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Land Cover Mapping in Canada with Respect to Ecosystem Accounting

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1 Purpose

This document is in contribution to the discussions on Issue #3 **Land Cover Mapping, Land Cover Classification and Accounting Units** as outlined in the proposal document (UNSD, 2011). The issue as stated in the document was divided into three separate areas and Canada was asked to prepare a paper discussing experience in land cover mapping.

This paper provides a background on land cover data, its sources and limitations as available in Canada. It also discusses some of the interrelated issues between land cover mapping, land cover classification and accounting units in terms of their relevance for environmental accounting. Lastly, the paper provides some examples of the experimental mapping Statistics Canada has undertaken to establish accounting units and land cover classifications for the Government of Canada's project on Measuring Ecosystem Goods and Services (MEGS[2]).

Land cover mapping in Canada is a very mature technology and therefore many federal departments and provincial agencies have developed their own applications. It is impossible to cover even a minority of them in this overview. As MEGS progresses, more of these sources and approaches will be inventoried and integrated into a Canadian System of Ecosystem Accounts. The project is currently funded for three years and is conducted in partnership between Statistics Canada, Environment Canada, Natural Resources Canada, Fisheries and Oceans Canada and Agriculture and Agri-food Canada.

2 Concepts

Land cover mapping, land cover (or ecosystem) classification and ecosystem accounting units are highly interrelated. Many ecosystem accounting approaches begin with remotely-sensed land cover data to establish uniform surface areas as basic "accounting units". The size of the accounting unit and the detail of the information attributed to it is dependent on the spatial, temporal and spectral resolution of the sensor (satellite in most cases). The spectral resolution of the sensor also determines the degree to which a given "signature" or combination of spectral bands imaged by the sensor can provide information that can be classified into the land cover classification.

Ideally, the accounting unit[3] is homogenous over the accounting period. This also implies that the unit is as small as possible to increase its homogeneity.

An ecosystem classification[4] serves several functions. It can be a high-level reporting classification but it can also be an important attribute of the accounting unit. As in industrial classifications, an establishment is given a code based on its properties and information on establishments in the same category can be aggregated. Ideally, the classification is sufficiently detailed to allow the assumption that the services provided by ecosystems of the same type are reasonably comparable. One reason for this is that data on the quality and value of the accounting

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[2] An early project description is available online at: http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/ENVIRONMENT/0,,contentMDK:22877286~pagePK:210058~piPK:210062~theSitePK:244381,00.html#ppt.

[3] Referred to in MEGS as an "ecosystem" or "separately identifiable natural systems of biotic and abiotic elements that provide welfare benefits through the provision of a variety of environmental goods and services (EG&S)". This is similar in purpose, if not in composition to the EEA's Socio-ecological Landscape Units (EEA, 2011).

[4] Called "biome" in Costanza et al., 1997,

unit are generally derived from local studies (such as inventoried in EVRI[5]) and a common method is to transfer the benefits calculated from one ecosystem type to another. The degree to which a grassland ecosystem in one part of the country resembles another sufficiently to assume the services provided have a similar value[6], depends largely on the accuracy/specificity of the classification.

3 Information required to delineate "ecosystems"

Ideally, many sources of information are combined to delineate homogenous "ecosystems". That is, once the nature of the accounting unit is defined, one can attribute information on land cover, soil type, climate, geomorphology, hydrology as well as socio-economic attributes such as ownership, management regime and land use. One question that is still under discussion is how much of that information is required to delineate the ecosystem and how much is simply an attribute of the ecosystem.

In the interest of simplification, it should be possible to determine a minimal necessary set of information. It is generally agreed that land cover is essential and the Canadian MEGS project is investigating the possibility of combining land cover, soil and elevation information to delineate its accounting unit. An example is provided later in this paper.

One reason for a minimal set of information is that complete data (for example of land use or ownership) may be difficult to assemble at the national level—especially for a country as large as Canada. Another reason is that fewer parameters will lead to less variability in the delineation of the accounting unit over time.

This can be likened somewhat to a business register in a statistical agency that records only the name, address, industrial classification, number of employees and revenues for each business establishment in the country. The purpose of the business register is to provide the sample frame for business surveys. Establishments are sampled randomly from the frame (possibly stratified by size, industry and location). Only a small proportion of the total number of businesses provides more detailed information but that information is deemed to be representative of similar businesses that weren't sampled. As with business surveys, it is not necessary to collect full information on each accounting unit.

4 Sources of land cover information

Land cover information at the national level is commonly obtained from satellite imagery. In Canada, two main sources are used: MODIS[7] (250m) and AVHRR[8] (1km). These provide different levels of resolution and complete national coverages are assembled only about every 5 years. A 30m resolution land cover dataset is being compiled by the Canadian Centre for Remote Sensing once for 2005 and it may be compiled again for 2010.

For some purposes, interpreting remotely-sensed data is too labour intensive to allow frequent and automated updates. Statistics Canada, for example, uses statistical information to delineate

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[5] The global Environmental Valuation Research Inventory (www.evri.ca) is maintained by Environment Canada and supported by several partners: the government of Australia, France, New Zealand, US and UK.

[6] This is not to imply that the ecosystem classification is the only information required to allow benefits to be transferred from one location to another (or to generalize from local studies to a regional or national estimate). Other information such as proximity to population centres, ownership and level of protection, for example, may also be relevant.

[7] Moderate Resolution Imaging Spectroradiometer.

[8] Advanced Very High Resolution Radiometer.

certain types of land cover, as a means of reducing the analytical burden. Censuses of agriculture[9] and population can provide useful land cover information. "Settled" or "human-influenced" areas have been delineated using census block information together with information on the residential and working population (Filoso, 2011). Using statistical geographic units to represent biophysical information does have some limitations. For an agricultural census, it has been the practice to record the location of the residence of the farmer, not the location of the land that he or she cultivates. In the case of using a census block as an accounting unit for determining settled area, the average population density of a large census blocks may misrepresent the observed land cover. Both limitations are well understood and are being addressed.

Aerial photographs are another source of useful land cover information. Although the spatial and temporal coverage of aerial photography may be limited, it is often used to establish an historical baseline for a local area of concern.

Topographic maps can also provide useful land cover information as they often contain information on hydrography, landform, relief, transportation corridors and vegetation. As with land cover and aerial photography, the process of producing these maps is labour intensive. Map series are generally not frequently updated.

Another source that is eminently useful but difficult to implement on a national scale is ground truthing. That is, sending experts into the field to assess exactly what the land cover is. The Canadian Forest Service, for example, randomly selects one percent of the National Forest Inventory[10] surface area for field sampling. This is an essential component for calibrating the land cover information obtained from satellite images.

5 Issues

5.1 Sufficiency and necessity of land cover information

There is still a debate in Canada as to whether land cover information is sufficient and necessary to delineate the accounting unit (Thie, 2010). In fact, the Ecological Classification of Canada[11] is based on the Soil Landscape Classification of Canada[12]. Neither uses land cover information as a basis for delineating the basic unit (eco-district and Soil Landscape Unit (SLU), respectively) but land cover is an attribute (see Table 3 in Section 7).

Land cover information itself can be seen as problematic, especially in a country as varied geographically and seasonally as Canada. Firstly, land cover can change rapidly from year to year. New settlements, insect invasions, floods as well as natural succession can permanently change the landscape such that a land cover maps representing one year will no longer be valid the next year.

Secondly, land cover changes over the season. During some points in most winters, all of Canada can be snow-covered. As well, seasonal floods and changes in leaf cover require care in the use of land cover information. Generally, some of these issues are overcome by averaging and creating composite remote sensing "scenes" over several points in time.

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[9] Agriculture census data is available in the form of agri-environmental indicators. See: http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1181580464260&lang=eng.

[10] See https://nfi.nfis.org/documentation/general/Design_overview_v3.2.pdf.

[11] See www.ecozones.ca.

[12] See http://res.agr.ca/cansis/nsdb/slc/intro.html. The Soil Landscape Classification covers all of Canada and is frequently updated. Attribute data for agricultural areas is generally more complete than for non-agricultural areas.

"Land cover" information by definition says little about what exists under the water. Canada is home to a large number of lakes[13], most of which have never been surveyed or named. The depth, profile and vegetation lying under the surface of these lakes are largely unknown. However, information on navigable waters[14] and lakes popular for recreation is widely available on GPS for boaters. Good information also exists for many of Canada's coastal and marine areas (this is discussed later in this paper).

5.2 Quality of interpretation of satellite imagery

Most land cover information is obtained from satellite imagery. Interpretation of this imagery is, to some degree, a manual exercise, based on comparing the spectral layers obtained from the satellite with known (i.e., ground-truthed) land covers. This is assuming that one "signature" obtained from one area of the country (for example, wetlands) represents the same land cover type in another area of the country.

There is also an issue of consistency of interpretation. In Canada, different departments and provincial agencies have access to the same raw satellite imagery and will likely have differing interpretations.

5.3 Consistency of satellite imagery

There are issues in consistency in the surface area covered by any one "pixel" of raw satellite data. For example, the stated resolution of MODIS is 250m. National land cover images are built up from several passes of a given satellite and one 250m pixel will not often line up with one from an adjacent pass. Furthermore, passes of the same area at another time in the future will not line up with the ones done in the past. The message here is that the resolution of the data will not represent the resolution of the accounting unit. An approach is required to average the data over a larger area.

5.4 Frequency of satellite imagery

As mentioned previously, comprehensive, national maps of high-resolution land cover are produced only about once every 5 years. It is a labour and data-intensive process. Since ecosystems are quite dynamic, ideally, information would be available annually or sub-annually. The Canada Centre for Remote Sensing overcomes this to some extent by monitoring annual changes at a lower resolution (e.g., 250m) and updating its 30m resolution product only for those areas that have changed (Latifovic et al., 2009).

6 Canadian experience

Canada has a long and rich history in ecological classification and using land cover information not only for environmental assessments and reporting but also in support of the natural resource sectors: forestry, fisheries and agriculture. In fact, the world's first Geographic Information System (GIS) was developed by Environment Canada for this purpose. Thie (2010) provides a useful historical perspective.

Table 1 shows the long-term satellite data record for Canada. The temporal resolution means that raw data are available from the satellite at this frequency but land cover time-series are assembled

[13] The exact number is unknown according to Natural Resources Canada: http://atlas.nrcan.gc.ca/auth/english/learningresources/facts/lakes.html. There are 31,752 lakes with a surface area of over 3km^2. One unofficial estimate is that there are about one million lakes smaller than 3km^2.

[14] See http://www.charts.gc.ca/index-eng.asp.

only for every 5 years from AVHRR 1km (1985-2005) and annually from MODIS 250m (2005-2010). A higher resolution (30m) product is being developed for 2005 and 2010 (Latifovic, 2009).

Table 1 Long-term satellite data record for Canada

Mission / Sensor	Extent		Resolution	
	Spatial	Temporal	Spatial	Temporal
NOAA 06 -19 / AVHRR	Canada	1985-2010	1km	1 and 10-days
SPOT / VEGETATION	Canada	1989-2010	1km	10-days
TERRA / MODIS	Canada	2001-2010	0.25km	10-days
ENVISAT / MERIS	Canada	2008-2010	0.25km	1 and 10-days
TERRA / MODIS	Northern America	2005-2006 2009-2010	0.25km	1 and 10-days

Source: Canada Centre for Remote Sensing, Natural Resources Canada, 2011.

The Canadian Forest Service uses land cover information derived from LANDSAT to monitor land cover change in forested areas (Wulder et al., 2004).

Fisheries and Oceans Canada have proposed a hierarchical framework to classify marine waters surrounding North America into 24 different marine ecoregions based on large-scale oceanographic features such as salinity, temperature, dissolved oxygen, depth, slope, and variability in landscape and sediments (Dutil et al. 2011).

Agriculture and Agri-food Canada[15], together with Statistics Canada, provide detailed agri-environmental indicators that include GHG emissions, biodiversity, soil quality, water quality and agricultural extent.

Natural Resources Canada also maintains a rich National Air Photo Library[16] that contains over six million aerial photographs from the 1920s to the present. The department also manages the National Topographic System, which maintains coverage for Canada at 1:250,000 scale and some areas at 1:50,000 scale.

Statistics Canada has developed a methodology for delineating settled areas based on its Standard Geographical Classification (Statistics Canada, 2007). This is being investigated as not only an ecosystem type in itself but also as a basis for assessing the distance of other ecosystems from populated areas.

For reporting on general environmental trends, many Canadian federal departments adhere to the Ecological Classification of Canada framework. The framework, based on the Soil Landscape Classification of Canada, provides a classification of 1,021 ecodistricts which are then aggregated to 194 "ecoregions", 53 "ecoprovinces" and 15 ecozones. For example, Environment Canada's Ecosystem Status and Trends Report (Environment Canada, 2010) provides an assessment of the status of Canada's 15 ecozones. The same framework is used in Statistics Canada's socio-economic ecoregion profiles (Trant et al., 2010).

[15] See: http://atlas.agr.gc.ca/agmaf/index_eng.html#context=aei-iae_en.xml for an interactive map of Canada's agri-environmental indicators.
[16] See: http://airphotos.nrcan.gc.ca/index_e.php.

7 Examples of current work

The sources described above represent only a sampling of the rich sources of data available with which to establish the basic accounting units for the MEGS project. Detailed data on wetlands also exist and are being further investigated. One initiative is to validate the satellite data on wetlands with ground-truthed information.

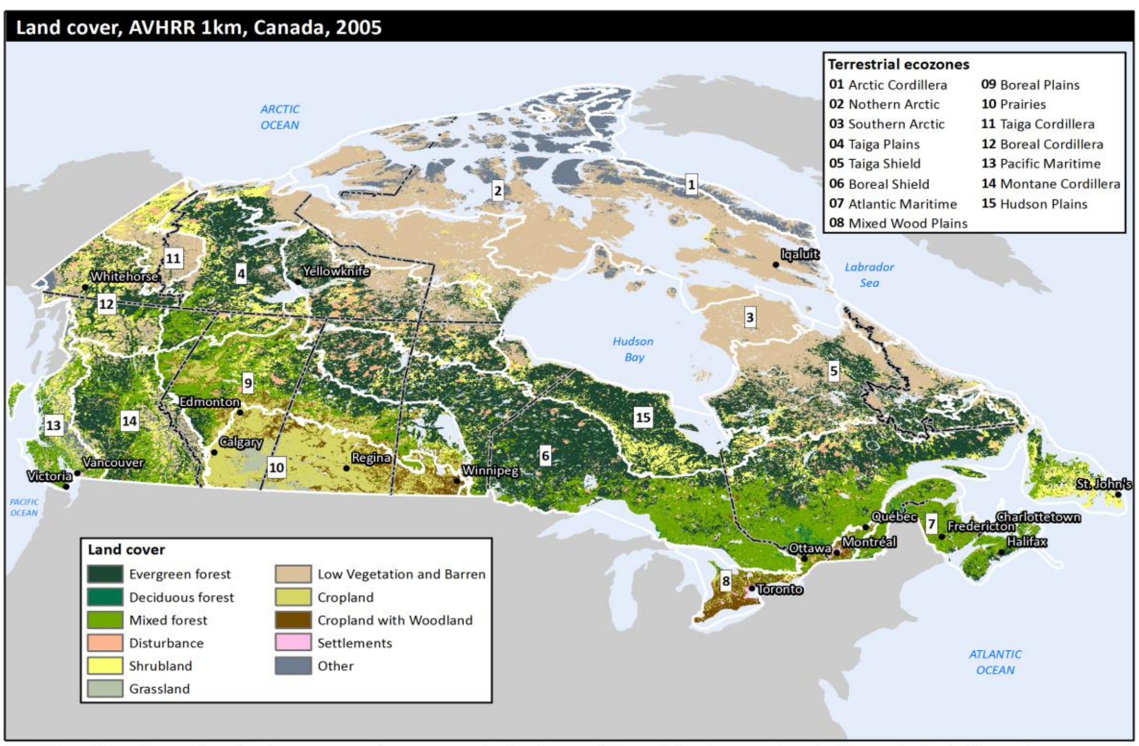
One challenge for MEGS is to develop land cover information, classifications and accounting units that are appropriate for the various applications of the partners. At the same time, these need to be statistically rigorous and, ideally compatible with the concepts, standards and classifications being developed internationally.

One criterion for the accounting unit is that it is a subset of the Soil Landscape Unit (SLU). Since the SLU is the basis for the Ecological Classification of Canada, MEGS "ecosystems" will be able to be aggregated to ecodistrict, ecoregion and ecozone. Another advantage of this approach is that substantial information is already available for each ecodistrict (Table 3) and SLU.

Furthermore, it would be desirable for the accounting unit not to cross provincial, ecodistrict or drainage area boundaries since reporting is also desirable at these levels.

Figures 1 and 2 show the 2005 AVHRR and MODIS land cover for Canada. Both are shown with respect to the 15 terrestrial ecozones. From these maps it is evident that each ecozone contains a rich variety of land cover types and that no land cover type is unique to any one ecozone.

Figure 1 Land Cover AVHRR 1km for Canada, 2005



Source(s): Agriculture and Agri-Food Canada and Environment Canada, 2005, *A National Ecological Framework for Canada*, http://sis.agr.gc.ca/cansis/nsdb/ecostrat/gis_data.html (accessed January 13, 2009).
Latifovic, Rasim and Darren Pouliot, 2005, "Multi-temporal land cover mapping for Canada: Methodology and Products," *Canadian Journal of Remote Sensing*, Vol. 31, no. 5, pages 347 to 363.
Statistics Canada, Environment Accounts and Statistics Division, 2010, special tabulation.

Figure 2 Land Cover, MODIS 250m, Canada 2005

Source(s): Agriculture and Agri-Food Canada and Environment Canada, 2005, *A National Ecological Framework for Canada*, http://sis.agr.gc.ca/cansis/nsdb/ecostrat/gis_data.html (accessed January 13, 2009). Trishchenko, A.P., Y.Luo, K.V.Khlopenkov, W.M.Park, 2007: Multi-Spectral Clear-Sky Composites of MODIS/Terra Land Channels (B1-B7) Over Canada at 250m Spatial Resolution and 10-Day Intervals Since March, 2000: Top of the Atmosphere (TOA) Data. Canada Centre for Remote Sensing, 2007

The detailed land cover categories from Figure 2 are shown in Table 2. It is worth considering if the standard land cover categories are appropriate for ecosystem accounting. Some appear at the outset to be too aggregate for the purpose (for example, 37, Water Bodies, 38 Mixes of Water and Land; and 39 Snow/Ice).

Table 2 Detailed MODIS land cover categories

1. Evergreen needleleaf forest / close canopy
2. Deciduous broadleaf forest
3. Mixed evergreen-deciduous forest / mature to old closed canopy
4. Mixed evergreen-deciduous forest / young closed canopy
5. Mixed evergreen-deciduous forest / closed canopy
6. Evergreen needleleaf forest / medium crown density / moss-shrub understory
7. Evergreen needleleaf forest / medium crown density / lichen-shrub understory
8. Evergreen needleleaf forest / low crown density / shrub-moss understory
9. Evergreen needleleaf forest / low crown density / lichen (rock) understory
10. Evergreen needleleaf forest / low crown density / poorly drained
11. Deciduous broadleaf forest / low to medium density
12. Deciduous broadleaf forest / young regenerating
13. Mixed evergreen-deciduous forest / mixed coniferous / low to medium density
14. Mixed evergreen-deciduous forest / mixed deciduous / low to medium density
15. Mixed evergreen-deciduous forest / mixed deciduous / low regenerating young mixed cover
16. Shrubland / high-low shrub dominated
17. Herbaceous vegetation / temperate or subpolar grassland / grassland, prairie region
18. Herbaceous vegetation / temperate or subpolar grassland / herb-shrub-bare cover
19. Herbaceous vegetation / saturated temperate or subpolar grassland / wetland
20. Herbaceous vegetation / temperate or subpolar grassland with a sparse tree layer / coniferous sparse
21. Herbaceous vegetation / short sod polar grassland / herb-shrub
22. Herbaceous vegetation / polar grassland with sparse shrub layer / shrub-herb-lichen-bare
23. Herbaceous vegetation / polar grassland with sparse shrub layer / herb-shrub poorly drained
24. Herbaceous vegetation / polar grassland with sparse dwarf-shrub layer / lichen-shrub-herb, bare soil
25. Herbaceous vegetation / polar grassland with sparse dwarf-shrub layer / low vegetation cover
26. Annual graminoid or forb vegetation / cropland-woodland
27. Annual graminoid or forb vegetation / temperate or subpolar annual grassland or forb vegetation / high biomass cropland
28. Annual graminoid or forb vegetation / temperate or subpolar annual grassland or forb vegetation / medium biomass cropland
29. Annual graminoid or forb vegetation / temperate or subpolar annual grassland or forb vegetation / low biomass cropland
30. Nonvascular dominated / temperate or subpolar lichen vegetation / lichen barren
31. Nonvascular dominated / temperate or subpolar lichen vegetation / lichen-sedges, moss low shrub wetland
32. Nonvascular dominated / temperate or subpolar lichen vegetation / lichen-spruce bog
33. Vegetation not dominated / consolidated rock sparse vegetation / rock outcrops
34. Recent burns
35. Old burns
36. Urban and built-up
37. Water bodies
38. Mixes of water and land
39. Snow/ice

Table 3 Information available for each ecodistrict in Canada

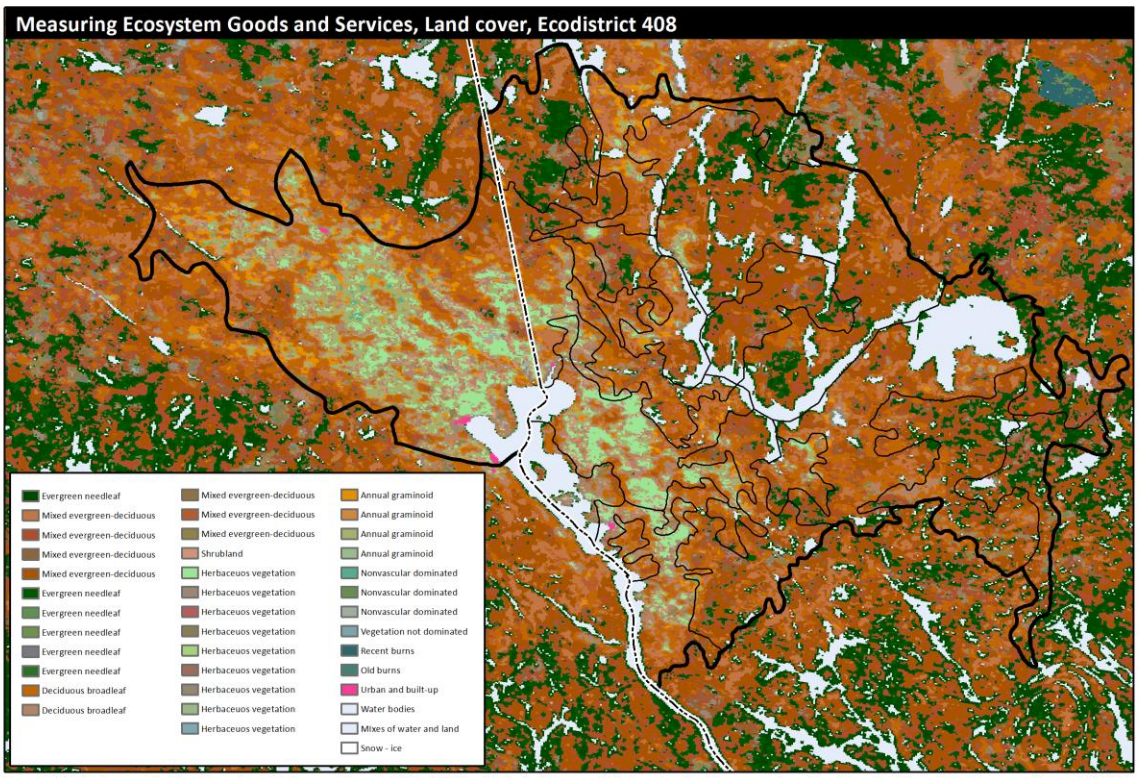
Attribute	Measure or approach
Area	Land, water, total
Elevation	Minimum, maximum, mean, difference
Landform	
Surface form	Mineral, wetland
Surface material	
Texture	Parent material
Soil development	
Land cover	AVHRR
Permafrost	
Surficial geology	
Temperature	Minimum, maximum, mean
Precipitation	Rainfall, snowfall, total precipitation
Vapour pressure	
Wind speed	
Sunshine	
Solar radiation	
Dew point	
Potential evapotranspiration and water deficit	Penman
Potential evapotranspiration and water deficit	Thornthwaite
Precipitation surplus / deficit	Penman
Precipitation surplus / deficit	Thornthwaite
Growing degree days	Above 0°c, 5°c, 10°c, 15°c
Growing season	Start, end, length
Effective growing degree days	Above 5°c
Population 1991	Male, female, rural and Urban total

Source: Agriculture Canada. , accessed, Nov. 21, 2011.

The current experiment is to investigate whether combining the MODIS 250m land cover with the Soil Landscape Unit together with elevation will result in a reasonable delineation of ecosystems. Also under consideration is the form and size of the ecosystem. Should the shape be free form or a grid? A grid is desirable for many purposes. It is stable over time but heterogeneity within the grid needs to be considered. If for example, a 250m grid is chosen, the variety within that grid (e.g., 40% water and 60% shrubland) can be represented either in terms of the majority of the classification or as a mixed classification. Mixed classifications can be more complex to analyse statistically and can result in a complex classification system (e.g., permutations of 2, 3, 4 or more types).

Figure 3 shows the MODIS 250m land cover for a small area on the Ontario-Quebec border. This shows a high degree of land cover variation within each Soil Landscape Unit. Furthermore, although the SLUs generally follow river boundaries, they cross provincial boundaries and contain bodies of water. Visually, there appears to be some correlation between the SLU and the land cover type but that many land cover types can exist within one SLU.

Figure 3 MODIS land cover superimposed on one ecodistrict

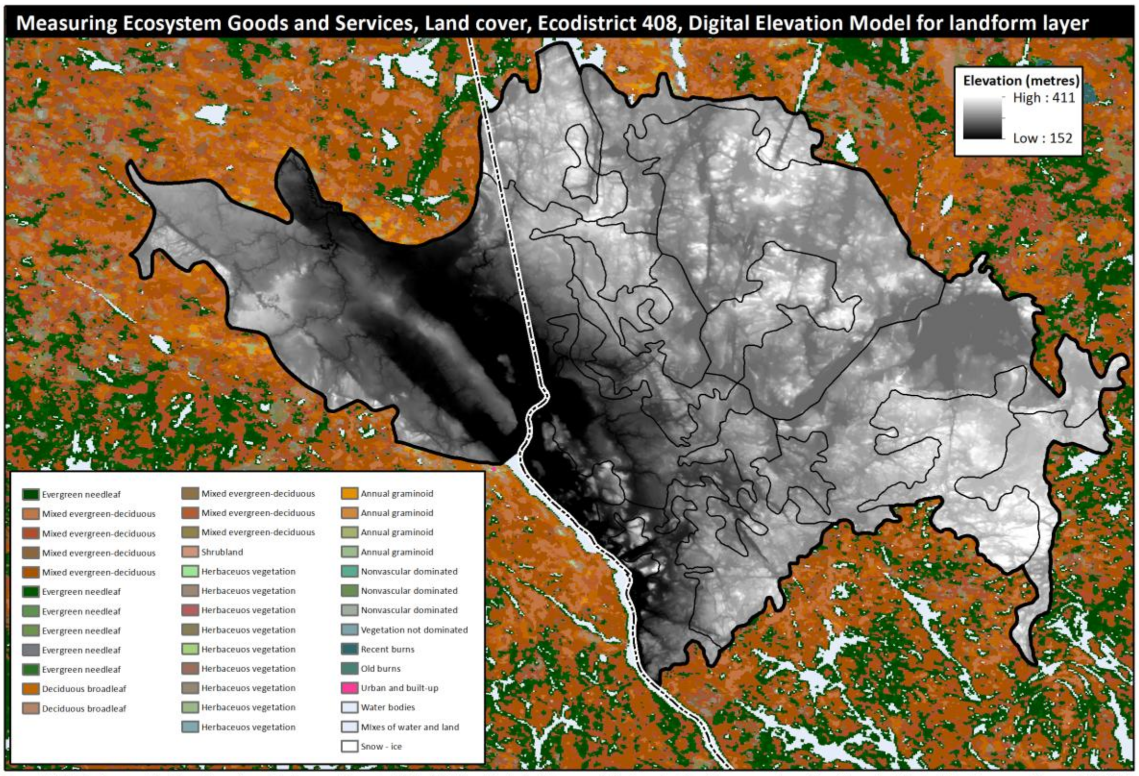


Source(s): Agriculture and Agri-Food Canada and Environment Canada, 2005, *A National Ecological Framework for Canada*, http://sis.agr.gc.ca/cansis/nsdb/ecostrat/gis_data.html (accessed January 13, 2009). Trishchenko, A.P., Y.Luo, K.V.Khlopenkov, W.M.Park, 2007: Multi-Spectral Clear-Sky Composites of MODIS/Terra Land Channels (B1-B7) Over Canada at 250m Spatial Resolution and 10-Day Intervals Since March, 2000: Top of the Atmosphere (TOA) Data. Canada Centre for Remote Sensing, 2007

Note: The full description of the land cover categories is given in Table 2. The heavy black lines delineate the ecodistrict. The light black lines delineate the Soil Landscape Unit. The broken black line shows the Ontario-Quebec provincial border. Water bodies are shown in light blue. The length of the ecodistrict is approximately 160km.

Figure 4 shows the elevation information for the same area. Although the areas is not greatly varied in elevation (152m to 411m above sea level), the difference between the hills and valleys is evident. Visually, there seems to be a good correlation between the SLU and the elevation. That is, some SLUs are generally lowland and others generally highland but there is still some variation within an SLU.

Figure 4 Digital elevation data for one ecodistrict

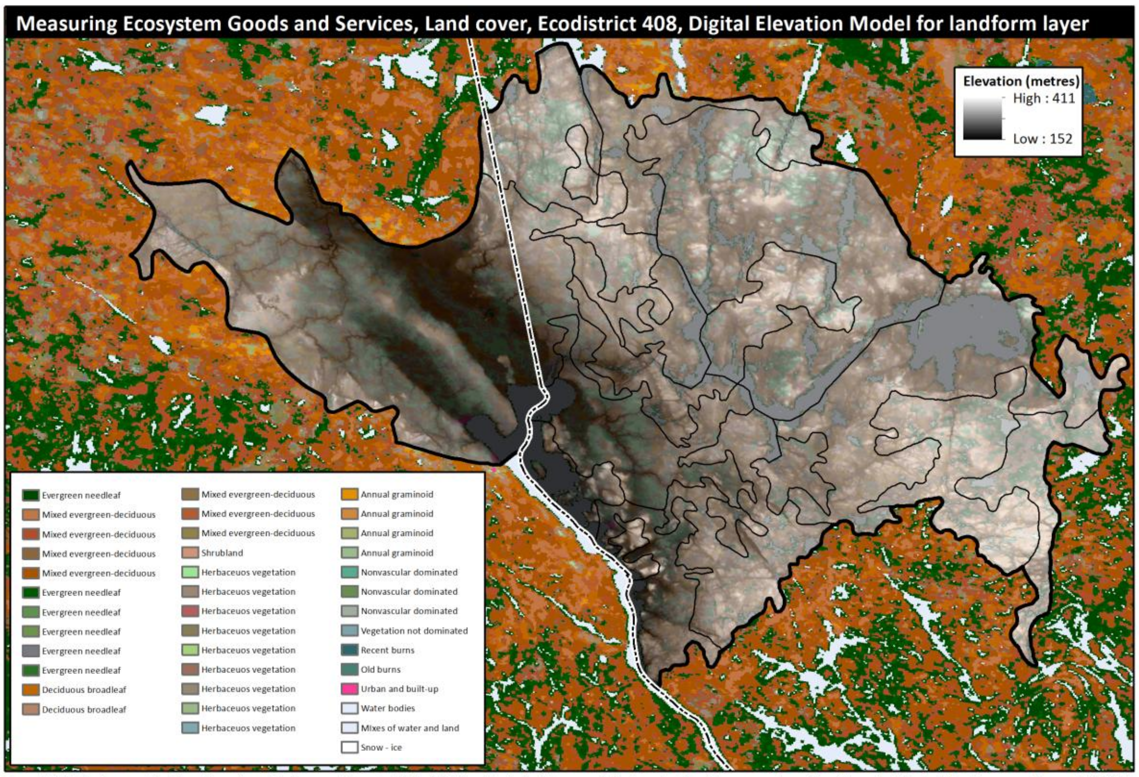


Source(s): Agriculture and Agri-Food Canada and Environment Canada, 2005, *A National Ecological Framework for Canada*, http://sis.agr.gc.ca/cansis/nsdb/ecostrat/gis_data.html (accessed January 13, 2009). Trishchenko, A.P., Y.Luo, K.V.Khlopenkov, W.M.Park, 2007: Multi-Spectral Clear-Sky Composites of MODIS/Terra Land Channels (B1-B7) Over Canada at 250m Spatial Resolution and 10-Day Intervals Since March, 2000: Top of the Atmosphere (TOA) Data. Canada Centre for Remote Sensing, 2007

Figure 5 shows the combined digital elevation and land cover information. Since the elevation information is largely already included in the delineation of the SLU, it is not evident that elevation information reduces the variability of the land cover types within the SLU. That is, it is not clear that elevation data is required to delineate the ecosystems. It is possible that land cover with an SLU is sufficient.

Similar tests will need to be done on other areas of the country to determine whether or not elevation data is required and what the appropriate elevation classes are.

Figure 5 Combined elevation and land cover data for one ecodistrict



Source(s): Agriculture and Agri-Food Canada and Environment Canada, 2005, *A National Ecological Framework for Canada*, http://sis.agr.gc.ca/cansis/nsdb/ecostrat/gis_data.html (accessed January 13, 2009). Trishchenko, A.P., Y.Luo, K.V.Khlopenkov, W.M.Park, 2007: Multi-Spectral Clear-Sky Composites of MODIS/Terra Land Channels (B1-B7) Over Canada at 250m Spatial Resolution and 10-Day Intervals Since March, 2000: Top of the Atmosphere (TOA) Data. Canada Centre for Remote Sensing, 2007

8 Conclusions

Further investigations will be required to determine the appropriate land cover data, classifications and accounting units for MEGS. It will be necessary to develop an approach that is applicable nationally. It may be possible for example to produce a custom interpretation of land cover for the purposes of ecosystem accounting. This would result in a land cover classification that is more finely-tuned to delineate ecosystems.

The drivers of this will not only be the quality of available data but also the requirements of the participants in the project and the emerging international standards, classifications and methods through deliberations on SEEA Volume 2.

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