REFINING DETAIL OF FOREST ECOSITE CLASSIFICATION FOR THE FUNDY MODEL FOREST IN NEW BRUNSWICK

by

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ABSTRACT

The original method for forest ecosite classification in New Brunswick was refined using geospatial data, digital elevation model (DEM), cartographic depth to water index (DTW), and explicit values for soil morphological attributes to predict ecosite values at high resolution (10m). Two hundred and forty plot-based field observations in the Fundy Model Forest were used to verify results. Ecosite values were based on the edatopic grid, defined by soil moisture regime and soil fertility. Predicted ecosites were 85% correctly classified when compared to observed conditions, an improvement of 30% over the original Ecological Land Classification (ELC) map, with ecosites 2, 5, and 7 correctly classified 93%, 88%, and 85% respectively. Mapped area of ecosite 7 (rich conditions) increased by 74%. Vegetation type and forest cover type were the most influential variables at initial nodes of a regression tree, while DTW and mottles had greater influence at terminal nodes.

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INTRODUCTION

Terrestrial features known as landforms, which developed from glacial till deposits, exhibit patterns of flat lands, depressions, small hills and high ridges that contribute to the flow and accumulation of water across the landscape. Some examples of these surface features are ground morainal tills, terminal moraines, and glaciofluvial deposits (Gimbarzevsky, 1964). The amount of water and how well it drains through the underlying soil impacts soil development and fertility. Soil fertility arises from the interaction of soil and water, and the release of nutrients for plant uptake (Brady and Weil 2002). Local variations in soil drainage can cause differences in the types of plants growing in an area, which in turn continues to influence the soil nutrient status from decomposing vegetation. These differences are reflected as different values for forest "ecosites" that describe soil moisture regime and soil nutrient richness. This thesis uses the term soil fertility throughout when referring to nutrient richness, assuming the effect of water on the soil.

Ecosites are usually mapped at the forest stand scale (New Brunswick Department of Natural Resources (NBDNR) 2007). Refined ecosite classification and mapping can contribute to improvements in precision of forest management planning with respect to wet, dry, rich and poor locations. Recent advances in mapping flow channels, wet areas and the cartographic depth-to-water (DTW) (Meng et al. 2006, Murphy et al. 2006) have found immediate applications in day-to-day forest operations, and strategic planning (Arp 2002, Arp et al. 2003, J. D. Irving, Limited (JDI) 2005, Murphy et al. 2008, Foreman 2009, Holehouse 2009) involving:

- forest stratification

- growth and yield estimation
- soil trafficability
- evaluation of ecosite-specific management plans and silviculture prescriptions
- best management practices for riparian and buffer zone management
- species habitat mapping
- watershed and flow network mapping

Geospatial data (DEM, DTW, orthorectified aerial photography, ecological land classification, hydrographic features, geologic and topographic features, and forest resource information) now available for New Brunswick (NB) in digital format allow many landscape attributes to be mapped at high resolution (5 to 10m), highlighting the relationships between topography, geology, soil drainage and ecosite conditions. The focus of refined ecosite classification in this study was on using detailed geospatial information about both soil drainage and inherent soil fertility to improve the prediction of ecosite values. The specific objectives of the research were to:

1) use the DTW to classify local variability in soil moisture regime,
2) use the DEM and DTW to refine discrete soil polygon mapping,
3) develop explicit methodologies for soil fertility classification and ecosite classification based on DTW and refined soils map, and
4) verify the proposed methodology for a refined ecosite classification with field observations.

This was done on a case study in the Fundy Model Forest (FMF) in southeastern NB, through the use of GIS (geographic information system) (ArcMap, ESRI 1992-1999)

thematic and continuous raster data, and by collecting plot-based information to determine actual ecosite conditions.

Thesis outline

The thesis Introduction introduces the concept of ecosite classification, some of its applications in forest management decision-making, and lists the objectives of the study. **The Background** reviews ecological land classification from global and national perspectives to the NB Ecological Land Classification (NBELC) (NBDNR 2007) system. Particular emphasis is placed on explaining the "edatopic grid" and the description of ecosite classification based on soil moisture regime and soil fertility, as used in the approach taken for the study. The FMF landbase is described in geomorphologic detail to provide insight into the variability amongst landforms that give rise to the complex mosaic of ecosites in the study area. In the **Methods** section field data and interpretation of observed conditions are explained, and the use of the DTW to classify soil moisture regime and soil fertility is demonstrated. The incorporation of geospatial data into a new method for predicting ecosite values is described. **Results** are presented with maps and analyses that show the effect of using the DTW to refine ecosite classification and mapping. Insights follow in the **Discussion and Conclusion.** Figure 1 is an information flowchart that describes the general development of this thesis.

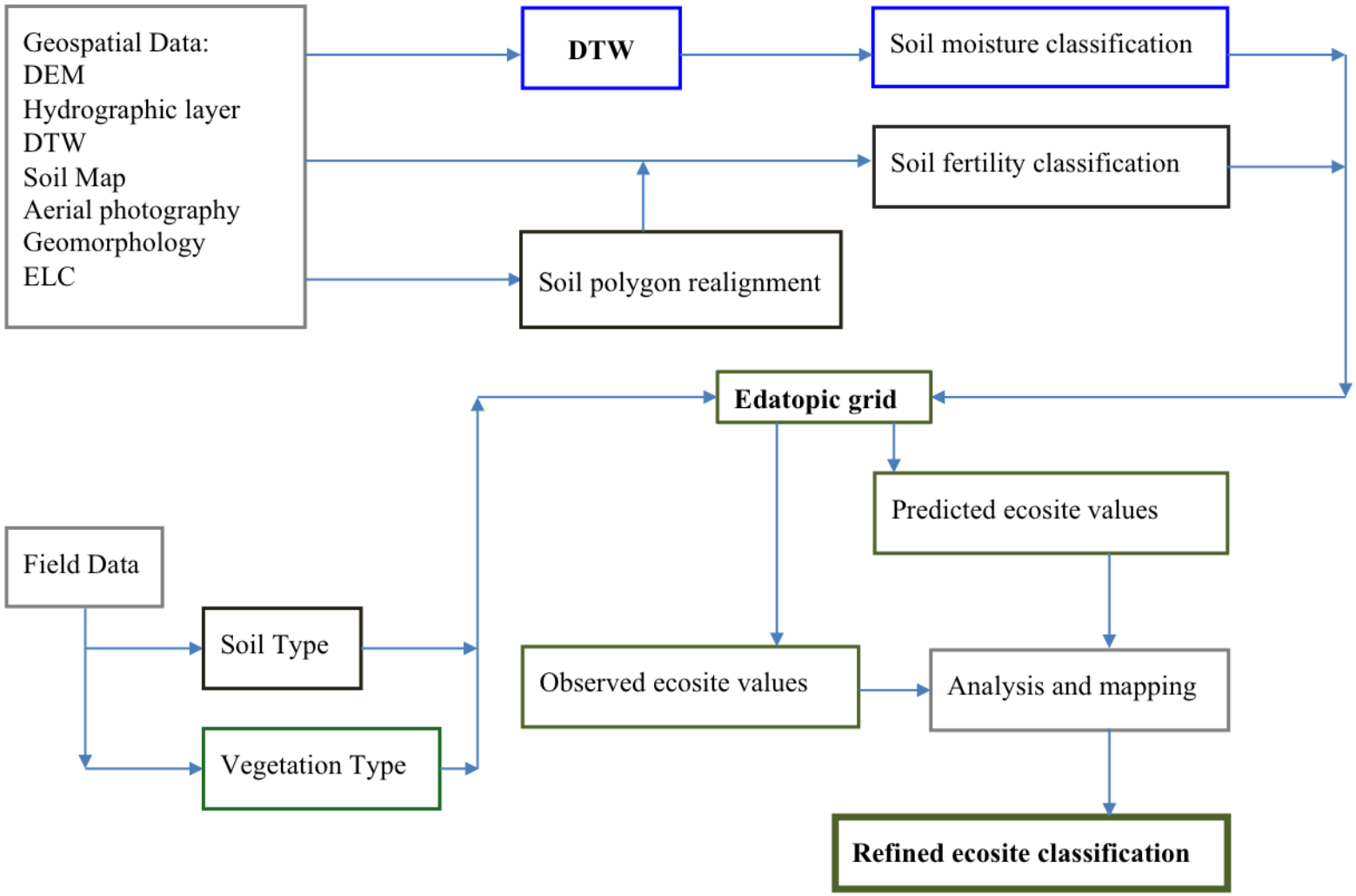


Figure 1. Thesis information flowchart.

BACKGROUND

Ecological Land Classification

Many jurisdictions in North America, Europe, Australia, Africa, South America and China have developed, or are developing, ways to accurately classify forest lands to reflect ecological conditions and related landscape variations (Schlatter and Gerding 1995, Thwaites 2002, Zhang and Beernaert 2002, Keys et al. 2003, Moosmayer et al. 2003, Šamonil and Viewegh 2005, Smith et al. 2005, Wall and Westman 2006). Soil morphological characteristics were considered in all of those studies.

The Canadian Land Inventory developed in the 1960s and 1970s led to landscape classification of ecological conditions related to climate, topography, geology and soil across the country at various scales (NBDNR 2007). These scales range from broad, national-level zones (forest types) to fine-scale, local forest stands.

Geological history (e.g., glaciers, volcanoes, earthquakes, tectonic shift, and weathering) has produced the underlying structure, or "skeleton", of the landscape. Bedrock that formed as a result of this activity has determined the shape of the land (e.g., mountains, valleys, hills, plains), and is the source of minerals and materials that contribute to soil development. Topography, and more specifically landforms that have developed from geologic events, and changes due to constant weathering and shifting of materials, are expressed in varying degrees of elevation, slope, and aspect. Depending on characteristics of the landform (lithology, soil texture, depth, and coarse fragment content), water may drain rapidly leading to dry conditions, or very slowly, creating wet areas. Distinct soil characteristics have developed as a result of soil weathering (water moving through the soil, and slow grinding and mixing of material), which has also produced a medium that supports a variety of plant life and other biotic organisms. The

action and interaction of these organisms within the soil also contribute to the availability of soil nutrients, and thus soil fertility. Climatic effects are mapped in ELC through differences in temperature and precipitation at various levels: broad, regional scale (overall climate of Maritime Provinces), provincial, topographical scale (effects of landscape features on local climate such as ridge tops and valleys), and local forest stand level (NBDNR 2007).

New Brunswick Ecological Land Classification (NBELC)

Land use in NB since early settlement has resulted in a much altered landscape from original forest conditions, no longer necessarily reflective of typical ecosite conditions with respect to soil and drainage, and perhaps no longer indicative of vegetation species associations (Zelazny et al. 1997). It is therefore difficult to predict potential ecosite conditions from original forest species composition maps alone.

Development of ecosite classification for NB has proceeded from that of Loucks (1962), who recognized seven forest zones, to the original ELC classification which also incorporates "enduring features" (climate, topography, geology and soil) to describe various levels of ecological conditions (NBDNR 2007). van Groenewoud and Ruitenberg (1982) championed soil classification as critical to a detailed understanding of forest growth and, with concerns about biodiversity conservation that emerged in the 1990's, soil descriptions became the basis for ecosystem evaluation (NBDNR 2007).

Earlier efforts to describe the landscape in the Lowlands region of NB resulted in a classification based on factors for soil and vegetation, and their relationship to the productivity of *Picea glauca* (white spruce; Zelazny 1984). Ecosites were classified based on soil wetness and soil nutrient status indicated by vegetation type, and depicted

on a two-dimensional "edatopic" grid (NBDNR 2007). Examples of known species associations with these extremes are *Picea mariana* (black spruce) bogs on wet, poor ecosites, and tolerant hardwoods on well-drained, rich ecosites.

In 1996 the NBELC was used as the basis for ecosystem mapping. The combination of climate, geology, topography, hydrology, and soils was delineated at four different scales: ecoregions (areas of broad climatic influences -1:500,000), ecodistricts (areas within ecoregions with major changes in rock formations -1:250,000), ecosections (delineations pertaining to landforms and watersheds -1:250,000), and ecosites (fine-scale, forest stand level physical characteristics -1 to 50 hectares) (NBDNR 2007).

Edatopic Grid in NBELC

The term "forest ecosite classification" refers to the process of assigning an index value to represent the combined effects of soil moisture regime and soil fertility to a forested area, usually at the scale of a forest stand (NBDNR 2007). Ecosite refers to a distinctive soil and successional forest cover type combination, which has developed due to the soil-water interaction. In addition, soil wetness related to local soil drainage also influences forest cover type, expressed by the range from hygric (wet, black spruce bogs) to xeric (dry, *Pinus* spp. (pine) stands) plant associations, and forest vegetation growth.

The soil parent material derived from underlying bedrock and glacial till contains a predominant source of nutrients for any particular soil, with nutrients also being added from precipitation, soil organisms and other organic matter. The physical soil attributes (soil morphology) such as texture, depth, and coarse fragment content, as well as soil mineralogy, determine how nutrients are "locked in", or released from the soil. The availability and movement of water through the soil (soil moisture regime), is the key to

unlocking that supply of nutrients and making them available for plant growth. The glacial tills associated with particular landforms are also associated with various conditions of soil morphology and acidity, leading to combinations of wet, dry, poor or rich conditions – namely, ecosites.

Basal till conforms to the shape of bedrock and is described as a "smear of putty" deposited as advancing glaciers shaped the land (NBDNR 1985). Soils are often so poorly drained in wet areas on basal till that nutrient release is slow, reducing soil fertility (Gimbarzevsky 1964). However, where basal tills are adequately drained soils are nutrient-rich.

Ablation tills occur in hilly areas with poorly drained areas between and around the higher ground (NBDNR 1985). These tills are described as "piles of rubble" from retreating melting glaciers. They are coarser textured and less nutrient rich than basal tills. However, deep, non-compact ablation till has improved drainage and ecosites are often richer because of nutrient availability (Gimbarzevsky 1964).

Other glacial deposits in the FMF are residual tills – rapidly drained shallow deposits over bedrock, often with rocky outcrops occurring in areas of high relief (NBDNR 1985), and those deposited by water – alluvium, glaciofluvial and glaciomarine found along freshwater floodplains, river valleys and tidal areas respectively (Colpitts et al. 1995).

In NB a grid has been developed (NBDNR 2007) that uses eight index values to classify the most likely ecosite conditions that have developed due to combinations of soil moisture regime and soil fertility (Figure 2). Values from 1-3 represent a scale of dry

to wet and nutrient poor ecosites; 4 and 5 are dry to moist and moderately rich ecosites; and 6-8 range from wet to dry and are nutrient rich (NBDNR 2007).

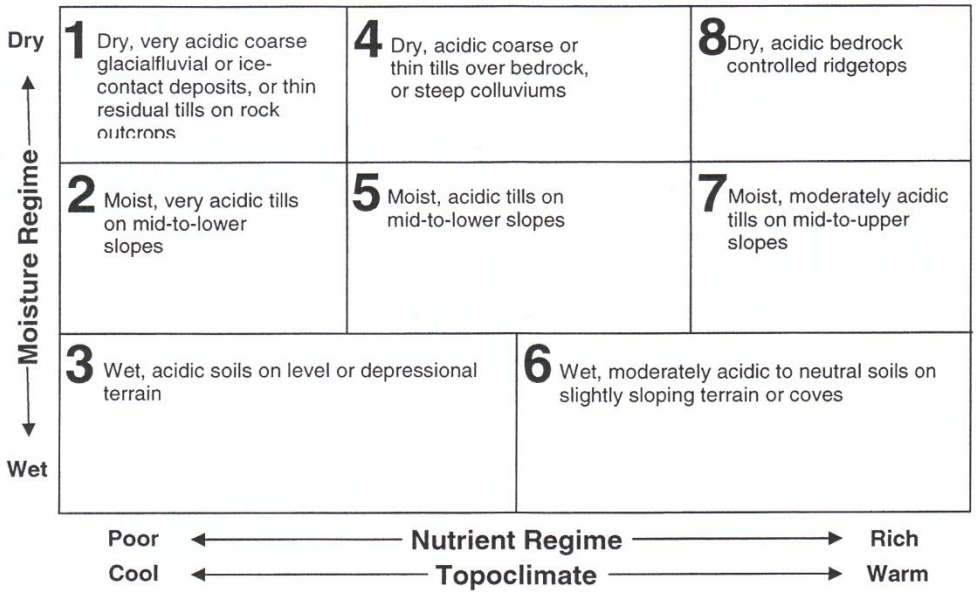


Figure 2. Edatopic grid and landform attributes associated with ecosite values (NBDNR 2007).

Approach to Refining Ecosite Classification

Forest operations managers who use the wet areas mapping process routinely report conformance between mapped and actual locations of flow channels and wet areas of approximately 80% (Gaetan Pelletier pers. commun.). Data analysis (Moore 2007) indicated conformance of field-assessed ecosite values to original ELC mapped values (NBDNR 2007) ranging from 4% (6-nutrient rich and wet), to 95% (5-moderate nutrient richness and wetness). The wide range of conformance suggested that a refinement of the existing classification map would be useful. Although the conformance of ecosite 5 classifications was high (95%), it was not useful for detailed planning for wet and dry areas, as it described the mid-range of conditions, providing little detail. The apparent

incongruities mirror the unclear nature of the existing soils map to indicate conditions due to fine-scale soil drainage variations.

The approach of this thesis involved first determining soil fertility from values assigned to soil morphological attributes, and then considered how soil moisture regime, represented by the DTW, enhanced or negatively impacted soil fertility. Guided by the premise of the edatopic grid, ecosite values were then derived. This was a refinement of ecosite classification that changed from using broad soil drainage classes to describe soil moisture regime, to a more precise mapping of soil drainage dependent on geomorphology and DTW.

Study Area

The study area for this project was the FMF located in southern NB (Figure 3). It is that portion of the province bordered on the north by the Canaan River and the Washademoak Lake, the south by the Bay of Fundy, the west by a line running southeast from Wickham towards Hampton, and the east by Elgin and the Pollett River watershed.

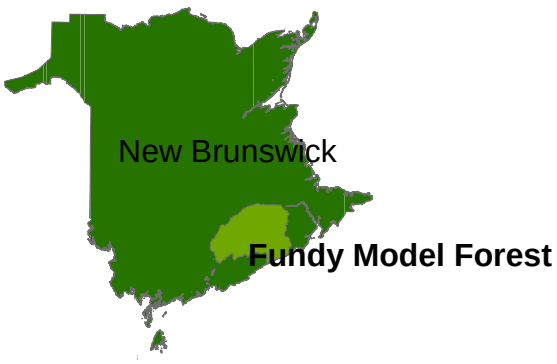


Figure 3. Location of the FMF in New Brunswick.

The landbase is approximately 420,000 hectares and the NBELC indicates portions of five ecoregions, all or portions of eight ecodistricts, and all ecosites occurring in the FMF (NBDNR 2007) (Figure 4). Many of the same soils are found covering the same landforms, but those landforms are influenced by differences in underlying rock formations (i.e., located in different ecodistricts), and/or climate influences (located in different ecoregions). This highlights the complexity and variability that arises in soils, and thus ecosite conditions, and the need for more detail in ecosite classification and mapping.

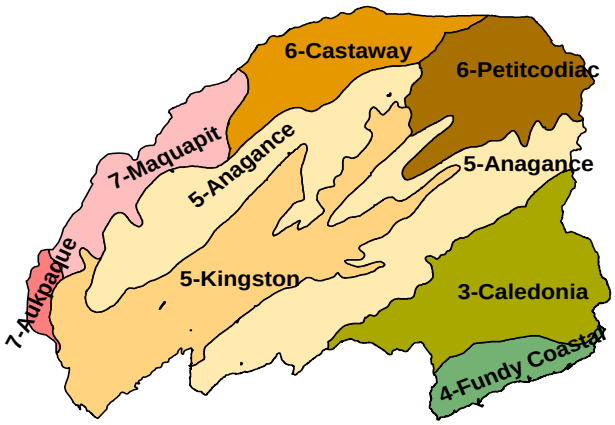


Figure 4. Map showing locations and names of eight ecodistricts in the FMF, and numbers representing associated ecoregions (NBDNR 2007).

Ecoregions and Ecodistricts in the Fundy Model Forest

Table 1 describes in some detail the ecoregions (broad climatic scale, 1:500,000) and ecodistricts (1:250,000) found within the FMF, and is followed by photos of landform changes in the area. The intent of this description is to highlight the complexity of conditions that give rise to the pattern of ecosites in the FMF.

Geomorphology of the Fundy Model Forest

This geologically diverse landscape was covered during separate periods by glaciers that advanced from the north and the northwest resulting in long morainal ridges that run the width of the FMF predominantly in a northeast, southwest direction. The major landforms defined by the bedrock delineate where the major changes in basal, ablation, and residual tills occur (Rampton and Paradis 1981).

Rising gradually out of the Grand Lake Lowlands and Eastern Lowlands ecoregions, bordering the south side of the Canaan River, the landscape profile (Figure 5) becomes more pronounced as it converges southward towards Sussex, which occupies the northeasterly portion of the Kennebecasis valley area. Here the hills are steeper and more numerous approaching the coast of the Bay of Fundy. Ridges and valleys are characteristic in the Valley Lowlands, Central Upland and Fundy Coastal ecoregions. Compact glacial tills cover the northern, flat regions whereas deeper ablation till and shallow residual till cover the hilly regions. Poor drainage in valley bottoms between ridges, in depressions, and in flat areas with shallow soils over bedrock, has resulted in numerous instances of ponding of water. Bedrock outcrops and narrow valley gorges are expressions of the hard rock, which weathers very slowly, intertwined with softer rock that weathered from the action of water running over it and eroding over time, resulting in the streams and rivers in the area (NBDNR 2007).



Figure 5. Photos highlighting landform changes in the FMF from flat lowlands to rugged coastal terrain where numerous ponds and bogs are found in poorly drained areas.

Tectonic events, glacial action, and the flow of water over bedrock have created the topographical expression of lowlands, wet areas, hills and valleys that are the complex landscape of the FMF. Subsequent soil development has been equally complex, in turn affecting local variations in ecosites.

Table 1. Landscape characteristics in the FMF (NBDNR 2007).

Ecoregion	Ecodistrict (where changes in rock formation occur)	Landforms (watersheds or "ecosections" within ecodistricts)	Till (description of glacial till deposited as landforms)
Central Uplands (3)	Caledonia	steep hills and valleys; upland plateau	Small, northeastern ecosection non-compact, ablation till and residual till; Larger, central ecosection predominately non-compact, ablation till surrounded by pockets of shallow ablation till over bedrock (ablation/residual), and compact, basal till
Fundy Coastal (4)	Fundy Coastal	lowlands to high cliffs	Western half is compact, basal till, and shallow ablation till over bedrock (ablation/residual) with pockets of residual till; Eastern half is predominately non-compact ablation till
Valley Lowlands (5)	Kingston	rolling hills, morainal ridges and floodplains	Kennebecasis River Valley - non-compact, ablation till with alluvium and glaciofluvial tills in the river valleys, and basal till on ridgetops with pockets of residual till; Kingston Peninsula - shallow ablation till over bedrock (ablation/residual); 1 smaller ecosection east of Kingston Peninsula: non-compact, ablation till with central area of residual till; 1 north of Belleisle Bay non-compact, ablation till with pockets of compact basal till (covers ridge along the north shore of the bay)
	Anagance	steep to rolling hills and valleys	Anagance: northwestern ecosection compact, basal till with pockets of residual till; northeastern ecosection non-compact, ablation till with pockets of residual till; most easterly, and 2 most westerly ecosections predominately non-compact, ablation till with some pockets of residual till in the west; central ecosection non-compact ablation till with pockets of compact basal till
Eastern Lowlands (6)	Castaway	lowlands and lower hills	Predominately compact, basal till
	Petitcodiac	hills and valleys	
Grand Lake (7)	Aukpaque and Maquapit	islands formed in lower Saint John River by alluvial deposition; some steep granite hills; floodplains; Grand Lake and Washademoak Lake	Predominately compact, basal till

(cont'd)

(Table 1 cont'd)

Ecoregion	Ecodistrict (where changes in rock formation occur)	Soil parent material	Soils (full soil names appear in Appendix 1)	Elevation (m)	Climate	Vegetation
Central Uplands (3)	Caledonia	felsic volcanic - low fertility; area of high-fertility, mafic minerals in granite intrusion	BD, BR, CT, EB, GG, IN, IR, JR, JU, KI, KN, LO, MV, PD, PI, PR, PT, SA, TT, TU	300	cool, wet; warmer in summer	tolerant hardwood on ridges; softwoods on lower slopes; some rare plants
Fundy Coastal (4)	Fundy Coastal	acid igneous - low fertility soils; some richer sediments in tidal areas	BR, CH, GF, GG, HT, IN, IR, JR, KI, LO, MV, OS, PD, PT, RI, SA, SB, SP	30 - 80; cliffs to 300	wet and cool; moderated by Bay of Fundy	mixed wood forest - mostly softwood; pure stands of *Picea rubens* (red spruce)
Valley Lowlands (5)	Kingston	diverse mix of igneous and sedimentary, gravelly material - fertile slopes	BR, CH, EB, GF, GG, IN, JR, KN, LL, LO, OS, PD, PR, PT, RI, SA, SB, SN, SS, TD	varied with highest at 220	dry and warm	tolerant and intolerant forests; some rare plants in floodplains and on rock ledges
	Anagance	mix of sedimentary and volcanic till; nutrient rich to less fertile soils and range of moisture conditions	BD, BR, CH, EB, FA, GG, HT, IN, IR, JR, JU, KI, KN, LL, LO, MV, OS, PD, PR, PT, RE, RI, SA, SB, SN, SS	average 125 with peaks over 200 and max 320	dry and warm	tolerant to intolerant forest species; some rare species in bogs
Eastern Lowlands (6)	Castaway	fine-textured soils, poor drainage, low fertility in lowlands; many acidic bogs; improved drainage and fertility on slopes	BB, CH, EB, FA, GG, HT, IN, KN, OS, PR, PT, RE, RI, SA, SB, SN, SS	70	dry and warm	black spruce, *Pinus banksiana* (jack pine) and ericaceous spp.
	Petitcodiac	limestone and fine textured soils in floodplains - more fertile; less fertile on slopes				tolerant hardwood on ridges and upper slopes
Grand Lake (7)	Aukpaque and Maquapit	sedimentary and conglomerate with granite intrusion; poor to moderately rich soils; high fertility in floodplains	BB,BE, BR, CH, FA, GF, GG, HT, IN, IR, JR, KI, LO, MV, OS, PD, PR, PT, RE, RI, SA, SB, SN, SP	54	driest and warmest in the FMF	mixed hardwood forests in warm district, with rare plants in seasonally flooded areas; extensive wetlands

DATA and METHODS

This section describes: 1) field plot data and methods used to define observed ecosite values, 2) geospatial data and methods used to predict ecosite values, and 3) analytical methods.

Observed Conditions

Field Plot Selection

The FMF was stratified by ecoregion, ecodistrict and ecosite to capture information about conditions represented by these various combinations of the original ELC map. Sampling intensity was originally set at a minimum of 1 plot/1500 hectares of productive forest for each ELC combination. Since some ELC data had previously been collected by landowners in the FMF this was reduced to 1/1600 ha. Two hundred and sixty sample plots were randomly located on a map prior to field visits. Plots were distributed to reflect area distribution of original ELC-mapped ecosites (Figure 6).

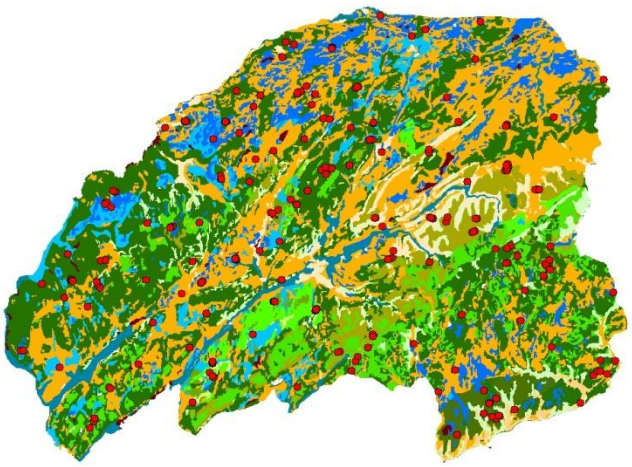


Figure 6. Field plot locations on original ELC ecosite map of FMF (NBDNR unpublished draft 2007).

Field Data Collection

A GPS unit was used to locate field plots on the ground (within 5m), and actual GPS coordinates were recorded. At each plot, general attributes about the location were recorded (Table 2). If there was an existing permanent sample plot (PSP) established at the field plot location by others (Canadian Forest Service, NBDNR, J.D. Irving, Limited, Fundy National Park, or Southern New Brunswick Wood Co-op), the soil survey and vegetation survey data previously recorded from that plot were used for this project (153 existing PSPs). If a PSP existed but soil and rock samples had not been collected, samples were gathered from a soil pit manually excavated as close as possible to a depth of 1 meter. Most were less than 1 meter deep due to compacted layers preventing further digging, and approximately 0.5-meter diameter, large enough to clearly see into, and access soil horizons (Figure 7). A soil sample was collected from each horizon, and rocks were collected from the bottom of the pit that represented pebble variability. If vegetation data had not been collected, presence of all vegetation within a 10m radius of the soil pit was recorded. If no PSP was available, then new soil and vegetation surveys were conducted (107 new plots).

Table 2. Attribute data collected at field plots.

Data collected	Attributes recorded
General plot attributes	elevation, slope position, slope, aspect, GPS coordinates
Vegetation	presence of all species within 10m radius of soil pit
Soil pit attributes	pit depth, seepage (presence/absence, seepage depth), mottles (presence/absence, mottle depth), root constricting layer, root constricting depth, maximum root depth, 80% root depth, surface stoniness, exposed bedrock, drainage
Soil Horizon attributes	forest floor thickness, name (e.g., Ae, Bf, C), thickness, soil texture, soil consistency, coarse fragment content (gravel, cobble, stones)
Comments	noteworthy remarks about plot location and access



Figure 7. Photo of a soil pit showing golf tees used to mark horizons for soil survey.

When sampling new plots data were collected along transects (Figure 8) to assess drainage variability, and conformance to the DTW. Twenty-two transects were established (76 points in total) that varied from 2 to 5 plots each, depending on terrain, with 100m distance between plots.

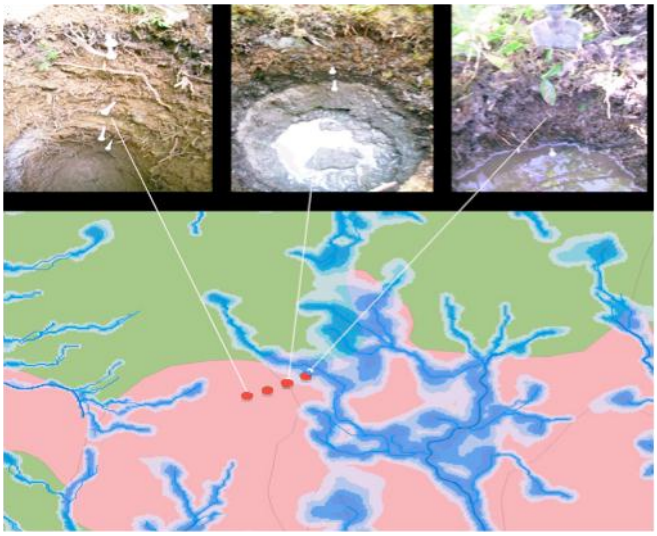


Figure 8. Photos and map showing location of three soil pits with varying drainage conditions, along a transect from wet area (blue) to upland (pink).

Field Data Analysis

Soil samples were analysed in the lab using the sedimentation method to confirm soil texture (Arp 2005). Rock samples collected from each soil pit, representing the visible petrologic variation of each plot, were analysed to assess mineralogy and weatherability, both factors affecting soil nutrient availability, and thus soil fertility, as follows:

- Counted and separated into groups by colour, using colour to approximate mineralogy (Figure 9);
- Each group was measured for approximate pebble size (cm) - a range was recorded if pebble size varied widely;
- Assigned a value for angularity from 1-10 (1 being round, and 10 being very angular);
- Assigned a value for roughness from 1-10 (1 being very smooth and 10 being very rough).



Figure 9. Photo of a pebble sample from a soil pit, separated into groups for rock type analysis.

A sample from each pebble group was visually inspected (10x field lens), and classified (Dr. Paul Murphy, pers. commun.) according to the 34 rock types listed by

NBDNR that are found in the parent material in NB (Appendix 2a), to determine acidity (or calcareousness) of the parent material. Each pebble sample contributed to a score for acidity (acid igneous, acid sedimentary, basic igneous, calcareous) based on rock type. Parent material acidity was assigned to the rock type that scored greater than 50%. Each sample was tested for reaction (effervescence) to carbonates by the application of several drops of HCl. No reaction was observed in the field plot samples.

Soil Type, Vegetation Type, and Ecosite Determination (Observed Conditions)

Established methods to determine soil type (ST) and vegetation type (VT) were used to determine value of field plot ecosites, and record observed conditions. ST for each plot was derived from soil moisture regime and acidity from pebble analysis for that plot (NBDNR 2007). ST values range from ST1 on wet and poor soil e.g., soil found in black spruce bogs, to ST7 on dry and rich soil e.g., soil found in pine stands and some tolerant hardwood stands. VT was assessed in the field through the use of keys and indicator species (NBDNR 2007) identified within a 10m radius from the soil pit. VT values range from VT1, predominately ericaceous species associated with poor soil conditions, to VT4, tolerant hardwood species associated with rich conditions. VT2 and VT3 are intermediate conditions and depend on the number of indicator species at an ecosite within a given ecoregion. Field drainage assessed at each plot (Arp 2005), and plot attributes slope, slope position, and texture, were used (NBDNR 2007) to define soil moisture regime –" wet, moist, fresh and dry".

To show how DTW could represent soil moisture regime in terms of drainage, even though it was not an observed variable, DTW values and DTW classes were matched to conventional drainage classes (Table 3). Shallow DTW values indicated wet

conditions, while greater DTW values were used to indicate well-drained or dry conditions. Overlap was allowed between soil moisture regimes for DTW classes 3 and 5 to account for variation in soil drainage at these depths. (DTW classes 4 and 5 both represented well-drained conditions but were classified separately in order to delineate areas of steep terrain in the mapping process where conditions tend to be drier.)

There is a change in field drainage classification when mottling of the soil is present below 40cm. This represents the change from imperfect to moderate drainage in a soil drainage classification key (Arp 2005). The DTW 0.50m contour was used to delineate this difference. If mottles were found at 0.40m or less, drainage was classified as imperfect, and greater than 0.40m, drainage was classified as moderate. The overlap between 0.40m and 0.50m would most likely account for some variation between DTW and drainage, but was not investigated here.

Table 3. Field-assessed drainage class and relevant soil moisture regime (NBDNR 2007), also represented as DTW value and corresponding DTW class.

FIELD DRAINAGE CLASS	SOIL MOISTURE REGIME	DTW (m)	DTW CLASS
very poor to poor	wet	0.0-0.25	1
imperfect	moist	>0.25-0.50	2
moderate	moist - fresh	>0.50-1.0	3
well	fresh	>1.0-4.5	4
well	fresh to dry	>4.5-20.0	5
rapid	dry	>20.0	6

ST-VT tables (NBDNR 2007), based on the edatopic grid with ST on the y-axis for moisture, and VT on the x-axis for fertility, were used to assign ecosite values to observed conditions for each field plot (range of values from 1 - poor, wet to 8 - rich, dry).

Predicting Ecosite Values from Geospatial Data

Geospatial data in the form of DEM and hydrographic layers were obtained from Service New Brunswick (http://www.snb.ca/gdam-igec/e/2900e_1c_i.asp), and their purpose in this study is described initially. This is followed by methods for their incorporation and use in classifying soil moisture regime, soil polygon realignment, soil fertility, and ecosite classification.

Geospatial data layers and their purpose in this study

1) A provincial DEM (1:10,000; ± 2.5m vertical accuracy) was re-sampled to a higher resolution (5-10m), and improved by using a provincial hydrographic layer as the basis to create flow accumulation patterns (Figure 10). Surface water flow was then calculated to conform to the DEM (Murphy et al. 2007a, b). The updated DEM was used as a guide for comparison and realignment (manual editing) of mapped water features, and soil polygons where necessary.

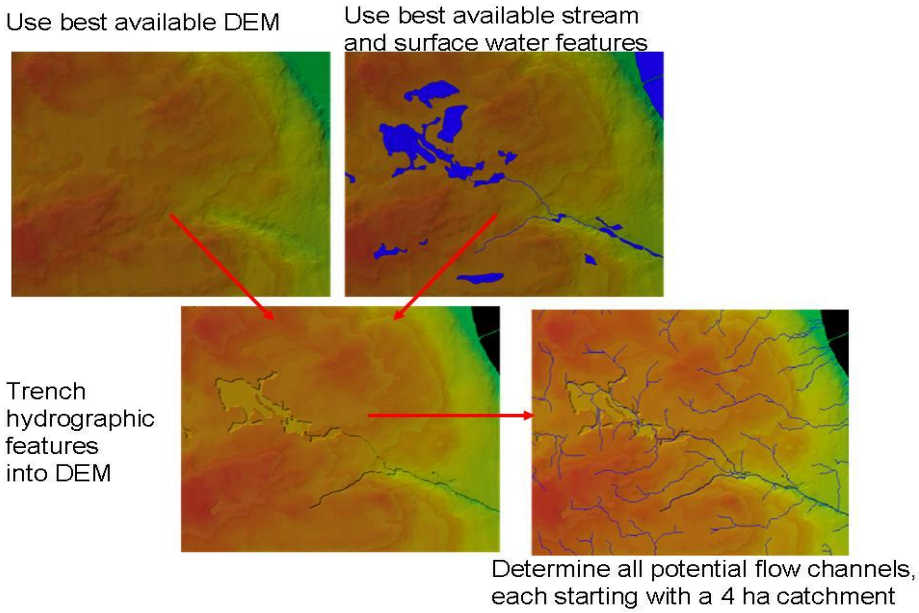


Figure 10. Creation of corrected hydrographic DEM and flow initiation to reveal the extent of wet areas (Arp 2007).

2) The hydrographic layer (1:10,000) depicting shorelines of streams and open water bodies was superimposed on the improved DEM to investigate photo interpretation errors in the hydrographic layer where flow was interrupted in the original mapping. In particular, where parallel streams were mapped, channels not joined, or streams were incorrectly mapped (i.e., flowed counter to the direction indicated by topography), they were assumed to be errors and removed from the hydrographic layer.

3) A high resolution (10 m) cartographic DTW index (Meng et al. 2006, Murphy et al. 2007a, 2007b, 2007c) was used to determine likely depth to water with changes in topography next to delineated surface water features (e.g., lakes, streams, ponds, pools, swamps, bogs, marshes, streams, creeks, rivers, shores). The DTW is a GIS tool developed at the University of New Brunswick (2007 version used for this project) that provides a 10m by 10m raster grid index of DTW where all surface water features contribute to the degree of wetness in adjacent soils. The principle of the model behind the tool (Arp 2007) assumes that at some depth all surface water features are connected (Figure 11). The DTW values in the adjacent landscape are referenced to the water level when delineated bodies of water are considered full, or at the upper limit of delineated shorelines (Meng et al. 2006).

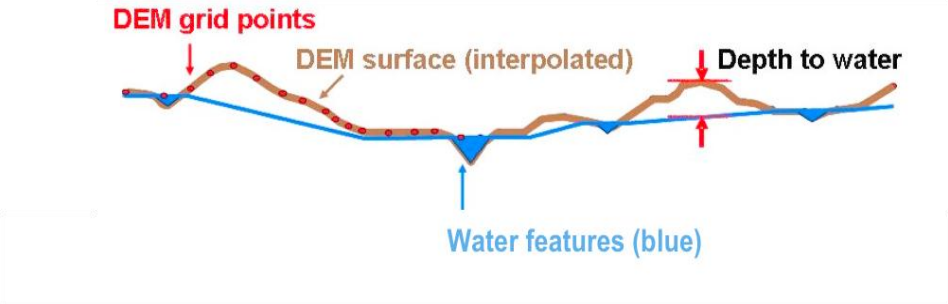


Figure 11. Diagram of the wet areas mapping principle (Meng et al. 2006). The depth to water model uses the DEM to "geospatially connect" water features at the full water mark.

In this manner, the use of a DEM to derive DTW (Murphy et al. 2007a) accounted for slope position, a variable that contributed to determining soil moisture regime (Colpitts et al. 1995). The delineation of the pattern of water in the landscape was key to understanding where certain ecosite conditions relating to soil moisture regime and soil fertility have developed.

4) Updated soil map: Formerly soil polygons on original soils maps were drawn by sketching, tracing, or digitizing polygon borders at 1:50,000 scale (Colpitts et al. 1995). Borders were discerned from various soil and surficial geology data (landforms), and vegetation borders as seen in aerial photographs. The interpretations were based on ground observations, yet the variable terrain conditions (in particular areas of steep slope) would have made consistency in interpretation difficult. Because soil variability is influenced by topography (Brady and Weil 2002), and earlier maps did not have the benefit of the current DEM, the result of this inconsistency is that soil maps do not necessarily align with other geo-referenced data (e.g., shoreline delineation of streams, lakes, wetlands and wet areas). In order to update the soil map, the DEM and DTW were used as guides in the realignment of soil polygon borders (Figure 12). The process of soil polygon realignment is described later in this section.

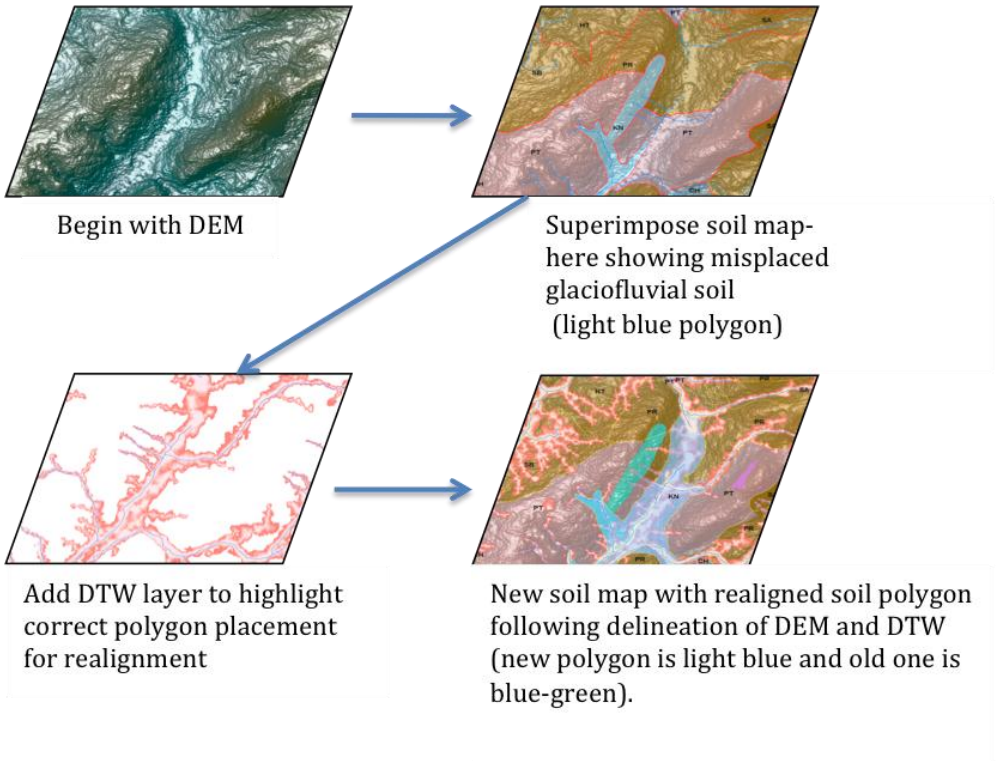


Figure 12. Example of superimposed GIS data layers used to realign a glaciofluvial soil polygon to correspond to the DEM and DTW and be properly aligned along the watercourse.

5) The NB provincial wetland layer (NBDNR 2006) was clipped and joined into the updated soils map (GIS functions). The purpose of its inclusion was to maintain consistency with the pattern of wetlands as delineated in the provincial wetland classification, while the DTW was used to delineate soils and other wet areas around the wetlands.

6) Orthorectified aerial photographs and mosaics (1:10,000), in MrSID format (multi resolution seamless image database), produced at a 1m resolution with a georeferenced accuracy of ± 6m (http://www.snb.ca/gdam-igec/e/2900e_1c_i.asp), were used with the DTW to verify that geomatic changes to soil polygons and water bodies conformed to actual ground conditions (Figure 13).

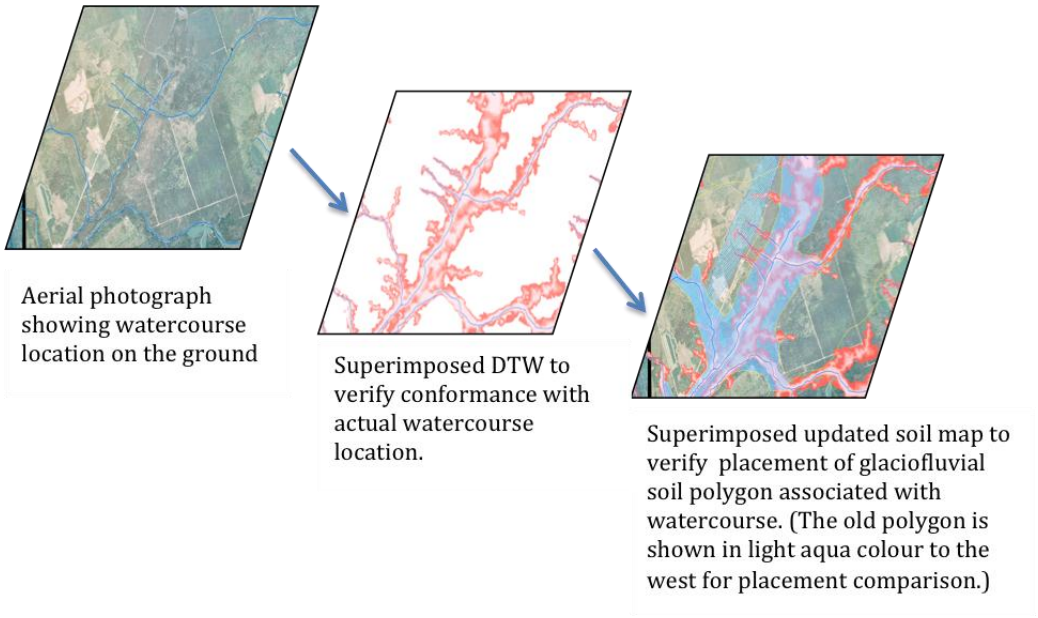


Figure 13. Verification of geomatic soil polygon changes using aerial photography as the basis for actual ground conditions.

7) Field data collected in various geological and forestry surveys (Table 4), available in digital format from other sources in NB, were consulted to augment geospatial data corresponding to field plot locations (e.g., landform, lithology, rock type). They contain information about bedrock geology, surficial geology, more detail about soil types, and ecological land classification, ecosites and forest stands, and were used as support information when determining ecosite values.

Table 4. Description of data sources and attribute data used to determine ecosite value.

Data	Source	Description of data used in this study
Surficial Geology	NBDNR, Geological Surveys Branch http://www.gnb.ca/0078/minerals/index-e.asp 2006 (1:50,000)	Vegetation, lithology, soil
Bedrock	NBDNR, Geological Surveys Branch http://www.gnb.ca/0078/minerals/index-e.asp 2006 (1:50,000)	Rock type, lithology, formation,
Ecological Land Classification	NBDNR, Timber Management Branch 2006 (various scales)	Mapped ecoregions, ecodistricts and ecosites in the FMF
Forest Inventory	NBDNR, Timber Management Branch 2006 (1:12,500)	Forest cover attributes based on NBDNR Data Dictionary, 2003 for FMF
Soil Data	NBDNR, Timber Management Branch 2006 (1:50,000)	Soil name, associated drainage class and landform for FMF

Soil Moisture Regime Classification

Classifications of DTW were represented by coloured contours, mapping the pattern of drainage across the landscape surface at a high resolution (Figure 14).

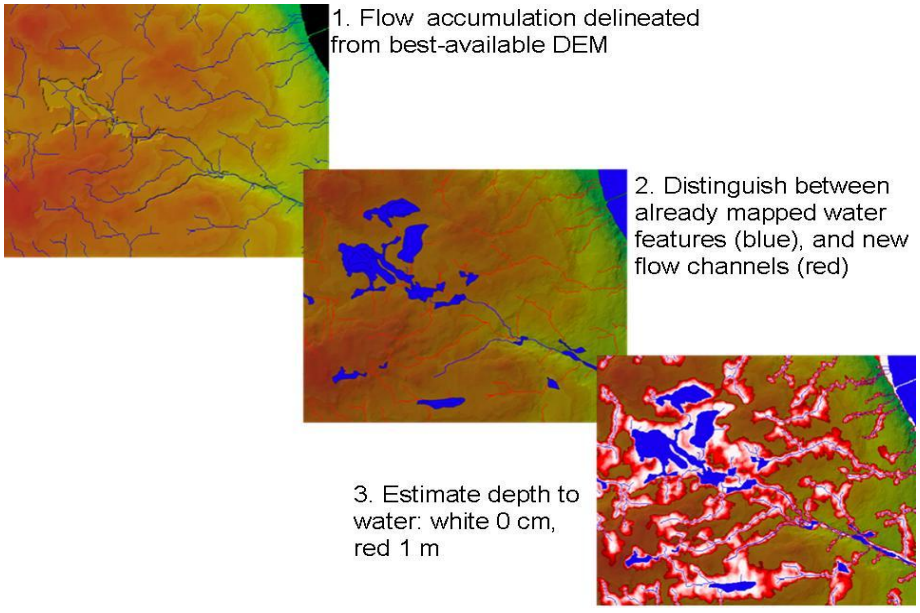


Figure 14. Delineation of wet areas and depth to water contours (Arp 2007).

The DTW was classified into six "contours" or levels of expected depth to water (Meng et al. 2006, Murphy et al. 2007a, b, c), which corresponded to drainage classes, and delineated the landscape into upland and wet areas. For this study contours were: 1) 0.0-0.25m (very poorly drained to poorly drained), 2) >0.25-0.50m (imperfectly drained), 3) >0.50-1.0m (moderately well drained), 4) >1.0-4.50m (well drained), 5) >4.50-20.0 (well drained to rapidly drained), and 6) >20.0m (rapidly drained). In order to represent hilly and steep areas, DTW contours were arbitrarily delineated at 4.5m, 20.0m, and > 20.0m, highlighting where well to rapidly drained conditions were expected.

The DTW data file in raster format (10m grid) was recreated as a polygon shapefile based on the contour levels described above (GIS function) . It was then used to represent soil moisture regime in the refined ecosite classification method explored in this study.

Soil Polygon Realignment

Soil drainage was previously mapped by broad classes that described the general moisture regime of the best-drained soil belonging to a particular group of soils (soil association) (Colpitts et al. 1995). At that time, through an "expert system" of individuals at NBDNR, data sources were compiled and individual soils were further delineated into numerous polygons to which drainage classes were assigned (very poor, poor, imperfect, moderate, well, and rapid) (Appendix 2b). In this study, the first step in soil polygon realignment was to simplify the soils map by eliminating soil drainage class polygons, returning to one polygon to represent the soil in any given area. Secondly, the DTW was used to represent a continuity of soil drainage conditions.

Soils in the FMF were originally delineated along borders of glacial tills. This method was maintained, and using the provincial map tile grid (1:10,000 scale) (Service New Brunswick 2007) as a guide to systematically inspect the FMF landbase tile by tile, soil polygon borders were visually examined and manually redigitized (edges of polygons were reshaped or moved in GIS editing function) in order to align with the DTW. The guiding principle in this manipulation was to respect the general mapping of soil types and landforms from previous work (Colpitts et al. 1995, Fahmy and Colpitts 1995 and 1997), yet to refine this delineation with the DTW.

For mapped organic soils, soils found in river valleys, soils in wet areas that were not delineated as part of the NB provincial wetland layer, or where wet areas indicated by the DTW inaccurately intersected water features, borders were adjusted manually to conform to the shallowest DTW contour. The assumption was that 0.10m represented the DTW for very poorly drained areas. DTW class 1 (0.0-0.25m) was reclassified temporarily to 0.0-0.10m during the realignment process in order to define areas assumed to be always or nearly always wet. For the purposes of the soil fertility classification and ecosite classification, however, we did not differentiate very poorly drained from poorly drained conditions, and assumed 0.0-0.25m represented them both as poorly drained. This ensured that soil polygons were defined along wet areas, yet allowed one DTW class to cover both conditions. This became a consideration during the refined ecosite value assignment when DTW indicated poor drainage however observed conditions between 0.01m and 0.25m DTW were sometimes not wet due to soil morphology.

For adjustments to soil polygon borders of upland soils the following procedure was used:

- If the pattern and extent of soil polygons across landforms was repeated across all polygons for the same soil, then this pattern was respected and borders were not adjusted. Otherwise, a process of visual inspection of soils superimposed on the DEM and DTW was carried out.
- Soil polygon borders were manually edited (GIS function), and drawn to best reflect: landscape position (crest, upper slope, mid slope, lower slope, valley, floodplain, level or flat areas), extent of that position given the terrain (flat, undulating, rolling, hilly) (Arp 2005), and where the particular soil under inspection was generally found (i.e., how far down from a ridge top or up from a valley bottom a soil polygon might extend) (Colpitts et al. 1995).

These changes to soil polygon borders were made based on interpretation of the DEM, the DTW, and an understanding of landforms and their associated soil attributes (texture, depth of soil, coarse fragment content). Provincial soil survey data (CanSIS 2005) provided soil attribute information (Appendix 3). This process was not a matter of large-scale changes, rather, small-scale adjustments that would have made a significant difference in the original soil mapping, had the DTW information been available at the time. This updated soil polygon layer became the basis for mapping refined ecosite values as determined for each individual soil and DTW combination.

Soil Fertility Classification

The focus of soil fertility classification was to devise a method to explicitly combine landform and soil morphological attributes for each soil in a way that expressed a value for soil fertility. At the sample plot level landform was assumed to be associated with the underlying glacial till deposits (Figure 15).

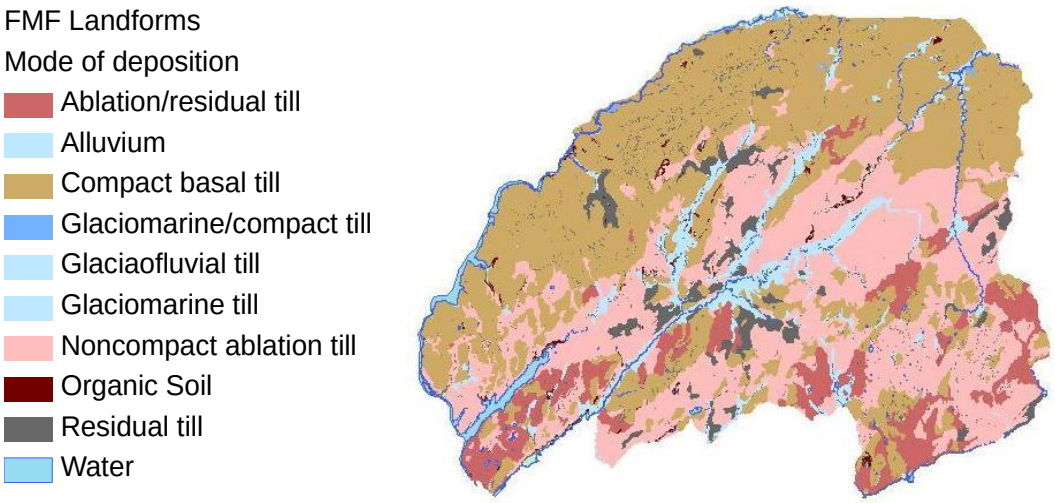


Figure 15. Map of glacial till deposits in the FMF (NBDNR 2006).

The attributes identified as important in contributing to soil fertility and plant growth are lithology, texture, and coarse fragment content (Colpitts et al. 1995, Fahmy and Colpitts 1997). Lithology refers to coarse to fine minerals where fine minerals weather more readily, silicon to mafic minerals (light, poor to dark, rich nutrient potential), and percent calcareousness of the rocks (higher nutrient potential). Texture of soil and soil parent material refers to the percentage of sand, loam, silt and clay and combinations thereof (Canadian Soil Information System, 2005) – grouped for this thesis into coarse, medium, and fine classes. Depth of soil refers to depth to a contrasting layer restricting root growth, either bedrock, water, or other compacted layer. Coarse fragment

content is the volumetric percent of mineral materials > 2mm within the soil profile (Colpitts et al. 1995).

Rather than evaluating soil fertility by plot-specific measures of individual attributes, ranges of values for each attribute were assigned an index value to indicate the relationship of that attribute to the soil fertility score (Amacher et al. 2007) (Table 5).

Table 5. Values and descriptions for the ranges of soil morphological attributes contributing to soil fertility score.

Attribute	Value	Description	Comment/Fertility indicator
Lithology (rock type):	1	Felsic volcanic	poor
	2	Igneous; igneous mix	
	3	Non-calcareous sedimentary; red mudstone; metasedimentary mix	
	4	Slightly calcareous sedimentary red; feldspathic/lithic sandstone; mudstone	
	5	Calcareous sedimentary; grey mudstone; feldspathic/lithic sandstone	rich
Soil Texture:	1	Coarse; Coarse-Medium (SL; LS; S)*	poor
	2	Medium; Medium-Coarse; Medium-Fine (SiL; L)*	
	3	Fine; Fine-Medium (SCL; CL; C)*	rich
Depth:	1	1-2; 1-2/R (average depth approx. 35cm - some soils overlay bedrock)	poor
	2	2; 1-3; 1-3/R (average depth approx. 50cm – some soils overlay bedrock)	
	3	2-3; 3; 3-4; 3-4/R; 4 (average depth approx. 75cm+ - some soils overlay bedrock)	rich
Coarse Fragment %:	1	High (51-100%)	poor
	2	Medium; M-H (21-50%)	
	3	L; L-M (<=20%)	rich
Parent Material Texture:	1	Coarse; Coarse-Medium (SL; LS; S)*	poor
	2	Medium; Medium-Coarse; Medium-Fine (SiL; L)*	
	3	Fine; Fine-Medium (SCL; CL; C)*	rich

* Texture class names listed in Appendix 4.

Attributes were weighted by the number of possible values within each category, three or five. This placed most emphasis on lithology (out of five), and the remainder of the attributes were valued out of three. The purpose of using this approach was to explicitly incorporate the information about tills derived from various landforms into the classification. Using this concept soil fertility values could be ascertained and compared for soils with a rich lithology that may be derived from slow weathering parent material or have a high percentage of coarse fragments (or both), thus reducing its overall fertility (nutrient availability) to a certain degree, to soils that have developed from bedrock that weathers more quickly yet is less rich in minerals and may still be considered moderately fertile because the nutrients are readily available to plants.

Attribute values for each soil type based on Table 5 were summed for a final fertility score, and percentage of the maximum possible score was calculated (Amacher et al. 2007). Deriving a value for soil fertility in this simple way, based on published soil morphological attributes, provided a method to discern and compare soil fertility that can be transferred and applied to soils in any area of interest where soil attributes are known.

Refined Ecosite Classification

The following steps were used to classify and map ecosites:

- List soils according to fertility score.
- Group soils into three groups by inherent mineral richness of the soil parent material (rich, moderate, low/poor) (Colpitts et al. 1995).
- Group tills by drainage characteristics into four groups, 1-4 as described below, to combine similar conditions and facilitate the sorting process. Within till groups

soils were listed from well drained to poorly drained with respect to nutrient release/retention potential (Colpitts et al. 1995). (In order to list soils in descending order the best-drained landform (ablation till) was given the value of 1. This is not to be confused with the value of 1 representing the lowest score for attributes' contribution to soil fertility score as described in Table 5.)

1 - ablation till-deeper; various texture; non-compact till-best drainage conditions

2 - basal till, alluvium-shallow to deep compact till; fine texture-moderate to poor drainage depending on slope and texture

3 - residual; residual/ablation; ablation/residual tills-shallow to medium depth over bedrock-rapid or poor drainage depending on slope

4 - glaciofluvial, glaciomarine tills-deep; coarse, gravelly-excessive coarseness/drainage; or compact and poorly drained-no nutrient retention or very slow release

- Sort each soil group by landform drainage characteristics.
- Assign ecosite value based on the edatopic grid to each soil at each DTW considering landscape position (i.e., ridgetop, midslope, floodplain, etc.) and its effect on drainage characteristics according to the following criteria:
  - non compact till is better drained and releases nutrients more readily than compact till when wet - richer in top group and better drained
  - compact tills are more poorly drained - don't release nutrients as much when wet, and stay wet at greater DTW
  - residual tills on ridge tops are excessively drained - sites are drier and nutrients leach from sites at greater DTW (i.e., greater slope)
  - glaciofluvial till considered low fertility (i.e., too coarse to hold soil nutrients)
- Intersect DTW polygons with realigned soils map, and reclassify the resulting map in terms of ecosite values described above (GIS functions).

- According to the mapped bedrock lithology (Figure 16), for all soils on substrate 4 (highest inherent fertility) (NBDNR 2006) adjust polygon ecosite value one level higher in final mapping process to reflect contribution of rich minerals from the bedrock layer to soil parent material, and for all soils on substrate 1 (lowest inherent fertility) adjust ecosite value one level lower to reflect lack of nutrients from bedrock layer.

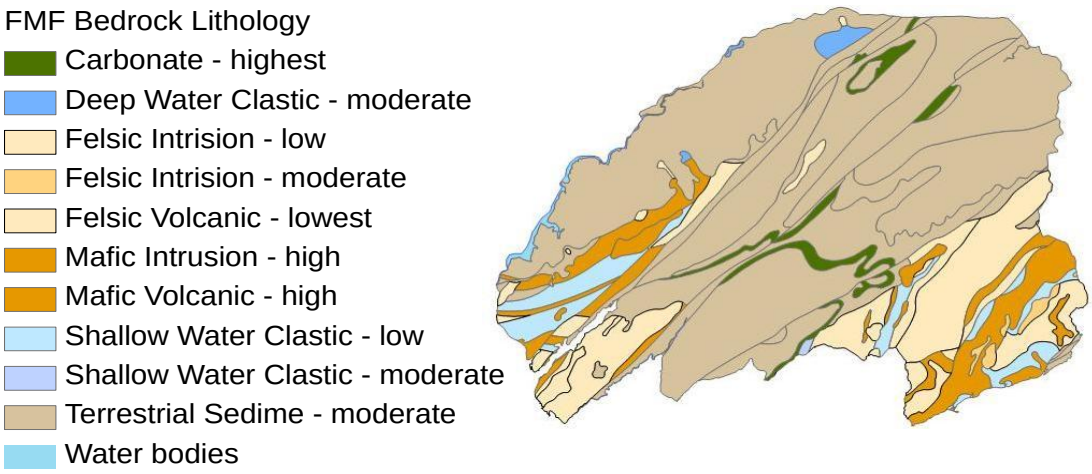


Figure 16. Pattern of bedrock lithology in FMF indicating high, moderate and low inherent fertility of parent material (NBDNR 2006).

Analytical Methods

Analyses of field data using StatView were examined to discern general relationships between DTW classes and conventional classes of drainage, soil moisture regime, soil type, vegetation type, and ecosite value. A logarithmic scale was used for DTW to graph results in order to reveal distribution of data within the first 1.0 meter DTW, where up to four classes might be seen due to the variable nature of soils and

drainage within that depth. DTW was also graphed on the y-axis to represent the vertical nature of depth.

All data were analysed through the functions for classification and regression in R (Kuhn 2008) to create a regression tree that classified ecosite values according to observed conditions. Observed ecosite values were then compared to predicted ecosite values for each plot determined by the process described in this study.

The nodes of the regression tree occurred where the values for a particular variable were divided into two groups that were most different, while the values within those groups were most alike. The variable indicated at each node was the most influential variable at that node in the creation of the tree. The relative distance between the levels of the tree indicated the relative influence of the variables at each node. In this manner the software evaluated each variable independently at each level of the tree, thus allowing the potential for any one variable to be influential at one or more nodes.

RESULTS

Observed Conditions

One hundred and eighteen plots were located on original ELC-mapped ecosites 2 and 5 (Figure 17).

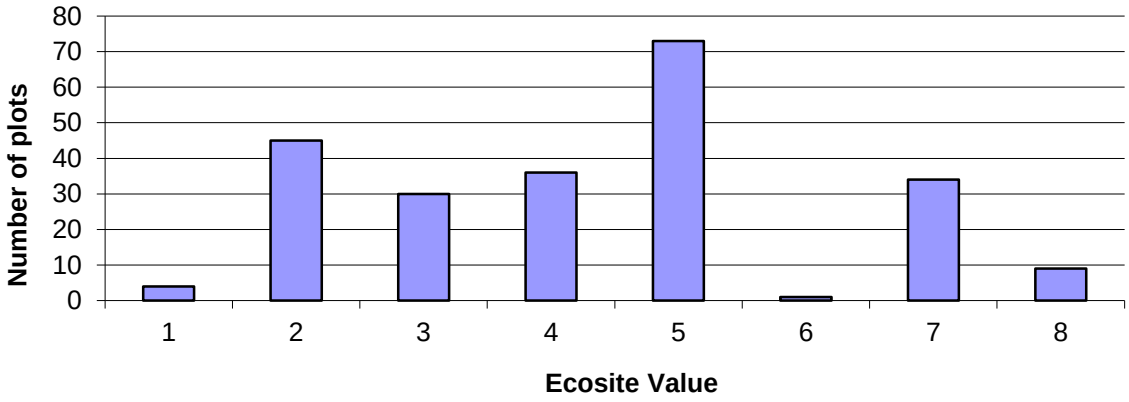


Figure 17. FMF plots per ecosite previous to refined ecosite classification.

There were 13 of 34 rock types recorded, the majority of which were acidic sedimentary (Appendix 2a) (Table 6) . This is consistent with the predominance of terrestrial sedimentary bedrock underlying the FMF, which forms the soil parent material (Service New Brunswick 2007). The sediments are moderately rich, consistent with ecosite 5, which was determined for the majority of field observations (Table 7).

Table 6. Soil parent material acidity derived from pebble analysis of rock types (Colpitts et al. 1995), and the number and percentage of field plots in each category.

Acidity	Rock type	Plots (#)	Field plots (%)
Acid igneous (AI)	felsic volcanics, gneiss, granite, granodiorite	50	21
Acid sedimentary (AS)	chert, conglomerate, quartzite, sandstone, schist, siltstone	173	72
Basic igneous (BI)	basalt, diorite, gabbro	17	7
Calcareous (CAL)		0	0

Table 7. Ecosite values (bolded numbers) associated with each combination of soil type (ST)/vegetation type (VT) for observed conditions. The number of occurrences of each ecosite value (n) at each ST/VT combination, and total "n" for each ecosite value are also indicated.

Soil Type (ST) →	ST1 wet	ST2 moist, acidic	ST3 moist, calcareous or basic igneous	ST4 fresh, calcareous or basic igneous	ST5 fresh, acidic sedimen-tary	ST6 fresh, acidic igneous		ST7 dry
Vegetation Type (VT) ↓								
VT1 (poor)	**3** n=14	**3** n=16		**5** n=2	**2** n=5			**1** n=1
VT2	**3** n=4	**2** n=40		**7** n=1	**5** n=25	**2** n=8		**4** n=2
VT3		**5** n=23	**7** n=1	**7** n=4	**5** n=30	**5** n=15		**4** n=7
VT4 (rich)		**6** n=4		**7** n=3	**7** n=15	**7** n=15		**8** n=5
Total "n" for each ecosite value	1 n=1	2 n=53	3 n=34	4 n=9	5 n=95	6 n=4	7 n=39	8 n=5

Relationship of DTW to Field Plot Data

The relationships between DTW and drainage, soil moisture regime, soil type, vegetation type, and observed ecosite values were investigated for ablation and basal tills (217/240 plots). For plots surveyed in the FMF DTW ranged from very shallow (0.01 m), with water at the surface, to very deep (35.23m) in steep, hilly terrain. Previously, DTW was found to correspond approximately 85% with soil moisture regime described in the Alberta Vegetation Inventory (Murphy et al. 2006). A hydric (wet) to xeric (dry) scale, where 0.50m depth delineated wet areas from surrounding uplands, used landform attributes, precipitation input, and drainage to describe the duration of water held in the

soil, reflecting dry, moderate, wet or aquatic soil moisture regimes (Alberta Sustainable Resource Development 2005). Figure 18 shows field plot data from this study represented by the hydric to xeric scale and from this pattern it was inferred that the DTW was positively correlated with conventional drainage classifications.

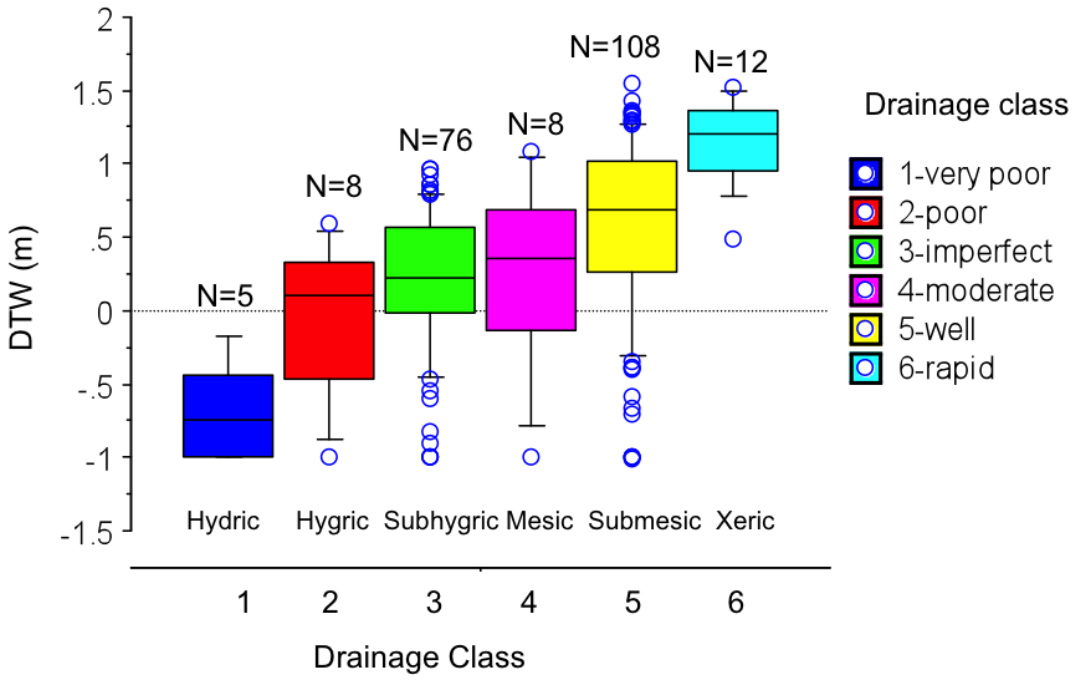


Figure 18. Distribution of DTW values for field plot assessed drainage classes, also showing relative hydric to xeric scale.

Soil moisture regime conformed to DTW for most plots, however moist (class 2) on ablation till was at the same depth as fresh (class3), where it was expected to be more shallow (Figure 19). This may be partly explained by the fact that half of the imperfectly drained soils, usually found in moist conditions, on ablation till were found in DTW class 5 (4.5m to 20.0m), expected to be deeper and better drained conditions. Plots with fresh soil moisture regime classifications for both tills were found to be at similar depths as

expected in deeper, well-drained soils. DTW on ablation till for wet conditions (class 1) was more shallow than basal till which was not expected. However, DTW for moist and dry soils was greater on ablation till, which generally is deeper and better drained.

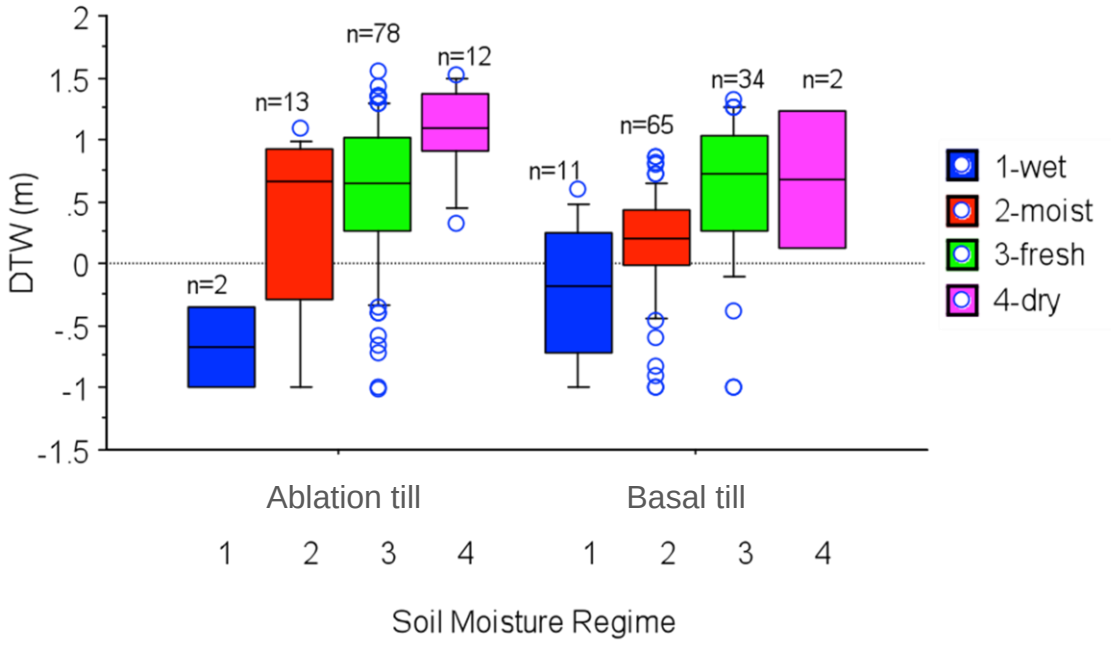


Figure 19. Distribution of DTW values for field plots on ablation and basal tills, split by soil moisture regime.

Soil types in the FMF followed the expected trend from wet to dry (Figure 20). DTW for soil types of igneous origin (ST4 and ST6) was deeper than that on soil type of sedimentary origin (ST5). There were too few plots on moist calcareous soil types to provide any information.

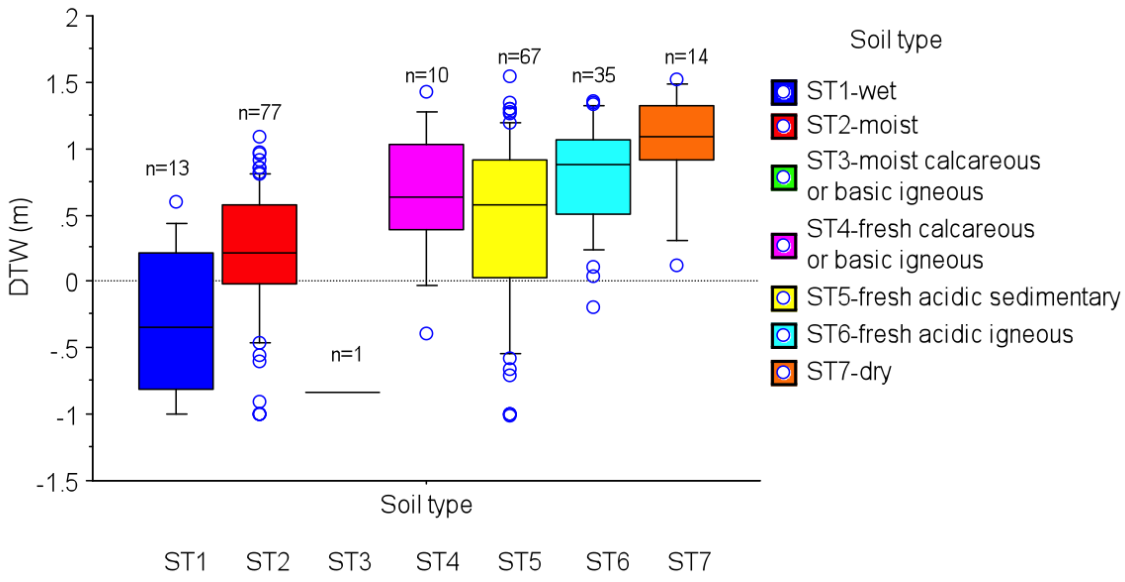


Figure 20. Distribution of DTW values for field plots on ablation and basal till split by soil type.

The relationship between DTW and vegetation type exhibits a similar pattern to soil moisture regime and soil type, with wet conditions at shallow DTW and dry conditions at greater depths (Figures 21 and 22). Due to variation in vegetation between upland ecoregions and lowland ecoregions (NBDNR 2007), they were graphed separately. In VT1 and VT2 DTW for uplands is deeper where more hilly terrain and greater occurrences of well drained ablation till were found that supported tolerant hardwood growth in rich conditions. In the lowlands ecoregions flat areas were more prevalent over sedimentary bedrock thus increasing the potential for poorer drainage and associated vegetation types. VT3 and VT 4 for both ecoregions were found with similar DTW values.

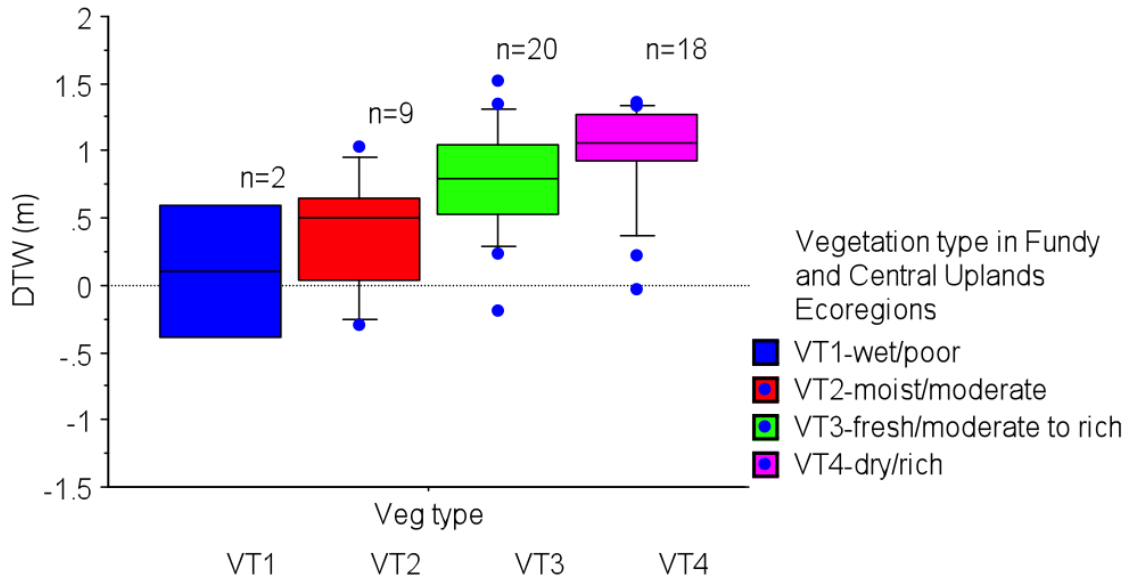


Figure 21. Distribution of DTW values for plots on ablation and basal till split by vegetation type for Ecoregions 3 and 4 (uplands).

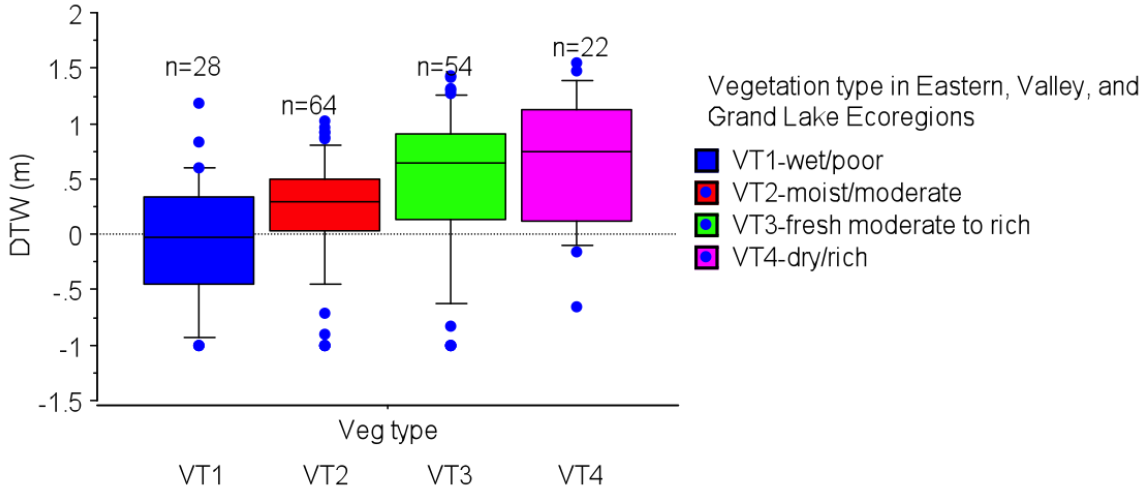


Figure 22. Distribution of DTW values for plots on ablation and basal till split by vegetation type for Ecoregions 5, 6, and 7 (lowlands).

The distributions of ecosite values for ablation and basal till show the predicted patterns with respect to DTW (Figure 23), with more poorly drained plots at shallow depths, and well drained plots at greater depths. Similar to the pattern seen earlier in this

section for soil moisture regime, on ablation till plots with ecosite value 2 (moist soil moisture regime and poor fertility) occurred on soils with greater DTW than did plots with ecosite value 5 (fresh soil moisture and moderate fertility). Again, this could be due to half the imperfectly drained plots being located on ecosite 5 when soil type and vegetation type were combined. Also, plots with ecosite value 1 (dry soil moisture regime and poor fertility) occurred at greater DTW than plots with ecosite value 4 (dry soil moisture regime and moderate fertility). Ecosite 1 plots were located on soils on steeper slopes, which indicate a greater DTW and drier conditions.

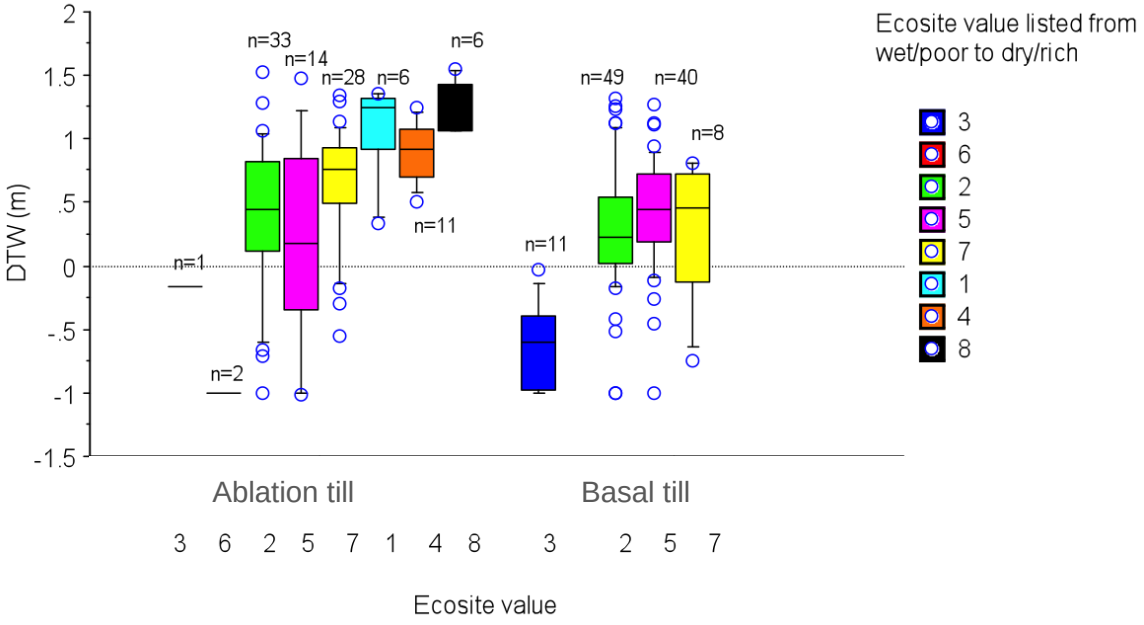


Figure 23. Distribution of DTW values for plots on ablation and basal till split by ecosite values in order from wet/poor to dry/rich.

Soil Polygon Realignment

Adjustments to soil polygons indicated very small differences in area between the original ELC map and the refined version (Figure 24). Area of many soils was slightly reduced with the inclusion of the NB provincial wetland layer which occupies

approximately 10,000 hectares that were not part of the original version of the soils map. Increases in area did appear for two soils found along watercourses (GG and KN). (Full soil names appear in Appendix 1). This was expected with the use of the DTW to guide the delineation, and thus is likely to have the most impact on soils located at shallow DTW near the water bodies.

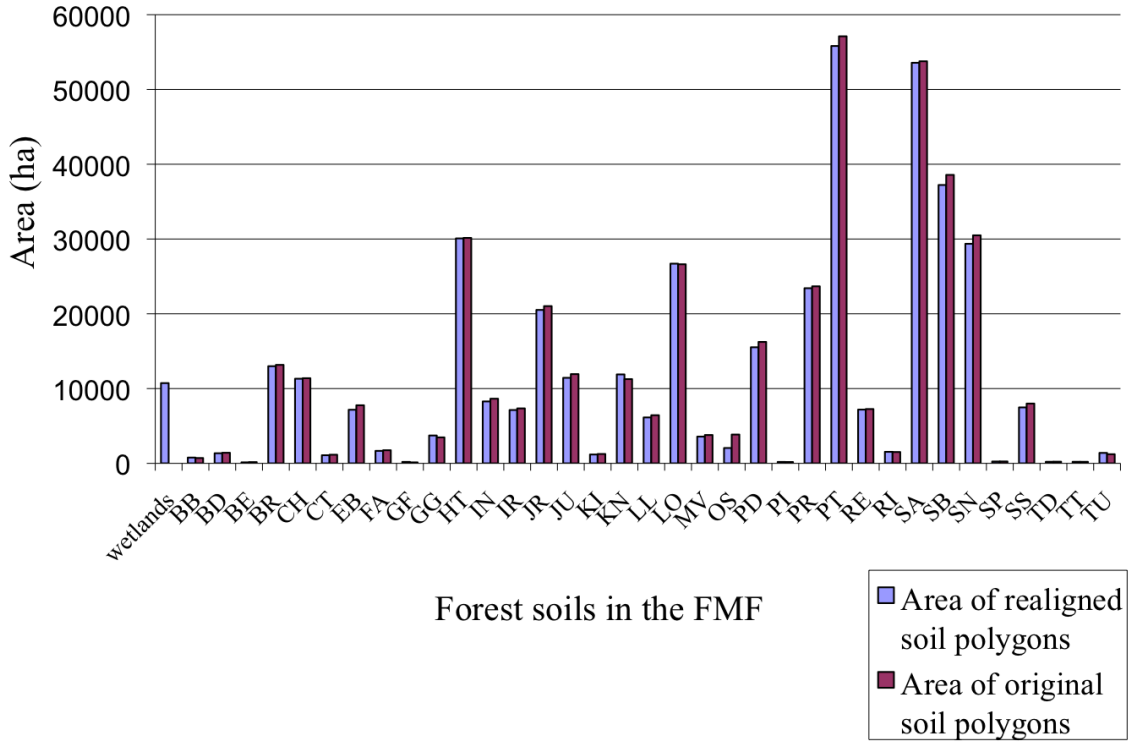


Figure 24. Area comparison of soils in the FMF before and after soil polygon realignment.

Soil Fertility Classification

Soil fertility rankings using methods developed in this thesis (Table 8) were similar to the current system in use. Breakpoints between inherent fertility values for % maximum score (represented as dark green for high, medium green for moderate, and light green for low in the table) were often the same or within 1 value of the expert system used previously (NBDNR, unpublished draft 2007), which ranked soil fertility

from1-4, high-low. Overlapping differences were expected in comparing three values to four.

Table 8. Soil fertility scores based on soil morphological attribute values, compared to 1997 DNR ranking system (NBDNR 2007 unpublished draft).

SOIL	Lithology	Texture of the upper soil	Texture of the parent material	Soil Depth	Coarse Fragment %	Score	% Max Score	Previous ranking (1997) (1 is high; 4 is low)
SS	5	3	3	3	3	17	100	1
IN	5	2	2	3	3	15	88	1
TD	4	2	3	3	3	15	88	1
EB	5	2	2	2	3	14	82	2
SA	4	2	2	3	3	14	82	2
PR	4	2	2	3	3	14	82	2
CH	4	2	3	2	3	14	82	2
PT	4	2	2	3	2	13	76	2
KN	4	2	2	3	2	13	76	2
HT	3	1	3	3	3	13	76	2
BR	3	2	2	3	3	13	76	2
BE	3	2	2	3	3	13	76	2
LL	3	2	2	2	3	12	71	3
BB	3	1	2	3	3	12	71	3
SB	3	2	3	1	3	12	71	3
TT	3	2	3	2	2	12	71	3
MV	3	2	3	2	2	12	71	3
KI	3	2	2	2	2	11	65	3
GF	3	2	1	3	2	11	65	4
CT	2	2	2	2	3	11	65	3
TU	2	2	2	2	3	11	65	3
JU	2	2	1	3	3	11	65	3
IR	2	2	2	3	2	11	65	3
SP	3	2	2	1	2	10	59	3
PI	2	2	2	2	2	10	59	3
PD	1	2	2	2	3	10	59	3
JR	1	2	2	3	2	10	59	3
RE	2	1	2	2	2	9	53	3
SN	2	1	1	3	2	9	53	3
FA	2	2	1	2	2	9	53	3
RI	2	1	1	3	2	9	53	4
LO	1	2	2	2	2	9	53	3
GG	1	2	1	3	2	9	53	4
BD	2	2	1	1	2	8	47	4

Ecosite Classification and Mapping

Mineral composition of local bedrock is a factor in ecosite classification with richer minerals contributing to greater ecosite quality (NBDNR 2007). Once mapped, predicted ecosites 1, 2, 3, 4 and 5 on parent material with high inherent fertility were adjusted to 4, 5, 6, 8 and 7, and vice versa for those ecosites on parent material with low inherent fertility. An example of this in the Caledonia Ecodistrict is Juniper soil (JU), which has inherent low fertility, however is underlain by granitic bedrock composed of "abundant mafic minerals". JU soils cover much of the hilly topography in the southeast section of the FMF where many tolerant hardwood stands are found. This could also explain the apparently rich ecosites (supporting tolerant hardwood growth) on a number of other poor soils in the same general area.

In some cases ecosites were classified at lower values due to the mode of deposition of glacial till in spite of the fact that the soils were moderately rich. For instance KN, GF, RI, and BB are of glaciofluvial origin, and for the most part their coarse, gravelly texture results in excessive drainage, no nutrient release, and thus poor ecosite value (Colpitts pers. commun., Gimbarzevsky 1964).

When mapping ecosite values the legend in Figure 25 was used. Figure 26 shows the results for ecosite classification of each soil at each DTW class.

Ecosite value	1	2	3	4	5	6	7	8
Ecosite description	poor-dry	poor-moist/ fresh	poor-wet/moist	moderate-dry	moderate-moist/fresh	rich-wet/moist	rich-moist/fresh	rich-dry

Figure 25. Legend for mapping ecosite values based on DTW and soil fertility.

Landscape position	Landform (till)	Soil	DTW Class (m)					
			0.0-.25	>0.25-.50	>0.50-1.0	>1.0-4.5	>4.5-20.0	>20.0
Group 1: high soil nutrient richness (lithology)								
hills to flats	ablation	PT						8
floodplain	alluvium	IN		6				
lower	basal	SS					5	
hills to flats	basal	SA		3				
hills to flats	basal	PR						
ridgetop	residual	CH						
crest upper	residual	EB						
outwash	glaciofluvial/marine	TD					2	
river valley	glaciofluvial/marine	KN					4	
Group 2: moderate soil nutrient richness (lithology)								
lower valley	ablation	BR						
gentle-acidic	ablation	BE						
gentle-acidic	basal	HT						
mid-lower	basal	LL						
undulating-acidic	basal	SB						
shore-acidic	basal	BB						
mid-lower	basal	TT						
highlands	basal	KI						7
crest upper	residual	MV						
upper	residual	SP						
river valley	glaciofluvial/marine	GF					4	
Group 3: low/poor soil nutrient richness (lithology)								
hilly	ablation	JU						
lower	ablation	IR						
lower flats	ablation	JR						
hills	ablation	SN						
mid slope	basal	CT						
hilly	basal	TU						
undulating	basal	PD						
undulating	basal	RE						
undulating	residual	LO						
upper	residual	PI						
rolling	residual	FA						
crest	residual	BD						
river valley	glaciofluvial/marine	RI						1
river valley	glaciofluvial/marine	GG						

Figure 26. New ecosite values represented by colours used to map where changes in DTW result in a change in ecosite value for each soil. Samples of cell colours include ecosite number values, related to wet to dry, and poor to rich conditions. Higher values indicate richer ecosites.

An area comparison of ecosite values (Figure 27) highlights increases and reductions resulting from this refined classification based on the DTW. There were increases in area for ecosites 2, 4, and 7, and decreases in ecosites 1, 3, 5, 6, and 8. Wet areas and uplands that may have been aggregated within the broad drainage classes of the original ELC mapping were clearly delineated, resulting in increased or reduced area. Notably wet ecosites 3 and 6 significantly decreased by 19% and 72%, respectively. This was most likely due, however, to the incorporation of the NBDNR wetland classification map which shows identified wetlands in areas formerly mapped as these ecosites.

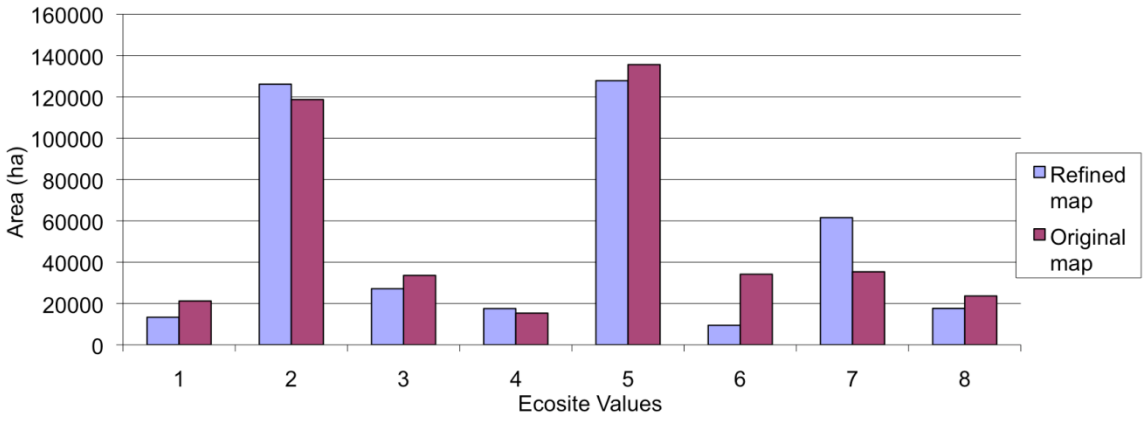


Figure 27. Area comparison of ecosites in the FMF between the original ELC map (NBDNR 2007 unpublished draft) and the predicted ecosite map.

Ecosites 2, 5, and 7 were associated with better drainage (not necessarily richer soils, however not as wet or dry as the extremes), thus predicting that they would be found in mid to upper slope positions i.e., DTW classes 4 and 5. One half of total plots were assessed as ecosites 2, 5, and 7 on DTW 4 and 5. Ecosite 7 increased by 74%.

Figures 28-30 demonstrate an example of the refined ecosite mapping process. Three soil polygons (CH-Cornhill, PT-Parleeville-Tobique, and KN-Kennebecasis) from the original ELC map (NBDNR 2007 unpublished draft) indicated that only ecosites 2 and 5 were found at this map extent (Figure 28). The DTW was superimposed on the updated soil polygon map to delineate wet areas (light pink - shallow DTW contours; poorer drainage), from uplands (darker pink to deep red - deeper DTW contours; relatively steeper, higher ground with improved drainage) (Figure 29). DTW class and soils were combined to map ecosite values (Figure 30).

In this example the CH soil, originally mapped predominantly as ecosite 5 with smaller areas of ecosite 2, was reclassified showing refined delineations of 2 at DTW 2, 3, and 4; 5 at DTW 5; 8 in steeper areas at DTW 6; and a wet area, ecosite 3, was revealed near the watercourse at DTW 1. The PT soil polygon was reclassified from ecosites 2 and 5, to reveal the pattern of ecosite 5 at DTW 3 and 4, ecosite 7 at DTW 5, and ecosite 8 at DTW 6 in the steep areas. There were no ecosites 2 in the refined PT polygon indicating generally richer conditions for that soil on that location than originally mapped. The KN soil polygon along the watercourse remained ecosite 2 at all DTW contours however a wet area, ecosite 3, was delineated at DTW 1. The refinement in this case was in the shape of the soil polygon, which conformed to that of the DTW.

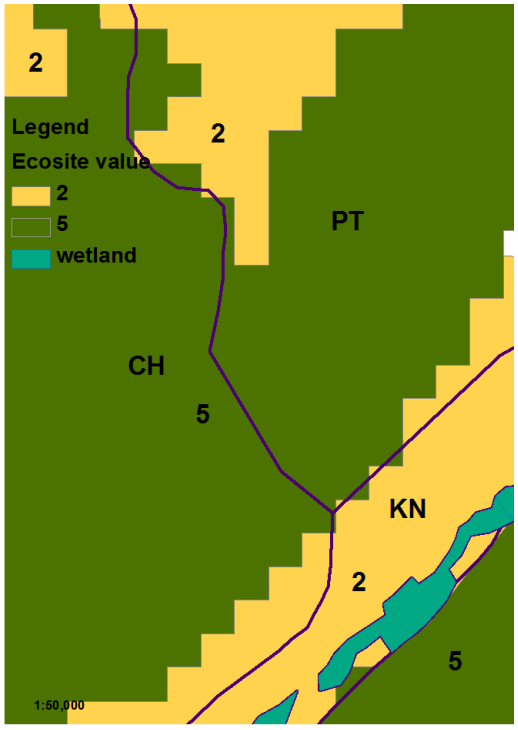


Figure 28. An example of original ELC ecosite mapping, showing three soil polygons (CH-Cornhill, PT-Parleeville-Tobique, and KN-Kennebecasis) and their associated ecosite values.

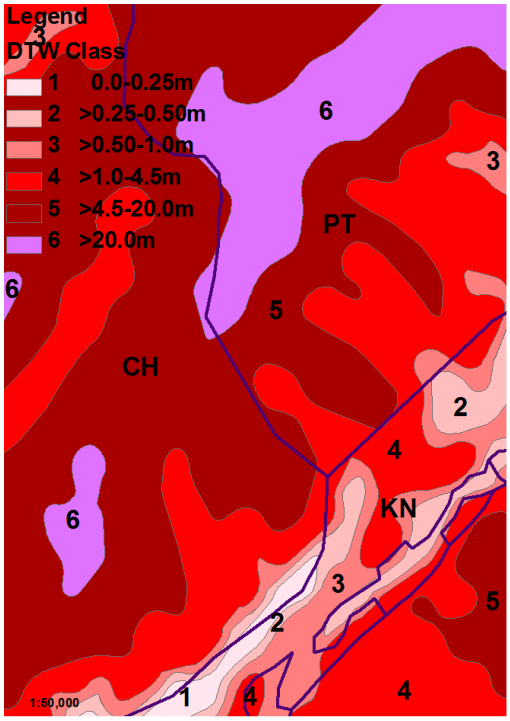


Figure 29. DTW class polygons superimposed on three soil polygons (CH-Cornhill, PT-Parleeville-Tobique, and KN-Kennebecasis), delineating soil moisture regime from wet areas (light pink) to uplands (dark red).

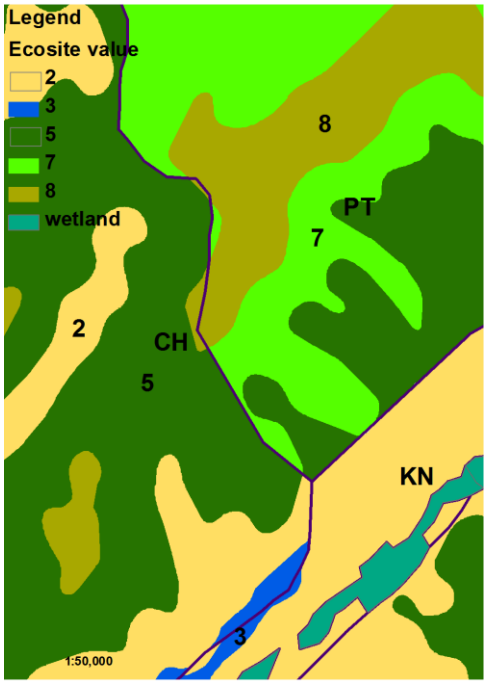


Figure 30. Refined ecosite classification following DTW delineation for three soil polygons (CH-Cornhill, PT-Parleeville-Tobique, and KN-Kennebecasis), with values reflecting local variation in soil moisture regime and soil fertility.

Comparing Predicted Ecosite Values to Observed

Results of field data analysis showed that the same variables were influential in developing regression trees when comparing both original mapped ecosite values, and refined ecosite values (Table 9). The difference however is at which level they appeared in the regression trees, and the relative influence they had, indicated by the length of the vertical lines between nodes (Figures 31 and 32).

Table 9. Description of variables at nodes of the regression tree determined by R to have the most influence on observed ecosite classification.

Variable name	Description
Vegetation type	VT 1-4 as determined by keys (NBDNR 2007)
Mottles	Absence or presence of mottles in the soil
Org. Mat. (%)	Organic matter percent
FUNA grp	Group of FUNAs influential at a particular node
DTW	Depth to water (m)
SLOPE_FLD	Slope measured in the field (%)

Forest unit name (FUNA) which describes the forest cover type associated with each field plot (Appendix 6a), and vegetation type (Appendix 6b) appear most often in each tree, evidence of the influence of vegetation on observed ecosite classification. FUNAs were grouped (FUNA grp) for ease of labelling on the tree (Table 10). Each FUNA as an individual variable could appear more than once since the program analyses all single variables at all nodes.

Table 10. Lists of forest unit names representing forest cover types (Appendix 6a) that form FUNA groups at nodes in the regression tree.

FUNA GROUP							
1A	1B	2A	2B	3A	3B	4A	4B
BFIH	IHSP	BFIH	AF	BFIH	BFTH	RGHW	INHW
BFSP	INHW	BFTH	BFSP	INHW	IHSP	SPTH	SPBF
IHTH	SPIH	IHSP	OTSW	PINE	IHTH	THIH	TOHW
PINE		IHTH	SPTH	RGSW	SPBF		
RGSW		INHW		THBF	SPIH		
SPBF		PINE		THIH			
SPTH		RGSW		THSP			
STUN		SPBF		TOHW			
THBF		SPIH					
THIH		THBF					
THSP		THIH					
		THSP					
		TOHW					

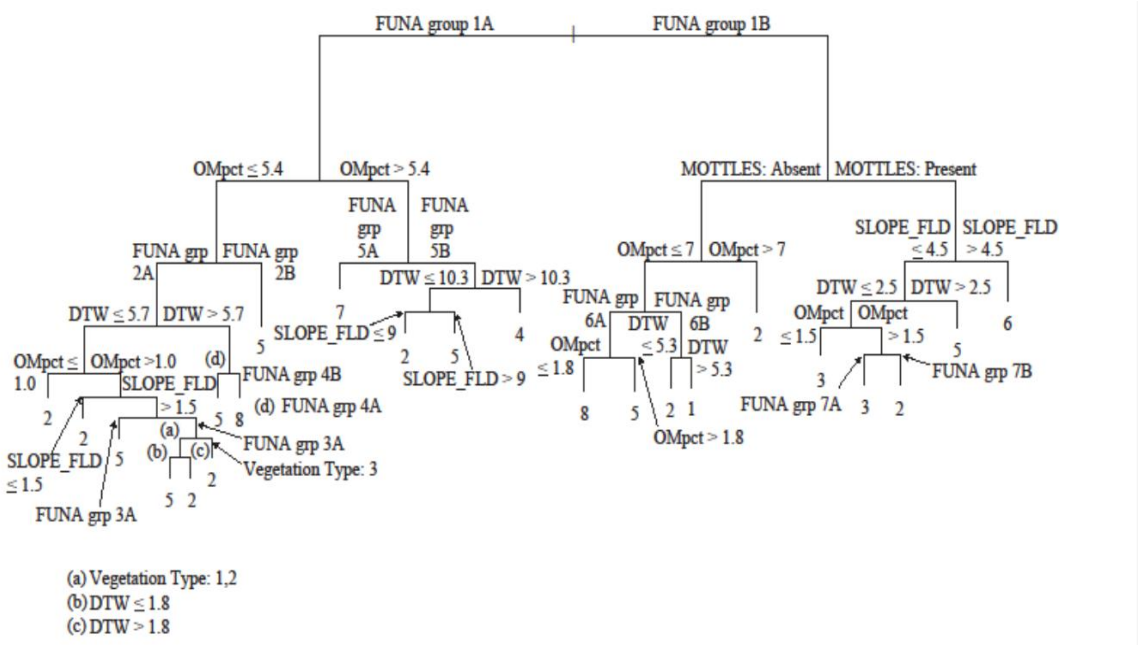


Figure 31. Regression tree showing influential variables at data subdivisions (nodes), leading to terminal nodes and ecosite classifications, comparing field data and original ecosite values.

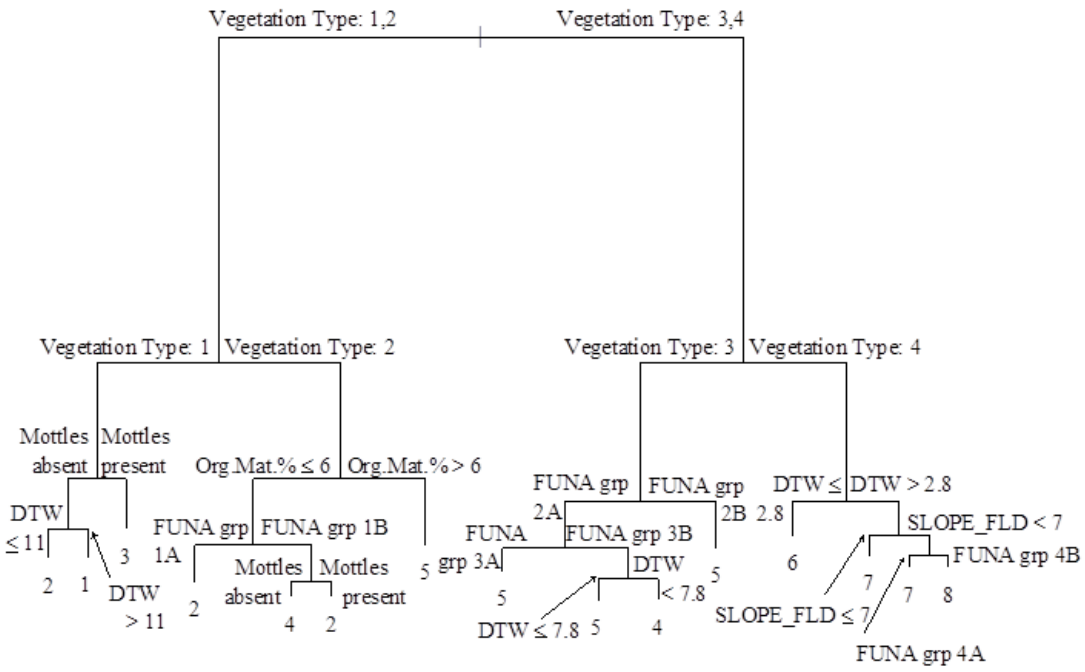


Figure 32. Regression tree showing influential variables at data subdivisions (nodes), leading to terminal nodes and ecosite values, comparing field data and refined ecosite values.

Inspection of the regression trees indicated that Figure 31, which represents the comparison of field data to original mapped ecosites did not follow the predicted pattern of the edatopic grid moving from left to right for ecosite values at terminal nodes. Ecosite values were classified predominantly as 2 or 5 both on the left and right side of the tree, even at the extremes where differentiation of original mapped values was expected. Wet ecosites appeared more to the right which is predicted for rich ecosite 6 but not for poor ecosite 3, while rich, dry ecosite 8 appeared more to the left than expected.

Figure 32 indicated that at each level, moving from left to right corresponded to changes in soil moisture regime from wet to dry, as well as soil fertility from poor to rich as represented by the edatopic grid. This was seen at level two of the tree where VTs 1-4

represent vegetation found in wet/poor to dry/rich conditions. FUNA groups also follow a general trend towards richer forest types, progressing from the left to the right side of the tree, but more often they appeared as influential in differentiating ecosite where soil moisture regime changed.

Working down through the tree on the far left side the first termination was at ecosite value 3 (wet/poor ecosites), followed by one more node where DTW distinguished ecosite 2 from 1 (both poor but 1 is drier on steeper slopes). Similarly the nodes at the centre of the tree terminated in ecosite values 2, 4, and 5, and nodes at the right side terminated in ecosite values 7 and 8. This followed the edatopic grid from wet/poor to dry/rich ecosite conditions.

There was a reduction in percent total deviance at each node as data was subsequently split to create the regression trees, progressing towards terminal nodes resulting in a value for ecosites classification (Tables 11 and 12).

Table 11. Reduction of percent total deviance for variables at nodes in the regression tree analyzing original mapped ecosite values with field data, as data can no longer be split and ecosite values were classified. The pattern and numbering of nodes is shown in this table (first column) to reflect branching of the tree.

Node	Num.Obs.	Deviance	Classification
0)	190	698.2	2
1)	99	307.1	5
11)	68	190.6	5
111)	53	142.6	2
1111)	40	88.38	2
11111)	6	15.96	2
11112)	34	62.82	2
111121)	10	10.01	2
111122)	24	44.08	2
1111221)	7	5.742	5
1111222)	17	29.71	2

Continued on next page…

11112221)	10	13.46	2
111122211)	5	5.004	5
111122212)	5	0	2
11112222)	7	8.376	2
1112)	13	34.1	5
11121)	5	5.004	5
11122)	8	19.41	8
112)	15	21.6	5
12)	31	82.52	7
121)	9	12.37	7
122)	22	59.05	2
1221)	15	34.11	2
12211)	10	12.22	2
12212)	5	13.32	5
1222)	7	15.11	4
2)	91	330.1	2
21)	43	154.8	2
211)	34	106.3	2
2111)	21	55.7	5
21111)	8	15.59	8
21112)	13	26.26	5
2112)	13	31.73	2
21121)	7	11.15	2
21122)	6	7.638	1
212)	9	27.41	2
22)	48	141.6	3
221)	40	110.8	3
2211)	34	84.71	3
22111)	14	22.3	3
22112)	20	51	3
221121)	11	16.71	3
221122)	9	21.87	2
2212)	6	14.91	5
222)	8	14.4	6

Table 12. Reduction of percent total deviance for variables at nodes in the regression tree analyzing refined ecosite values with field data, as data can no longer be split and ecosite values were classified. The pattern and numbering of nodes is shown in this table (first column) to reflect branching of the tree.

Node	Num.Obs.	Deviance	Classification
0)	190	646.2	2
1)	95	213.4	2
11)	31	40.87	3
111)	6	10.41	2
1111)	5	0	2
1112)	1	0	1
112)	25	0	3
12)	64	100.8	2
121)	58	60.94	2
1211)	45	25.86	2
1212)	13	17.32	2
12121)	7	8.376	4
12122)	6	0	2
122)	6	5.407	5
2)	95	232.4	5
21)	62	95.94	5
211)	52	59.37	5
2111)	26	0	5
2112)	26	45	5
21121)	19	24.06	5
21122)	7	8.376	4
212)	10	13.86	5
22)	33	51.04	7
221)	8	11.09	6
222)	25	25.02	7
2221)	12	0	7
2222)	13	17.32	7
22221)	5	0	7
22222)	8	10.59	8

Predicted ecosite values using the classification methodology described in this study were 85% correctly classified when compared to classification of observed conditions generated by R (Kuhn 2008). Predicted ecosites were 54 % correctly classified

when the original ecosite classifications currently used in NB were compared to observed conditions.

Classification matrices for the refined classification and the original ELC map (Appendix 7) were analysed (Table 12) and revealed that the original ELC map had a greater total percentage of plots for ecosites 1, 2, 5, 6, and 8, however the refined classification indicated from 22% to 33% higher correct classifications for all ecosites except 6, which was 23% lower, most likely due to the inclusion of the NBDNR wetlands layer in the mapping process which replaced some wet areas with identified wetlands.

Table 13. Comparison between original ELC map and refined ecosite classification of number of plots, percent total plots, and percent correct classifications, per ecosite.

Ecosites		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Total plots per ecosite									
	Refined classification	1	56	25	14	56	5	27	6
	Original ELC map	6	61	25	7	58	8	9	16
% Total plots									
	Refined classification	1	29	13	7	29	3	14	3
	Original ELC map	3	32	13	4	31	4	5	8
% Correct classification									
	Refined classification	100	93	100	71	88	40	85	83
	Original ELC map	67	62	72	43	66	63	56	50
	Difference	33	31	28	28	22	-23	29	33

DISCUSSION AND CONCLUSION

Sampling

Results for ecosites 1 (n=1), 4 (n=14), 6 (n=5), and 8 (n=6) were inconclusive as there were not enough field plot samples to determine whether the DTW accurately represented soil moisture regime in these cases. Although, for the most part, they were classified correctly according to the analysis (100%, 71%, 40% and 83% respectively) there were not enough samples in any of these ecosites to have confidence in the results. This could be attributed to the fact that the sampling design distributed the number of plots to reflect the area distribution of the original ELC map of ecosites in the FMF, and since the areas of these ecosites are relatively smaller, too few plots were located in these areas. It would have been prudent to make adjustments to the design to explicitly ensure samples were collected in these particular locations.

Similarly results were reported for ablation and basal till due to the predominance of plots located on them. Not enough data were collected on all till types to make conclusions about each one, however soils in most of the FMF developed from ablation and basal till and the information for each is assumed to be representative of the study area.

Because the scale of field ecosite assessment was 10 meters surrounding a soil pit, the assessed field ecosite may differ from the ecosite for the forest stand within which the plot was located. The final determination of ecosite for a forest stand would require stand level assessment. The forest stand assessment might represent the original ELC map more closely than the small plots used to assess field ecosites. There were enough samples in the FMF on mid-range ecosites 2 and 5, with correctly classified predicted

values (93% and 88%, respectively) that we can assume the methods work and apply them to all locations.

The 74% increase in area of ecosite 7, from 35,000 to 62,000 hectares, indicated more fertile conditions than originally mapped. This is possible due to the inclusion of bedrock information in the final step of the refined ecosite classification method, which accounts for abundant nutrient availability from parent material sources that underlies many of the already moderately rich soils in the FMF. This is consistent with soils classified as nutrient poor (Colpitts et al. 1995) supporting stands of tolerant hardwood trees on high ridges in the area.

Drainage and DTW

It is important to recall that the extent of wet areas was delineated into DTW contours representing conventional drainage classes during conditions when the water level reaches the delineated borders of mapped water features on the landscape (…"tendency of the soil to be saturated"…) (Murphy et al. 2007c). This does not, however, necessarily mean that shallow DTW always indicates wet conditions, since drainage may change with soil morphology (notably soil texture and compaction), associated landform attributes (slope, slope position, elevation and aspect), geomorphology (how underlying bedrock has influenced topography), and surficial deposition (glacial deposits of till which form the soil parent material). Transects were established to highlight local variation in soil drainage across a particular soil, on a particular landform. They revealed the complexity of soil moisture regimes that could

arise in any one area, which can lead to multiple possible ecosite values for one soil/landform combination.

Soil Polygon Mapping

Simply looking at the shape of the land when driving through the FMF on a daily basis and noting the road network in relation to the soils maps we were able to infer that the DEM corresponded to locations where noticeable, large-scale changes in slope occurred between hilly areas and other areas of pronounced relief, and lowlands or floodplains, indicating changes in soil type. This was particularly evident in the morainal ridges of the Kennebecasis Valley and Belleisle Valley areas, where abrupt changes in slope occur between upper slope forests and lower slope, cleared farmland. This visual evidence lends confidence to relying on the DEM to make adjustments to soil polygons where associated soils cover these landforms.

Soil polygon adjustments to upland soils, based on topography, were not as frequent as those in wet areas. For example, in any given 10m grid cell perhaps three or four small adjustments were made in the upland soil borders, compared to the shape of the entire length of a soil border that followed the 0.10 DTW contour along a watercourse. This was expected since the original mapping follows landforms that are permanent in nature, while the DTW highlights many previously unmapped streams and wet areas. Existing hydrographic layers produced by manually digitizing streams and shorelines often do not show low-order and ephemeral streams that can contribute to extensive wet areas in a landscape (Murphy et al. 2007a), because these small watercourses are not revealed clearly in aerial photography. In a few instances, small soil

polygons were shifted in their entirety to conform to the DEM, especially in the area of a ridge top or sloped area that corresponded to landscape position information about that soil (CanSIS 2005).

This approach to soils mapping involved a somewhat subjective, intuitive method of delineation based on knowledge (gathered from soil survey reports) of soil morphology related to landform, parent material, soil moisture regime, and topography. However using the DEM and DTW as guides to manual editing of soil polygon borders ensured limited subjectivity. For finer-scale management planning, wet areas delineated by the manual process, serve to highlight less prevalent ecosite conditions that may exist, whereas an automated process may be limited by the parameters required to run the software, and thus some detail would be omitted at a fine scale.

Soil Fertility Classification

Knowledge of local landforms and the drainage characteristics of the deposited glacial till (Appendix 5) provided a means to relate drainage and soil morphology to variation in local soil moisture regime. Glacial till deposit and drainage characteristics of landforms have a general relationship to inherent fertility of the soil parent material, soil moisture regime and the release of nutrients (Gimbarzevsky 1964).

The current system for describing soil fertility (NBDNR internal unpublished draft) was established in 1997 in efforts towards ecosite classification, and subsequent use in creating forest management plans. It was based on expert knowledge of inherent soil fertility (NBDNR Chris Norfolk pers. commun.). In this study soil morphological attribute index values were assigned to increase as their effect on the tendency towards

greater soil richness increased. It was assumed for the purpose of this study that a greater measure of the attribute meant a greater tendency towards soil fertility. This isn't always necessarily so especially for very coarse textured soils where drainage is rapid. This was taken into consideration at each individual DTW/soil interaction in the refined ecosite classification. Some soils, although rich were placed at the bottom of their fertility ranking because they would be too rapidly drained to retain nutrients (Mark Colpitts pers. commun.). Most of these are found in glaciofluvial soils along watercourses.

Ecosite Classification

Between 1997 and 2007 various models for ecosite classification used in forest management planning were derived using an "expert system" to classify climate, soil drainage and soil fertility data (NBDNR internal unpublished draft - Chris Norfolk pers. commun.). Soil fertility in particular was classified from 1-4, or high to low. In 2004 drainage classification was modified using an early version of the DTW model (only applying three contours: 0-0.25m, 0.25-0.50m, and greater than 0.50m), and soils classified into three texture classes (fine, medium, coarse). Ecosite classification was then updated by applying the revised soil drainage classification.

The focus of this study was to investigate how geospatial data, the DEM and DTW in particular, could be incorporated into a method to refine ecosite classification and mapping. We have seen that it was possible to account for 30% more of the variation associated with observed conditions, using a combination of forest inventory and DTW data layers compared to using the original ELC forest ecosite classification layer for NB (Colpitts et al. 1995). This is perhaps not surprising, because the original version lacks

the topographic detail to discern the variations in soil moisture regimes across and within the polygon-based map units. This is also in agreement with Ruitenberg and van Groenewoud (1982) who identified soil drainage as “an important limiting factor” to accurate ecosite classification.

Also influential in this classification were vegetation type and forest cover type as they each appeared at numerous levels and nodes of the classification tree. Even though the DTW and mottles had influence in the final steps of refinement when classifying wet and dry ecosites. This highlights the importance of accurate monitoring and collection of vegetation and forest cover type data in any area of interest.

While the above result is specific to the FMF area, it is reasonable to assume that the same methodology can be applied across NB since the required geospatial data for the province exist. This would be a somewhat time consuming process one grid tile at a time for the province, but not so much that it wouldn’t be worth the effort at least as a verification of original soil mapping. The subjectivity involved in both realigning soils polygons and assigning ecosite values is limited by relying on the DEM and DTW, and is not in the method as much, rather in the degree of knowledge of landforms, soil morphology and water interactions which can only increase the effectiveness of the method.

Some of the uses associated with ELC refinement will undoubtedly affect forest planning operations and regulations and guidelines for forest use, including habitat delineations, ecological planning, and land development. Future work is anticipated to include refinement of DEM data, and data based on the DEM, with even greater geospatial resolution, to at least 1m or finer, using LiDAR (light detection and radar)

technology. Higher resolution will also improve wet areas mapping by capturing 1st order streams and associated wet areas not only in finer detail geospatially, but also will provide a basis for digital mapping of soil morphology and soil moisture regimes at the same resolution. Ultimately, the original polygon-based approach to ecosite classification will be transformed into raster-based mapping and contouring of topographically and landform-based ecosite attributes and processes.

References

Alberta Sustainable Resource Development 2005. Alberta Vegetation Inventory. http://www.srd.gov.ab.ca/index.html Accessed May 22, 2010.

Amacher, M. C., O'Neill, K. P., Perry, C. H. 2007. Soil vital signs: A new soil quality index (SQI) for assessing forest soil health. USDA Forest Service. Rocky Mountain Research Station. Research Paper RMRS-RP-65WWW.

Arp, P. A. 2002. Stream and lake-side harvesting. Atlantic Forestry Review 9(1): 36–37.

Arp, P. A. 2005. Soils for plant growth. Field and laboratory manual. Faculty of Forestry and Environmental Management. University of New Brunswick, Fredericton, NB.

Arp, P. A. 2007. SFMN wet-areas mapping project update: towards better forest management planning and operations practices. Knowledge Extension Workshop Sustainable Forest Management Research and Practice. Hugh John Flemming Forestry Centre, Fredericton, NB, Canada.

Arp. P. 2009. High-resolution flow-channel and wet-areas maps: a tool for better forest operations planning. Sustainable Forest Management Network Research Note Series No. 55. 6p.

Arp, P. A., Meng, F. R., Bourque, C., Steeves, M. 2003. UNB's Nexfor/Bowater Forest Watershed Centre develops high-technology tools for better management of forested watersheds. The Forestry Chronicle 79 (1): 26-27.

Brady, N. C., Weil, R. R. 2002. The Nature and Properties of Soils. 13th edition. Pearson Education Inc., Upper Saddle River, New Jersey.

Canadian Soil Information System 2005 http://sis.agr.gc.ca/cansis Accessed June 15, 2007.

Colpitts, M. C., Fahmy, S. H., MacDougall J. E., Ng, T., McInnis, B., Zelazny, V. 1995. Forest soils of New Brunswick. NB Department of Natural Resources, Timber Management Branch, Fredericton, NB.

ESRI (Environmental Systems Research Institute, Inc.). 2008. ArcMap Version 9.3 http://www.esri.com/.

Fahmy, S. H., Colpitts, M. C. 1995. Soils of the Fundy Model Forest. NB Department of Natural Resources, Timber Management Branch, Fredericton, NB. CLBRR Contribution No. 95-56.

Fahmy, S. H., Colpitts, M. C. 1997. Forest soils interpretation for tree production in the Fundy Model Forest. NB Department of Natural Resources, Timber Management Branch, Fredericton, NB. PRC Contribution No. 97-01.

Foreman K. 2009. Alberta's new wet-areas mapping initiative. Bios 24(4): 6.

Gimbarzevsky, P. 1964. The significance of landforms in the evaluation of forest land. Pulp and Paper in Canada 65(7): 302-317

Holehouse, D. 2009. Wet areas mapping - the new wave in surprise-free land management. The Edge Forest Innovation. November 2009. pp. 6-7.

J.D. Irving, Limited. 2005. Development of improved depth to water table maps. J.D. Irving, Limited. Saint John, New Brunswick.

Keys, K., Neily, P., Quigley, E., Stewart, B. 2003. Forest ecosystem classification of Nova Scotia's model forest. Nova Scotia Department of Natural Resources. Truro, N.S.

Kuhn, M. 2008. Building predictive models in R using the caret package. Journal of Statistical Software 28(5): 1-26

Loucks, O. L. 1962. A forest classification for the Maritime Provinces. Proceedings of the Nova Scotia Institute of Science 25(2): 86-167.

MacDougall, A., Loo, J. 1996. Fine-scale community types of the Fundy Model Forest in south eastern New Brunswick. Canadian Forest Service – Atlantic Forestry Centre, Natural Resources Canada, Fredericton, NB. Information Report M-X-198E.

Meng, F.R., Castonguay, M., Ogilvie, J., Murphy, P., Arp, P.A. 2006. Developing a GIS-based flow-channel and wet-areas mapping framework for precision forestry planning. International Precision Forestry Symposium. 5-10 March 2006. Symposium Programme - "Precision Forestry in plantations, semi-natural and natural forests". University South Africa, Stellenbosch, South Africa. pp. 43-45.

Moore, J. 2007. Achieving greater precision in forest ecosite classification and mapping. Fundy Model Forest, Sussex, NB.

Moosmayer, H. U., Schöpfer, W., Kublin, E., Tuch, U. 2003. Site-mediated effects of growth changes of Norway spruce in Baden-Württemberg. (Original Title: Standörtliche Einflüsse auf Wachstumsänderungen der Fichte in Baden-Württemberg.) Mitteilungen des Vereins für Forstliche Standortskunde und Forstpflanzenzüchtung, 42: 23-30.

Murphy, P.N.C., Ogilvie, J., Castonguay, M., Connors, T. Meng, F.R., Arp, P.A. 2006. DEM-derived flow channel and wet area mapping: a new tool for forest operations planning. Sustainable Forest Management Network, Fourth International Conference. Edmonton, AB, Canada.

Murphy, P.N.C., Ogilvie, J., Castonguay, M., Meng, F.R., Arp, P.A. 2007a. Verifying calculated flow accumulation patterns of mapped and unmapped forest streams by culvert location. The Forestry Chronicle 83 (2): 198-206.

Murphy, P.N.C., Ogilvie, J., Connor, K., Arp, P.A. 2007b. Mapping wetlands: a comparison of two different approaches for New Brunswick, Canada. Wetlands 27(4): 846-854.

Murphy, P.N.C., Ogilvie, J., Meng, F.R., Arp, P.A. 2007c. Stream network modelling using LiDAR and photogrammetric DEMs: a comparison and field verification. Hydrological Processes. Published online in Wiley InterScience (www.interscience.wiley.com) DOI: 10.1002/hyp.6770

Murphy P. N. C., Ogilvie, J., Castonguay, M., Zhang, C., Men, F. R., Arp, P. A., 2008. Improving forest operations planning through high-resolution flow-channel and wet-areas mapping. The Forestry Chronicle 84(4): 568-574.

New Brunswick Department of Natural Resources. 1985. Reference manual for forest site classification in New Brunswick. Timber Management Branch. Fredericton, NB.

New Brunswick Department of Natural Resources 2006 http://www.gnb.ca/0078/minerals/index-e.asp Accessed May 2006

New Brunswick Department of Natural Resources. 2006. New Brunswick wetland classification for 2003-2012 photo cycle. Fish and Wildlife Branch. Fredericton, NB.

New Brunswick Department of Natural Resources. 2007. Our Landscape Heritage: The Story of Ecological Land Classification in New Brunswick. The Ecosystem Classification Working Group New Brunswick Department of Natural Resources, Fredericton, New Brunswick.

New Brunswick Department of Natural Resources and Energy. 2003. New Brunswick Natural Resources and Energy Data Dictionary. New Brunswick Department of Natural Resources and Energy, Fredericton, New Brunswick

Rampton, V. N., Paradis, S. 1981. Quaternary geology of Amherst map area (21H), New Brunswick. Map Report 81-3. Mineral Development Branch. Department of Natural Resources, Fredericton, New Brunswick.

Šamonil, P., Viewegh, J. 2005. Forest site classification of forest ecosystems in Bohemian Karst (Czech Republic). Forest Science 51: 508-518.

Schlatter, J.E., Gerding, V. 1995. A method of site classification for forestry production: a Chilean example. (Original Title: Método de clasificación de sitios para la producción forestal, ejemplo en Chile.) Bosque 16: 13-20.

Service New Brunswick. 2007a. Digital Topographic Data Base – 1998 (DTDB) - Information http://www.snb.ca/gdam-igec/e/2900e_1c_i.asp Accessed May 15, 2007.

Service New Brunswick. 2007b. Geographic Data and Maps - Information http://www.snb.ca/gdam-igec/e/2900e_1d_i.asp Accessed December 1, 2007

Smith, C.W., Pallett, R.N., Kunz, R.P., Gardner, R.A.W., du Plessis, M. 2005. A strategic forestry site classification for the summer rainfall region of southern Africa based on climate, geology and soils. ICFR Bulletin Series, No. 03/2005. 32 p.

Thwaites, R. 2002. Spatial terrain analysis for matching native tree species to sites: a methodology. New Forests 24: 81-95.

van Groenewoud H. and Ruitenberg, A. A. 1982. A productivity oriented forest site classification system for New Brunswick. Department of the Environment, Canadian Forest Service, Maritimes Forest Research Centre, Fredericton, N.B. Information Report M-X-136.

Vega-Nieva D.J., P.N.C. Murphy, M. Castonguay, J. Ogilvie, and P.A. Arp. 2009. A modular terrain model for daily variations in machine-specific forest soil trafficability Can. J. Soil Sci. 89: 93-109, 10.4141/CJSS06033

Wall, A., Westman, C.J. 2006. Site classification of afforested arable land based on soil properties for forest production. Canadian Journal of Forest Research 36: 1451-1460.

Zelazny, V. 1984. Toward a forest site classification for the New Brunswick lowlands ecoregion. University of New Brunswick, Faculty of Forestry MScF Thesis 2871.

Zelazny, V., Veen, H., Colpitts, M.C. 1997. Potential forests of the Fundy Model Forest. Fundy Model Forest and New Brunswick Department of Natural Resources and Energy. Forest Management Branch. Fundy Model Forest, Sussex, NB.

Zhang, Y.G., Beernaert, F. 2002. Interpretation and compilation of Landsat TM imagery for land-use and site classification mapping in the Korqin Sandy Lands, NE China. Chinese Forestry Science and Technology 1(3): 6-19.

Appendices

Appendix 1: Names of Soils in the FMF (Colpitts et al. 1995)

SOIL	SOIL NAME
SS	Saltspring
TD	Tracadie
IN	Interval
SA	Salisbury
PR	Parry
HT	Harcourt
LL	Long Lake
BR	Britt Brook
EB	Erb Settlement
BB	Barrieau-Buctouche
BE	Becaguimec
CH	Cornhill
SB	Stony Brook
TT	Tetagouche
PT	Parleeville-Tobique
CT	Catamaran
TU	Tuadook
KI	Kingston
JU	Juniper
PD	Popple Depot
KN	Kennebecasis
IR	Irving
RE	Reece
JR	Jacquet River
MV	Mafic Volcanic
GF	Grand Falls
SN	Sunbury
SP	Serpentine
PI	Pinder
FA	Fair Isle
LO	Lomond

RI	Riverbank
BD	Big Bald
GG	Gagetown
OS	Organic Soil

Appendix 2a: NBDNR Rock Types (Colpitts et al. 1995)

This table was created by NBDNR staff based on Figure 4 in the citation (Chris Norfolk pers. commun.)

RockType	Description	Properties
aC	arkosic conglomerate	acid sedimentary
aH	arkosic shale	acid sedimentary
aI	arkosic siltstone	acid sedimentary
aS	arkosic sandstone	acid sedimentary
C	conglomerate	acid sedimentary
cC	calcareous conglomerate	calcareous
cH	calcareous shale	calcareous
cI	calcareous siltstone	calcareous
cS	calcareous sandstone	calcareous
H	shale	acid sedimentary
I	siltstone	acid sedimentary
L	limestone	calcareous
qS	quartzose sandstone	acid sedimentary
S	sandstone	acid sedimentary
fA	felsic agglomerate	acid igneous
D	diorite	basic igneous
fV	felsic volcanics	acid igneous
G	gabbro	basic igneous
mV	mafic volcanics	basic igneous
O	granodiorite	acid igneous
Z	granite	acid igneous
E	slate	acid sedimentary
F	phyllite	acid sedimentary
M	schist	acid sedimentary
N	gneiss	acid igneous
Q	quartzite	acid sedimentary
qM	quartzose schist	acid sedimentary
T	chert	acid sedimentary
B	basalt	basic igneous
aSe	arkosic sedimentary	acid sedimentary
cSe	calcareous sedimentary	calcareous
OM	organic matter	organic
mA	mafic agglomerate	basic igneous
cE	calcareous slate	calcareous

Appendix 2b: NBDNR Soil Drainage Classes (NBDNRE 2003)

Drainage Class	Description
1	dominantly rapidly drained with significant well drained
2	dominantly well drained with significant rapidly or moderately well drained
3	dominantly moderately well drained with significant well or imperfectly drained
4	dominantly imperfectly drained with significant moderately well or poorly drained
5	dominantly poorly drained with significant imperfectly or very poorly drained
6	dominantly very poorly drained with significant poorly drained and organic soil
7	organic soil

Appendix 3: List of Canadian Soil Information System survey reports consulted for this study (CanSIS 2005)

Report #	Report Title	Edition
NB10SU	Soils of the Sussex Area of New Brunswick	10th report of the NB Soil Survey, 1986
NB7	Soils of Northern Victoria County New Brunswick	7th report of the NB Soil Survey, 1976
NB9	Soils of the Rogersville-Richibucto Region of New Brunswick	9th report of the NB Soil Survey, 1983
NB8	Soils of Madawaska County New Brunswick	8th report of the NB Soil Survey, 1980
NB9538	Forest Soils of New Brunswick	1995
NB95-56	Soils of the Fundy Model Forest	1995
NBFA	Soils of New Brunswick	1986

Appendix 4: Soil Texture Classes (Colpitts et al. 1995)

Soil texture classes

Coarse		Medium		Fine	
S	sand	L	loam	SCL	sandy-clay-loam
LS	loamy-sand	SiL	silty-loam	CL	clay-loam
SL	sandy-loam			C	clay

Appendix 5: Drainage characteristics of landforms in the FMF (Colpitts et al. 1995)

LANDFORMS (Deposits of glacial till)	DRAINAGE ATTRIBUTES	RELATIVE DRAINAGE BY LANDFORM (%)		
		RAPID/ WELL	MODERATE/ IMPERFECT	POOR/VERY POOR
ABLATION	Deep, non- compact, medium to coarse textured till; well to rapidly drained	81	17	2
ABLATION/ RESIDUAL	Medium depth over bedrock, medium to coarse textured till; well to moderately-well drained	86	14	0
ALLUVIUM	Deep, compact, medium textured till; imperfectly to moderately-well drained	17	67	16
BASAL	Shallow to deep, compact till, fine to medium parent material (3 soils have medium to coarse textured solum); well to poorly drained	30	60	10
GLACIO-FLUVIAL	Deep, coarse, gravelly textured till; poorly to rapidly drainage	55	9	36
GLACIO-MARINE	Deep, compact, fine to coarse textured till; poorly to moderately-well drained	NO FIELD SAMPLES WERE LOCATED ON THIS TILL		
RESIDUAL	Shallow to medium depth over bedrock, fine to coarse textured till; moderately-well to rapidly drained	60	40	0
RESIDUAL/ ABLATION	Medium depth over bedrock, fine to medium textured till; well to rapidly drained	100	0	0

Appendix 6a: Forest Unit Name Descriptions (New Brunswick Department of Natural Resources and Energy 2003)

AF Alders on a field

BFIH Forest stand comprised primarily of balsam fir and shade intolerant hardwood

BFSP Forest stand comprised primarily of balsam fir and spruce

BFTH Forest stand comprised primarily of balsam fir and shade tolerant hardwood

IHSP Forest stand comprised primarily of shade intolerant hardwood and spruce

IHTH Forest stand comprised primarily of shade intolerant hardwood and shade tolerant hardwood

INHW Forest stand comprised primarily of shade intolerant hardwood

OTSW Forest stand comprised primarily of softwood species other than pine, spruce or balsam fir

PINE Forest stand comprised primarily of pine

RGHW Regenerating forest stand comprised primarily of commercial hardwood species

RGSW Regenerating forest stand comprised primarily of commercial softwood species

SPBF Forest stand comprised primarily of spruce and balsam fir

SPIH Forest stand comprised primarily of spruce and shade intolerant hardwood

SPTH Forest stand comprised primarily of spruce and shade tolerant hardwood

STUN Regenerating forest stand of unknown species composition

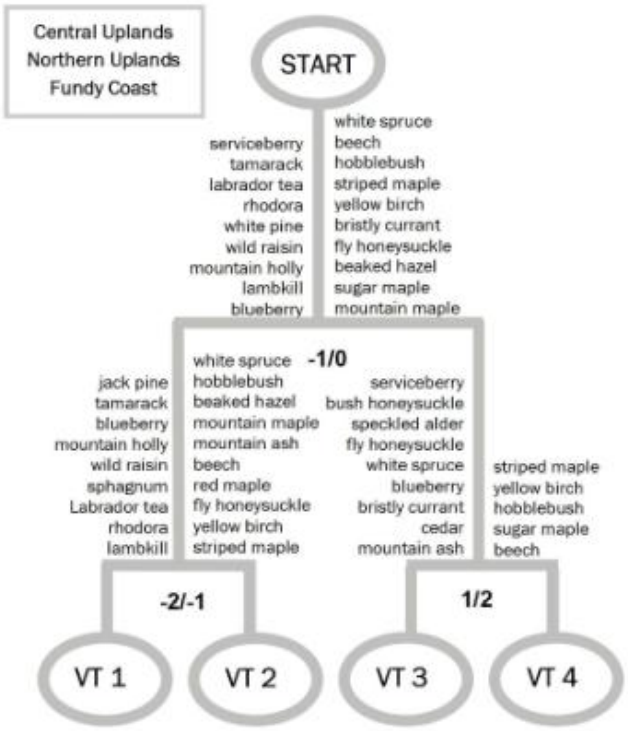
THBF Forest stand comprised primarily of shade tolerant hardwood and balsam fir

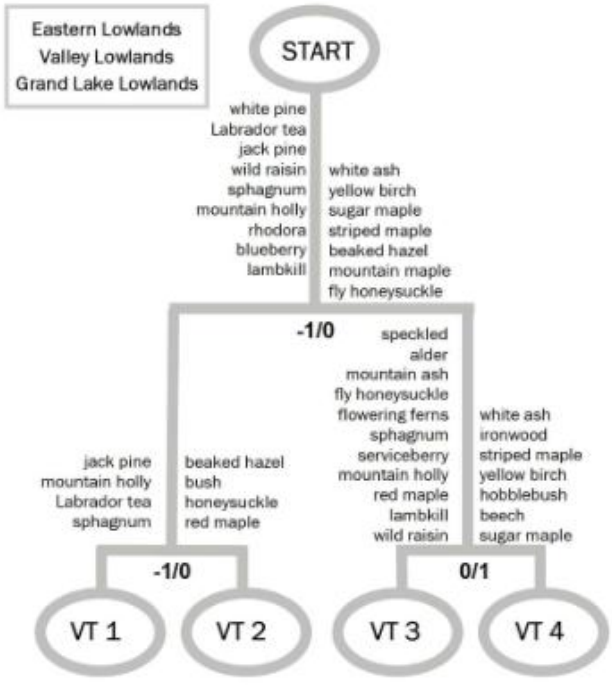
THIH Forest stand comprised primarily of shade tolerant hardwood and shade intolerant hardwood

THSP Forest stand comprised primarily of shade tolerant hardwood and spruce

TOHW Forest stand comprised primarily of shade tolerant hardwood

Appendix 6b: Keys used to determine vegetation type in the FMF (NBDNR 2007)





Appendix 7: Summary statistics for field data and original ELC mapped values compared to refined ecosite values

Field data compared to refined ecosite values.

	d.f.	Total	Mean
Residual deviance	174	100	0.574712644
Total Deviance	190	646	
psuedo-R^2		0.845201238	
	misclass	total	rate
misclassifications	22	190	0.115789474

classification matrix

Observed	Predicted Class							
Class	1	2	3	4	5	6	7	8
1	1	0	0	0	0	0	0	0
2	0	52	0	2	0	0	0	0
3	0	2	25	0	0	0	0	0
4	0	0	0	10	2	0	0	0
5	0	1	0	2	49	0	2	0
6	0	0	0	0	0	2	2	0
7	0	1	0	0	2	3	23	1
8	0	0	0	0	3	0	0	5

Original ELC mapped values compared to refined ecosite values.

	d.f.	Total	Mean
Residual deviance	167	322.4	1.930538922
Total Deviance	190	698.2	
psuedo-R^2		0.538241192	
	misclass	total	rate
misclassifications	70	190	0.368421053

classification matrix

Observed	Predicted Class							
Class	1	2	3	4	5	6	7	8
1	4	1	2	0	1	1	0	1
2	0	38	3	0	9	2	0	1
3	0	3	18	0	1	0	0	0
4	0	2	0	3	1	0	0	1
5	0	5	2	2	38	0	4	2
6	0	8	0	0	2	5	0	3
7	0	4	0	2	2	0	5	0
8	2	0	0	0	4	0	0	8