide. In this regard an examination of the resource mapping carried out to date in the Province leads to the conclusion that much of it is not suitable for use in a GIS. In addition it has become increasingly difficult to justify new natural resource mapping using traditional methods for two reasons: time and cost (Gray *et al.*, 1989).

In an attempt to overcome these limitations an efficient, cost effective method using presently available data sources to provide suitable geo-referenced natural resource map data is being prototyped. The final objective is a product capable of justifying a production level implementation.

The method involves the production of three natural resource data bases, specifically; ground cover, present land use and topographic features. After integration into a single database the resultant product is called a Baseline Thematic Map. The databases are derived from an integration of digital topography and satellite imagery by a series of procedures involving image analysis, topographic modelling and GIS processing.

2 SPECIFIC RESPONSE TO THE REQUIREMENT FOR PROVINCE-WIDE NATURAL RESOURCE DATABASES

Past pilot projects undertaken by the Surveys and Resource Mapping Branch have shown that classification of satellite imagery can meet traditional map accuracy specifications (Kenk *et al.*, 1988). Results reported in the literature indicate that by including topographic information the number of classes mapped can be increased while maintaining map accuracy (Cibula *et al.*, 1987).

The method being prototyped involves the production of three themes: ground cover, present land use and topographic features. The area chosen for this initial work is in the southern interior of the Province, specifically NTS map sheets 82 E (1:250 000) and 82 L/3 (a 1:50 000 map sheet, but mapped at 1:20 000).

The ground cover database provides the generalized type, extent and distribution of present vegetation cover. The main criteria for classification is vegetation structure and composition (i.e. physiognomy). The initial classification from the satellite imagery is refined using the relationship between specific vegetation distribution and topography. The ground cover theme is extended to include some detail on water bodies, wetlands, rock outcrops and the like. A ground cover classification schema is given in appendix "A".

The present land use theme is based on a modified form of the "Land Use Classification in British Columbia" (Sawicki *et al.*, 1986). The level of classification is restricted to area-based uses versus site uses. Site uses of the land are generally not extensive enough to be identified on satellite imagery. It should be noted that a combination of spectral classification of satellite imagery and interpretation is used to produce the present land use classification.

The topographic features database is derived by segmenting the digital elevation model (DEM) into significant landscape units. These units are described in both raster and vector format. Watershed boundaries are delineated. Attributes that are attached to these units are the maximum, minimum, and mean values for: elevation, slope and aspect. Also included are: area, surface irregularity, and surface shape. Potential solar radiation received is also calculated. It is anticipated that these attributes will significantly add value to the final Baseline Thematic Map product for many users.

The satellite imagery utilized is presently Landsat TM, which has good spectral information for the identification of ground cover and for interpreting present land use. Two versions of the product are being prototyped, corresponding to the two available topographic data sets. The digital elevation model and base map for the 1:250 000 version will be supplied from scanned 1:250 000 NTS map sheets. Energy Mines and Resources Canada has scanned all of the 84 sheets covering B.C. and these digital map files are available from them. The Terrain Resources Information Management (TRIM) program (the creation of 1:20 000 digital base mapping for B.C.) will supply the digital elevation model and the base map for the 1:20 000 version. Presently there are about 1200 of the 7000 map sheets completed with a current production rate of approximately 500 map sheets per year.

3 METHODOLOGY

For the 1:20 000 version the new digital mapping from the TRIM program forms the base map. For the 1:250 000 version product, scanned 1:250 000 NTS map sheets will provide the base map. The datum for the prototype work is NAD 83 (North American Datum 1983). It is envisioned that all provincial mapping will migrate to NAD 83 over the next five years. Transformations to other datums (NAD 27) and projections are well defined for those users desiring them.

The first manipulation of the input data is to co-register the different data sets (imagery, DEM's, and other ancillary map data). To avoid any systematic subpixel mis-registration all rasters follow the same convention about the origin with respect to the reference UTM grid. UTM coordinates ending in 00 (i.e. every 100 metres) align with the boundary between pixels. Pixel sizes are chosen in a nested hierarchy as follows: 6.25, 12.5, 25, 50, and 100 metres. The actual size is dependant upon the data utilized and the map scale produced.

For areas of high relief Landsat TM imagery has geometric distortions due to the panoramic view of the sensor. At the edge of the 185 kilometre wide image swath the look angle is 7.47 degrees, causing a horizontal displacement of 30 m for every 230 m change in ground elevation (Wong *et al.* 1981). Many parts of B.C. have relief in the order of thousands of metres. This is an unacceptable amount of distortion for 1:20 000 mapping.

Correcting for relief displacement is accomplished using a DEM. We have demonstrated that the 1:20 000 TRIM data produces a DEM that is sufficiently precise to allow correction of Landsat TM to plus or minus one pixel (25m) accuracy. Currently we are investigating the precision obtainable utilizing 1:250 000 topographic data.

The present land use classification was produced through interpretation of a transparency of the Landsat TM imagery using the PROCOM projection device. The transparency was the same date as the digital data with bands 3, 4 and 5 portrayed as blue, green and red. The interpretation depends upon colour, tone and pattern recognition and adjacency considerations. The initial interpretation work was done at 1:100 000 scale with the results then being digitized into the existing digital base maps.

Image classification for ground cover identification proceeds from field work to selection and refinement of training sites on the satellite imagery. To reduce the complexity of the task the classifications where stratified according to the land use classification. Thus many separate classifications (eg. agricultural, rangeland, logging clear cuts, etc.) with a restricted number of classes where performed. Within these strata single ground cover classes are described by more than one set of training sites so illumination and ecological differences due to topographic position are accounted for. After classification with these separate training sites, the results are merged into a single class type.

Post-classification processing is of two main types: context filtering to transform the raw image classification into a more acceptable map like product and modification of the resulting classification through the use of ancillary (primarily topographic) data.

Context filtering makes use of the similarity between classes as well as length of common boundary and minimum area rules for amalgamating groups of pixels. This kind of filtering results in a cartographically acceptable map and is also required to reduce the number of homogeneous areas (polygons) as many GIS's are limited in the number of polygons that they can handle. A record is kept of the percentages of the original classes that were amalgamated to form the single class output polygons.

Improvements in digital classification through the use of ancillary data (including digital elevation data) can be achieved in three ways: incorporating those data either before, during or after classification, through stratification, classifier operations or post classification sorting (Hutchinson, 1982). Ancillary data is used to construct masks within the image analysis system then Boolean logic is employed to separate classes that are spectrally similar. Equivalent results can be achieved through GIS processing, with potentially a wider selection of attributes available for post-classification accuracy improvement.

Topography plays a dominant role in many biological and geomorphic processes. Terrain segmentation as implemented is based on: surface morphology, hierarchical watershed boundaries, and potential solar radiation received at the surface. Segmentation based on morphology begins with irregularly spaced points, from which a triangulated irregular network (TIN) is created. Units are defined through the amalgamation of neighbouring triangles, based on similarity with respect to slope and aspect. Watersheds are formed by the examination of hydrologic flow across the triangles. Radiation based segments are created through merging of contiguous triangles based on criteria examining the results of shading and shadowing values sampled at set intervals from sunrise to sunset over specific days of the year.

At some point the raster products require conversion to a vector format to be compatible with most current GIS formats. Currently our capability is limited in the size of raster supplied as input and the number of resultant polygons output. Presently a single value attribute can be attached to the vector database created, there is a requirement for the transfer of multiple attributes, for example the record of the original composition of a context filtered polygon.

4 RESULTS

The following discussion of results is restricted to the 1:250 000 version. At the time of writing (June 1990) work on the ground cover part of the 1:20 000 version is proceeding under contract.

4.1 Present Land Use

The following land uses were identified and delineated from the satellite image transparency (codes based on "Land Use Classification in British Columbia", (Sawicki *et al.*, 1986));

A000	rural activities
A100	mixture of tillage crops, forage crops and tree and vine fruits
A130	orchards and vine fruits
C000	urban built-up areas and residential concentrations
E100	surface extraction
F110	recent logging (i.e. visible clear cuts)
F111	clear cuts or groups of clear cuts with up to 30% standing trees)
R100	ski hills, parks
N100	no perceived activity with grass cover
N200	no perceived activity with forest cover
N320	bedrock
N400	lakes

Because the logging clear cuts were a highly visible land use, smaller units than usual for the final map scale of 1:250 000 were delineated. This resulted in 1300 land use polygons in total for the 1:250 000 map sheet.

4.2 Ground Cover Classification

For the 1:250 000 ground cover classification the imagery was decimated to 100 m pixels. This represents a reduction in data volume by sixteen. The effect of this decimation on the accuracy of the ground cover classification was tested for the clear cut areas. The overall accuracy for this particular ground cover classification (12 vegetation types) was 89% for 25m pixels and 93% for 100m pixels.

Ground truth was derived from fieldwork for ground cover within logging clear cuts. Ministry of Forest 1:20 000 forest cover maps provided the ground truth for forested areas for approximately 10% of the area under consideration. Intensive agricultural land use mapping for three 1:20 000 map sheets provided the ground truth for the ground cover within the agricultural areas.

Classification accuracy is presently being assessed. Preliminary results for the ground cover within clearcuts indicate overall thematic mapping accuracy in the 70% to 90% range.

Context filtering was applied to reduce the complexity of the raw classification in a cartographically acceptable manner. This process reduced the number of polygons by a factor of 50 to 100. Usually, but not always, this process would result in increased map accuracy.

4.3 Topographic segmentation

The TRIM program 1:20 000 topographic data provides a dense grid of elevation points from which it is possible to construct a high quality digital elevation model (DEM). For the 1:250 000 topographic data the elevation data is conveyed by digitized (scanned) contour lines. Although experienced map users find it easy to infer surface information from contours typical DEM interpolation algorithms often give incorrect results because of the lack of elevation data between contour intervals.

In an attempt to improve the quality of the DEM derived from the 1:250 000 data, the density of elevation points was increased in two ways. A "z" value was interpolated for the hydrographic network based on intersections with contour lines. Areas with sparse contour lines were manually assigned elevation points from 1:50 000 topographic maps. These processes resulted in a greatly improved DEM.

Currently the software employed for topographic segmentation is limited in the number of triangles (formed from the irregularly spaced elevation points) that can be processed. This problem is being addressed, but consequently the initial Baseline Thematic Map prototype will have a restricted number of topographic features. These will include: elevation, slope and aspect averages for individual ground cover polygons.

4.4 GIS Integration

The three themes are integrated within the GIS environment. The derived attributes for land use, ground cover and topographic features are input into a geo-referenced database. Final editing and quality checking is facilitated by the analysis capabilities of the GIS.

5 DISCUSSION

This method for providing a highly standardized Province-wide resource database is being prototyped now. The prototype dataset will be available for distribution by August, 1990. This product has the potential to meet many of the information requirements of Provincial resource management. If the results of the prototype effort merit a production level implementation it is realistic to expect the private sector to become involved in the production of Baseline Thematic Maps.

6 REFERENCES

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APPENDIX A

DRAFT Ground Cover Classification for Baseline Thematic Mapping from Landsat TM Data.

Code				
CF	Coniferous Forest			> 79% of the tree cover provided by coniferous species
CFm	1.	Mature		> 10 m tall or > 80 years old
CFmd		a.	Dense	> 59% cover by vertical projection of all trees
CFmo		b.	Open	25% - 59% cover
CFmp		c.	Parkland	5% - 24% cover
CFi	2.	Immature		< 10 m tall or < 80 years old
CFid		a.	Dense	> 59% cover
CFio		b.	Open	25% - 59% cover
CFip		c.	Parkland	5% - 24% cover
		(Coniferous forest may be further classified by species composition.)		
DF	Deciduous Forest			> 79% of the tree cover provided by deciduous species
		(subdivisions as for coniferous forest above)		
MF	Mixed Forest			Coniferous and deciduous species each provide more than 20% of the total tree cover
		(subdivisions as for coniferous forest above)		
AT	Alpine Tundra			Typically a high elevation, open to dense herbaceous or dwarf shrub cover, characterized by cold resistant vegetation consisting of low dwarf shrubs, graminoids, hardy forbs and lichens.
AM	Alpine Meadow			Typically a high elevation, herbaceous plant community, dominated by moisture-loving herbs and sedges, on wetter sites in alpine areas.
AH	Alpine Heath			Typically a high elevation dwarf shrubland cover, characterized by cold resistant vegetation, consisting of mountain-heathers, forbs, graminoids, and lichens.
K	Krummholz			Areas in which, in response to severe and fluctuating climatic conditions, subalpine tree species occur in stunted and layered forms as scattered individuals, in clumps or in discontinuous coverage with the non-treed areas dominated by herbs, lichens, and/or shrubs.
		(Krummholz may be further classified by species composition)		

M	Meadow	Treeless area deaminated by herbaceous plants in response to improved moisture conditions (in relation to the general climate) from snow melt, seepage and/or high water tables for at least part of the year.
Mg	1. Grassy M.	A meadow dominated by narrow-leaved (grass-like) herbs, with less than 25% of cover of broadleaved plants.
Mf	2. Forb M.	A meadow dominated by broadleaved herbs (forbs) with more than 25% of cover formed by broadleaved herbs.
	(Meadow may be further classified by species composition.)	
S	Savannah	Areas virtually devoid of trees and dominated by drought-tolerant shrubs, with herbs and grasses forming the under story.
ST	Steppe	Areas virtually devoid of trees and shrubs and dominated by drought tolerant grasses and herbs.
SH	Shrubs	Areas dominated by shrubs (not drought-tolerant).
SHh	1. High	> 1.5 m tall
SHhd	a. Dense	> 59% cover by vertical projection of all shrubs
SHho	b. Open	25% - 59% cover
SHl	2. Low	< 1.5 m tall
SHld	a. Dense	> 59% cover
SHlo	b. Open	25% - 59% cover
	(Shrubs may be further classified by species composition.)	
W	Wetland	Swamps, marshes, fens, bogs or inundated ares with emergent wetland vegetation.
Wb	1. Wetland Bog	Organic substrate covered by ombrotrophic (mineral-poor, rain fed) mosses.
Wf	2. Wetland Fen	Organic substrate covered by minerotrophic (mineral-rich, groundwater-fed) sedges.
Wm	3. Wet. Marsh	Mineral substrate inundated for significant portions of the year, supporting herbaceous vegetation.
Ws	4. Wet. Swamp	Mineral substrate inundated for significant portions of the year, supporting woody vegetation which is dominate over the herbaceous vegetation.
W_t	a.Treed	As above but including up to 24% tree cover.
	(Wetland may be further classified by species composition.)	
OW	Open Water	Water deeper than 2 m without aquatic vegetation.
SW	Shallow Water	Water less than 2 m without aquatic vegetation.
SWv	1. Aquatic Veg.	Shallow water with submerged and/or floating aquatic plants present.
	(Water may be further classified as clear or sediment laden)	
L	Logged	Areas devoid of trees because of recent logging with less than 10% cover of merchantable trees remaining.
Lp	1. Selective	Partial or selective logging with more than 10% cover of merchantable trees remaining.
Lw	2. Slash	Areas recently logged and dominated by more than 24% cover of exposed (visible above any vegetation) dead wood or logging slash.
Ls	3. Bare Soil	Areas recently logged with more than 24% exposed rock or disturbed soil.
Lr	4. Regen.	Areas of recent logging where there is a regenerating crop tree species present.
Lrd	a. Dense	> 24% cover of crop tree species present
Lro	b. Open	< 25% cover of crop tree species present
	(Logged areas may be further classified by the vegetation present as noted above for Meadow and Shrub classes and by the regenerating crop tree species.)	
B	Burned	Areas devoid of trees because of recent fire with less than 10 cover of merchantable trees remaining.
	(subdivisions as for Logged above)	
C	Cultivated	Lands used for agricultural crop production (more fully separated by utilizing present land use classification).
	(Cultivated may be further subdivided by state of cultivation and crop.)	
OR	Orchard/Vineyard	Typically an agricultural area used for growing hard and soft fruit crops, with some form of symmetrical arrangement of the trees, shrubs or vines.
	(Orchard/Vineyard may be further subdivided by crop.)	
R	Rock	Bedrock areas devoid of vegetation (except certain pioneer lichen and mosses).
Rt	1. Talus	Talus areas, rubbly or blocky colluvial areas, at the base of rock outcrops or escarpments.
Rd	2. Disturbed	Nonvegetated areas such as gravel pits and other recently disturbed surfaces.
G	Glacier	Glaciers or snowfields, areas where snowfall exceeds melting. These areas may or may not show evidence of past or present glacier movement.
U	Urban	Urban areas (more fully separated by utilizing present land use classification).
Ur	1. Residential	Residential areas.