Cariboo PEM: Predictive Ecosystem Mapping Knowledge Base and Attribute Summary

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1.0 Introduction

This report provides documentation of the inputs and modeling procedures used in the production of the predictive ecosystem map (PEM) for the former Cariboo Forest Region in B.C. The former Cariboo Forest Region occupies approximately 8.2 million ha in the south central portion of B.C. (Figure 1).

The PEM modeling was undertaken by the first author, Dr. R. A. (Bob) MacMillan of LandMapper Environmental Solutions Inc., with the support and collaboration of Ray Coupé, the Regional Research Ecologist for B. C. Ministry of Forests and Range, Southern Interior Region.

Design and implementation of the PEM modeling procedures was strongly influenced by both Dr. David Moon of CDT-Core Data Technologies Inc. and by Ray Coupé, B.C. MFoR.

However, this document was prepared solely by the first author, who assumes full responsibility for any errors, omissions or inconsistencies in the description of inputs or modeling procedures.

The descriptions presented here represent a reworking and updating of materials contained in previously written project reports (MacMillan , 2004, 2006 a,b) and a journal article (MacMillan et al., 2007).

Figure 1. Location and extent of the former Cariboo Forest Region PEM map area.

1.1 Background, project history and project organization

The Cariboo PEM was a cooperative project, initiated in 2002 by a group of timber licensees under the auspices of the Cariboo Site Productivity Assessment Working Group (C-SPAWG). This group developed a vision for producing a single, comprehensive and consistent PEM map of ecological entities for the entire extent of the former Cariboo Region in support of a variety of forest management and planning objectives. They championed the project, located and provided funding for it and undertook its management.

In the first instance, the primary intended use of the PEM map was to be as a principal input to efforts to assess forest site productivity with a view to revising estimates of annual allowable cut. As the PEM project progressed, the list of potential uses changed and expanded to reflect changing circumstances, in particular the un-expected effects of the Mountain Pine Beetle (MPB) infestation. For example, the PEM map has already been used for planning MPB salvage operations and as an input to wildlife habitat assessment projects.

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The overall Cariboo PEM project was a collaborative effort with contributions made by a variety of consulting companies, government employees and forest industry client representatives. This report is restricted to describing the inputs and methods utilized in the LandMapper Environmental Solutions Inc. (LMES) PEM modeling process. The LMES PEM modeling represents a significant component of the overall project, but other contributions that are not described in this report were made by other contributors.

Preparation of many of the key input data layers was completed by contractors employed by private sector companies Timberline Forest Inventory Consultants Ltd., JMJ Holdings Inc. and Meridian Mapping Ltd. Employees of the B.C. Ministries of Sustainable Resource Management (MSRM) and Forests and Range (MFoR) assisted with acquisition of government owned TRIM, VRI and satellite imagery data. The localized ***Large Scale Biogeoclimatic mapping*** (Big BEC) was prepared by the Ministry of Forests and Range under the supervision of the Regional Ecologist. Description of the methods and results associated with preparation of these critical input layers is outside the scope of the present report and is provided in other reports written by the individuals and companies who prepared these other data layers.

The project owes much of its original design to Dr. David Moon of CDT Core Decision Technologies Inc., who was engaged as the project manager, technical advisor, and project monitor by the forestry industry clients and who advised them as to how to design and organize a PEM project that was likely to be successful in meeting their information needs and in achieving an acceptable level of predictive accuracy at a reasonable cost. Details of the rationale, history and development of the overall Cariboo PEM Project are provided in a separate project monitor's Cariboo PEM TSA Final Report (Moon et al., 2008).

A number of individuals were engaged by the forest industry clients to provide project management services. For the initial PEM pilot, the Canim Lake operational pilot and the initial Quesnel PEM, project Dr. David Moon, acted as project designer, project technical monitor, project manager, and QA/QC authority. In these initial projects contract management services were supplied by Tracy Earle (Lignum Ltd.) and Sandra Neill. For the greater part of the operational PEM mapping, project management was provided by Nona Philips of Nona Philips Forestry Consulting. Project managers secured the funds, devised and wrote the contracts and supervised and coordinated the activities of the various i contributors.

Other than the Big BEC, the major activity that required field work was the collection of field observations along randomly selected traverses for use in assessing the accuracy of the final PEM maps. This work was carried out independently, at arm's length from LandMapper, by ecological experts employed by Timberline Forest Inventory Consultants Ltd. under the direction of Mr. Shikun Ran, with correlation provided by The Regional Ecologist. In order to ensure that the data collected to assess the accuracy of the maps were not used in any way in the production or revision of the maps, LandMapper was never provided with any access to the field data and was not even told the locations where accuracy traverses had been made. Discussions pertaining to the collection, interpretation or use of the accuracy assessment field data are therefore also outside the scope of this report. Reports describing the accuracy assessment field procedures and analytical methods have been prepared and submitted separately by the responsible parties.

Assessment of the relative accuracy of the PEM maps produced using the LMES modeling procedures was carried out by Dr. David Moon of CDT-Core Decision Technologies Inc. using ground truth data collected in the field by the Timberline's teams of locally experienced ecologists. Accuracy assessment was conducted using procedures developed specifically for the project and adopted as a provincial standard (Moon et al. 2005). Three final accuracy reports have been prepared, one for each TSA (Moon, 2008 abc).

LMES delivered its final products as raster maps in ESRI GRID format. These GRID maps were turned into final cartographic products in topologically structured ESRI vector format for submission to the provincial LRDW and for use by the clients by GISmo Solutions Inc. under the supervision of Ms. Cindy Post. Submission of all final maps, legends, look-up tables and documentation to the provincial LRDW was undertaken by the project technical monitor, Dr. David Moon.

Organization and response to project audits was undertaken by the project manager, Ms. Nona Philips.

2.0 An overview of the LMES DSS procedures

LandMapper Environmental Solutions Inc. (LMES) employed a set of in-house programs referred to as the LandMapR toolkit to produce predictive ecosystem maps (PEM) for the Cariboo PEM project using a set of procedures referred to as the LMES Digital-Direct-to-Site-Series (LMES DSS) method.

This section provides a brief overview of the LMES DSS procedures (Figure 2) in order to provide readers with the context required to understand why the input layers described and documented in the main portion of this report were selected, how they were used and where they were used.

The report then documents the methods applied to manually prepare or automatically compute each of the input layers used in the LMES DSS procedures.

Finally, the report explains the process used to create and apply heuristic rules to extract output classes from the input data layers. Examples are provided of how each layer or variable was used to define either hard (Boolean) classes or soft (Fuzzy) classes that were subsequently used to predict the spatial distribution of ecological site units (Site Series and non-forested ecological classes).

The PEM entities produced by the modeling procedures are documented in a separate report and appendix (MacMillan et al., 2008b).
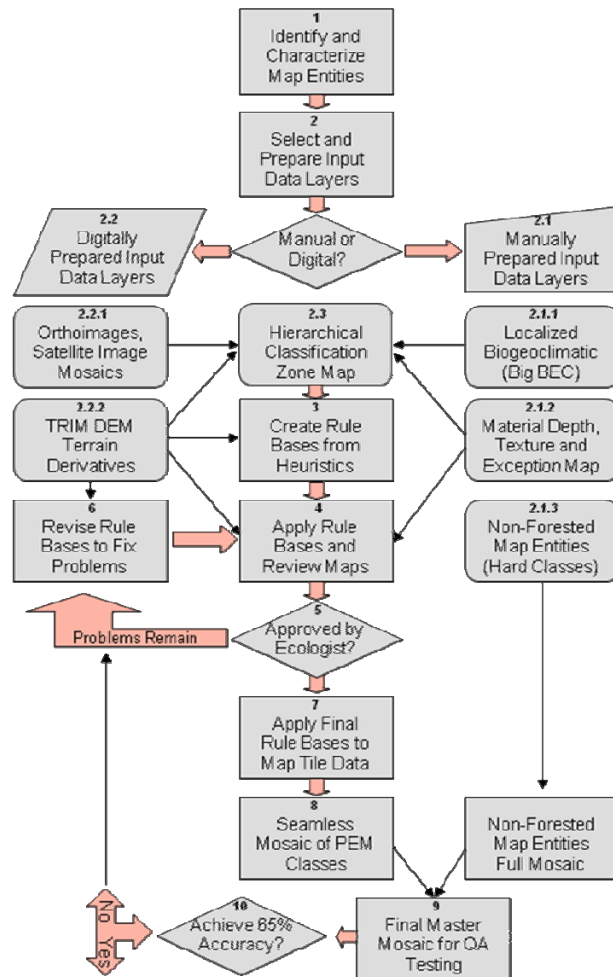
Figure 2. Flow diagram illustrating the major steps in the LMES PEM mapping process

The methods described here (see Figure. 2) comprise a hybrid of automated, semi-automated and manual procedures that develop and apply heuristic, rule-based conceptual models of ecological-landform and soil-landform relationships in a manner similar to the CLORPT or SCORPAN approaches, as described by McBratney et al. (2003). The procedures attempt to directly parallel, or mimic, the logic and decision making process followed by local ecological experts as outlined in "A Field Guide to Forest Site Identification and Interpretation for the Cariboo Forest Region" (Steen and Coupé, 1997).

The LMES DSS procedures strive to adhere to the ***principal of parsimony***, otherwise known as ***Ockham's Razor***, which states that all models should try to utilize as few input variables as possible to achieve their goals while at the same time using as many variables as are absolutely necessary. Experience in developing and applying the LMES DSS procedures in the initial projects in the former Cariboo Forest Region led to recognition of a more or less standard set of both automatically and manually prepared input layers that were judged to be necessary and sufficient to capture and apply all relevant ecological concepts for all Biogeoclimatic Ecosystem Classification (BEC) Subzones located in this Region.

2.1 Step 1: Identify and characterize the mapping entities.

The first step in the LMES PEM mapping process is to identify, list and describe the spatial entities that are to be predicted for each unique ecological zone or classification region (See Figure 2, item 1).

For the Cariboo PEM, wherever possible, this process made use of existing documentation as presented in published Field Guides, and in particular in the Field Guide for the former Cariboo Forest Region (Steen and Coupé, 1998). For a number of BGC units, there was no finalized and published Field Guide or classification system. In these instances, the Regional Research Ecologist (Ray Coupé) was consulted and asked to prepare a list of provisional Site Units and to indicate, to the best of his knowledge, the conditions and landscape positions under which these Site Units were believed to occur. In several instances, the list of potential Site Units to model, and the conditions under which they were believed to occur, was obtained through consultation of Field Guides for adjacent forest regions (e.g. Prince George or Kamloops).

All LMES PEM map entities were treated as relatively simple 3D conceptual models. Each entity was viewed as occurring in a particular part (or parts) of the landscape under a relatively restricted set of defining site conditions. These conditions included, but were not limited to, relative slope position (e.g. crest versus mid versus toe), aspect or orientation, slope gradient, relative moisture regime, other contextual conditions (e.g. proximity to a wetland or stream) and, occasionally general vegetative land cover class.

Each of the PEM map entities produced by application of the LMES DSS PEM procedures was envisaged as representing a particular **compartment** or **segment** of the landscape along a **toposequence** from a local crest or divide to a local channel or depression. Each of these **compartments** or **segments** was thought of as an **environmental setting** or **landscape situation** that was characterized by a limited and describable range of site conditions. The site conditions in each **environmental setting** were, in turn, associated with a limited and describable population of ecological site types (Site Series and non-forested ecological entities) subjectively considered most likely to occur under these conditions.

Each LMES PEM map entity is described as being occupied by a single dominant Site Unit. However, descriptions also include recognition that each mapped area is also very likely to include smaller proportions of secondary inclusions of other Site Units or non-forested ecological entities. Procedures used to assess the accuracy of the LMES DSS PEM maps only tested the ability of the PEM entities to identify a single dominant Site Unit for each entity. Consequently, any use of the maps for official purposes should treat each PEM entity as if it were occupied 100% by the dominant named Site Unit.

A more complete description of the methods used to identify, conceptualize and describe the LMES PEM map entities can be found in the introductory section of the separate report that describes and documents all of the PEM entities defined for the Cariboo PEM (MacMillan et al., 2008b).

2.2. Step 2: Select and prepare input-data

The second step in the LMES PEM mapping process is to select and prepare a number of input-data layers to use in the predictive process (See Figure 2, item 2). The input data layers were prepared in two different ways and were also used in two different ways.

2.2.1 Mostly manual inputs used mainly to define classification domains or zones

One set of input data layers was used to define and delineate domains or zones within which a single set of classification rules could be used to define and map a particular set of defined ecological classes at the level of individual Site Series or non-forested ecological entities (See Figure 2, item 2.3). Most (but not all) of the input layers used to create these zone files were prepared using more or less conventional manual methods of air photo interpretation combined with on-screen, heads-up digitizing. These inputs are identified in Figure 2 as manually-prepared input layers (See Figure 2, item 2.1).

Manual procedures were used to produce an updated, or localized, version of the Biogeoclimatic Ecosystem Classification (BGC) map for the entire extent of the former Cariboo region (referred to hereafter as Big BEC). This map established the spatial limits of BGC units within which PEM map entities at the level of Site Series were defined to occur (See Figure 2, item 2.1.1).

Manual procedures were also used to produce maps of parent material depth and texture and of ecological exception classes (See Figure 2, item 2.1.2). The "exceptions" maps were prepared over a period of 4 years by experienced air photo interpreters employed by private sector consultants Timberline Forest Inventory Consultants Ltd. and JMJ Holdings Inc. The intent of these maps was to use manual visual review of existing hard copy air photos, digital orthoimagery, TRIM vectors and secondary source maps (e.g. soils or geology) to isolate and delineate areas that represented "exceptions" to normal, expected conditions rapidly and affordably. Once identified, the boundaries of such "exception areas" were edited or digitized on-screen using heads-up digitizing against a backdrop of a digital orthoimage.

With respect to parent material, all parts of a map area were assumed to be occupied by medium textured parent materials, except for those "exception areas" where the texture was notably coarser, finer or organic. Interpreters reviewed maps and imagery to identify and digitize boundaries around areas that they felt were likely to be coarser or finer than normal or to be occupied by organic soils. Similarly, all parts of an area were considered to have a depth to bedrock of 100 cm or greater except for "exceptions areas" where the manual interpreters felt the depth to bedrock was shallow (< 50 cm) (See Figure 2, item 2.1.2).

The interpreters also identified and digitized boundaries for all areas that were clearly non-forested, such as open water, wetlands, pastures, meadows or avalanche tracks. These manually delineated areas were extracted from the "exceptions map" and retained as a separate grid coverage that was "cookie-cut" into the final PEM map to retain hard boundaries for all such manually mapped entities (See Figure 2, item 2.1.3).

In the initial stages of the Cariboo PEM (PEM pilot and Canim Lake PEM) manual interpretation and mapping procedures were also used to identify and delineate areas that differed from the norm in terms of size and scale of landforms or topography. Beginning with the Quesnel PEM, a semi-automated procedure was developed to analyse the digital elevation model (DEM) to classify landforms into areas of low, medium, high or very high relief. These maps of relief classes were then used, as one input, in the manual preparation of the hierarchical classification zone map (See Figure 2, item 2.3).

Some situations arose during PEM modeling that required additional manual delineation of areas that differed from the norm in terms of specific conditions such as prevalence of frost accumulation or presence of extremely long gentle, or long steep, slopes that exhibited unusual patterns of moisture accumulation. Such areas were also delineated manually and then used to over-ride or displace the initial sub-division of a Big BGC unit by landform relief class and parent material texture. Manual delineation was generally aided and guided by visual review of patterns evident in one or more of the terrain derivatives computed from the DEM (usually Log of Quinn Upslope Area) (See Figure 2, item 2.2.2).

In later stages of the Cariboo PEM project, several BGC units were encountered where it was deemed necessary to use land cover zones as the dominant means of sub-dividing BGC units in preparing the hierarchical classification zone map. In these BGC units, a physiognomic classification system existed in which each ecological class was defined as a cross product of land cover type intersected with physical considerations such as landform position or drainage regime. In these areas semi-automated procedures were used to classify an available LandSat false color image to define land cover classes within each Big BGC unit (See Figure 2, item 2.2.1). These land cover classes defined classification zones or domains within which a particular set of ecological classes that all developed under a particular land cover (e.g. bare soils, thin tundra, heather tundra, scrub brush, sparse parkland (krumholz) or thicker trees) might occur. In these areas, sub-divisions of the Big BGC units in terms of land cover classes over-rode and displaced any initial sub-divisions that had been based on physiography or parent material texture.

2.2.2 Digitally prepared input data layers used mainly to define PEM map entities using fuzzy logic

The second set of input layers was prepared by applying automated methods of analysis and classification to continuous data sets of digital data in grid or raster format. This set of digital input data layers (See Figure 2, item 2.2) was mainly used to define and delineate PEM map entities using classification procedures based on application of fuzzy logic. These digital data sets were also used, to a lesser extent, in the manual preparation of the hierarchical classification zone map (See Figure 2, item 2.3).

Most (but not all) of these automatically computed digital input layers were prepared through automated analysis and classification of a digital elevation model (DEM) prepared from the original source TRIM elevation data and organized as a 25 m grid or raster DEM (See Figure 2, item 2.2.2). Some of the digital inputs were extracted from a geo-registered false color satellite image, also organized as a 25 m raster grid (See Figure 2, item 2.2.1).

Inputs derived from the DEM are referred to as terrain derivatives (See Figure 2, item 2.2.2). Most terrain derivatives were computed from the DEM using functionality provided by the FormMapR module of the LandMapR toolkit. Several terrain derivatives were prepared using custom programs or scripts that were not part of the normal LandMapR toolkit but were written to compute specific inputs needed to capture particular concepts. These small custom programs mostly made use of output from the FlowMapR module of the LandMapR toolkit to "flow down" along simulated paths of surface water flow until some target cell (such as a lake, wetland, major river or exposed bedrock) was first encountered. The terrain derivatives were prepared and used in the belief that specific terrain derivatives could act as surrogates for, or predictors of, a particular defining aspect of a conceptual ecological-landform model (for example; slope position, relative moisture regime, orientation, steepness or shape).

The full list of terrain derivatives computed for, and used in, the PEM modeling for the former Cariboo Forest Region is presented and described in a Chapter 3. It is sufficient to know here that the terrain derivatives were used to define attributes of the terrain that were then used to help predict the likelihood that any location in the terrain belonged to, or was most properly classified as, a particular ecological entity (e.g. Site Series or non-forested ecological class). These terrain derivatives were used to provide an approximation of terrain attributes such as slope position, slope orientation (aspect), slope steepness, landform shape, moisture regime or landform context (e.g. proximity to lakes, streams or wetlands; elevation above water table or base level). Typically, most ecological classes in most Field Guides are defined in terms of site factors or conditions that reference concepts such as slope steepness, slope position, landform shape, slope orientation or moisture regime. Consequently, terrain derivatives can often be used as surrogates for these site factor conditions and can be used to predict the likelihood that any given location exhibits site conditions that are within the range established for a defined ecological class.

Digital data extracted from the geo-registered satellite image were not used very often in the initial PEM modeling efforts in the Cariboo. However, as the project progressed, more and more situations were encountered in which recognition and classification of defined ecological entities required information on the land cover at a particular location. This was particularly true for areas located in alpine, sub-alpine and grassland environments. In such areas, the type of land cover is often the first determinant considered in any classification.

The digital data from the satellite image were used in a number of different ways. In some cases, the raw digital numbers for bands 1 (red), 2 (green) and 3 (blue) of the false color image were extracted from the image and used as inputs to the fuzzy classification rules. The most common way of using the satellite image data was as an input to procedures that classified the image into land cover classes that were then used to define classification domains within specific Big BGC units where the classification system was based on consideration of land cover type.

Once all initial input layers were prepared, it was possible to move forward with preparing, applying and evaluating knowledge-based rules (KB rules) aimed at classifying and mapping defined ecological entities.

2.3. Step 3: Create fuzzy KB rule bases using existing expert knowledge

The third step in the LMES PEM mapping process is to develop initial rule bases using existing expert knowledge about what ecological entities exist in any given Big BGC unit and under what defining conditions each PEM entity is known, or believed, to occur (See Figure 2, item 3).

Within the extent of the former Cariboo Forest Region, this process of creating and codifying existing knowledge as fuzzy knowledge rule bases (KB rules) was entirely subjective and visual. The process was accomplished principally by visually relating maps of available digital inputs (mainly terrain derivatives) to concepts used to describe the site factors under which each ecological entity (Site Unit) in a given BGC unit was known, or believed to occur.

At the time of the original Cariboo PEM Pilot, LMES was assigned the challenge of doing the best job it could of predicting the spatial distribution of ecological classes using only currently available data and knowledge. LMES was explicitly prohibited from undertaking expensive and time consuming field exercises to collect data to help develop or train classification rules or to develop input data layers. The expectation was that the LMES approach would help to establish a "worst case" scenario associated with no opportunity to collect or use field data to build and apply knowledge bases to classify ecological entities.

Analysis of the results of the PEM Pilot indicated that the LMES approach actually produced the most accurate PEM maps of all the evaluated alternative approaches (Moon, 2005). As the LMES DSS approach was able to produce PEM maps of acceptable accuracy without the need to undertake expensive and time consuming field observations, the decision was made to apply the LMES DSS approach Cariboo-wide without attempting to collect field observations to guide and inform the development of KB rules.

The LMES DSS procedures do make extensive use of existing knowledge and local ecological expertise to develop rules for classifying ecological entities. In particular, the LMES DSS procedures were strongly based on the ability to consult, and make use of, the extensive local experience and knowledge possessed by the Regional Research Ecologist. An argument could be made that the LMES DSS procedures could not be applied or might not be successful, in any other locality without access to a local expert of similar experience and knowledge. The counter argument to this would be that, under such circumstances, it would be necessary to collect and utilize field observation data to replace the experience and knowledge of the local ecological expert.

For each BGC unit in any given project area, the list of ecological entities to model was developed by reviewing the appropriate published Field Guide and the list of provincially approved ecological map codes and then consulting the local ecological expert (the Regional Ecologist) to ascertain if there were any noted departures from the typical list. Often the Regional Ecologist could identify cases where certain site units did not occur within the current map area of interest or where the current area of interest might contain site units that departed from the typical description in where or how they occurred.

Once a list of potential ecological entities to model had been formulated (see Step 1), the criteria used to characterize and distinguish each ecological entity in a given BGC unit, as listed in the appropriate Field Guide or interim classification guides, were reviewed. Materials reviewed included ecological keys, Landscape Profile diagrams, Edatopic Grids, textual descriptions and site features summary tables. Of these, the ecological keys were found to provide the most definitive representation of ecological knowledge and classification rules.

Ecological keys are presented as a form of a binary decision tree that closely resembles decision trees produced using automated decision tree analysis (see Bui et al., 1999; Bui and Moran, 2001). Fortunately for the LMES PEM procedures, within the former Cariboo Forest Region, the criteria referenced by the ecological keys are almost exclusively related to observable physical site characteristics such as depth and texture of soils, slope gradient and exposure (aspect), relative position in the landscape, relative moisture regime, relative nutrient regime and, less commonly, a distinctive vegetative pattern or cover. Rules set out

in the ecological keys were regarded as definitive and if a particular location exhibited all of the physical site characteristics listed for a particular ecological class then, by definition, it was considered to be capable of being classified as that class and only that class.

Landscape Profile diagrams are the ecological equivalent of two dimensional cross sections prepared to illustrate conceptual soil-landscape models (Figure 3). Each Landscape Profile diagram attempts to capture and illustrate local tacit expert knowledge about how Site Series ecological classes are understood to be distributed in the landscape relative to the controlling factors of size and scale of the landscape, slope, aspect, relative landform position, moisture regime, soil depth and soil texture. Landform Profile diagrams act as helpful aids in trying to understand and visualize the concepts associated with each Site Series.
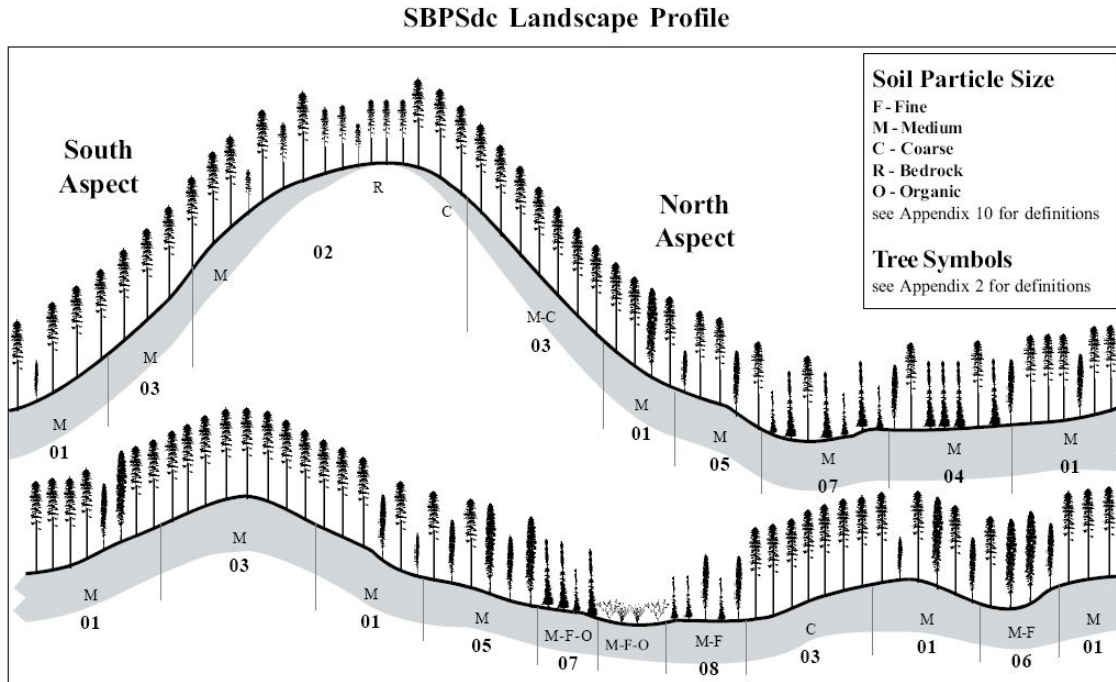
Figure 3. Example of a Landscape Profile Diagram for the SBPS dc BGC Subzone

Except where inadvertently incomplete or incorrect, the Field Guides, or interim classifications, identified, for each defined classification zone, all significant classes of ecological entities defined according to the BC Biogeoclimatic Ecosystem Classification (BEC) system of site classification (Pojar et al., 1987) and presented clear and mostly unambiguous rules for differentiating all recognized entities.

Our goal, then, was to translate this existing knowledge of ecological-landscape relationships into explicit, programmable rules that could be applied to available input data layers to automatically extract and classify the listed entities.

2.3.1 Capturing expert knowledge of ecological-landform relationships as fuzzy logic rules

The process of creating knowledge-based, or heuristic, rule bases is relatively straightforward and has been described in detail by MacMillan et al. (2007).

In short, each class identified in step 1 as one that should be predicted is defined using a fuzzy semantic import (SI) model, as described by Burrough (1989) and implemented by MacMillan et al. (2000). Each class of ecological entity is defined as a weighted linear average of a series of defining attributes; where attribute values are computed in terms of fuzzy membership functions that relate the value of an input

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parameter (e.g. slope gradient) to the likelihood of that value matching the concept of the class used to define the attribute (e.g. steep slopes).

In building rule bases, the knowledge engineer first has to decide which land-surface parameters, or other digital input values, appear to exhibit a consistent and predictable spatial relationship with the known, or anticipated, pattern of distribution of the class that is being predicted. The knowledge engineer then has to select a value, or, more often, a range of values, for each selected input variable that appears to give the best spatial match with the output class that is being investigated. This range of values is expressed as a fuzzy likelihood membership value, by using one of three fuzzy SI membership functions (Figure 4) as originally presented in Burrough (1989).
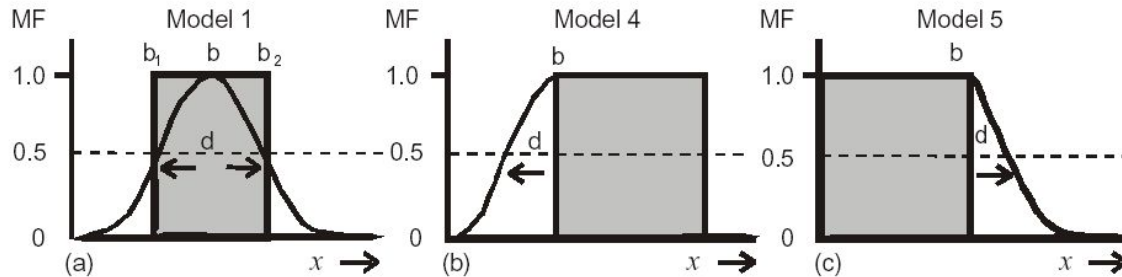
Figure 4. Three Fuzzy Semantic Import (SI) models used to compute fuzzy attribute membership functions

In Figure 4, the value for b is the value of the predictor variable that the knowledge engineer has elected to associate with complete likelihood that this value fully satisfies the concept being approximated by the variable. For example, to define the concept of a "steep slope" the knowledge engineer may select a value for b of 30% and a model 4. Model 4 in Figure 4 represents a one tailed model of the greater than variety. Any value of slope greater than 30% fully satisfies the requirement for membership in the attribute class of "steep slopes". The user selected value for d controls the dispersion or spread of the bell curve or one tailed curve. The value for d establishes the point on the curve at which the likelihood of the variable satisfying the requirement for membership in the fuzzy class being defined is 0.5 (or 50%). The larger the value selected for d the wider the spread and the more likely that values quite different than b will still be considered to have a high likelihood of belonging to the attribute class being defined.

Conversion of raw continuous or classed input variables into fuzzy values that express the likelihood of occurrence of a particular defining attribute class is accomplished using equation 1 as reported in Burrough et al., (1992) and MacMillan et al., (2000).

$$MF_x = \frac{1}{1 + \left[(x - b)/d\right]^2} * 100$$

(Equation 1)

Where MF_x is the membership function that describes the degree of fuzzy membership of value x of a given input variable for a defined attribute class such as being in a "crest" position or being a "steep slope". Values are selected manually and subjectively for b to define the central value (or upper or lower threshold value) for each defined attribute class and for d to establish a dispersion index which defines the point at which the computed MF_x value decreases to 0.5 (or 50 where integers are used).

In the LMES DSS PEM procedures, the rules for computing fuzzy membership values for attribute classes (fuzzy attributes) are recorded in an "arule" file. Each attribute class is created and defined to capture or approximate some attribute that is believed to be definitive for one or more ecological map entities to be predicted. The FacetMapR program used to apply the classification rules reads in the "arule" file to

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determine what fuzzy attribute classes need to be evaluated at any given location, what input variable to use to define each attribute class and where to go to find the values for any input variable selected to define an attribute class.

The second step in developing a fuzzy classification knowledge base involves defining and computing fuzzy membership values for all recognized ecological classes in each classification zone. The fuzzy membership value for each ecological class is computed as a weighted linear average of the fuzzy membership values for all attributes used to define that class according to equation 2 as presented in Burrough et al., (1992) and MacMillan et al., (2000).

$$JMF_A = \sum_{j=1}^{k} W_j * MF_{Aj} \qquad \text{(Equation 2)}$$

Where JMF_A is the overall fuzzy likelihood of a given site belonging to a given ecological class A; W_j is a value for relative weight to assign to each input attribute j used to define each ecological output class and MF_{Aj} is the fuzzy likelihood value computed for defining attribute j for class A using Equation 1 above.

The knowledge engineer subjectively decides on a value for the relative weight W_j to assign to each attribute used to define each class of ecological map entity being predicted. For any given attribute, the relative weights place more or less emphasis on its fuzzy likelihood value, thereby making some attributes more important than others when calculating the final overall weighted average for fuzzy membership in the particular ecological class being predicted. It would be possible to analyze training data sets to compute optimum values for relative weights, if a sufficiently large data set of correctly classified, and spatially located, observation points existed. In the absence of reliable training data, the subjective opinion of the knowledge engineer is used, reinforced by input solicited from the local ecological expert.

In the LMES DSS PEM procedures, the rules for computing overall weighted mean fuzzy membership values (Equation 2) for ecological spatial entities (Site Units) are recorded in a "crule" file. Each potential ecological output class is defined as a weighted linear combination of fuzzy likelihood values for those attributes that are considered to be definitive of that class. The FacetMapR program used to apply the classification rules reads in the "crule" file to determine how many ecological classes to define at any given location, what defining attributes to use to compute the overall mean fuzzy membership value for each class and what label to give to a cell that is determined to be best represented by a given ecological class.

The LMES DSS PEM procedures adopted the practice of constructing, revising and maintain all fuzzy KB rules for each BGC unit within a single Excel file. Each Excel file was subdivided into "workspaces" with one "workspace" for each unique classification zone in each BGC unit. Each workspace contained a working copy of the "arule" file used to define and compute attribute classes. The "crule" file used to define and compute fuzzy membership values for defined ecological map classes was situated adjacent to the matching "arule" file so that both could be viewed and consulted simultaneously. The workspaces also included a copy of the relevant Landscape Profile diagram to assist in remembering the conceptual models used to describe the spatial distribution of the defined ecological classes.

Examples of the LMES DSS workspaces used to construct and maintain fuzzy KB rules are provided in section 5 and in the standard templates used to describe and document the final PEM entities for each BGC unit in the former Cariboo Forest Region (see MacMillan et al., 2008b).

2.4. Step 4: Apply KB rule bases to produce interim PEM maps

The custom, in-house program (FacetMapR) used to compute fuzzy likelihood values for all defined ecological output classes first reads in a control file (a Zone file) that contains an integer ID number which identifies each unique classification domain or zone as defined by the hierarchical zone classification map prepared in Step 2. A paired set of attribute class "arule" and output class "crule" rule files is therefore needed for each unique classification zone within each defined BGC unit.

FacetMapR then reads in the appropriate "arule" file and computes the fuzzy membership likelihood value of each attribute class defined in the attribute rule table for each grid location in any given classification zone (MacMillan, 2003). The program then reads in the appropriate "crule" file and computes the overall weighted mean fuzzy likelihood value of each grid cell belonging to each of the ecological classes defined in the "crule" table for that classification zone.

FacetMapR computes a value for fuzzy likelihood of occurrence for only the specific classes defined for the specific classification zone that a particular grid cell belongs to. Once the likelihood of occurrence is computed for all possible ecological classes that might occur at any given grid cell, a single integer ID number is recorded to identify the output class with the largest fuzzy likelihood of occurring at that grid cell. This value is recorded in the field MAX_CODE in a DBF output file named ID#DSS, where ID# is a label used to identify a particular area for which calculations are being made.

The integer ID numbers stored in the field MAX_CODE in the DBF file ID#DSS are extracted from the DBF file and reformatted for import into a GIS (here ArcView 3.2 or ArcGIS 9.2) for visual review and assessment. Each unique integer GRID CODE is assigned a specific color in the GIS so that all instances of a particular PEM entity can be identified and differentiated visually, by color (see Figure 5).
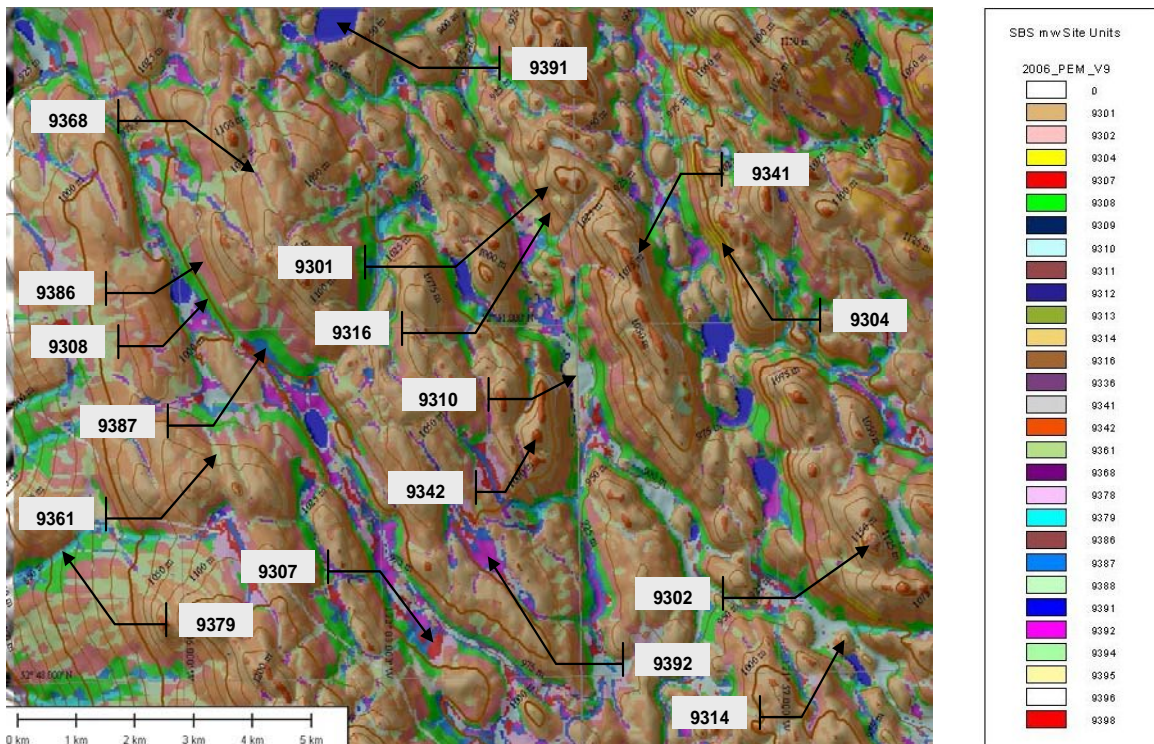
Figure 5. Illustration of a portion of a LMES DSS PEM map prepared for review and evaluation

The colors assigned to each unique LMES GRID CODE tend to follow a particular convention so that entities associated with wetter than mesic Site Units are assigned green or blue colors, entities associated with drier than mesic Site Units are assigned yellow, orange or light pink colors and normal mesic Site Units are typically assigned variations of brown colors that range from dark to medium to light (see Figure 5). Numbers that represent areas that may all eventually be classified as being occupied by the same dominant Site Units are still assigned different colors, so that they may be differentiated for review and assessment purposes. In the example presented in Figure 5, several different areas are assigned colors that are variations of brown. All of these areas were ultimately described as being dominated by normal mesic 01 Site Series, but it was useful to be able to differentiate them during the review and assessment process.

2.5 Step 5: The initial PEM maps are reviewed with the local ecological expert

Initial grid maps depicting the spatial extent and pattern of predicted ecological classes are reviewed visually to assess the degree to which the predicted and expected patterns match. The predicted pattern can be compared to either actual site locations classified in the field or, more routinely, to conceptual models formulated by someone who has considerable local experience (See Figure 2, item 5).

Conceptual models are presented in the Field Guides using ecological keys, 2D or 3D conceptual landscape profile diagrams, site-features tables or textual descriptions. The predicted pattern is first reviewed, by the knowledge engineer and the local ecological expert working together, to assess the degree to which the predicted classes match conceptual models in terms of a notional crest-to-channel toposequence of entities. Assessments are made of the extent to which the predicted entities follow a logical and expected sequence based on landform position, exposure, moisture conditions and slope gradient (See Figure 5).

Next, an assessment is made of whether the total amount or geographical extent of each predicted class matches well with the known or expected extent of each class. This assessment requires someone with considerable local experience to ascertain whether each predicted class occurs in about the correct geographic locations, and to about the extent, that they would expect; based on their experience.

The knowledge engineer takes notes of comments made by the local expert regarding logical inconsistencies in the spatial arrangement of predicted classes relative to the expected conceptual arrangement. Notes are also taken regarding whether specific instances of predicted classes are too spatially extensive or not extensive enough. Finally, notes are taken to record any comments that identify specific locations where a predicted class occurred where the local expert did not believe it should occur, or vice versa. These notes and comments are later used to revise and refine the KB rules to produce the next iteration of PEM maps.

After creating rules for more than fifty different ecological subzones, it has been observed that only a small number of iterations (2–4) have typically been required to create knowledge-based rules comprehensive enough to predict a relatively reasonable pattern of output classes for most BGC unit areas.

2.6 Step 6: Revise the KB rule bases in order to address problems

The observations and comments of the local ecological expert are used to revise and refine the rule bases (or input data sets) in order to remove or reduce errors that lead to what the local expert would consider an incorrect prediction of patterns (See Figure 2, item 6).

During each assessment, any classes that have been predicted in an incorrect toposequence order first have to be identified and the classification rules have to be manually adjusted to correct such errors. Once the rules are observed to produce a series of output classes occurring in approximately the desired locations along a toposequence, they are then refined further. This is done by adjusting the ranges associated with the defining attributes to either expand or contract a given output class, or to move the boundaries for a given output class either up or down slope. The rules can be adjusted by adding one or more attributes to the definition of a specific class, or by deleting rules for specific classes. Changes are also effected by

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modifying the range of values of one of the input variables used to define an attribute class, or by altering the weight placed on any given attribute of an existing output class. A third option is to remove an entire class or to add a definition for a completely new output class. These changes are made by trial and error, using expert judgment.

The knowledge engineer, in consultation with the local expert, decides which classes should be revised, removed or added, which attributes should be used for defining each revised class, and which ranges of input predictor variables should be used for defining each class of attributes. It has sometimes been necessary to identify and obtain a new input variable for use in a revised set of rules, or to alter the zone classification of a map by refining a boundary, or by adding an entirely new zone to the classification.

Steps 4 to 6 are repeated until the local ecological expert is satisfied that the predicted output maps correspond as closely as possible with the best available understanding of the actual conceptual and geographical arrangement of ecological classes within any given map area.

2.7 Step 7: Apply the final rule bases to produce the final predictions

The local ecological expert acts as a sort of internal quality-control assessor. Knowledge-based rules, and the maps produced by applying them, are not considered final until they have been approved by the local regional ecologist. Once approved, the rules are applied to the assembled input-data layers to produce a predictive ecological map (PEM) (See Figure 2, item 7). This is then subjected to more formal and systematic assessment and evaluation. In many respects, this knowledge-based approach is similar to the definition of classes, using prototype category theory, recently described by Qi et al. (2006).

2.8 Step 8: Create a seamless mosaic of predicted PEM classes

Once approval of the rules and predictive maps has been received from the regional ecologist, a complete and seamless mosaic of predicted classes is produced by applying the rules to the layers of input data, which are subsequently joined to produce a seamless single mosaic (See Figure 2, item 8).

2.9 Step 9: 'Cookie-cut' the non-forested exception classes into the final map

All non-forested exception classes are treated as Boolean objects with hard boundaries and a single correct classification. These Boolean non-forested classes are 'cookie cut' into the previously prepared map of predicted ecological classes, covering and displacing all forested ecological classes predicted by using the fuzzy modeling procedures. This step ensures that spatial entities that have clear, hard boundaries retain these boundaries in the final PEM map (See Figure 2, item 9).

2.10 Step 10: Send the PEM map for an external assessment of its accuracy

To date, all predictive ecosystem maps produced for operational mapping projects in the former Cariboo Forest Region have been subjected to an arms-length accuracy assessment by an independent third-party contractor (see Moon, 2003; 2005a,b; 2006; 2008). These accuracy assessment procedures do not require the maps to predict accurately the exact class at exact point locations. Rather, they assess the extent to which predictions of the proportions of predicted classes match the proportions of actual classes observed in the field, along randomly-selected, closed, linear traverses.

The intent is to assess the ability of the maps to predict correctly the proportions of ecological classes within small areas that are equivalent to a minimum-sized area for which management decisions are likely to be taken. If the maps fail to achieve a minimum of 65% predictive accuracy, determined according to the approved accuracy assessment protocol (Moon 2005c), they can be returned to the knowledge engineer for further refinement. So far, this has only been necessary to address problems that occurred with 2 similar ecological entities in one BGC unit in one project area (SBS wk1 in East Quesnel).

2.11 Downstream activities not illustrated in Figure 2

Several additional, downstream, activities occur once the PEM maps for any given project area have been assessed for accuracy and have been demonstrated to have achieved, or surpassed, the minimum level of accuracy (65%) required for acceptance for mandated uses (e.g. timber supply analysis).

The first such downstream activity is to complete and finalize all documentation required to support use of the PEM maps. The most important item of documentation is the legend or look-up table. In the LMES DSS approach, the look-up table is structured as an extended version of the ECP table required by current PEM standards (RIC, 1999; 2000) (see Table 1).

Table 1. A portion of a LMES look-up table or legend for the ICH dk Subzone

LM_Code	Roll-Up	Subzone	Sdec_1	Site_S1	SiteMC_S	Site_M1a	Site_M1b	Sdec_2	Site_S2	SiteMC_S	Sdec3	Site_S3	SiteMC_S	PEM Entity Description and Comments
5901	5901	ICH dk	90	01	RF	d	j	10	05	RT				5901 was mapped ONLY on MEDIUM TEXTURED MATERIALS as mapped by TFIC. 5901 occurs across a wide range of upper to lower convex or shedding landform positions from upper slopes and crests to lower to toe slopes (< 20%) and on ALL ASPECTS. This is the predominant site series in the BEC variant.
5902	5902	ICH dk	80	02b	RS	s	r	10	04	FF	10	01	RF	5902 was mapped ONLY in areas that were mapped as MEDIUM TEXTURED and SHALLOW to BEDROCK by TFIC. 5902 occurs on the driest crest positions of high ridges that are shallow to bedrock. 5902 can occur in areas of MEDIUM texture as mapped by TFIC as long as the depth to bedrock is indicated as less than 50 cm and the landscape position is a dry shedding upper slope or crest.
5903	5903	ICH dk	90	03	FS	c	j	10	04	FF				5903 was mapped ONLY on COARSE TEXTURED MATERIALS as mapped by TFIC. 5903 occurs across a wide range of upper to lower convex or shedding landform positions from upper slopes and crests to lower to toe slopes (< 20%) and on ALL ASPECTS. This is the predominant site series in areas of COARSE TEXTURED materials.
5904	5904	ICH dk	80	04	FF	w	x	20	01	RF				5904 was mapped ONLY in areas of MEDIUM TEXTURED materials as mapped by TFIC. 5904 occupies STEEP SLOPES with a WARM SW ASPECT in MID to LOWER landform positions. Slope gradient must be greater than 20% and the aspect must be from 135 to 315. The regional ecologist indicated that the MID TO LOWER portions of STEEP SW slopes tended to be dominated by the somewhat less dry 04 Site Series.
5905	5905	ICH dk	70	05	RT	d	j	30	06	RR				5905 was mapped ONLY in areas of MEDIUM TEXTURED MATERIALS as mapped by TFIC. 5905 occupies moderately to gently sloping lower to toe slopes (5-20%) that receive moisture from above but that do not accumulate and retain seepage to create permanently high water tables. 5905 is a slightly moist seepage unit. Lower to toe slope, receiving, deep, medium textured soils.
5908	5908	ICH dk	70	08	SD	d	y	30	05	RT				5908 was mapped ONLY in areas of MEDIUM TEXTURED MATERIALS as mapped by TFIC. 5908 areas occur in sloping valleys and draws and along the margins of active stream channels. 5908 occurs in sloping hollows, draws, some toe slopes and depressions that maintain rich, moving, rather than stagnant, sub-surface water regimes. Rich, moist devil's club unit in sloping valleys.
5909	5909	ICH dk	80	09	SH	d	y	20	07	ST				5909 was mapped ONLY in areas of MEDIUM TEXTURED materials as mapped by TFIC. 5909 areas occur in the lowest, wettest and flattest bottoms of hollows, drainage ways and depressions. 5909 areas are predicted to have permanently high water tables and very wet cool conditions (water table < 30 cm).

Table 1 differs from a standard ECP table in that it includes a column that contains a short textual description of each uniquely identified PEM map entity. The comments for each PEM entity attempt to describe the main characteristics of its environmental setting and to explain the conceptual model each entity is meant to try to capture and apply. These written comments were consistently found to be very useful when interim maps were reviewed by the knowledge engineer and the local ecological expert working together. They capture the essence of the ecological-landform model that each unique entity is trying to capture. They provide the reader with insight into what the model concept is trying to accomplish and how it is trying to accomplish it.

Table 1 also contains estimates of the dominant and sub-dominant Site Units predicted to occur within each unique PEM entity as identified by the LM_Code. All values are estimates only and are based on the expert experience and judgment of the Regional Ecologist. The accuracy assessment procedures only evaluated the ability of the LMES PEM maps to predict the dominant site units for each PEM entity. For

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this reason, users should consider each entity to be correctly described as if it were a pure entity occupied entirely (100%) by the named dominant Site Series (or non-forested ecological class). ***Estimates of the possible presence and extent of second and third components in the description are purely conjectural and have not been subjected to a formal assessment of accuracy.*** These estimates are provided only to alert users to the possible presence of likely inclusions within these notionally pure map entities. All estimates are reviewed and approved by the Regional Ecologist before the look-up table is considered to be finalized and ready for submission to the provincial LRDW. Any errors or omissions in the look-up table are, however, the responsibility of the first author, who prepared the final documentation.

The next downstream activity is to complete the written report, as required by current PEM standards, to document the input data layers used in a PEM and to explain and document the procedures used to develop and apply knowledge based rules to predict ecological entities. This report represents the effort undertaken by LandMapper to meet the PEM standards with respect to describing the input data layers used in the PEM modeling and to describing the LMES DSS procedures used to develop and apply the KB rules.

A separate report (MacMillan et al., 2008b) documents the final PEM map entities produced by application of the modeling procedures to the described input data layers. This report is also only prepared after the final PEM maps have been assessed for accuracy and have been determined to be of acceptable accuracy. There is little point in preparing the final documentation until such time as a PEM map has passed accuracy assessment and all PEM entities are final and stable. The information illustrated in Table 1 is incorporated into this second report for all LMES PEM Map entities defined for all BGC units that occur within a particular project area or map area. Additional information is incorporated into this second report to identify the concepts and KB rules used to model each documented PEM entity and to list the extent of each BGC unit and of each PEM entity defined for it within a given PEM map area.

Current PEM standards (RIC, 1999; 2000) require that final PEM maps for any project area be submitted as clean, topologically structured vector polygon files in ArcGIS E00 format. The LMES DSS procedures operate on regular raster grids of fixed dimensions (here 25 x 25 m horizontal). The final PEM maps submitted by LMES are therefore in 25 m grid raster format and are not yet suitable for submission to the provincial land resource data warehouse (LRDW) as vector polygon files.

Conversion of the original LMES PEM raster grid files into topologically structured vector polygon files in ArcGIS E00 format was carried out by a separate contractor (GISmo Solutions Inc.) under a separate contract. This activity is therefore outside the mandate of the present report to describe. However, the process of converting the original raster map into a clean, topologically structured, vector polygon file did make use of information provided by LMES. The roll-up code illustrated in Table 1 was added by LMES after all PEM modeling had been completed and the final PEM maps had been determined to have achieved in excess of 65% accuracy. The purpose of the roll-up code was to permit GISmo to simplify and generalize the original LMES grid map prior to vectorization. All initial LM_Code integer values that described entities that were occupied by the same dominant Site Units and that were characterized by otherwise similar site conditions (e.g. slope gradient range, aspect range, moisture regime, texture) were assigned the same integer value for roll-up code. GISmo created a new grid map in which the new roll-up codes replaced the original LM_Codes. This new grid map had fewer areas of unique ID numbers because several original LM_Code numbers were rolled-up into a single new roll-up number for many of the original LM_Code numbers. This reduced the number of un-necessary vector polygons without in any way changing the information content of the final vector maps. Each resulting polygon still predicted the same dominant Site Series (or non-forested ecological class) using the roll-up code as would have been predicted using the original LM_Code.

The final activity that LMES undertook after completion of the PEM mapping and the accuracy assessment procedures was to assemble all digital data sets used, or generated, in the production of the final PEM maps into a GIS project where they could be displayed, queried and visually reviewed by the client and by any other interested users. This GIS project included seamless mosaics that portrayed the spatial distribution of all key inputs, as well as the final output PEM grid map for the entire extent of the Cariboo Forest Region.

3.0 Description of the LMES DSS input layers

In reports prepared by LMES for the initial Quesnel and East Williams Lake PEM project areas, a distinction was made between those LMES DSS input layers that were prepared using manual visual interpretation and manual digitizing and those prepared using automated processing of available digital input data, specifically the TRIM II 25 m DEM data and satellite imagery (Figure 2, items 2.1 versus 2.2).

In this current report, we adopt a slightly different approach and differentiate the LMES DSS input layers primarily in terms of whether they were used to produce the hierarchical classification zone map (see Figure 2, item 2.3) or whether they were used as inputs to the procedures that applied fuzzy logic to the numeric data for each individual grid cell to predict final PEM map entities (see Figure 2, item 7).

In general, most of the inputs used to construct the final classification zone map were prepared using manual methods of visual interpretation and digitizing. However, as the project progressed, some of the inputs for the classification zone map were produced using automated analysis of digital data sets. Conversely, most of the data used as inputs to the procedures that applied fuzzy logic to predict the most likely ecological class (PEM map entity) at each grid cell were prepared using automated analysis of digital data layers, these being the DEM and the satellite image. However, some manually prepared data were used as input to the fuzzy logic procedures that predicted individual PEM entities at each grid location.

In simple terms, the function of the mostly manually prepared classification zone map was to partition the entire Cariboo map area into smaller and more internally homogeneous classification domains (defined as subdivisions of BGC units) following the basic principles of hierarchical ecological classification as implemented in BC by the Biogeoclimatic Ecosystem Classification (BEC) system of Pojar et al., 1987. The function of the mostly digital data layers used in application of the fuzzy classification rules was to further subdivide domains defined by classification zones into PEM map entities along a toposequence from crest or divide to channel or depression, according to commonly accepted conceptual models of topographically controlled ecological-landform relationships.

3.1 Layers used to construct the classification zone maps

Consider first the approach used to decompose space hierarchically into classification domains as defined by a classification zone map. This map of classification zones was used as a Boolean operator to restrict the number of ecological classes that had to be considered as possible within any given classification region. Bui and Moran (2001) recognized a similar need to develop and apply different rule sets to recognize different classes within different classification domains.

The philosophy behind utilizing mainly manually prepared input layers to prepare the map of classification zones is basically one that recognizes that it is better and more economical to directly map those inputs that are more easily recognized and delineated using manual visual interpretation than by automated modeling.

It does not make sense, from the point of view of either cost or scientific validity, to attempt to model those spatially distributed features that are more clearly, unambiguously and easily identifiable using manual visual interpretation. It is a simple matter of cost/benefit. If there are only a few features or areas that need to be identified and delineated, and this can be done more rapidly and cost-effectively by manual visual interpretation and digitizing, then there is no valid reason for trying to automate this process using predictive models applied to digital inputs. For example, Timberline (and JMJ) produced maps that depicted the location and extent of non-forested "exception areas" and that outlined the inferred locations of areas of coarse-textured parent materials and shallow soils at a cost of less than 3.5 cents per ha. No effort to model the spatial distribution of these features using digital data sets could have produced equivalent or superior results at an equivalent or lower cost. From a cost standpoint, therefore, it has so far proven more efficient and economical to generate manually interpreted maps of readily visible surface features or areas than to attempt to model and classify these features from digital data or imagery.

The approach used to construct the classification zone map evolved over the course of the Cariboo PEM project. Slightly different criteria and slightly different inputs were used in the preparation of this map in different parts of the overall project area. In general, the hierarchical classification zone map partitioned space as outlined in Table 2.

Table 2. Generalized overview of LMES DSS process used to prepare classification zone maps

Step	Ecological Consideration	Source of Input Data Layer
1	Climatic Eco-regionalization	Big BEC Subzones and Variants
2	Physiographic Considerations	
	- Size and scale of landforms	Automated landform classification map
3	Parent Material Texture Controls	Manually prepared map of soil texture
4	Overlay of Anomalous areas	
	- Anomalous areas (Frost)	Manually prepared frost zone polygons
	- Anomalous areas (Geology)	Manually prepared lithology polygons
	- Anomalous areas (Slopes)	Manually prepared long-slope polygons
	- Anomalous areas (Ad Hoc)	Manually prepared ad-hoc polygons
5	Land Cover in non-forested areas	Semi-automated land cover class map

At the highest level, Eco-regionalization of climate was represented by an updated (localized) map of Biogeoclimatic Ecosystem Classification (BEC) sub-zones and variants (Big BEC). This Big BEC map was used to sub-divide the entire Cariboo region into different classification zones. Within each BGC unit only a limited set of ecological PEM entities (Site Units) were defined and could possibly occur.

At the second level, BGC units were (usually) further sub-divided according to significant regional physiographic differences as revealed by geomorphic attributes such as size and scale of relief, length and gradient of slopes and wavelength or frequency of inflections of slopes. LMES developed and applied semi-automated procedures for classifying landforms according to their relative size and scale. These procedures evolved over the course of the Cariboo PEM project and consequently, slightly different landform entities, defined using slightly different logic and inputs, were created for different parts of the overall project area.

At the third level, the LMES DSS procedures recognized a need to differentiate areas within BGC units that exhibited markedly different parent material textures. A review of the ecological keys and Landscape Profile diagrams in the Field Guides indicated that a completely different suite of ecological units (Site Units) could be anticipated to occupy the various defined landform positions in areas of coarse textured parent materials versus areas of medium (and sometimes fine) textured parent materials. It was therefore clearly necessary to be able to devise and apply a different set of classification rules that identified a completely different suite of predicted ecological classes, within areas of coarse textured materials than in areas of medium or fine textured materials. Maps of parent material texture were produced by contractors Timberline and JMJ using rapid and inexpensive manual visual interpretation of available digital aerial imagery, satellite imagery and terrain derivatives computed from the 25 m DEM.

At the fourth level the LMES procedures identified a requirement to define and recognize anomalous local variations in more site-specific conditions within parts of BGC units. Over the course of the Cariboo PEM project a number of locally different anomalous areas were encountered within which spatial patterns of ecological entities differed from those found in "normal" portions of a given BGC unit. These areas were seen as "anomalous" due to differences imposed by cold air drainage and frost, variations in substrate geology and lithology, variations in moisture regimes associated with very long steep or long and gentle slopes, and various other "ad-hoc" differences that favored the development or exclusion of particular ecological entities (Site Units) in particular geographic locations. LMES developed a practice of manually identifying and delineating such anomalous areas and cookie-cutting the resulting ad-hoc polygons into the

initial classification zone map to over-ride and displace the initial sub-divisions of BGC units defined by physiography (step 2) and texture (step 3). Manual delineation of such ad-hoc areas was frequently guided by visual review and analysis of patterns evident in terrain derivatives computed from the DEM. In most instances, the very specific local knowledge of the Regional Ecologist was used to identify the need to define ad-hoc anomalous areas and to determine where the boundaries for such areas should be placed.

The fifth and final step in preparing classification zone maps applied mainly to BGC units that were non-forested or to portions of normally forested BGC units where forest cover was absent. In BGC units dominated by non-forested alpine, parkland or grassland environments there was a need to define ecological classes using a physiognomic classification system in which the first consideration was typically the type and density of vegetative land cover. In such areas, the normal considerations of landform size and scale intersected with parent material texture were no longer as important to the classification process as were considerations of dominant land cover. LMES developed and applied a semi-automated process for classifying a false color satellite image to infer land cover classes in those BGC units where land cover was an essential component of the ecological classification rules. In these areas, the land cover classes defined by LMES for any given BGC unit were also cookie-cut into the initial classification zone map to over-ride and displace the initial sub-divisions of BGC units defined by physiography (step 2) and texture (step 3). These land-cover based classification zones permitted LMES to develop and apply classification rules that recognized land cover as the initial consideration in the classification.

The first three maps discussed above were intersected to produce an initial map of "classification regions" or zones for each unique combination of BGC unit, relief class and parent material texture class. The initial map of classification zones was then refined or altered on an ad-hoc basis to accommodate any observed anomalous areas or to permit recognition of land cover as a criterion in the classification rules. A separate set of classification rules was then developed for, and applied within, each of these unique classification zones. This enabled the procedures to assign different ecological entities (Site Units) to identical landform positions, or ecological settings, to reflect differences in climate, relief, frost hazard, parent material texture and lithology or land cover type.

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3.1.1 Localized Biogeoclimatic Ecosystem Classification (Big BEC) Input Layer

The localized BEC maps (referred to as Big BEC) were prepared by the Regional Research Ecologist for use in all portions of the Cariboo PEM project (Figure 6). Because the BEC maps were supplied by the regional ecologist, there is no requirement that they be subjected to an input data quality assessment. They are assumed to be correct and to present an accurate depiction of the spatial extent of each of the BGC unit recognized to occur within all portions of the Cariboo PEM study area.

LMES simply received the localized BEC information as a polygonal map in ArcView shape file vector format and UTM Zone 10 projection, NAD83 datum. LMES then assigned a unique integer ID number to each of the BGC units identified on the ArcView shape file vector map (Table 3). The unique integer ID number associated with each of the BGC units was subsequently used in the construction of integer ID numbers for unique "classification regions" defined by the intersection of the BEC polygons with polygons representing physiographic, frost hazard or land cover and parent material texture classes.
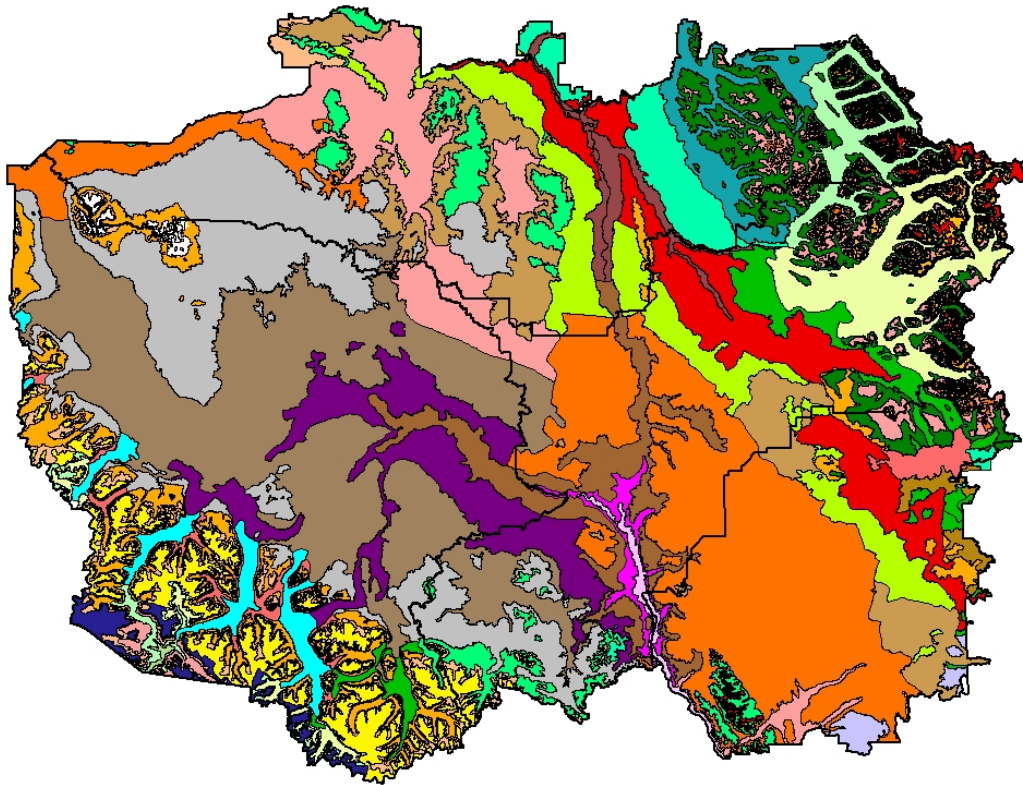
Figure 6. Illustration of BGC Subzones and Variants within the former Cariboo Forest Region

The unique integer ID numbers listed under the heading BEC ID in Table 3 are purely arbitrary and carry no underlying meaning. All BGC units known to occur within the extent of the former Cariboo Forest Region were identified and arranged in alphabetical order. These were then assigned unique integer ID numbers in sequence beginning with the number 34. This number was used as a starting point because a previously completed LMES PEM project (the Quesnel PEM) had already used most of the integer numbers between 1 and 34 to identify BGC units for that project. Note that BGC Unit #34 (AT un) which existed at the time the Quesnel PEM was completed is now separated into 36 = BAFA and 58 = ESSF xvp.

Table 3. Extent (ha) of BGC Units within the former Cariboo Forest Region

BEC ID	Subzone	Quesnel TSA (ha)	Williams Lake TSA (ha)	100 Mile TSA (ha)	Total Cariboo (ha)	Percent
34	IMA	7,949	23,573	1,904	33,427	0.41%
35	AT un	9,352	14,061	0	23,413	0.28%
36	BAFA	0	257,350	0	257,350	3.12%
38	BG xh3	0	16,378	10,945	27,323	0.33%
39	BG xw2	0	45,851	6,203	52,054	0.63%
40	CMA	0	52,904	0	52,904	0.64%
41	CWH ds1	0	3,808	0	3,808	0.05%
42	CWH un	0	1,629	0	1,629	0.02%
44	ESSF mv1	1,053	0	0	1,053	0.01%
45	ESSF mw	0	31,623	0	31,623	0.38%
47	ESSF mwp	0	22,038	0	22,038	0.27%
48	ESSF wc3	67,116	99,585	24,518	191,218	2.32%
49	ESSF wcw	24,050	28,964	6,707	59,722	0.72%
50	ESSF wcp	15,631	51,287	4,470	71,388	0.87%
51	ESSF wk1	157,956	121,564	37,252	316,772	3.84%
52	ESSF dc3	0	0	15,575	15,575	0.19%
53	ESSF xc3	0	0	8,017	8,017	0.10%
54	ESSF xcp	0	0	2,633	2,633	0.03%
55	ICH dk	18,648	246,676	0	265,324	3.22%
56	ESSF xv2	0	65,487	0	65,487	0.79%
58	ESSF xvp	3,353	163,445	0	166,798	2.02%
59	ICH dk	0	0	34,642	34,642	0.42%
60	ICH mk3	0	78,263	28,779	107,042	1.30%
61	ICH mw3	0	0	5,359	5,359	0.07%
62	ICH wk2	0	203,762	0	203,762	2.47%
63	ICH wk4	78,677	20,762	0	99,438	1.21%
64	IDF xw	0	0	31,710	31,710	0.38%
65	IDF dk3	13,348	364,740	578,569	956,657	11.61%
66	IDF dk4	0	372,646	0	372,646	4.52%
67	IDF dw	0	107,834	0	107,834	1.31%
68	IDF mw2	0	0	14,890	14,891	0.18%
69	IDF xm	8,339	236,832	13,555	258,727	3.14%
70	IDF xh2	0	0	1,107	1,107	0.01%
72	MS xk2	0	0	31,959	31,959	0.39%
73	MS xk3	0	0	29,745	29,745	0.36%
75	MH mmp	0	11,391	0	11,391	0.14%
76	MS dc2	0	47,595	0	47,595	0.58%
77	MS dv	0	28,263	0	28,263	0.34%
78	MS xk	0	4,734	0	4,734	0.06%
80	MS xv	287,158	570,321	0	857,479	10.41%
81	SBPS dc	297,353	98,929	0	396,282	4.81%
82	SBPS mc	104,784	30,670	0	135,454	1.64%
83	SBPS mk	223,509	67,592	103,475	394,577	4.79%
84	SBPS xc	11,214	1,123,462	0	1,134,677	13.77%
85	SBS dk	720	0	0	720	0.01%
86	SBS dw1	84,206	162,043	117,906	364,156	4.42%
87	SBS dw2	186,390	75,419	84,893	346,702	4.21%
88	SBS mc1	9,916	14,048	27,676	51,641	0.63%
89	SBS mc2	111,969	0	0	111,969	1.36%
90	SBS mc3	19,999	434	0	20,433	0.25%
91	SBS mh	73,784	11,255	0	85,039	1.03%
92	SBS mm	0	0	11,398	11,398	0.14%
93	SBS mw	133,784	3,174	0	136,958	1.66%
95	SBS wk1	125,621	13,181	0	138,802	1.68%
96	CWH ms1	0	16,892	0	16,892	0.20%
97	IDF ww	0	817	0	817	0.01%
98	MH mm2	0	19,538	0	19,538	0.24%
		2,075,880	4,930,819	1,233,888	8,240,587	100%

3.1.2 The LMES prepared map of initial physiographic classes

Experience in the initial PEM projects in the Cariboo region led to the realization that a single set of LMES DSS rules was often not able to be applied successfully to different landscapes within the same BGC unit if the landscapes exhibited significantly different expressions of relief, slope gradient, slope length and wave length (short range complexity). KB rules that produced acceptable results when applied to normal or modal landscapes that exhibited the most common range of slope lengths, gradients and relief often performed unsatisfactorily when applied to landscapes within the same BGC unit that exhibited markedly different ranges of these physiographic characteristics.

It was determined that better results could be obtained if the LMES procedures were set up to permit slightly different KB rule bases to be applied to areas that exhibited markedly different relief and physiography within any given BGC unit. The LMES procedures were therefore adapted to permit creation and use of maps that distinguished regions of different physiography and relief within BGC units (see Figure 7) and that then applied different versions of KB rule tables for any given subzone or variant within these different physiographic regions.
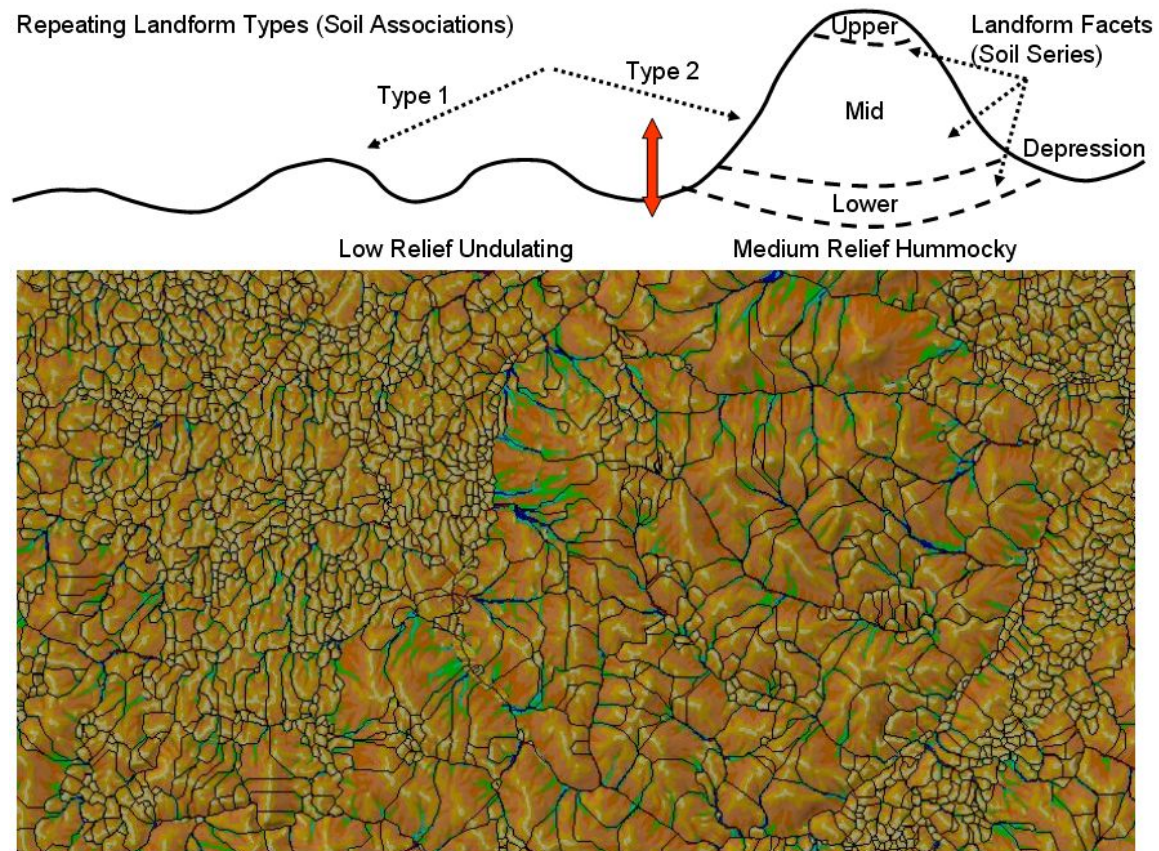
Figure 7. Illustration differences in the size and scale of landforms for a portion of the Cariboo

If one analyzes the logic that is inherent in the Landscape Profile diagrams (See Figure 3) presented in the Field Guide(s), it becomes obvious that the size and scale of landscape features has a direct bearing on the spatial distribution of defined Site Units. For example, almost all Landscape Profile diagrams illustrate the point that different Site Units are anticipated to occur in the exact same relative landform position of a crest or ridge top depending upon whether the ridge top was associated with a steep high ridge, a low rolling knoll or a very minor undulation in an area of relatively flat terrain. Similar differences were also noted with respect to other landform positions, such as toe slopes, where seepage and wetter ecological conditions

were mainly anticipated to occur at the base of long slopes with large upslope accumulation areas and were judged less likely to occur at the base of short slopes with little upslope accumulation area.

LMES devised a semi-automated method to differentiate areas into the several different relief classes. The classification of physiography into areas of different relief classes was accomplished by a modeling effort that first extracted each individual hill slope from the DEM for each individual PEM project area. Figure 8 illustrates how the flow modeling component of the LMES FlowMapR module was used to identify and outline each and every individual hill slope over the entire extent of each individual project area in the Cariboo region. Each individual hill slope was then characterized in terms of its maximum range in elevation values (e.g. its relief), its area or size, its distribution of slope classes and slope lengths.
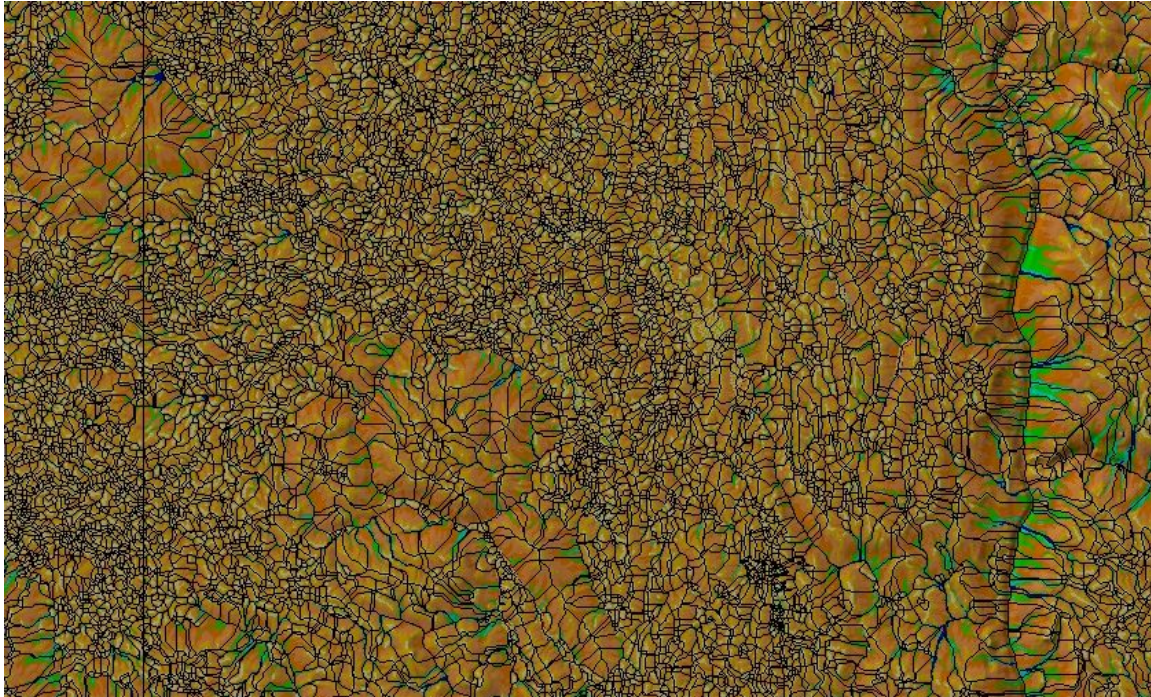
Figure 8. Example illustrating the procedure used to extract individual hillslopes in the Cariboo

The number of relief classes defined has varied amongst the various different PEM project areas. Most commonly, four classes of relief were defined as 1) very low relief, 2) low relief, 3) moderate to high relief and 4) very high relief (see Table 4). Hillslopes with total relief of less than 30 m were classified as very low relief, those with 30-100 m as low relief, those with 100-500 as high relief and those with > 500 m of total relief as very high relief. In the earliest completed Quesnel PEM project, only two main classes of relief were recognized, these being low to moderate relief (< 100 m elevation change) and moderate to high relief (> 100 m elevation change). It most BGC units, 4 classes of relief were found to be more than was absolutely needed, and two or more similar classes of relief often received identical KB rules.

Table 4. Codes used by LMES to identify classes of landforms with different physiography and relief

Zone ID	Description of the topography and physiography of the LMES defined zones
10	Areas of very low relief (< 30 m ridge to channel) and very short slopes.
20	Areas of relatively low relief (30-100 m ridge to channel) and relatively short slopes.
30	Areas of relatively high relief (100-500 m ridge to channel) & relatively long slopes.
40	Areas of very high relief (> 500 m ridge to channel) and very long slopes.
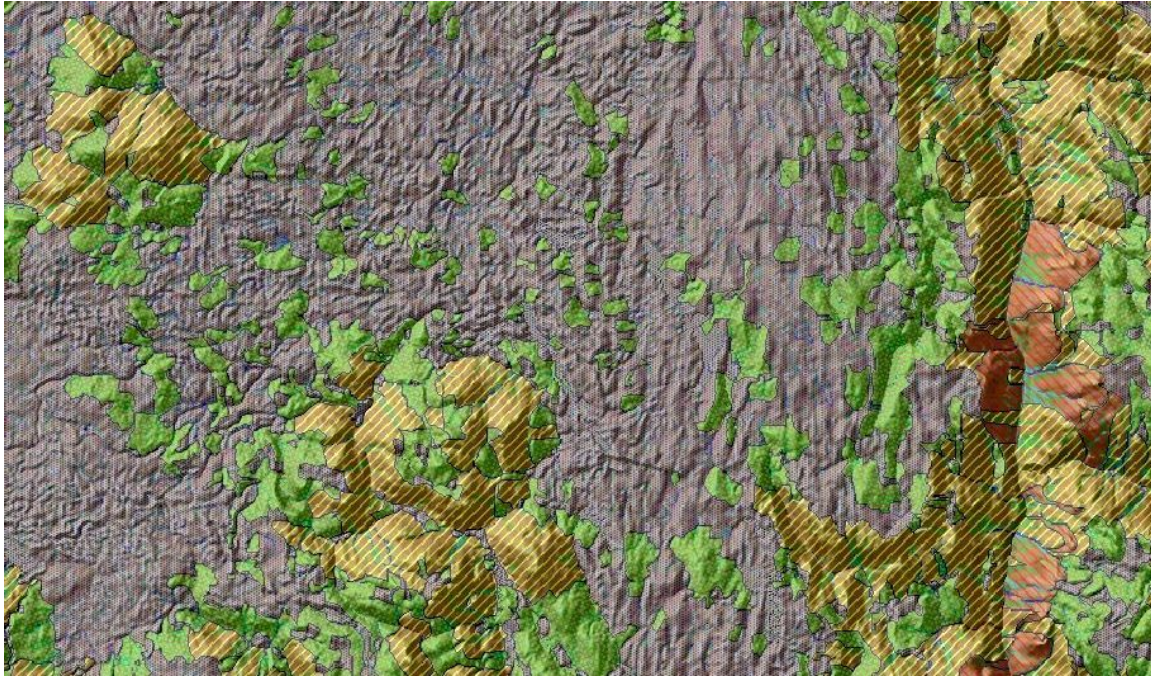
Figure 9. 2D illustration of the classification of terrain into four different classes of relief

Figure 9 illustrates how the individual hill slopes were grouped and assigned to landform classes on the basis of total relief of each hill slope. In this image, bluish areas are very low relief (< 30 m), greenish areas are low relief (30-100 m), yellow striped areas are moderately high relief (100-500 m) and reddish striped areas are very high relief (> 500 m).

Areas of high to very high relief tended to exhibit long continuous slopes that developed high values for diffuse upslope contributing area and wetness index, two terrain derivatives that were used extensively in the LMES DSS knowledge base rule tables. Conversely, areas of very low to low relief tended to develop and exhibit significantly lower values for diffuse upslope accumulation area and wetness index. These variables were used as surrogates for approximating relative landform position and relative moisture status in the LMES DSS rule bases. They were used in a relative sense, but their absolute values were only comparable within areas that had landscapes with similar relief and slope lengths. Therefore, it was necessary to be able to apply different threshold values to these variables in areas with different landscapes in order to achieve comparable results in recognizing relative landform positions or relative degrees of wetness.

The automated landform modeling was considered to have done an acceptable job of partitioning each PEM project area into regions that could be thought of as exhibiting high or very high versus low or very low relief and for which different LMES KB rule bases could be developed and applied. At the end of the project, our experience indicated that, while identifying different sizes and scales of landforms was useful, there was frequently not a lot of benefit in identifying and creating separate KB rules for more than 2 classes of relief, for most BGC units. It was quite common to either amalgamate two or more similar classes of relief to reduce the number of relief classes, or to create exact duplicate copies of KB rules for one class of relief for subsequent application in two or more different relief classes.

The practice of partitioning BGC units into subdivisions based on size and scale of landforms is useful but further improvements would be welcome. One particular improvement that we identified would have been to automatically extract and classify fluvial and glaciofluvial landforms such as terraces, fans, benches, eskers, valley sides and similar definable landform classes. Such classes would be very helpful in establishing local context so that specific KB rules could be applied in these areas.

3.1.3 The separately prepared map of parent material depth, texture and exception classes

LMES was provided with a map (Figure 10) of parent material depth, texture and exception classes prepared incrementally; first by JMJ Holdings Inc. then by Timberline Forest Inventory Consultants Ltd. (TFIC) following specifications originally developed by LMES. JMJ and TFIC were responsible for preparing this map and for preparing and submitting the input data quality report associated with it.
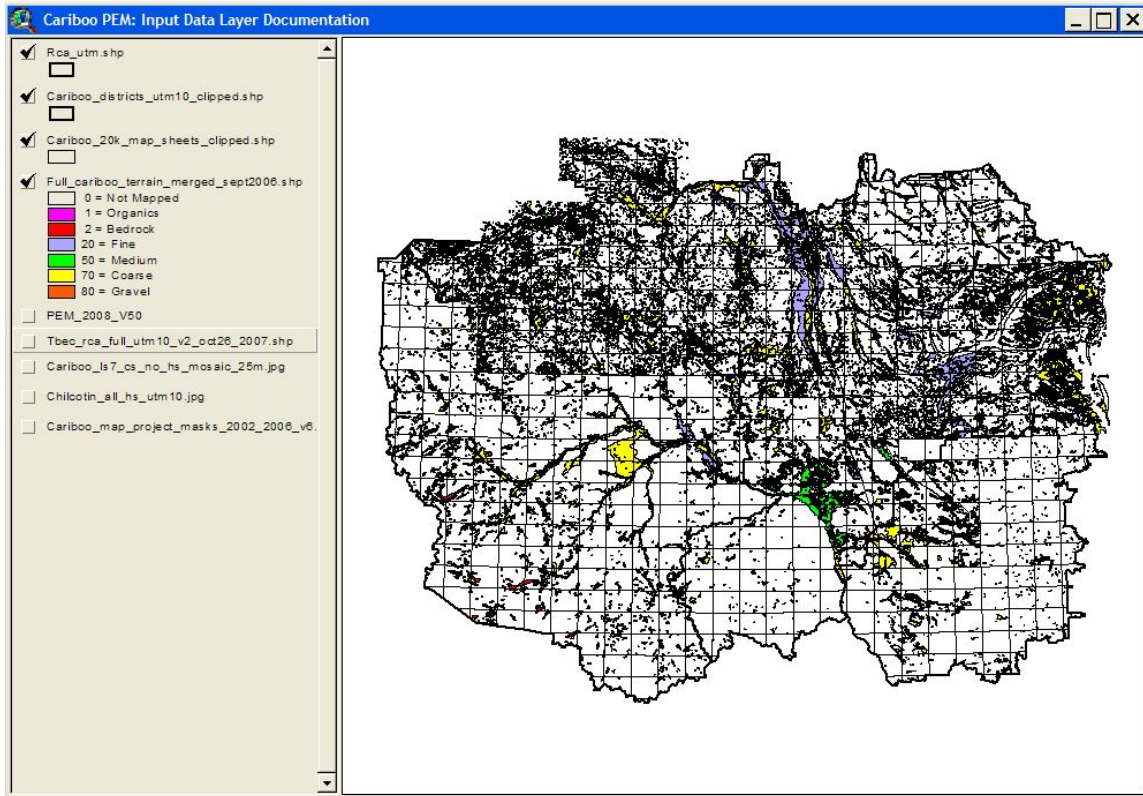
Figure 10. Illustration of the contractor prepared map of parent material texture exception classes

LMES received this map from the consultants that produced it in ArcView shape file format, UTM Zone 10 projection and NAD 83 datum. Each polygon on these exceptions maps was associated with a data base record that stored several pieces of information about that polygon (Tables 5 & 6).

Table 5. Example of the data base records linked to each polygon on the TFIC-prepared map

poly_id	geocode	depth	texture	non_forest	seepage
1	1	100	1	0	0
2	2	100	1	0	0
3	3	100	20	0	0
4	4	100	1	0	0
5	5	20	50	0	0
6	6	100	1	0	0
7	7	20	50	0	0
8	8	100	50	0	31
9	9	100	70	0	0
10	10	100	1	0	0

Table 6. Codes used on the contractor-prepared map to identify different classes of "exceptions"

Field Name	Field Description	Original Code	LMES Code	Description of Code
Poly_ID	The ArcView or ArcInfo polygon ID number			A provincially acceptable polygon ID
Geocode	Empty (copy of Poly_ID used by LMES)			Used by LMES to copy data to GRID format
Depth	Depth to bedrock	20	20	Identifies areas of shallow depth to bedrock (< 50 cm) (all other areas are coded as 100)
Texture	General material/texture of the dominant parent material			All areas are assumed to be medium texture by default (coded as 50)
	Some organic areas were originally coded as 21, 51, 71 to indicate organic over a texture class	1	1	Organic Wetland
		2	2	Exposed bedrock
		20	20	Fine Textured
		50	50	Medium (default)
		70	70	Coarse Textured
		80	80	Very Coarse Textured (Gravels)
Non-forest	Areas that do not support forested ecosystems			Identifies "exception areas" consisting of lakes and non-forested wetlands, and non-forested uplands
		10	91	Lakes and open water
		11	92	Non-forested wetlands
		21	93	Meadow
		22	94	Pasture
		23	95	Non productive brush
		24	98	Avalanche track
		25	96	Disturbed Land or Urban
		26	90	Gravel Bar (sometimes LMES used 00)
		29	97	Talus or Rock Slopes
		30	99	Grassland
		40	NA	Ice (Not Used by LMES)
		50	NA	Bare Soil or Dirt (Not Used by LMES)
Seepage	Identifies wetter "seepage" areas	31	31	Wetter than expected

This manually prepared vector polygon map has variously been referred to as a "focused bioterrain map" a "bioterrain light" map and a map of "parent material depth, texture and exceptions". The key aspect of this map is that the manual photo interpreters were requested to assume than any given area was mainly occupied by normal conditions of deep (> 100 cm) and medium to moderately fine textured parent materials. They were instructed to concentrate on identifying and isolating only areas that represented "exceptions" to these normal conditions of deep and medium textured materials. Consequently, they could rapidly review existing air photos and secondary source maps of geology and soils to identify and digitize areas that appeared to them to be occupied by either shallow (< 50 cm) or coarse textured materials.

Each polygon on the contractor-prepared map of parent material depth, texture and exceptions contained an entry for each of the fields of information identified in Table 5. The poly-id field provided the link to the vector polygon map. The field named geocode is an exact copy of the poly_id field and was used by a custom LMES program that created a GEOFILE DBF table for use in the LMES DSS procedures in which the geocode attached to each and every grid cell in an area of interest was used to look up and enter values for depth, texture, non-forest exception type and seepage into the GEOFILE. By this mechanism, the polygon map was converted into a grid-based DBF file that contained data for each of the fields in Table 5 for every 25 m grid cell in the study area.

The numbers in that appear in the columns labeled depth, texture, non-forest and seepage in Table 5 represent codes (see Table 6) for estimates of parent material depth and texture, non-forest class and presence or absence of visible seepage that were made by air photo interpreters. Thus, for example, all parts of the study area were assumed to have a default depth to bedrock of 100 m or greater (code 100) and the air photo interpreters would only delineate and attribute areas that were conspicuously and clearly shallow to bedrock (code 20).

Similarly, the contract interpreters were instructed to seek out areas that appeared to be associated with parent material textures that were significantly coarser (codes 70, 80) or finer (code 20) than normal or were obviously organic (code 1). All other areas were considered to possess normal, medium textured parent materials (code 50). Only the "exception areas" of clearly coarser, finer or organic parent materials were identified and delineated (see Figure 10). Recognition of areas of coarser or finer textured materials was aided by visual observation and interpretation of patterns of vegetation and land use that were observable on air photos and geo-registered digital orthoimagery.

With respect to the identification of areas of coarser parent materials, manual interpreters were instructed to look for obvious exceptions to medium texture, anomalous drainage conditions, and non-forested organic soils and meadows etc. that would not be explicable by local slope hydrology. For example, they looked for areas that were occupied by thinner stands of tree species that preferred drier conditions (e.g. pine or Douglas fir) and that were located in landscape settings that could be reasonably assumed to be associated with coarser textured materials (e.g. flood plains, terraces, fans). This rapid seeking out of "exception areas" proved to be both cost-effective and acceptably accurate.

For the purposes of constructing the LMES map of classification zones, areas mapped manually as having coarser textures (codes 70 and 80) were extracted and used to define subdivisions of BGC units were coarser textured materials were believed to occur. These contractor supplied maps of coarser textured areas did not accurately locate all areas of coarser materials but they did usually identify the largest and most obvious areas. As such, they were useful for identifying areas where different LMES KB rules would be needed. They were also cost effective, as any efforts to map coarse areas more precisely would undoubtedly have required considerably more effort and expenditure.
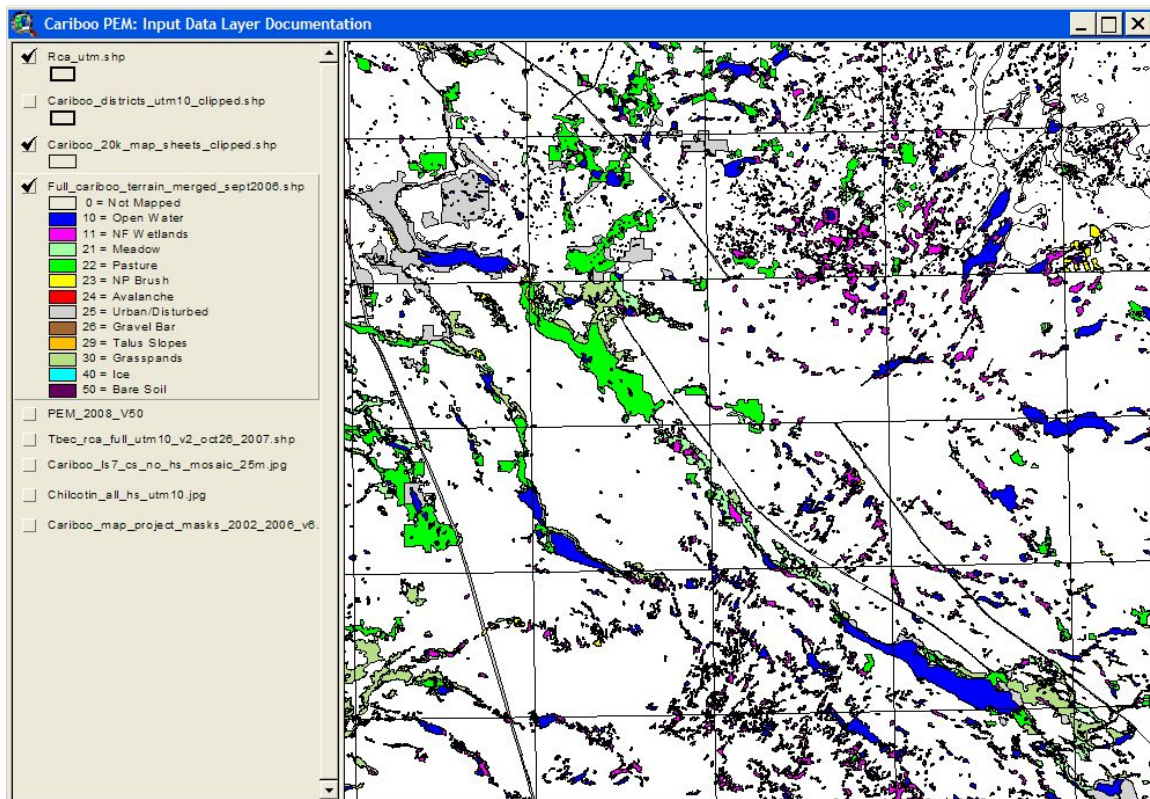
Figure 11. Illustration of non-forested exceptions areas as manually interpreted by contractors

Non-forested areas (Figure 11) represented a different sort of "exception area" than areas of shallow soils or coarser or finer parent materials. Areas of different texture or depth were still expected to be occupied by forested ecological entities (Site Series). The main difference in exception areas of different texture or depth is that the Site Series expected to occur would likely differ from the Site Series normally expected to occupy the same location in areas of deep, medium textured materials.

Non-forested "exception areas" are viewed as not being capable of supporting forested ecosystems according to the manual interpreters. There is therefore no expectation that any defined forested ecological class can occur in these locations. The approach adopted by LMES has been to predict an expected forested Site Unit for each and every grid cell in non-forested areas, as if these areas had not been identified as non-forested. The non-forested "exception areas" are maintained in a separate grid coverage which is "cookie cut" into the final LMES PEM map at the last possible moment, after all operations related to predicting, correcting, smoothing, filtering or otherwise improving the LMES predictions of forested ecological entities have been completed.

Most of these non-forested "exception areas" represent surface features such as lakes, wetlands, pastures, meadows or areas of non-productive brush that are clearly identifiable on available imagery and that have clearly defined, hard boundaries. The original integer code values assigned by the contractors for exception classes were renumbered in the final LMES procedures to values that ranged from 90 to 99 (see Table 6). Users encountering LMES grid code values between 90 and 99 can usually assume that the grid code describes the exception class associated with that integer value in Table 6. However, classes 90 and 99 are sometimes used for real forested ecological classes and not to identify non-forested exceptions areas.

Non-forested exceptions classes can be thought of as a kind of special "classification zone" in which only one class can occur, that being the non-forested class identified by that number.

The final field in the TFIC-produced map of material texture, depth and exceptions is the column labeled as "SEEPAGE". The seepage field was added at the suggestion of the Regional Ecologist. It is an attempt to provide a mechanism for manually recognizing areas that appear to the interpreter to be wetter than expected for any given location in the landscape.

The "SEEPAGE" field allows manual interpreters to alert the LMES DSS procedures to the presence of wetter than normal conditions. Such conditions might be associated with seepage from bedrock sources on hillslopes that is not modeled adequately by any of the terrain derivatives or they might be associated with areas of shallow depth to groundwater table that are also not well modeled by any of the available terrain derivatives. Typically, such "seepage areas" represent areas that would normally have been expected to exhibit normal, mesic Site Units but that, for whatever reason, exhibit a Site Unit associated with somewhat moister conditions. This code can serve as a flag that causes the LMES DSS procedures to utilize a different rule that will identify a wetter than normal Site Unit at a location at which a wetter Site Unit would not normally be predicted. The code 31 is simply used as a binary flag to identify these wetter conditions and flag them for the LMES DSS procedures.

The contractor-prepared map of material texture, depth and exception classes is a key input to the LMES DSS procedures. It provides the opportunity to make the most effective possible use of human visual capabilities and human interpretation. This map represents an attempt to directly map what is easily and readily visible and that can be mapped more rapidly, accurately and cost-effectively through direct manual interpretation than through more complex and costly modeling.

The manually interpreted map of parent material depth, texture and non-forested exceptions classes was prepared by contractors Timberline Forest Inventory Consultants Ltd. and JMJ Holdings Inc. LMES was grateful to be able to obtain and use these maps but LMES does not assume any responsibility for the quality or reliability of these map products. There is no doubt that improvements to these maps might have been possible and desirable but, at an average cost of 3.5 cents per ha, they did quite well at delineating the major exception areas within the former Cariboo Forest Region.

3.1.4 Preparation by LMES of ad-hoc polygon maps to delineate anomalous areas

Over the course of the Cariboo PEM project, LMES encountered a number of different instances in which spatial patterns of ecological classes (Site Units) differed from the patterns normally encountered with any given BGC unit. These "anomalous areas" possessed some critical differences in ecological or environmental conditions that caused the expected toposequence pattern of ecological classes to change from what would normally be expected in that unit (Table 7).

The first types of anomalous areas encountered were areas that exhibited an elevated incidence of cold air drainage and prolonged frosty conditions. These were termed "frost zones" and they were identified and delineated as separate "classification zones". Subsequently, other anomalous areas were encountered in which differences in the expected pattern of ecological classes could be attributed to local differences in geology or lithology (e.g. areas of coarser granite or nutrient rich limestone bedrock), long slopes and associated unusual moisture regimes, physiographic setting (e.g. flood plains or benches) or simply geographic location (e.g. some Site Series were known to occur only in specific geographic localities).

Table 7. The main kinds of anomalous areas defined as classification zones for Cariboo PEM project

Zone ID	Description of the defining characteristics of LMES defined anomalous zones
40	Identifies areas of accumulation of cold air drainage and elevated risk of frost
50	Mostly identifies areas with long gentle slopes that are less moist than expected
60	Mostly identifies areas with long steep slopes that are less moist than expected
71	Identifies areas extracted and classified as low benches
72	Identifies areas extracted and classified as medium benches
73	Identifies areas extracted and classified as high benches
81	Identifies non-forested areas of bare rock predicted from classified satellite image
84	Identifies non-forested areas of snow and ice predicted from classified satellite image
85	Identifies non-forested areas of snow and ice predicted from classified satellite image
00	Identifies areas of significantly different geology or bedrock lithology (e.g. granite areas)

LMES developed a practice of simply outlining the estimated extent of any given type of anomalous area using manual visual interpretation and on-screen, heads-up digitizing. The location and extent of such unique anomalous zones were usually identified by making use of the extensive local knowledge and experience of the Regional Ecologist. Such manually delineated areas were treated as a special kind of "classification zone" for which different sets of KB rules could be developed and applied that reflected the observed differences in patterns or toposequences of ecological classes.

Consider first the manually prepared map of "frost zones" that depicts the location and extent of areas deemed likely to have an elevated risk of frost (Figure 12). Frost area polygons were digitized manually following input and suggestions made by the Regional Ecologist. The Regional Ecologist had background knowledge about those locations where he was aware that frost was more likely to present a hazard and of areas where increased concentrations of frost tolerant species were indicative of increased incidence of frost.

Once the Regional Ecologist had identified any particular region where he felt there was a reason to expect elevated levels of frost hazard, it was found that visual review of several of the terrain derivatives that had been computed from the 25 m DEM for the study area proved helpful in deciding where to digitize polygon boundaries for areas of elevated frost hazard (see Figure 12). Graphical backdrops consisting of colored and hillshaded depictions of the variables wetness index (Qweti), log of diffuse upslope area (LnQarea) and slope gradient (Slope) helped to reveal the most likely geographic locations of areas of elevated risk of frost. These areas were seen to occur mainly within the lowest portions of large structural basins in areas

with low slope gradients and low relief that exhibited complex topography with relatively short slopes and frequent reversals of slope (e.g. low relief hummocky to undulating). These conditions were highlighted in the backdrop images of LnQarea and Qweti which helped to guide the manual placement of polygon boundaries outlining areas of elevated frost hazard. The Regional Ecologist reviewed the polygon boundaries as they were being digitized and offered suggestions for changes or confirmed the correctness of boundaries that seemed reasonable to him.
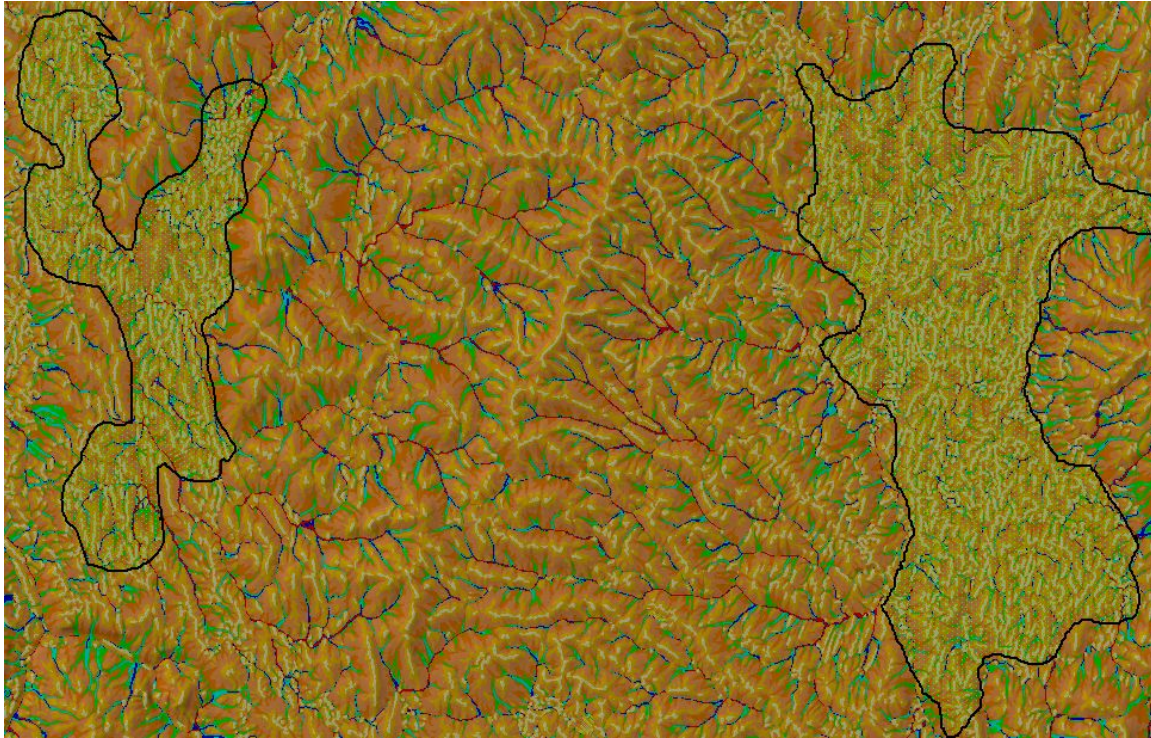
Figure 12. Illustration of manual delineation of frost zone areas on a backdrop of DEM derivatives

Once digitized, the LMES prepared map of areas of elevated frost hazard was simply treated as another kind of physiography/landform class and used to define unique regions within BGC units within which separate knowledge bases (KBs) and LMES DSS rules could apply. The separate rules permitted the LMES DSS procedures to assign different Site Units to particular landform positions than would be assigned to the same landform positions in areas that did not experience elevated risk of frost. Assessments of map accuracy revealed that these frost zone areas were often not as effective as hoped.

A similar manual process was followed to identify and digitize areas that were considered anomalous because of very long gentle slopes or long steep slopes (See Figure 13). In these areas, the values computed from the DEM for the variables of diffuse upslope area (LnQarea) and Quinn wetness index (Qweti) tended to over-estimate the likelihood that moisture would accumulate towards the bottom ends of these long slopes. These terrain derivatives model the movement and accumulation of moisture as if all water moves down slope following a process of matrix flow in the near surface materials. In this model, moisture accumulates continuously in the down-slope direction, in direct proportion to the total extent of the upslope areas that can contribute flow to any given down slope grid cell. In many such areas, the Regional Ecologist indicated that lower slopes that were predicted by this model to have a high likelihood of being moist, or wet, in fact displayed normal mesic moisture conditions. In these areas, it was necessary to adjust the threshold values used to define the likelihood that a given grid cell would exhibit elevated moisture conditions so that higher values of LnQarea and Qweti were required before a location was modeled as likely to be moist or wet.
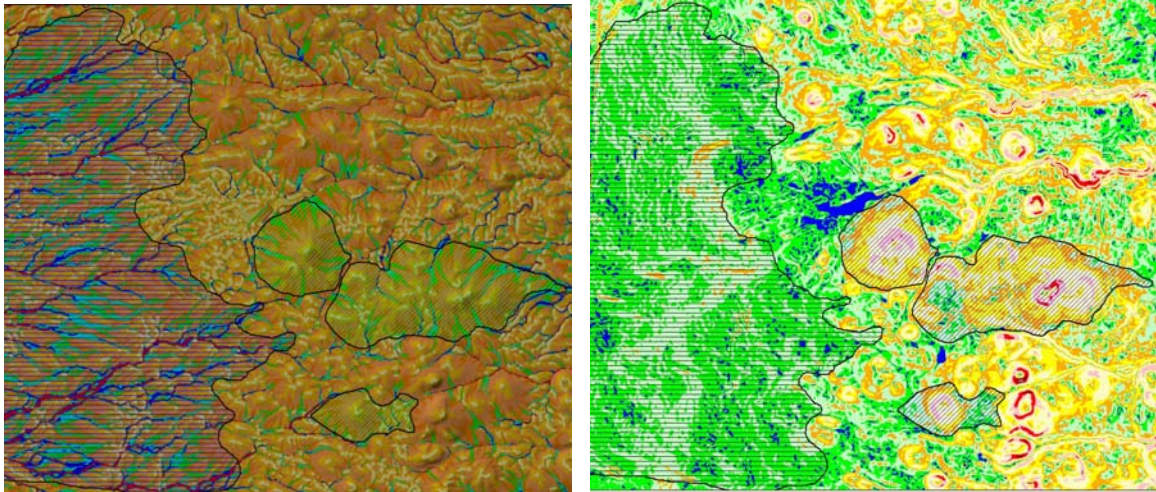
Figure 13. Illustration of manual delineation of long slope areas on a backdrop of DEM derivatives

The manual delineation of areas of long slopes on gentle versus steep topography is illustrated in Figure 13. Areas of gentle slopes are identified by a horizontal cross hatching while areas of steeper slopes are given an oblique cross hatch. The blue to green colors on the backdrop of LnQarea (left image) would typically be interpreted as indicative of moist to wet moisture regimes. In these areas of long gentle and long steep slopes, the Regional Ecologist indicated that many areas that appear as blue or green on the left image were occupied by normal mesic Site Units. KB rules were modified for these areas of long slopes to restrict the extent of areas considered likely to be characterized by moist or wet site conditions.
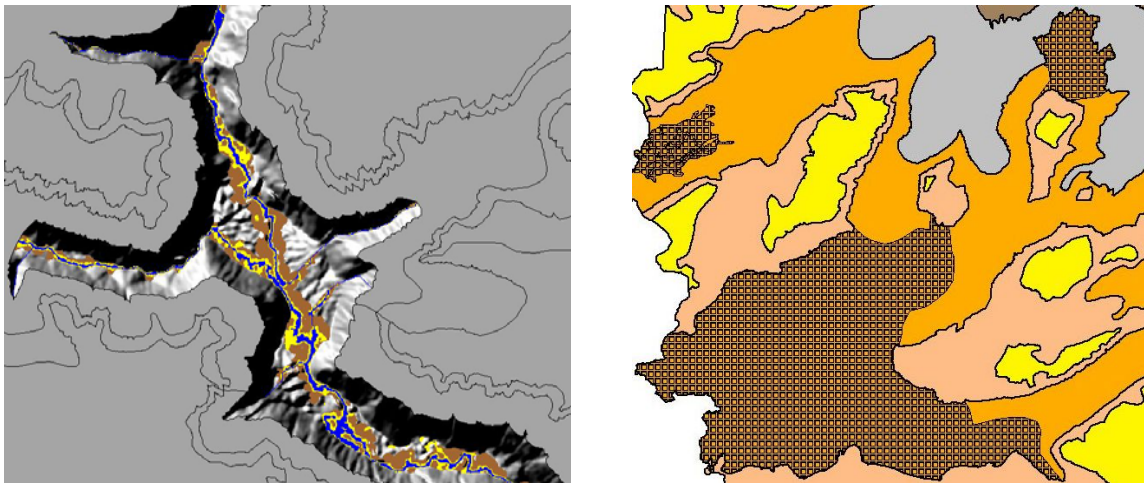
Figure 14. Illustration of delineation of benches (left) and of areas of different lithology (right)

Figure 14 (left) illustrates the semi-automated delineation of low (blue), medium (yellow) and high (brown) benches for a portion of a main river valley in BGC unit CWH ms1. This was accomplished by using the terrain derivatives of vertical elevation above a major stream (Z2St) and horizontal distance to a major stream (L2St) to identify areas that were < 1 m above the base stream level (low benches), 1-3 m above base level (medium benches) and high benches that were more than 3 m above base stream level and gently sloping (< 10%) and not more than 500 m back from the stream in a horizontal direction (L2St).

Figure 14 (right) illustrates how a portion of the ESSF xv1 variant was subdivided to recognize an area that was characterized by granitic bedrock (cross hatched area) that contained different Site Units.

3.1.5 Preparation by LMES of land cover class zones by classification of a satellite image

In some portions of the Cariboo PEM project area, LMES encountered BGC units in which the classification rules required information about the dominant land cover type at each location. LMES made use of two different mosaics of LandSat 7 Satellite imagery and of two different approaches for incorporating the imagery into the PEM classification procedures. Accuracy assessment of the PEM was restricted to the timber harvesting land base, so we the efficacy of these classes remains untested.

In the initial Quesnel PEM project area, LMES produced a composite image from a series of individual false color images tiled by NTS map sheet number and available for free download from the Government of Canada Toporama web site (http://toporama.cits.rncan.gc.ca/En/frame.html).   This image (Figure 15) contained quite a large amount of variation in contrast and tone between tiles and was missing data for parts of the Quesnel PEM project area, as well as for areas outside the Quesnel PEM project. It was not a particularly good image, but it was sufficient for the rather minor use made of satellite imagery for the Quesnel portion of the Cariboo PEM project.

This image was decomposed to produce raw band data for the three color separation bands of Red (1), Green (2) and Blue (3). Each of the three bands of raw band data was filtered with a 5x5 mean filter and the filtered data for bands 1, 2 and 3 were reformatted for use in the LMES DSS fuzzy classification procedures. The data for bands 1, 2 and 3 were added to the geofile for each tile of the Quesnel PEM map area and some KB rules used the filtered band data to infer the type and density of land cover for a few PEM map entities that were defined for non-forested areas. The main use of the LandSat image band data was to define land cover based PEM entities in the alpine, which at the time of completion of the Quesnel PEM was referred to as the AT. It was necessary to define generic Site Units based primarily on land cover type because there was no finalized classification to the level of Site Series for alpine and subalpine areas at the time that the Cariboo PEM was conducted.
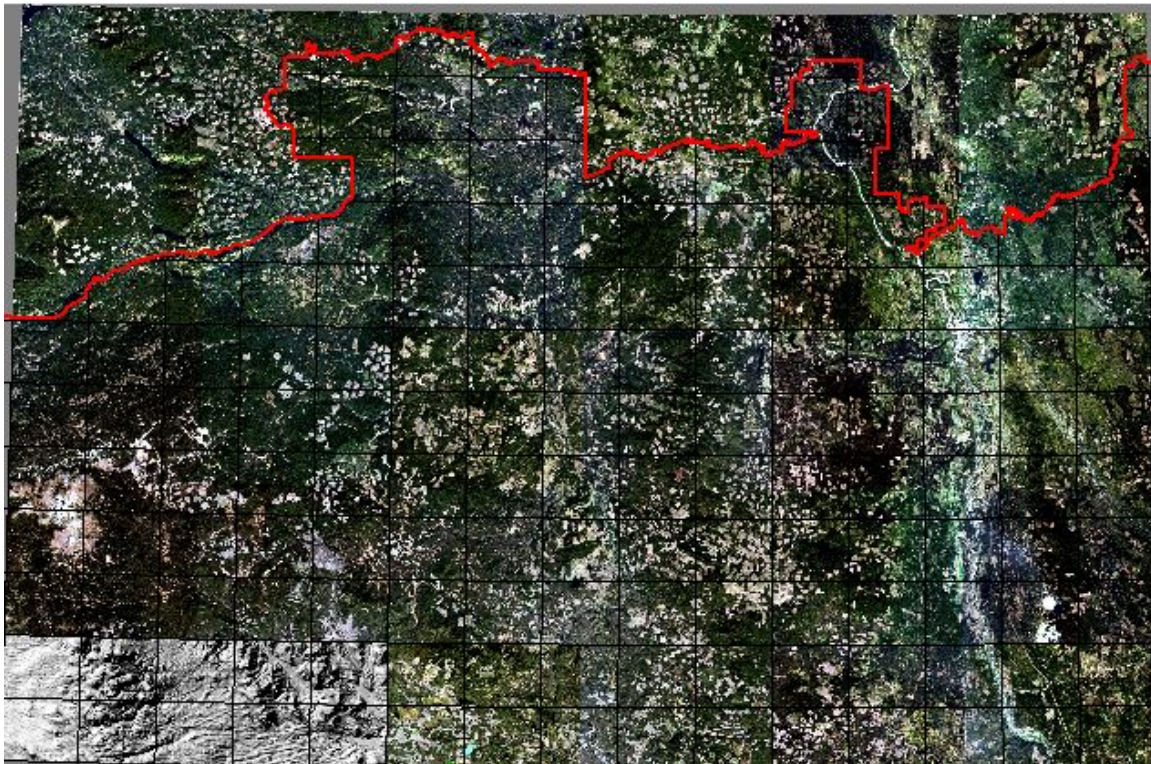
Figure 15. The LandSat ETM false color composite Satellite image used for the Quesnel PEM
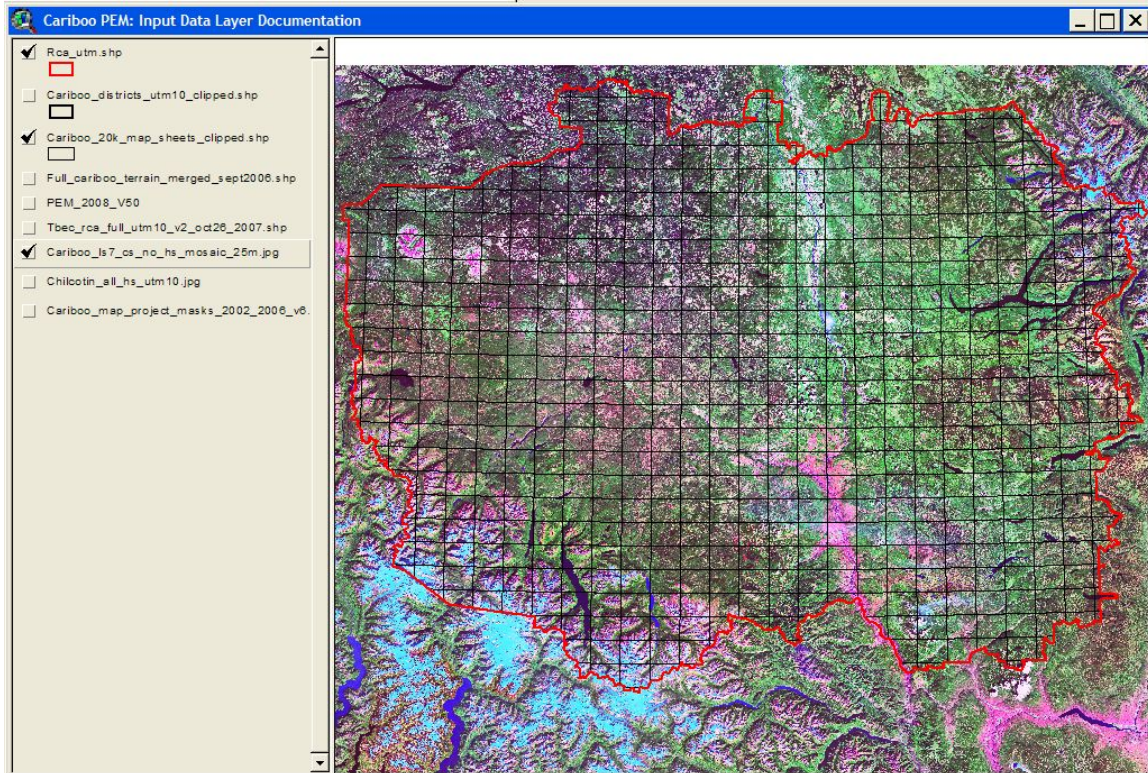
Figure 16. Improved LandSat ETM False Color Composite Mosaic obtained for the entire Cariboo

After completion of the initial Quesnel PEM project, LMES was able to find and obtain a second LandSat ETM false color composite satellite image mosaic that exhibited improved contrast and uniformity and that covered the entire extent of the former Cariboo Forest Region (Figure 16). This image was supplied to LMES by personnel at the BC Ministry of Sustainable Resource Management (SRM).

This second image had uniform contrast, tone and brightness across its entire extent. This uniformity of characteristics made the image particularly useful for differentiating normal forested areas from different types of land cover in non-forested areas in alpine, parkland and grassland environments. This image was decomposed to create grid files of raw band data for bands 1 (Red), 2 (Green) and 3 (Blue) and each of these bands of data was then filtered using a 5x5 mean filter (Figure 17). The filtering was done to reduce speckle or pixilation in the resulting map of land cover classes produced using these data sets.
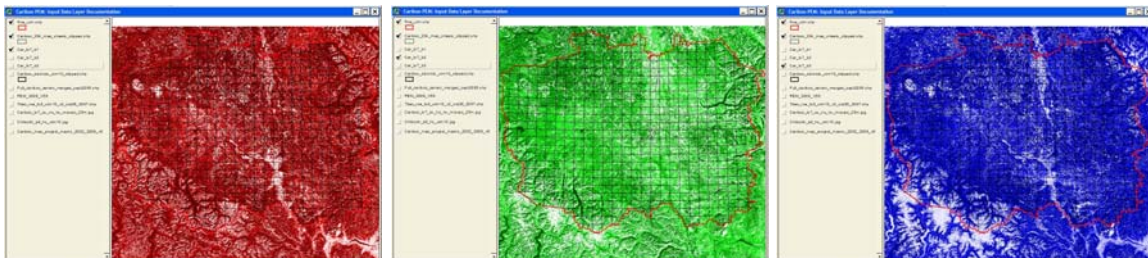
Figure 17. Illustration of the false color satellite image decomposed into three bands of raw data

Table 8. Criteria used to classify the false color satellite image into 22 color classes for Eastern areas

Band 1	Band 2	Band 3	ID No.	Color	Interpretation	Zone ID
< = 100	0-255	> 200	10	Bright Cyan & Dark Blue	Cores of Glaciers & Deep Lakes	50
	55-100	<= 40	20	NA	None occurred	
	55-100	40-60	11	Very Dark Green	Thick dark trees, like 5 in shadow	62
	55-100	60-80	12	Very Dark Green, purple flecks	Thick dark trees, may be in shadow	63
	55-100	80-130	13	Purple, with Green flecks	Thick dark trees, may be in shadow	64
	55-100	> 130	14	Dark Blue to Bright Blue	Looks like Ice and Snow in shadow	53
	< 55	<= 40	21	NA	None occurred	
	< 55	40-60	16	Very Dark Purple, Green flecks	Thick dark trees in shadows	72
	< 55	60-80	17	Dark Purple, not as dark as 16	Dark purple trees in shadow	71
	< 55	80-130	18	Mid to Light Purple	Trees in shadows, Rock in alpine	73
	< 55	> 130	19	Dark Blue to Dark Purply Blue	Glacier Ice or Lakes in Shadow	53
	> 100	80-130	15	Light to Dark Green	Continuous Trees, vigorous	65
	> 100	< 80, > 130	22	Bright Mid Green	Continuous Trees, vigorous	11
> 100 - 175	<= 160					
	100-160	<= 160	5	Dark Green, some pink flecks	Definitely trees	61
	< 100	<= 160	9	Very Dark Purple	Trees to shrubs in shadows	70
	< 160	> 160	6	Blue to purple, near glaciers	Rock with snow, ice and rubble	51
	> 160	<= 200	7	Bright Light Green	Brush to thin trees in parkland	40
	> 160	>200	8	Bright Cyan	Glacier Ice and Snow in alpine	52
175 - 220	<= 170	0-255	1	Bright Pink, white flecks	Bare Rock	00
	> 170	0-255	2	Very Light Green	Low shrubs and grasses	31
> 220	<= 210	0-255	3	Light Pinkish, some white	Very Low to no cover	10
	> 210	0-255	4	Very Light Green, pink flecks	Sparse grass & forbs, no trees	20

Table 9. Criteria used to classify the false color satellite image into 22 color classes for Western areas

Band 1	Band 2	Band 3	ID No.	Color	Interpretation	Zone ID
< = 100	0-255	> 200	10	Bright Cyan & Dark Blue	Cores of Glaciers & Deep Lakes	50
	55-100	<= 40	20	NA	None occurred	
	55-100	40-60	11	Very Dark Green	Thick dark trees, like 5 in shadow	62
	55-100	60-80	12	Very Dark Green, purple flecks	Thick dark trees, may be in shadow	63
	55-100	80-130	13	Purple, with Green flecks	Bright Green trees, may be in shadow	64
	55-100	> 130	14	Dark Blue to Bright Blue	Looks like Ice and Snow in shadow	53
	< 55	<= 40	21	NA	None occurred	
	< 55	40-60	16	Very Dark Purple, Green flecks	Thick dark trees in shadows	72
	< 55	60-80	17	Dark Purple, not as dark as 16	Dark purple trees in shadow	71
	< 55	80-130	18	Mid to Light Purple	Trees in shadows, Rock in alpine	73
	< 55	> 130	19	Dark Blue to Dark Purply Blue	Glacier Ice or Lakes in Shadow	53
	> 100	80-130	15	Bright to Dark Green	Continuous Trees, vigorous	65
	> 100	< 80, > 130	22	Bright Mid Green	Continuous Trees, vigorous	11
> 100 - 175	<= 160					
	100 -160	<= 160	5	Dark Green, some pink flecks	Definitely thick green trees	61
	< 100	<= 160	9	Very Dark Purple	Trees to shrubs in shadows	70
	< 160	> 160	6	Blue to purple, near glaciers	Rock with snow, ice and rubble	51
	> 160	<= 200	7	Bright Light Green	Brush to thin trees in parkland	40
	> 160	>200	8	Bright Cyan	Glacier Ice and Snow in alpine	52
175 - 220	<= 170	< = 140	1	Lighter Pink colors on LS Image	Sparse heather-type vegetation	00
		>= 140	2	Very Light Green	Low shrubs and grasses	31
	> 170	<= 200	2	Very Light Green	Low shrubs and grasses	31
		> 200	6	Blue to purple, near glaciers	Rock with snow, ice and rubble	51
> 220	<= 210	<= 160	3	Darker Pink colors on LS image	Bare to slightly thicker ground cover	10
		>= 160	1	Lighter Pink colors on LS Image	Sparse heather-type vegetation	00
	> 210	> 200	4	Very Bright White on LS Image	Bright White Bare Rock in Apline	20
		<= 200	2	Very Light Green, pink flecks	Low shrubs and grasses, Scrub Brush	31

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LMES did not make use of commercial image analysis and classification software to process and classify the raw band data obtained from the false color composite satellite image obtained for the entire Cariboo. Instead, LMES wrote a small data base program (see Appendix A) to process the filtered band data to apply a simple box, or parallelepiped, classifier. This program classified the image into 22 different classes that were each associated with an identifiable color or range of colors on the original satellite image.

In each successive PEM project area, the filtered band data for the 3 bands was extracted into a database file (named ID#_3Bands.DBF) that covered the entire extent of the project area at a grid resolution of 25 m. This grid file exactly matched the location and resolution of the DEM grid used to produce the main input layers used in the LMES DSS fuzzy classification programs. The filtered data for the 3 bands was processed through the small LMES classification program (See Appendix A) to classify the area into 22 different color classes (Tables 8 and 9). In any given BGC unit, a particular color could be visually interpreted as being associated with a particular type and density of land cover.

An initial set of rules (see Table 8) was used to classify the false color satellite image for the alpine IMA and related parkland Subzones for the East Williams Lake and East Quesnel PEM Project areas only (see Figure 18). When this initial set of rules was applied to classify land cover types in the alpine BAFA and related parkland Subzones for the Western Williams Lake TSA project area, some inconsistencies were noted with respect to the classification of areas of bare rock to thin dry tundra vegetation covers. Classes 1 and 4 in the original rules contained a mixture of both bare and vegetated areas. The classification rules were therefore revised for use in the West Williams Lake TSA project area only. Revisions to the initial rules are highlighted in Table 9. The revised rules were not back applied to the East Quesnel and East Williams Lake PEM project areas because the initial rules were judged to have performed adequately in those areas and there was no desire to introduce changes to a PEM that had been finalized and had passed accuracy assessment.
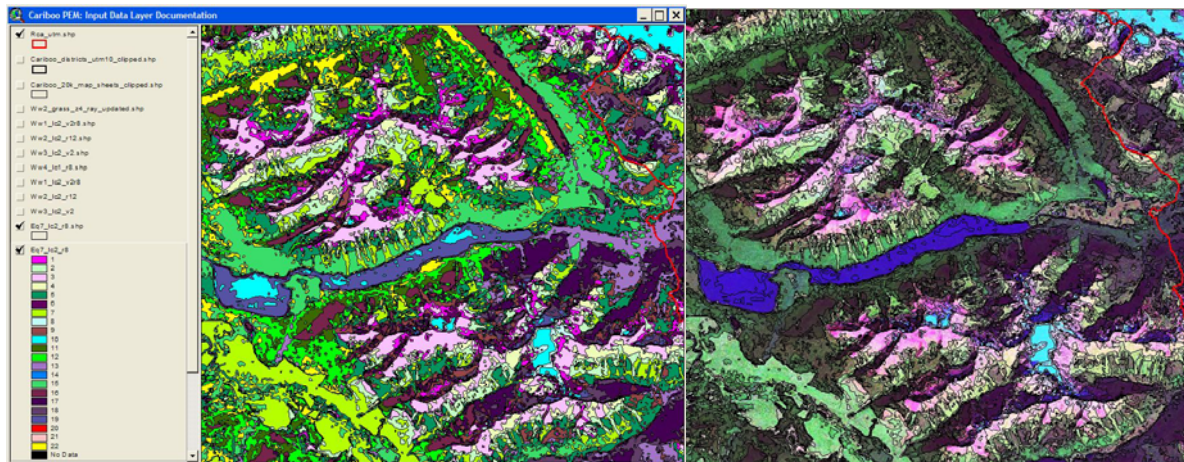
Figure 18. Illustration of the classification of 22 land cover (color) types in Eastern Williams Lake

Figure 18 shows the results of applying the image classification rules listed in Table 8 to the 3 bands of satellite image data in the East Williams Lake and East Quesnel PEM project areas. The 22 different color classes in the resulting classified grid (left image) were each assigned a color that was similar to the color that was visible in the original false color satellite image (right image). In alpine and subalpine areas, whitish areas were interpreted as being bare rock, different shades of pink were interpreted as having a sparse grass, forb or heather vegetative cover, cyan areas were interpreted as glacier snow and ice, very light green areas were interpreted as brush and sparse trees in a grass or heather matrix, green areas were interpreted as having a continuous forest cover, purple areas were mostly interpreted as being trees (or sometimes rock or ice) in shadows and dark blue areas were interpreted as open water or ice in shadows.

The 22 different colors were interpreted to define a smaller number of land cover classification zones for each BGC unit where land cover was used as a key criterion in the classification of ecological entities. Table 8 indicates how the 22 different colors were interpreted to define classification zones for use in the IMA in the Eastern Williams Lake and Eastern Quesnel PEM project areas. The land cover classes were meant to identify a notional gradient from bare rock and soil (class 00) through classes of low ground cover with no trees or brush (10, 20), to low ground cover with an increasing presence of scrub brush (31) and stunted trees (40) to thick green trees (61-64) to thick trees in purple shadows (71, 72, 73). The numbers from 50-54 were used to identify various combinations of permanent snow and ice and bare rock with seasonal snow and ice in alpine and sub-alpine environments.

These land cover classes were based purely on manual visual interpretation of the colors visible in the false color satellite image. The local knowledge of the Regional Ecologist was consulted to try to associate each color class with its most likely dominant land cover class. The Regional Ecologist was able to identify errors and inconsistencies in the land cover classes, with, for example, up to 10% stunted trees (krumholz) often present in pinkish areas classified as low ground cover. However, the land cover classification produced from the LandSat image was an improvement over any other information available to the project, including the manually interpreted map of non-forested exceptions classes. The boundaries of the LMES land cover classes matched quite well with boundaries meant to separate forested from non-forested areas that were present on several other manually interpreted maps available for parts of the study area (e.g. previously completed TEM projects and the TFIC/JMJ manually mapped non-forest classes).

Figure 19 shows the results of applying the slightly revised set of classification rules listed in Table 9 to a portion of the West Williams Lake TSA PEM project area. The lighter whitish areas evident in the SW corner of the image correspond to the bare white areas associated with class 4 (Zone 20) in Table 9.
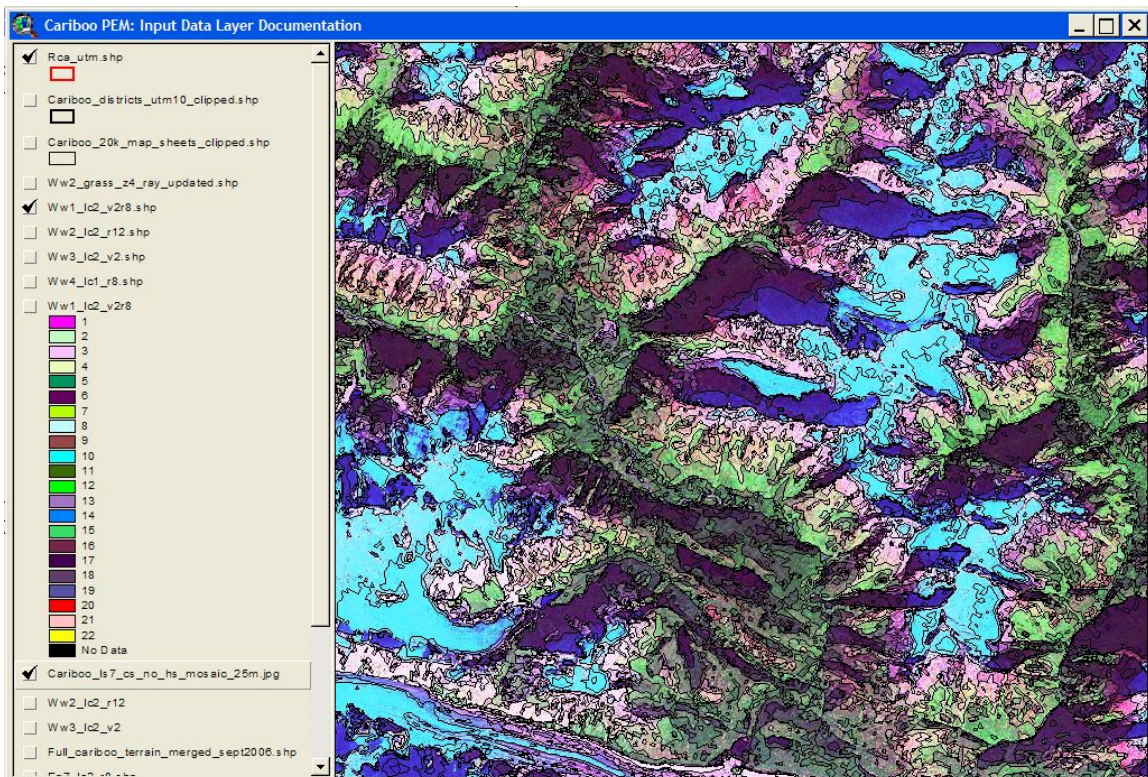
Figure 19. Illustration of the classification of 22 land cover (color) types in Western Williams Lake
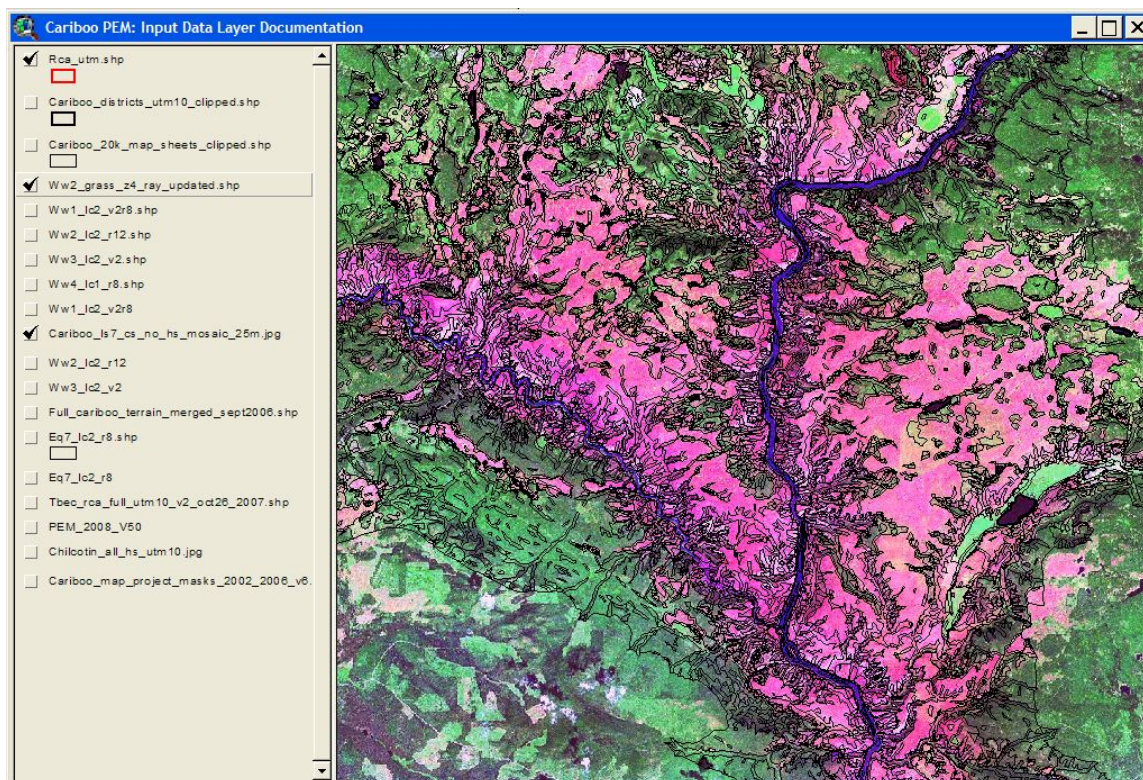
Figure 20. The land cover classification as modified for a grassland area in West Williams Lake TSA

Figure 20 illustrates how the 22 initial LandSat color classes were re-interpreted and grouped to define a different grouping of land cover classes applicable to the grassland environments of the BG xh3 and BG xw2 BGC units (Table 10). Grassland was separated from forested areas quite effectively.

Table 10. List of land cover classification zones defined for use in grassland environments

Zone ID	Color	Interpretation
10	Dark Purple	Water in dark purple shadows
11	Dark Purple	Water adjacent to major river
20	Dark Pink	Dry Grassland - not in concave gully
21	Dark Pink	Dry Grassland - in concave gully
30	Very Bright Green	Meadows and pasture - not in concavity
31	Very Bright Green	Meadows and pasture - in concavity
40	Dark Purple Pink and Whitish	Grass and Brush - not in concave gully
41	Dark Purple Pink and Whitish	Grass and Brush - in concave gully
50	Purple to very dark blue	Non-concave purple trees and water
51	Purple to very dark blue	Concavity - purple trees and water
60	Bright to Dark Greens	Forested - not in concave gully
61	Bright to Dark Greens	Forested - located in concave gully

3.1.6 The LMES prepared map of "classification regions"

The spatial information contained in the individually prepared maps of BGC units, physiography-topography, parent material texture, ad-hoc anomalous areas and land cover classes as described above was used to produce a final grid map that depicted "classification zones" as sub-divisions of BGC units.

The grid map of "classification zones" treated the various input layers as Boolean constraints that determined whether a particular set of classification rules would apply within any given "classification region" or would not apply. These Boolean constraints imposed the hierarchical classification logic described previously. This logic required BGC units, as depicted on the updated localized "Big BEC" map, to be further sub-divided according to considerations of physiography, landform type and parent material texture , then to be updated to recognize any locally important anomalous areas and then to be further updated, if necessary, according to considerations of land cover type. Computationally, the overlaying and merging of the five different source maps was accomplished as follows.

Firstly, the polygon map of unique integer BEC ID numbers assigned to each of the BGC units (Table 3) was converted into a grid map with a grid size of 25 m and dimensions (rows and columns) identical to the 25 m raster DEM grid used to establish the analysis extent for each unique PEM proejct area. This grid map of unique integer ID numbers was multiplied by 100 to convert numbers such as 35 to 3500 and so on to produce a temporary map named MAP 1.

Secondly, the polygon map of initial physiographic classes was also converted to a temporary grid map (MAP 2) with a grid size of 25 m and dimensions identical to the DEM and BEC zone grid (MAP 1) maps. The integer values associated with each of the initial physiographic relief classes (e.g. 20, 30, & 40) were maintained and assigned to every grid cell located within a polygon labeled with a given physiographic class ID number. Note that for the Quesnel PEM project only 2 landform classes (20, 30) were defined.

Thirdly, the contractor produced polygon map of parent material texture, depth and exception classes was used to create a temporary grid map of parent material texture classes (MAP 3), also with a grid size of 25 m and dimensions identical to the other grid maps described above. For this grid map, all areas mapped by the interpreters as being expected to contain coarse textured parent materials received an integer value of 1 while all other areas were assigned an integer value of 0 (e.g. were assumed to be medium textured).

Then, the three grid maps of identical grid size and dimensions were simply added together to create a single new grid map of integer values according to ZONE MAP = MAP 1 + MAP 2 + MAP 3.

This new ZONE MAP assigned a unique integer number to every grid cell. The unique integer number identified a specific combination of BGC unit, physiographic class and parent material texture for every cell. For example, 9351 = BEC zone 93 (SBS mw) + physiographic class 20 (low relief) + texture class 1 (coarse textured).

At this point, each BGC unit was subdivided according to climate, physiography and texture. If any BGC unit was found to contain demonstratively anomalous regions within it, these regions were then identified and boundaries encompassing them were digitized manually, on-screen. These anomalous areas were assigned an integer ID number such as 40 (frosty), 50 (long gentle slopes) or 60 (long steep slopes). These values were inserted into the initial Zone file in such a way as to preserve the last digit in the classification zone ID (0 or 1) so as to maintain the distinction with respect to texture. These new ID values displaced the previous ID value for the initial classification zone for each grid cell located in the newly defined anomalous zone. This over-writing was done into the LMES ID#ZONE.DBF file.

Finally, for any BGC unit where knowledge of land cover was determined to be a key requirement for successful classification of ecological entities, the 22 color classes extracted from the false color satellite image were interpreted and renumbered to define a limited number of land cover classes that could act as classification zones within that particular BGC unit. These new zone ID numbers were inserted into the

ID#ZONE.DBF file defined for each tile in a project area where they displaced (e.g. covered over) the last two digits of any initial classification zone ID number. In these areas information on the texture of the parent material was no longer retained as part of the classification zone ID number.

Over the course of the Cariboo PEM project, these classification zone files tended to be quite fluid and to require relatively frequent updating. Changes were made each time a decision was taken to recognize and delineate a new anomalous area. Changes were also made whenever a decision was made to use the classified LandSat image data to partition all or parts of a Subzone or Variant into zones based on land cover. In the latter stages of the project a number of zones were encountered in which only parts of the zone were differentiated on the basis of land cover classes and the remainder of the zone was treated as a normal forested area subdivided normally, according to physiography and texture. Updates were made to the classification zone files for completed PEM project areas if, as often happened, work completed in new areas to update the Big BEC map resulted in recognition of new BGC units or resulted in changing boundaries for BGC units in previously completed project areas. LMES undertook to go back to previously completed areas, update the classification zone file with the most current version of the Big BEC map, or other subdivision criteria, and re-run the PEM for the updated area or areas. This was done in order to maintain consistency and uniformity of input data and of final PEM entities between the 6 or more separate project areas that collectively made up the overall Cariboo PEM.

A complete list of all unique integer ID numbers generated by this process and used to define "classification regions" for the entire Cariboo PEM map area is presented in Table XX.

The grid map of unique ID numbers for "classification regions" was exported from ArcView and reformatted into a DBF table with a root identifier of "ID#Zone" that was used as an input file in the LMES DSS classification program FacetMapR. The ZONE file is used to tell FacetMapR the file name of the KB rule file to consult to read and apply classification rules for any particular grid cell in the data base. The FacetMapR program requires the existence of a pair of KB rule files named Arule*nnnn* and Crule*nnnn* for each and every unique "classification region" integer ID number, where *nnnn* is the unique integer ID number.

LMES prepared a separate set of KB rule files for each and every unique ID number listed in Table XX. Each pair of rule files, for each unique "classification region", contained fuzzy logic definitions for the specific set of ecological classes (Site Units) defined to occur in a particular classification region (Crule*nnnn*) and contained definitions for the fuzzy attribute classes that were used in the fuzzy classification of each specified Site Units (Arule*nnnn*).

The full extent of the overall Cariboo PEM was covered by several overlapping data sets prepared for each of several independent PEM projects. These were, in chronological order:

a) Original Quesnel PEM   (2003-2004)
b) East Williams Lake PEM   (2004-2005)
c) East Quesnel PEM   (2005-2006)
d) West Quesnel PEM   (2005-2007)
e) West Williams Lake PEM   (2006-2007)
f) 100 Mile House TSA PEM   (2007-2008)

Completion of PEM modeling for the entire Cariboo PEM map area required construction of at least six different sets of zone files, one for each of the 6 different PEM project areas. Due to changes over time, the list of unique classification zone ID numbers is not always consistent in the meaning attached to specific integer values (e.g. 40 can mean high relief in one BGC unit, Frosty Medium textured in another and scrub brush land cover in another). A complete list of classification zones defined for the Cariboo PEM project is provided as Table 11. This list identifies the main attributes of each defined classification zone.

Table 11. Complete list of unique ID numbers for "classification regions" for the Cariboo PEM

LM Code ID #	BGC Unit Name	Relief or Land Cover Class	Texture	Quesnel TSA (ha)	Williams Lake TSA (ha)	100 Mile TSA (ha)	Cariboo (ha)
3400	IMA	Bare - Little or no vegetation	ALL	1,213	2,820	307	4,340
3410	IMA	Bare - Little or no vegetation	ALL	2,156	2,646	847	5,649
3411	IMA	Snow and Rock in Alpine	ALL	0	17	0	17
3420	IMA	Sparse Dry Meadow	ALL	280	1,886	552	2,718
3431	IMA	Low Shrubs and Grasses in Alpine	ALL	336	1,284	51	1,671
3440	IMA	Vigorous Brush and Forbs	ALL	5	24	1	31
3450	IMA	Cores of Glaciers in Alpine	ALL	1,330	6,367	0	7,696
3451	IMA	Rock, Snow and Ice in Alpine	ALL	955	3,116	48	4,120
3452	IMA	Edges of Glaciers in Alpine	ALL	657	2,583	3	3,243
3453	IMA	Glacier Ice in Shadows	ALL	320	1,034	1	1,354
3461	IMA	Thick Green Trees and Brush	ALL	9	86	10	105
3464	IMA	Bright Green Trees	ALL	1	3	0	4
3470	IMA	Purple Trees in Shadow	ALL	415	932	64	1,411
3471	IMA	Dark Purple Trees in Shadow	ALL	79	118	5	202
3472	IMA	Very Dark Purple Trees in Shadow	ALL	20	11	0	32
3473	IMA	Dark Rock and Rubble in Alpine	ALL	174	656	14	844
3520	AT un	Low Relief	ALL	1	220	0	222
3530	AT un	Moderate - High Relief	ALL	9,350	13,841	0	23,191
3600	BAFA	Sparse Dry Meadow	ALL	0	62,916	0	62,916
3610	BAFA	Sparse Dry Meadow	ALL	0	30,443	0	30,443
3611	BAFA	Snow and Rock in Alpine	ALL	0	771	0	771
3620	BAFA	Bare - Little or no vegetation	ALL	0	6,394	0	6,394
3631	BAFA	Low Shrubs and Grasses in Alpine	ALL	0	15,909	0	15,909
3640	BAFA	Vigorous Brush and Forbs	ALL	0	701	0	701
3650	BAFA	Cores of Glaciers in Alpine	ALL	0	15,948	0	15,948
3651	BAFA	Rock, Snow and Ice in Alpine	ALL	0	36,134	0	36,134
3652	BAFA	Edges of Glaciers in Alpine	ALL	0	25,510	0	25,510
3653	BAFA	Glacier Ice in Shadows	ALL	0	14,141	0	14,141
3661	BAFA	Thick Green Trees and Brush	ALL	0	1,616	0	1,616
3662	BAFA	Thick Dark Green Trees in Shadow	ALL	0	1	0	1
3663	BAFA	Very Dark Green Trees in Shadow	ALL	0	13	0	13
3664	BAFA	Bright Green Trees	ALL	0	229	0	229
3665	BAFA	Bright Green Trees	ALL	0	3	0	3
3670	BAFA	Purple Trees in Shadow	ALL	0	25,273	0	25,273
3671	BAFA	Dark Purple Trees in Shadow	ALL	0	6,222	0	6,222
3672	BAFA	Very Dark Purple Trees in Shadow	ALL	0	1,393	0	1,393
3673	BAFA	Dark Rock and Rubble in Alpine	ALL	0	13,734	0	13,734
3810	BG xh3	Water and Dark Purple Shadows	ALL	0	79	0	79
3811	BG xh3	Water and Dark Purple Shadows	ALL	0	384	0	384
3820	BG xh3	Dry Grassland	ALL	0	5,625	4,588	10,213
3821	BG xh3	Dry Grassland	ALL	0	3,069	3,447	6,517
3830	BG xh3	Green Meadows and Pasture	ALL	0	277	200	477
3831	BG xh3	Green Meadows and Pasture	ALL	0	91	73	165
3840	BG xh3	Thick Brush with scattered Trees	ALL	0	1,804	667	2,471
3841	BG xh3	Thick Brush with scattered Trees	ALL	0	3,190	1,054	4,244
3850	BG xh3	Purple Trees and Water	ALL	0	109	234	343
3851	BG xh3	Purple Trees and Water	ALL	0	1,448	573	2,021
3860	BG xh3	Forested Areas	ALL	0	51	6	57
3861	BG xh3	Forested Areas	ALL	0	252	102	354
3910	BG xw2	Water and Dark Purple Shadows	ALL	0	37	0	37
3911	BG xw2	Water and Dark Purple Shadows	ALL	0	139	0	139
3920	BG xw2	Dry Grassland	ALL	0	16,383	1,780	18,164
3921	BG xw2	Dry Grassland	ALL	0	5,385	986	6,371
3930	BG xw2	Green Meadows and Pasture	ALL	0	1,625	104	1,729

LM Code ID #	BGC Unit Name	Relief or Land Cover Class	Texture	Quesnel TSA (ha)	Williams Lake TSA (ha)	100 Mile TSA (ha)	Cariboo (ha)
3931	BG xw2	Green Meadows and Pasture	ALL	0	757	97	854
3940	BG xw2	Thick Brush with scattered Trees	ALL	0	5,159	986	6,145
3941	BG xw2	Thick Brush with scattered Trees	ALL	0	5,239	793	6,033
3950	BG xw2	Purple Trees and Water	ALL	0	419	150	568
3951	BG xw2	Purple Trees and Water	ALL	0	1,181	256	1,437
3960	BG xw2	Forested Areas	ALL	0	5,336	518	5,854
3961	BG xw2	Forested Areas	ALL	0	4,191	533	4,724
4000	CMA	Sparse Dry Meadow	ALL	0	5,835	0	5,835
4010	CMA	Sparse Dry Meadow	ALL	0	1,090	0	1,090
4011	CMA	Snow and Rock in Alpine	ALL	0	267	0	267
4020	CMA	Bare - Little or no vegetation	ALL	0	1,717	0	1,717
4031	CMA	Low Shrubs and Grasses in Alpine	ALL	0	2,185	0	2,185
4040	CMA	Vigorous Brush and Forbs	ALL	0	99	0	99
4050	CMA	Cores of Glaciers in Alpine	ALL	0	12,256	0	12,256
4051	CMA	Rock, Snow and Ice in Alpine	ALL	0	8,433	0	8,433
4052	CMA	Edges of Glaciers in Alpine	ALL	0	14,435	0	14,435
4053	CMA	Glacier Ice in Shadows	ALL	0	4,391	0	4,391
4061	CMA	Thick Green Trees and Brush	ALL	0	100	0	100
4064	CMA	Bright Green Trees	ALL	0	26	0	26
4070	CMA	Purple Trees in Shadow	ALL	0	877	0	877
4071	CMA	Dark Purple Trees in Shadow	ALL	0	84	0	84
4072	CMA	Very Dark Purple Trees in Shadow	ALL	0	10	0	10
4073	CMA	Dark Rock and Rubble in Alpine	ALL	0	1,100	0	1,100
4110	CWH ds1	Very Low Relief	Medium	0	17	0	17
4111	CWH ds1	Very Low Relief	Coarse	0	21	0	21
4120	CWH ds1	Low Relief	Medium	0	42	0	42
4121	CWH ds1	Low Relief	Coarse	0	31	0	31
4130	CWH ds1	Moderate - High Relief	Medium	0	747	0	747
4131	CWH ds1	Moderate - High Relief	Coarse	0	298	0	298
4140	CWH ds1	Very High Relief	Medium	0	1,847	0	1,847
4141	CWH ds1	Very High Relief	Coarse	0	402	0	402
4171	CWH ds1	Low Benches	ALL	0	141	0	141
4172	CWH ds1	Medium Benches	ALL	0	118	0	118
4173	CWH ds1	High Benches	ALL	0	57	0	57
4181	CWH ds1	Bare - Little or no vegetation	ALL	0	88	0	88
4210	CWH un	Very Low Relief	Medium	0	79	0	79
4220	CWH un	Low Relief	Medium	0	27	0	27
4230	CWH un	Moderate - High Relief	Medium	0	90	0	90
4240	CWH un	Very High Relief	Medium	0	637	0	637
4241	CWH un	Very High Relief	Coarse	0	15	0	15
4271	CWH un	Low Benches	ALL	0	651	0	651
4272	CWH un	Medium Benches	ALL	0	50	0	50
4273	CWH un	High Benches	ALL	0	64	0	64
4281	CWH un	Bare - Little or no vegetation	ALL	0	16	0	16
4430	ESSF mv1	Moderate - High Relief	ALL	1,053	0	0	1,053
4520	ESSF mw	Low Relief	Medium	0	505	0	505
4521	ESSF mw	Low Relief	Coarse	0	87	0	87
4540	ESSF mw	Moderate - High Relief	Medium	0	29,856	0	29,856
4541	ESSF mw	Moderate - High Relief	Coarse	0	1,176	0	1,176
4700	ESSF mwp	Sparse Dry Meadow	ALL	0	3,559	0	3,559
4710	ESSF mwp	Sparse Dry Meadow	ALL	0	505	0	505
4711	ESSF mwp	Snow and Rock in Alpine	ALL	0	43	0	43
4720	ESSF mwp	Bare - Little or no vegetation	ALL	0	641	0	641
4731	ESSF mwp	Low Shrubs and Grasses in Alpine	ALL	0	4,266	0	4,266
4740	ESSF mwp	Vigorous Brush and Forbs	ALL	0	2,012	0	2,012

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LM Code ID #	BGC Unit Name	Relief or Land Cover Class	Texture	Quesnel TSA (ha)	Williams Lake TSA (ha)	100 Mile TSA (ha)	Cariboo (ha)
4750	ESSF mwp	Cores of Glaciers in Alpine	ALL	0	1,040	0	1,040
4751	ESSF mwp	Rock, Snow and Ice in Alpine	ALL	0	2,521	0	2,521
4752	ESSF mwp	Edges of Glaciers in Alpine	ALL	0	406	0	406
4753	ESSF mwp	Glacier Ice in Shadows	ALL	0	482	0	482
4761	ESSF mwp	Thick Green Trees and Brush	ALL	0	1,755	0	1,755
4762	ESSF mwp	Thick Dark Green Trees in Shadow	ALL	0	1	0	1
4763	ESSF mwp	Very Dark Green Trees in Shadow	ALL	0	82	0	82
4764	ESSF mwp	Bright Green Trees	ALL	0	256	0	256
4765	ESSF mwp	Bright Green Trees	ALL	0	53	0	53
4770	ESSF mwp	Purple Trees in Shadow	ALL	0	1,768	0	1,768
4771	ESSF mwp	Dark Purple Trees in Shadow	ALL	0	903	0	903
4772	ESSF mwp	Very Dark Purple Trees in Shadow	ALL	0	109	0	109
4773	ESSF mwp	Dark Rock and Rubble in Alpine	ALL	0	1,639	0	1,639
4810	ESSF wc3	Very Low Relief	Medium	53	240	68	361
4811	ESSF wc3	Very Low Relief	Coarse	5	86	1	93
4820	ESSF wc3	Low Relief	Medium	475	2,086	378	2,938
4821	ESSF wc3	Low Relief	Coarse	39	361	1	401
4830	ESSF wc3	Moderate - High Relief	Medium	27,487	26,809	7,110	61,406
4831	ESSF wc3	Moderate - High Relief	Coarse	1,363	2,978	60	4,401
4840	ESSF wc3	Very High Relief	Medium	35,709	52,773	8,896	97,378
4841	ESSF wc3	Very High Relief	Coarse	1,985	10,758	72	12,815
4850	ESSF wc3	Very High Relief and Long Slopes	Medium	0	3,496	7,925	11,421
4900	ESSF wcw	Bare - Little or no vegetation	ALL	1,760	917	480	3,157
4910	ESSF wcw	Bare - Little or no vegetation	ALL	1,720	504	372	2,595
4911	ESSF wcw	Snow and Rock in Alpine	ALL	12	536	12	561
4920	ESSF wcw	Sparse Dry Meadow	ALL	697	1,260	442	2,400
4931	ESSF wcw	Low Shrubs and Grasses in Alpine	ALL	2,949	2,751	838	6,537
4940	ESSF wcw	Vigorous Brush and Forbs	ALL	3,569	3,395	188	7,152
4950	ESSF wcw	Cores of Glaciers in Alpine	ALL	2	28	0	29
4951	ESSF wcw	Rock, Snow and Ice in Alpine	ALL	303	185	0	488
4952	ESSF wcw	Edges of Glaciers in Alpine	ALL	26	6	0	31
4953	ESSF wcw	Glacier Ice in Shadows	ALL	581	23	0	604
4961	ESSF wcw	Thick Green Trees and Brush	ALL	6,331	8,412	2,268	17,011
4962	ESSF wcw	Thick Dark Green Trees in Shadow	ALL	521	433	41	996
4963	ESSF wcw	Very Dark Green Trees in Shadow	ALL	1,347	2,567	679	4,593
4964	ESSF wcw	Bright Green Trees	ALL	352	937	78	1,367
4965	ESSF wcw	Bright Green Trees	ALL	449	434	28	911
4970	ESSF wcw	Purple Trees in Shadow	ALL	1,897	2,571	859	5,327
4971	ESSF wcw	Dark Purple Trees in Shadow	ALL	730	1,859	199	2,787
4972	ESSF wcw	Very Dark Purple Trees in Shadow	ALL	318	1,576	221	2,116
4973	ESSF wcw	Dark Rock and Rubble in Alpine	ALL	486	575	5	1,065
5000	ESSF wcp	Bare - Little or no vegetation	ALL	2,394	5,624	557	8,576
5010	ESSF wcp	Bare - Little or no vegetation	ALL	4,790	4,433	1,134	10,357
5011	ESSF wcp	Snow and Rock in Alpine	ALL	0	73	0	73
5020	ESSF wcp	Sparse Dry Meadow	ALL	1,294	6,429	1,247	8,971
5031	ESSF wcp	Low Shrubs and Grasses in Alpine	ALL	1,512	9,443	691	11,646
5040	ESSF wcp	Vigorous Brush and Forbs	ALL	399	3,656	40	4,095
5050	ESSF wcp	Cores of Glaciers in Alpine	ALL	80	448	0	528
5051	ESSF wcp	Rock, Snow and Ice in Alpine	ALL	1,250	3,204	0	4,455
5052	ESSF wcp	Edges of Glaciers in Alpine	ALL	111	204	0	315
5053	ESSF wcp	Glacier Ice in Shadows	ALL	265	410	0	675
5061	ESSF wcp	Thick Green Trees and Brush	ALL	701	7,480	499	8,680
5062	ESSF wcp	Thick Dark Green Trees in Shadow	ALL	1	22	2	24
5063	ESSF wcp	Very Dark Green Trees in Shadow	ALL	15	342	30	387
5064	ESSF wcp	Bright Green Trees	ALL	19	517	3	539

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LM Code ID #	BGC Unit Name	Relief or Land Cover Class	Texture	Quesnel TSA (ha)	Williams Lake TSA (ha)	100 Mile TSA (ha)	Cariboo (ha)
5065	ESSF wcp	Bright Green Trees	ALL	3	81	1	84
5070	ESSF wcp	Purple Trees in Shadow	ALL	1,408	4,550	201	6,158
5071	ESSF wcp	Dark Purple Trees in Shadow	ALL	438	1,803	52	2,292
5072	ESSF wcp	Very Dark Purple Trees in Shadow	ALL	98	474	17	589
5073	ESSF wcp	Dark Rock and Rubble in Alpine	ALL	851	2,103	5	2,960
5110	ESSF wk1	Very Low Relief	Medium	385	607	2,387	3,379
5111	ESSF wk1	Very Low Relief	Coarse	140	50	17	207
5120	ESSF wk1	Low Relief	Medium	2,443	5,622	5,983	14,047
5121	ESSF wk1	Low Relief	Coarse	500	429	12	941
5130	ESSF wk1	Moderate - High Relief	Medium	81,631	36,282	1,548	119,461
5131	ESSF wk1	Moderate - High Relief	Coarse	2,728	2,157	44	4,929
5140	ESSF wk1	Very High Relief	Medium	57,622	60,899	2,999	121,521
5141	ESSF wk1	Very High Relief	Coarse	1,610	9,911	57	11,579
5150	ESSF wk1	Very High Relief and Long Slopes	Medium	10,896	5,608	24,208	40,712
5220	ESSF dc2	Low Relief	Medium	0	0	3,996	3,996
5230	ESSF dc2	Moderate - High Relief	Medium	0	0	11,578	11,578
5320	ESSF dc2	Low Relief	Medium	0	0	46	46
5330	ESSF dc2	Moderate - High Relief	Medium	0	0	7,964	7,964
5331	ESSF dc2	Moderate - High Relief	Coarse	0	0	8	8
5400	ESSF xcp	Sparse Dry Meadow	ALL	0	0	536	536
5410	ESSF xcp	Sparse Dry Meadow	ALL	0	0	24	24
5411	ESSF xcp	Snow and Rock in Alpine	ALL	0	0	22	22
5420	ESSF xcp	Bare - Little or no vegetation	ALL	0	0	340	340
5431	ESSF xcp	Low Shrubs and Grasses in Alpine	ALL	0	0	475	475
5440	ESSF xcp	Vigorous Brush and Forbs	ALL	0	0	127	127
5451	ESSF xcp	Cores of Glaciers in Alpine	ALL	0	0	209	209
5452	ESSF xcp	Rock, Snow and Ice in Alpine	ALL	0	0	6	6
5453	ESSF xcp	Edges of Glaciers in Alpine	ALL	0	0	1	1
5461	ESSF xcp	Thick Green Trees and Brush	ALL	0	0	340	340
5462	ESSF xcp	Thick Dark Green Trees in Shadow	ALL	0	0	3	3
5463	ESSF xcp	Very Dark Green Trees in Shadow	ALL	0	0	52	52
5464	ESSF xcp	Bright Green Trees	ALL	0	0	26	26
5465	ESSF xcp	Bright Green Trees	ALL	0	0	26	26
5470	ESSF xcp	Purple Trees in Shadow	ALL	0	0	286	286
5471	ESSF xcp	Dark Purple Trees in Shadow	ALL	0	0	69	69
5472	ESSF xcp	Very Dark Purple Trees in Shadow	ALL	0	0	66	66
5473	ESSF xcp	Dark Rock and Rubble in Alpine	ALL	0	0	26	26
5500	ESSF xv1	Area of Granitic Materials	Medium	0	11,523	0	11,523
5501	ESSF xv1	Area of Granitic Materials	Coarse	0	2,529	0	2,529
5520	ESSF xv1	Low Relief	Medium	4,744	14,703	0	19,447
5521	ESSF xv1	Low Relief	Coarse	0	513	0	513
5530	ESSF xv1	Moderate - High Relief	Medium	12,529	198,408	0	210,937
5531	ESSF xv1	Moderate - High Relief	Coarse	1	7,703	0	7,704
5550	ESSF xv1	Very High Relief and Long Slopes	Medium	527	0	0	527
5560	ESSF xv1	Specific Geographic Locality	Medium	0	1,016	0	1,016
5581	ESSF xv1	Rock, Snow and Ice in Alpine	ALL	656	9,992	0	10,648
5585	ESSF xv1	Cores of Glaciers in Alpine	ALL	190	290	0	479
5610	ESSF xv2	Very Low Relief	Medium	0	1,265	0	1,265
5611	ESSF xv2	Very Low Relief	Coarse	0	1	0	1
5620	ESSF xv2	Low Relief	Medium	0	5,088	0	5,088
5621	ESSF xv2	Low Relief	Coarse	0	13	0	13
5630	ESSF xv2	Moderate - High Relief	Medium	0	47,811	0	47,811
5631	ESSF xv2	Moderate - High Relief	Coarse	0	94	0	94
5640	ESSF xv2	Very High Relief	Medium	0	11,018	0	11,018
5641	ESSF xv2	Very High Relief	Coarse	0	196	0	196

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LM Code ID #	BGC Unit Name	Relief or Land Cover Class	Texture	Quesnel TSA (ha)	Williams Lake TSA (ha)	100 Mile TSA (ha)	Cariboo (ha)
5800	ESSF xvp	Sparse Dry Meadow	ALL	496	27,783	0	28,278
5810	ESSF xvp	Sparse Dry Meadow	ALL	171	5,961	0	6,133
5811	ESSF xvp	Snow and Rock in Alpine	ALL	14	1,770	0	1,784
5820	ESSF xvp	Bare - Little or no vegetation	ALL	149	3,857	0	4,006
5831	ESSF xvp	Low Shrubs and Grasses in Alpine	ALL	1,239	33,209	0	34,448
5840	ESSF xvp	Vigorous Brush and Forbs	ALL	815	17,910	0	18,725
5850	ESSF xvp	Cores of Glaciers in Alpine	ALL	0	2,090	0	2,090
5851	ESSF xvp	Rock, Snow and Ice in Alpine	ALL	0	8,267	0	8,267
5852	ESSF xvp	Edges of Glaciers in Alpine	ALL	0	1,086	0	1,086
5853	ESSF xvp	Glacier Ice in Shadows	ALL	0	829	0	829
5861	ESSF xvp	Thick Green Trees and Brush	ALL	227	22,161	0	22,388
5862	ESSF xvp	Thick Dark Green Trees in Shadow	ALL	2	474	0	476
5863	ESSF xvp	Very Dark Green Trees in Shadow	ALL	25	2,977	0	3,002
5864	ESSF xvp	Bright Green Trees	ALL	12	1,484	0	1,496
5865	ESSF xvp	Bright Green Trees	ALL	90	1,113	0	1,202
5870	ESSF xvp	Purple Trees in Shadow	ALL	105	16,595	0	16,700
5871	ESSF xvp	Dark Purple Trees in Shadow	ALL	6	7,678	0	7,683
5872	ESSF xvp	Very Dark Purple Trees in Shadow	ALL	1	2,753	0	2,754
5873	ESSF xvp	Dark Rock and Rubble in Alpine	ALL	2	5,449	0	5,451
5920	ICH dk	Low Relief	Medium	0	0	13,785	13,785
5921	ICH dk	Low Relief	Coarse	0	0	55	55
5930	ICH dk	Moderate - High Relief	Medium	0	0	20,794	20,794
5931	ICH dk	Moderate - High Relief	Coarse	0	0	8	8
6010	ICH mk3	Very Low Relief	Medium	0	4,113	1,983	6,095
6011	ICH mk3	Very Low Relief	Coarse	0	79	16	95
6020	ICH mk3	Low Relief	Medium	0	28,848	5,101	33,949
6021	ICH mk3	Low Relief	Coarse	0	62	16	78
6030	ICH mk3	Moderate - High Relief	Medium	0	41,162	16,240	57,402
6031	ICH mk3	Moderate - High Relief	Coarse	0	362	185	547
6040	ICH mk3	Very High Relief	Medium	0	3,497	5,157	8,654
6041	ICH mk3	Very High Relief	Coarse	0	142	79	222
6120	ICH mw3	Low Relief	Medium	0	0	963	963
6130	ICH mw3	Moderate - High Relief	Medium	0	0	4,396	4,396
6210	ICH wk2	Very Low Relief	Medium	0	5,850	0	5,850
6211	ICH wk2	Very Low Relief	Coarse	0	977	0	977
6220	ICH wk2	Low Relief	Medium	0	23,671	0	23,671
6221	ICH wk2	Low Relief	Coarse	0	1,729	0	1,729
6230	ICH wk2	Moderate - High Relief	Medium	0	78,034	0	78,034
6231	ICH wk2	Moderate - High Relief	Coarse	0	3,065	0	3,065
6240	ICH wk2	Very High Relief	Medium	0	81,211	0	81,211
6241	ICH wk2	Very High Relief	Coarse	0	9,225	0	9,225
6310	ICH wk4	Very Low Relief	Medium	4,143	1,080	0	5,223
6311	ICH wk4	Very Low Relief	Coarse	1,505	18	0	1,523
6320	ICH wk4	Low Relief	Medium	4,583	903	0	5,486
6321	ICH wk4	Low Relief	Coarse	747	40	0	787
6330	ICH wk4	Moderate - High Relief	Medium	21,988	5,247	0	27,234
6331	ICH wk4	Moderate - High Relief	Coarse	982	161	0	1,144
6340	ICH wk4	Very High Relief	Medium	43,436	12,733	0	56,169
6341	ICH wk4	Very High Relief	Coarse	1,293	580	0	1,873
6420	IDF xw	Low Relief	Medium	0	0	1,452	1,452
6421	IDF xw	Low Relief	Coarse	0	0	68	68
6430	IDF xw	Moderate - High Relief	Medium	0	0	29,587	29,587
6431	IDF xw	Moderate - High Relief	Coarse	0	0	588	588
6510	IDF dk3	Very Low Relief	Medium	5,151	128,168	254,810	388,129
6511	IDF dk3	Very Low Relief	Coarse	671	9,322	27,109	37,102

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LM Code ID #	BGC Unit Name	Relief or Land Cover Class	Texture	Quesnel TSA (ha)	Williams Lake TSA (ha)	100 Mile TSA (ha)	Cariboo (ha)
6520	IDF dk3	Low Relief	Medium	5,841	102,098	132,337	240,276
6521	IDF dk3	Low Relief	Coarse	1,220	5,001	8,682	14,902
6530	IDF dk3	Moderate - High Relief	Medium	465	113,075	114,136	227,675
6531	IDF dk3	Moderate - High Relief	Coarse	0	1,950	4,457	6,407
6540	IDF dk3	Very High Relief	Medium	0	5,115	17,194	22,309
6541	IDF dk3	Very High Relief	Coarse	0	27	274	301
6550	IDF dk3	Very High Relief and Long Slopes	Medium	0	0	19,558	19,558
6610	IDF dk4	Very Low Relief	Medium	0	81,446	0	81,446
6611	IDF dk4	Very Low Relief	Coarse	0	7,593	0	7,593
6620	IDF dk4	Low Relief	Medium	0	97,930	0	97,930
6621	IDF dk4	Low Relief	Coarse	0	9,886	0	9,886
6630	IDF dk4	Moderate - High Relief	Medium	0	141,210	0	141,210
6631	IDF dk4	Moderate - High Relief	Coarse	0	13,466	0	13,466
6640	IDF dk4	Very High Relief	Medium	0	20,396	0	20,396
6641	IDF dk4	Very High Relief	Coarse	0	720	0	720
6710	IDF dw	Very Low Relief	Medium	0	4,630	0	4,630
6711	IDF dw	Very Low Relief	Coarse	0	587	0	587
6720	IDF dw	Low Relief	Medium	0	12,897	0	12,897
6721	IDF dw	Low Relief	Coarse	0	1,417	0	1,417
6730	IDF dw	Moderate - High Relief	Medium	0	25,840	0	25,840
6731	IDF dw	Moderate - High Relief	Coarse	0	3,194	0	3,194
6740	IDF dw	Very High Relief	Medium	0	54,532	0	54,532
6741	IDF dw	Very High Relief	Coarse	0	4,737	0	4,737
6820	IDF mw2	Low Relief	Medium	0	0	4,608	4,608
6830	IDF mw2	Moderate - High Relief	Medium	0	0	10,282	10,282
6910	IDF xm	Very Low Relief	Medium	0	30,950	468	31,418
6911	IDF xm	Very Low Relief	Coarse	0	3,442	43	3,485
6920	IDF xm	Low Relief	Medium	390	41,562	1,112	43,063
6921	IDF xm	Low Relief	Coarse	918	3,016	138	4,072
6930	IDF xm	Moderate - High Relief	Medium	6,279	125,631	7,270	139,180
6931	IDF xm	Moderate - High Relief	Coarse	753	4,754	388	5,895
6940	IDF xm	Very High Relief	Medium	0	27,077	4,122	31,199
6941	IDF xm	Very High Relief	Coarse	0	387	15	402
7020	IDF xh2	Low Relief	Medium	0	0	118	118
7030	IDF xh2	Moderate - High Relief	Medium	0	0	990	990
7220	MS xk2	Low Relief	Medium	0	0	9,205	9,205
7221	MS xk2	Low Relief	Coarse	0	0	854	854
7230	MS xk2	Moderate - High Relief	Medium	0	0	21,452	21,452
7231	MS xk2	Moderate - High Relief	Coarse	0	0	448	448
7320	MS xk3	Low Relief	Medium	0	0	229	229
7321	MS xk3	Low Relief	Coarse	0	0	22	22
7330	MS xk3	Moderate - High Relief	Medium	0	0	29,344	29,344
7331	MS xk3	Moderate - High Relief	Coarse	0	0	142	142
7500	MH mmp	Sparse Dry Meadow	ALL	0	1,864	0	1,864
7510	MH mmp	Sparse Dry Meadow	ALL	0	116	0	116
7511	MH mmp	Snow and Rock in Alpine	ALL	0	20	0	20
7520	MH mmp	Bare - Little or no vegetation	ALL	0	895	0	895
7531	MH mmp	Low Shrubs and Grasses in Alpine	ALL	0	1,709	0	1,709
7540	MH mmp	Vigorous Brush and Forbs	ALL	0	555	0	555
7550	MH mmp	Cores of Glaciers in Alpine	ALL	0	1,764	0	1,764
7551	MH mmp	Rock, Snow and Ice in Alpine	ALL	0	1,701	0	1,701
7552	MH mmp	Edges of Glaciers in Alpine	ALL	0	591	0	591
7553	MH mmp	Glacier Ice in Shadows	ALL	0	479	0	479
7561	MH mmp	Thick Green Trees and Brush	ALL	0	439	0	439
7564	MH mmp	Bright Green Trees	ALL	0	53	0	53

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LM Code ID #	BGC Unit Name	Relief or Land Cover Class	Texture	Quesnel TSA (ha)	Williams Lake TSA (ha)	100 Mile TSA (ha)	Cariboo (ha)
7565	MH mmp	Bright Green Trees	ALL	0	3	0	3
7570	MH mmp	Purple Trees in Shadow	ALL	0	647	0	647
7571	MH mmp	Dark Purple Trees in Shadow	ALL	0	14	0	14
7573	MH mmp	Dark Rock and Rubble in Alpine	ALL	0	540	0	540
7620	MS dc2	Low Relief	Medium	0	1,046	0	1,046
7621	MS dc2	Low Relief	Coarse	0	172	0	172
7630	MS dc2	Moderate - High Relief	Medium	0	41,186	0	41,186
7631	MS dc2	Moderate - High Relief	Coarse	0	3,835	0	3,835
7681	MS dc2	Bare - Little or no vegetation	ALL	0	1,357	0	1,357
7720	MS dv	Low Relief	Medium	0	4,972	0	4,972
7721	MS dv	Low Relief	Coarse	0	182	0	182
7740	MS dv	Moderate - High Relief	Medium	0	22,107	0	22,107
7741	MS dv	Moderate - High Relief	Coarse	0	1,002	0	1,002
7810	MS xk	Very Low Relief	Medium	0	0	0	0
7820	MS xk	Low Relief	Medium	0	13	0	13
7830	MS xk	Moderate - High Relief	Medium	0	3,595	0	3,595
7840	MS xk	Very High Relief	Medium	0	1,126	0	1,126
8020	MS xv	Low Relief	Medium	82,981	128,161	0	211,142
8021	MS xv	Low Relief	Coarse	3,942	14,887	0	18,829
8030	MS xv	Moderate - High Relief	Medium	133,999	245,185	0	379,184
8031	MS xv	Moderate - High Relief	Coarse	3,394	9,903	0	13,297
8050	MS xv	Low Relief and Very Long Slopes	Medium	61,055	28,536	0	89,591
8051	MS xv	Low Relief and Very Long Slopes	Coarse	1,787	1,283	0	3,070
8060	MS xv	Very High Relief and Long Slopes	Medium	0	142,365	0	142,365
8120	SBPS dc	Low Relief	Medium	111,405	71,545	0	182,950
8121	SBPS dc	Low Relief	Coarse	19,887	3,820	0	23,707
8130	SBPS dc	Moderate - High Relief	Medium	95,709	19,398	0	115,108
8131	SBPS dc	Moderate - High Relief	Coarse	4,714	441	0	5,155
8140	SBPS dc	Frosty Area of Low Relief	Medium	56,276	0	0	56,276
8141	SBPS dc	Frosty Area of Low Relief	Coarse	8,559	0	0	8,559
8150	SBPS dc	Low Relief and Very Long Slopes	Medium	378	3,722	0	4,100
8160	SBPS dc	Very High Relief and Long Slopes	Medium	424	3	0	427
8210	SBPS mc	Very Low Relief	Medium	12,275	5,323	0	17,597
8211	SBPS mc	Very Low Relief	Coarse	0	492	0	492
8220	SBPS mc	Low Relief	Medium	36,160	15,630	0	51,790
8221	SBPS mc	Low Relief	Coarse	3,637	1,183	0	4,820
8230	SBPS mc	Moderate - High Relief	Medium	34,864	5,463	0	40,327
8231	SBPS mc	Moderate - High Relief	Coarse	1,943	61	0	2,004
8240	SBPS mc	Frosty Area of Low Relief	Medium	5,929	0	0	5,929
8241	SBPS mc	Frosty Area of Low Relief	Coarse	590	0	0	590
8250	SBPS mc	Low Relief and Very Long Slopes	Medium	8,725	0	0	8,725
8260	SBPS mc	Specific Geographic Locality	Medium	662	2,509	0	3,171
8261	SBPS mc	Specific Geographic Locality	Coarse	0	9	0	9
8310	SBPS mk	Very Low Relief	Medium	0	33,676	27,089	60,765
8311	SBPS mk	Very Low Relief	Coarse	0	357	673	1,030
8320	SBPS mk	Low Relief	Medium	52,939	20,505	43,803	117,247
8321	SBPS mk	Low Relief	Coarse	6,426	173	600	7,199
8330	SBPS mk	Moderate - High Relief	Medium	145,261	10,268	31,124	186,653
8331	SBPS mk	Moderate - High Relief	Coarse	4,239	25	186	4,450
8350	SBPS mk	Low Relief and Very Long Slopes	Medium	6,646	2,575	0	9,221
8351	SBPS mk	Low Relief and Very Long Slopes	Coarse	4,505	0	0	4,505
8360	SBPS mk	Very High Relief and Long Slopes	Medium	3,493	13	0	3,505
8420	SBPS xc	Low Relief	Medium	4,391	691,425	0	695,816
8421	SBPS xc	Low Relief	Coarse	3,227	62,516	0	65,743
8430	SBPS xc	Moderate - High Relief	Medium	2,872	323,059	0	325,931

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LM Code ID #	BGC Unit Name	Relief or Land Cover Class	Texture	Quesnel TSA (ha)	Williams Lake TSA (ha)	100 Mile TSA (ha)	Cariboo (ha)
8431	SBPS xc	Moderate - High Relief	Coarse	709	13,880	0	14,589
8450	SBPS xc	Low Relief and Very Long Slopes	Medium	0	29,815	0	29,815
8451	SBPS xc	Low Relief and Very Long Slopes	Coarse	15	2,767	0	2,782
8520	SBS dk	Low Relief	Medium	243	0	0	243
8530	SBS dk	Moderate - High Relief	Medium	477	0	0	477
8610	SBS dw1	Very Low Relief	Medium	400	15,455	9,901	25,756
8611	SBS dw1	Very Low Relief	Coarse	0	273	18	291
8620	SBS dw1	Low Relief	Medium	26,875	74,460	34,550	135,885
8621	SBS dw1	Low Relief	Coarse	709	1,708	118	2,536
8630	SBS dw1	Moderate - High Relief	Medium	52,406	67,454	70,660	190,521
8631	SBS dw1	Moderate - High Relief	Coarse	3,815	831	120	4,766
8640	SBS dw1	Very High Relief	Medium	0	1,792	2,535	4,327
8641	SBS dw1	Very High Relief	Coarse	0	70	0	70
8710	SBS dw2	Very Low Relief	Medium	411	15,274	21,704	37,389
8711	SBS dw2	Very Low Relief	Coarse	0	10	42	52
8720	SBS dw2	Low Relief	Medium	67,640	44,289	33,311	145,239
8721	SBS dw2	Low Relief	Coarse	8,883	115	76	9,074
8730	SBS dw2	Moderate - High Relief	Medium	100,580	15,731	29,722	146,033
8731	SBS dw2	Moderate - High Relief	Coarse	4,734	0	43	4,777
8740	SBS dw2	Frosty Area of Low Relief	Medium	3,637	0	0	3,637
8741	SBS dw2	Frosty Area of Low Relief	Coarse	489	0	0	489
8750	SBS dw2	Low Relief and Very Long Slopes	Medium	11	0	0	11
8760	SBS dw2	Very High Relief and Long Slopes	Medium	6	0	0	6
8810	SBS mc1	Very Low Relief	Medium	47	549	1,386	1,982
8811	SBS mc1	Very Low Relief	Coarse	0	41	5	46
8820	SBS mc1	Low Relief	Medium	535	3,096	6,730	10,362
8821	SBS mc1	Low Relief	Coarse	0	52	15	67
8830	SBS mc1	Moderate - High Relief	Medium	9,334	7,538	18,740	35,612
8831	SBS mc1	Moderate - High Relief	Coarse	0	54	17	71
8840	SBS mc1	Very High Relief	Medium	0	482	783	1,266
8841	SBS mc1	Very High Relief	Coarse	0	7	0	7
8850	SBS mc1	Specific Geographic Locality	Medium	0	2,228	0	2,228
8920	SBS mc2	Low Relief	Medium	5,335	0	0	5,335
8921	SBS mc2	Low Relief	Coarse	248	0	0	248
8930	SBS mc2	Moderate - High Relief	Medium	105,601	0	0	105,601
8931	SBS mc2	Moderate - High Relief	Coarse	725	0	0	725
8940	SBS mc2	Frosty Area of Low Relief	Medium	60	0	0	60
9010	SBS mc3	Very Low Relief	Medium	18	4	0	22
9011	SBS mc3	Very Low Relief	Coarse	0	5	0	5
9020	SBS mc3	Low Relief	Medium	4,848	290	0	5,138
9021	SBS mc3	Low Relief	Coarse	1	3	0	4
9030	SBS mc3	Moderate - High Relief	Medium	12,374	133	0	12,506
9031	SBS mc3	Moderate - High Relief	Coarse	4	0	0	4
9040	SBS mc3	Frosty Area of Low Relief	Medium	2,725	0	0	2,725
9050	SBS mc3	Low Relief and Very Long Slopes	Medium	30	0	0	30
9110	SBS mh	Very Low Relief	Medium	696	332	0	1,029
9111	SBS mh	Very Low Relief	Coarse	180	66	0	247
9120	SBS mh	Low Relief	Medium	12,987	1,091	0	14,078
9121	SBS mh	Low Relief	Coarse	7,708	488	0	8,196
9130	SBS mh	Moderate - High Relief	Medium	37,238	8,471	0	45,709
9131	SBS mh	Moderate - High Relief	Coarse	8,262	750	0	9,011
9140	SBS mh	Very High Relief	Medium	562	55	0	618
9141	SBS mh	Very High Relief	Coarse	54	1	0	55
9150	SBS mh	Low Relief and Very Long Slopes	Medium	5,875	0	0	5,875
9151	SBS mh	Low Relief and Very Long Slopes	Coarse	221	0	0	221

LM Code ID #	BGC Unit Name	Relief or Land Cover Class	Texture	Quesnel TSA (ha)	Williams Lake TSA (ha)	100 Mile TSA (ha)	Cariboo (ha)
9220	SBS mm	Low Relief	Medium	0	0	2,241	2,241
9230	SBS mm	Moderate - High Relief	Medium	0	0	9,158	9,158
9310	SBS mw	Very Low Relief	Medium	4,923	33	0	4,956
9311	SBS mw	Very Low Relief	Coarse	422	0	0	422
9320	SBS mw	Low Relief	Medium	42,548	492	0	43,039
9321	SBS mw	Low Relief	Coarse	2,611	0	0	2,611
9330	SBS mw	Moderate - High Relief	Medium	53,225	2,600	0	55,825
9331	SBS mw	Moderate - High Relief	Coarse	1,086	0	0	1,086
9340	SBS mw	Very High Relief	Medium	1,856	48	0	1,904
9341	SBS mw	Very High Relief	Coarse	9	0	0	9
9350	SBS mw	Frosty Area of Low Relief	Medium	22,234	0	0	22,234
9351	SBS mw	Frosty Area of Low Relief	Coarse	4,870	1	0	4,872
9510	SBS wk1	Very Low Relief	Medium	8,804	198	0	9,002
9511	SBS wk1	Very Low Relief	Coarse	1,710	3	0	1,713
9520	SBS wk1	Low Relief	Medium	21,133	2,851	0	23,984
9521	SBS wk1	Low Relief	Coarse	2,958	19	0	2,977
9530	SBS wk1	Moderate - High Relief	Medium	70,428	9,270	0	79,698
9531	SBS wk1	Moderate - High Relief	Coarse	5,392	84	0	5,476
9532	SBS wk1	Seepage Areas of all Relief	Coarse	3,069	157	0	3,226
9540	SBS wk1	Very High Relief	Medium	11,107	595	0	11,702
9541	SBS wk1	Very High Relief	Coarse	1,021	3	0	1,024
9610	CWH ms1	Very Low Relief	Medium	0	541	0	541
9611	CWH ms1	Very Low Relief	Coarse	0	223	0	223
9620	CWH ms1	Low Relief	Medium	0	428	0	428
9621	CWH ms1	Low Relief	Coarse	0	30	0	30
9630	CWH ms1	Moderate - High Relief	Medium	0	2,379	0	2,379
9631	CWH ms1	Moderate - High Relief	Coarse	0	293	0	293
9640	CWH ms1	Very High Relief	Medium	0	10,893	0	10,893
9641	CWH ms1	Very High Relief	Coarse	0	699	0	699
9671	CWH ms1	Low Benches	ALL	0	438	0	438
9672	CWH ms1	Medium Benches	ALL	0	429	0	429
9681	CWH ms1	Bare - Little or no vegetation	ALL	0	540	0	540
9710	IDF ww	Low Relief	Medium	0	97	0	97
9740	IDF ww	Moderate - High Relief	Medium	0	687	0	687
9741	IDF ww	Moderate - High Relief	Coarse	0	34	0	34
9820	MH mm2	Low Relief	Medium	0	176	0	176
9821	MH mm2	Low Relief	Coarse	0	34	0	34
9830	MH mm2	Moderate - High Relief	Medium	0	15,273	0	15,273
9831	MH mm2	Moderate - High Relief	Coarse	0	373	0	373
9881	MH mm2	Bare - Little or no vegetation	ALL	0	3,177	0	3,177
9885	MH mm2	Cores of Glaciers in Alpine	ALL	0	503	0	503

3.2 Digital input layers used in the Fuzzy prediction of PEM map entities

The fuzzy logic procedures used to estimate the likelihood that any given grid cell belonged to any defined ecological class (Site Unit) mostly made use of automatically computed digital data layers. The philosophy behind utilizing automatically prepared input layers is basically one that recognizes that there are instances where it is far more effective and cost efficient to automate tedious and repetitive tasks than it is to utilize manual visual interpretation and manual digitizing. In adherence to the principal of parsimony, the LMES Fuzzy logic procedures made use of only 18 different input variables (Table 12) of which several (the last 6) were used only rarely. Each of the input was selected to represent or approximate one or more of the site factors referenced in the definition of the conceptual models used to describe the conditions under which ecological entities were expected to occur.

Table 12. List of digital input layers used in the prediction of LMES Fuzzy ecological entities

Input No.	Source DBF File	Input Name	Description of Digital Input Layer	Concept(s) that the Input Layer was used to Represent	Reference for Method of Calculation	Example Attribute
1	formfile	LNQAREA	Log of Upslope Area (m2)	Used to estimate relative landform position	Quinn et al., 1991	Crest
2	formfile	QWETI	Quinn Wetness Index (dimensionless)	Used to estimate relative moisture regime	Quinn et al., 1991	Dry_WI
3	formfile	SLOPE	Slope gradient in percent (%)	Used as a direct measure of slope steepness	Eyton, 1991	Steep
4	formfile	NEW_ASP	Values for aspect rotated 45° counter clockwise to put the 0° aspect value at 325°	Rotated aspect was used to infer degree of exposure as for warm (SW) or cool (NE) aspects		NE_Aspect
5	relzfile	PCTZ2ST	Percent change in elevation (Z) of a cell relative to the closest stream and ridge cells to which it is connected by paths of simulated surface flow.	This variable was used as the main measure of local relative landform position or relative relief. Think of it as expressing relative distance upslope in percent.	MacMillan et al., 2007	Crest2Mid
6	relzfile	PCTZ2PIT	Percent change in elevation (Z) of a cell relative to the closest pit and peak cells to which it is connected by paths of simulated surface flow.	This variable was used as a secondary measure of a more general or regional relative landform position.	MacMillan et al., 2007	Near_Base
7	geofile	DEPTH	Code for depth to bedrock estimated by contract air photo interpreters	This input variable was used to identify areas that were shallow to bedrock (< 50 cm).	TFIC, 2007	Deep
8	geofile	TEXTURE	Code for texture class as estimated by contract air photo interpreters	This input variable was used to identify areas of coarse, fine or organic textures	TFIC, 2007	Organic
9	relzfile	SEEPAGE	Manualy interpreted areas of elevated likelihood of seepage.	Seepage areas were used as a flag to alert KB rules to treat cells as wetter than normal.	TFIC, 2007	Hi_Seep
10	relzfile	Z2St	Absolute vertical change in elevation (Z) from a cell to the nearest stream channel cell to which it is connected by a path of simulated surface flow.	Used as a measure of absolute vertical change in elevation relative to a local base level at the nearest cell recognized as a channel cell.	MacMillan et al., 2007	Hi_Ridge
11	relzfile	Z2Pit	Absolute vertical change in elevation (Z) from a cell to the nearest stream pit cell to which it is connected by a path of simulated surface flow.	Used as a measure of absolute vertical change in elevation relative to a local base level at the nearest cell recognized as a pit cell.	MacMillan et al., 2000	Hi_Bench
12	geofile	Z2wet	Vertical distance (m) of a cell from the nearest cell classified as a wetland or water body to which it is connected by a path of simulated surface flow.	This variable was used as a measure of vertical distance above a manually mapped wetland or water body. It was used to create elevation sensitive buffers around wetlands.	MacMillan et al., 2007	WetZ_LT05
13	geofile	L2Wet	Horizontal distance (m) of a cell from the nearest cell classified as a wetland or water body to which it is connected by a path of simulated surface flow.	This variable was used as a measure of horizontal distance back from a manually mapped wetland or water body. It was used to create buffers around wetlands.	MacMillan et al., 2007	WetL_LT200
14	geofile	N2Wet	Buffered horizontal distance of a cell from the nearest cell that was manually mapped as a pasture or meadow in only 2 BEC Subzones.	This variable was used in one particular area to define narrow buffers around non-forested meadiws in frosty, coarse textured areas.	MacMillan et al., 2007	Sand_Fringe
15	formfile	PLAN	Across-slope or plan curvature (given in °/100 m)	Used infrequently as an additional indication of convergence or divergence of surface flow.	MacMillan et al., 2007	Convex_a
16	formfile	PROF	Down-slope or profile curvature (given in °/100 m)	Used infrequently as an indication of surface concavity or convexity.	MacMillan et al., 2000	Concave
17	geofile	ELEV	Elevation above sea level as reported by the 25 m GRID DEM.	Several Site Series were defined in terms of a range in elevation over which they occurred.	Not Necessary to document	GT1800
18	geofile	B3	Digital number for Band 3 extracted from the false color satellite image	The Band 3 contract stretched data was level sliced to indicate relative type of land cover.	This report.	Treed

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Most of the digital input layers listed in Table 12 were computed by analyzing the 25 m DEM prepared from the provincial TRIM II digital elevation model data set by Meridian Mapping Ltd. Meridian was responsible for preparing a separate input data quality report and for documenting the procedures used to prepare the DEM.

Essentially, the 25 m DEM was prepared using the TOPOGRID interpolation procedure available in ESRI's Arc Info. TOPOGRID provides some functionality to enforce drainage constraints. Drainage constraints are imposed by forcing the interpolated DEM to respect lines of drainage identified by digitized vector stream channels and recognized ridges. Meridian utilized the available TRIM II vector source data, including regular and breakline x,y,z elevation data and vector data on locations of streams and ridges as input to the TOPOGRID interpolation procedures. They selected control parameters that maximized conformance of the interpolated DEM to the recorded drainage network for all cells that were close to a mapped drainage network. For cells that were not close to a mapped drainage network, maximum weight was placed on the individual data points in the region of the cell. This approach produced a DEM that provided maximum detail on variation in the interpolated topographic surface in areas that were not close to a mapped drainage channel while preserving maximum fidelity to the drainage network for all cells close to a mapped drainage network. Meridian applied a succession of mean filters to the original 25 m grid DEM produced by application of the TOPOGRID interpolation procedures. The original 25 m DEM was filtered using three passes of mean filters of dimensions 3x3, 3x3 and 5x5 respectively. This filtering almost surely degrades the absolute vertical accuracy of the DEM surface but it has been found to improve the relative utility of the DEM by removing a considerable amount of local noise and bringing out the longer range signal associated with landscape features of interest (e.g. hillslopes and portions of hillslopes).

The overall Cariboo PEM project required creation of several different working blocks of DEM data. Each block of data covered the geographic extent of an LMES PEM Project area. In earlier projects, the DEM that LMES received was truncated exactly at the boundaries of the project area (Quesnel and East Williams Lake PEMs). For later projects (East Quesnel, West Williams Lake and 100 Mile House), LMES received a single seamless DEM for the entire Cariboo that permitted LMES to create working blocks of DEM data that overlapped onto adjacent working blocks, including blocks defined for previously completed PEM project areas.

The only other source of automatically generated digital data used in the Cariboo PEM project was false color composite mosaics of LandSat 7 ETM satellite imagery. These digital image data sets were initially used mainly as graphical backdrops for visual review and analysis of the various input layers and of the final PEM maps. As the PEM mapping progressed, increasing use was made of the satellite image data to help in the production of the "classification zone" maps described in the previous section. The raw digital numbers extracted from the LandSat false color composite images were used very infrequently as direct inputs into the LMES Fuzzy classification procedures.

The LMES fuzzy logic procedures did make use of a few manually prepared input data layers. Specifically, many of the LMES KB rules made reference to parent material depth and texture as manually interpreted by the contract interpreters. The SEEPAGE input was also produced by manual air photo interpretation and digitizing. It was treated by the KB rules as a kind of Boolean class within which the likelihood of encountering wetter than normal ecological classes was considered to be very high. In such areas, the LMES fuzzy procedures almost always predicted the occurrence of only one or at most two wetter than normal ecological classes.

Each of the data layers listed in Table 12 is illustrated and described in greater detail in the following sections. The order of presentation in Table 12 reflects the relative frequency with which the various digital inputs layers were used by the LMES Fuzzy classification procedures. The first few input layers were used extensively in almost all LMES KB rule bases. Input layers listed towards the bottom of the table were used much less frequently and some may only have been used in one or two KB rule sets. None of the LMES KB rules contain any input variables that are not listed in Table 12.

3.2.1 Log of Upslope Area (LnQarea) as a measure of relative landform position

This terrain derivative is computed from the 25 m DEM data using the LandMapR program FormMapR. It is one of two derivatives (the other being percent Z to stream – PCTZ2STR) that is commonly used as a measure of relative landform position in the LMES DSS procedures (Figure 21). This variable is used to approximate the concept of relative landform position as expressed by such terms as crest, upper-slope, mid-slope, lower-slope, toe-slope and depression. In most LMES KB rule bases, LnQarea was used mainly to identify the extreme ends of the landform position spectrum, that being crests and valleys while the variable PctZ2St was used for most other landform positions. (See Table 13 left). Table 13 right lists some of the other conceptual landform positions that LnQarea was used to approximate in other KB rule sets.
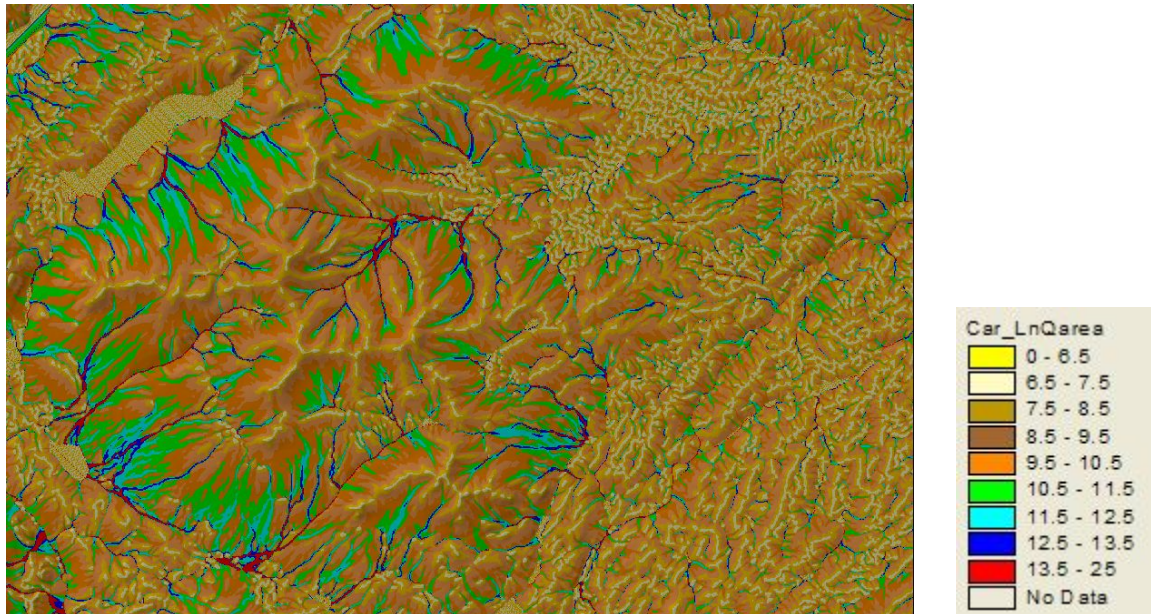
Figure 21. Illustration of the input variable Log of Quinn Upslope Area for an area in the Cariboo

This variable has also been used as a surrogate for relative moisture regime in some KB rules. In some localities, this variable provided a more convenient and useful measure of relative moisture than the more commonly used Quinn wetness index. The LMES approach is to use whatever variable seems to work best for capturing a concept, and sometimes log of diffuse upslope area was judged to provide a more relevant approximation of moisture regime that wetness index.

Table 13. Listing of typical attribute classes defined using the Log of Upslope area input variable

No.	file_in	attr_in	class_out	model_no	b	d	No.	file_in	attr_in	class_out	model_no	b	d
1	formfile	LNQAREA	Crest	5	7.5	0.5	1	formfile	LNQAREA	Crest	5	7.0	0.5
2	relzfile	PCTZ2ST	Crest2Mid	1	60.0	20.0	2	formfile	LNQAREA	Crest2Up	5	6.0	0.5
3	relzfile	PCTZ2ST	Up2Mid	1	50.0	30.0	4	formfile	LNQAREA	Crest2Mid	5	8.5	0.5
4	relzfile	PCTZ2ST	Mid2Low	1	30.0	20.0	5	formfile	LNQAREA	Crest2Toe	5	8.9	0.5
5	relzfile	PCTZ2ST	Low2Toe	1	12.0	10.0	6	formfile	LNQAREA	Up2Mid	1	7.9	2.0
6	relzfile	PCTZ2ST	Toe	1	6.0	4.0	7	formfile	LNQAREA	Toe2Valley	4	9.8	0.5
7	relzfile	PCTZ2ST	Toe2Valley	1	4.0	2.0	8	formfile	LNQAREA	Valley	4	12.0	0.5
8	formfile	LNQAREA	Valley	4	13.0	0.5	9	formfile	LNQAREA	Hollow	4	11.0	0.5
							10	formfile	LNQAREA	Hi_Toe	1	25.0	4.0

The derivative LnQarea is computed using an algorithm described by Quinn et al., (1991) that is implemented in the LMES program FormMapR as documented in MacMillan et al., (2000). The algorithm is relatively simple and can be summarized as follows. First, all cells in a DEM are sorted by elevation, from highest to lowest elevation. The highest cell is visited and each of its neighbors is located. All

neighbor cells that are of equal or lower elevation are candidates for receiving input (accumulated upslope area) from the center cell. The total amount of upslope area passed to each down-slope cell is partitioned according to the steepness of the slope from the center cell to each neighbor cell. Thus, the algorithm computes the slope gradient from each cell into each neighbor cell (in terms of rise over run) and then adds up the total slope from the center cell into all neighbor cells that are of equal or lower elevation. The proportion of the total accumulated flow passed from the center cell to each neighbor cell is equal to the ratio of the slope into a neighbor cell divided by the total slope into all neighbor cells. The total accumulated area of upslope cells is partitioned according to this formula and each potential down-slope cell receives the portion of the total upslope accumulated area that it is due, according to the proportion of the total slope that is directed into that cell. Thus, for example, in a case where there are only 2 cells lower than the center cell and the slope into one cell is twice as steep as the slope into the second, the steeper cell will receive 2/3 of the total accumulated upslope area recorded for the center cell while the less steep cell will receive 1/3 of the total accumulated area. Each cell, of course, is computed to receive 100% of its own area. Once all neighbor cells of a central cell that are of equal or lower elevation have been visited and have received their allotted proportion of the total upslope area of the central cell, the algorithm moves to the next lowest cell in the data matrix and repeats all calculations. This continues until the lowest cell in the DEM matrix is reached and there are no lower cells into which to pass accumulated upslope area.

The derivative Log of Upslope area (LnQarea) provides a useful measure of relative distance down-slope from a crest or divide. Cells located at true divides have no (or only a few) cells upslope of them that can contribute flow (upslope area) into them. Because a divide cell may be located below another divide cell (topographically) some divide cells may exhibit a small amount of accumulated upslope area, but this is seldom very large. Thus, divide cells can be recognized quite effectively by associating them with low values of the variable LnQarea. Because accumulated upslope area is passed to each and every cell that occurs down-slope from a central cell, the spatial pattern exhibited by the variable LnQarea tends to display a smooth and monotonic (diffuse) increase in value in progressing from upslope to down-slope landform positions. The absolute value of upslope area computed for any cell provides a quite useful indication of the relative slope position of the cell, as long as the absolute value is only used to compare cells that occur in similar landscapes with slopes that are of similar and uniform length. Since LnQarea is really more like a measure of distance down-slope from a crest, it can only be used in a relative, or comparative, sense for landscapes that all have similar slope lengths. A toe slope at the base of a very long slope will inevitably exhibit a much higher value for accumulated diffuse upslope area (LnQarea) than a toe slope at the base of a much shorter slope. One therefore needs to be cautious in using the variable LnQarea as a measure of relative slope position. It can only be used comparatively within areas that have similar landforms with more or less consistently similar slope lengths. This is one of the reasons that the LMES DSS procedures incorporate the definition and recognition of "relief zones" into the classification hierarchy. Relief zones are assumed to encompass similar landforms that have a narrow and similar range of slope lengths that permit the use of absolute value variables such as LnQarea in a comparative or relative sense.

LnQarea was the principal derivative used to approximate relative landform position in the initial Cariboo PEM pilot and, to a lesser extent, in the Canim Lake PEM. Experience with using this variable to approximate relative landform position in these initial projects led to a decision to reduce use of this variable in subsequent project areas and to increase use of the variable PctZ2Str to represent relative landform position. PctZ2Str was considered to provide a more relative measure that was less sensitive to the absolute size and scale of the landscape and to changes in slope lengths and upslope areas counts for landforms of different scale. The variable LnQarea was still found to be preferable to PctZ2Str for recognizing the highest (crest) and lowest (valley or depression) relative landform positions but was otherwise not widely used to approximate other landform positions.

In the case of the input variable LnQarea described here, the units of measure are log of upslope area in square metres. LnQarea is computed for 25 m by 25 m pixel entities and values of LnQarea apply to each individual pixel entity. In general terms, the classes of relative relief or moisture regime defined using LnQarea can be considered to be ordered classes, insofar as each class is defined to occur conceptually above or below adjacent defined classes in an ordered topographic sequence.

3.2.2 Quinn Wetness Index (Qweti) as a measure of relative moisture regime

This terrain derivative is computed from the 25 m DEM data using the LandMapR program FormMapR. It is used as a measure of relative moisture condition (or wetness) in the LMES DSS procedures.
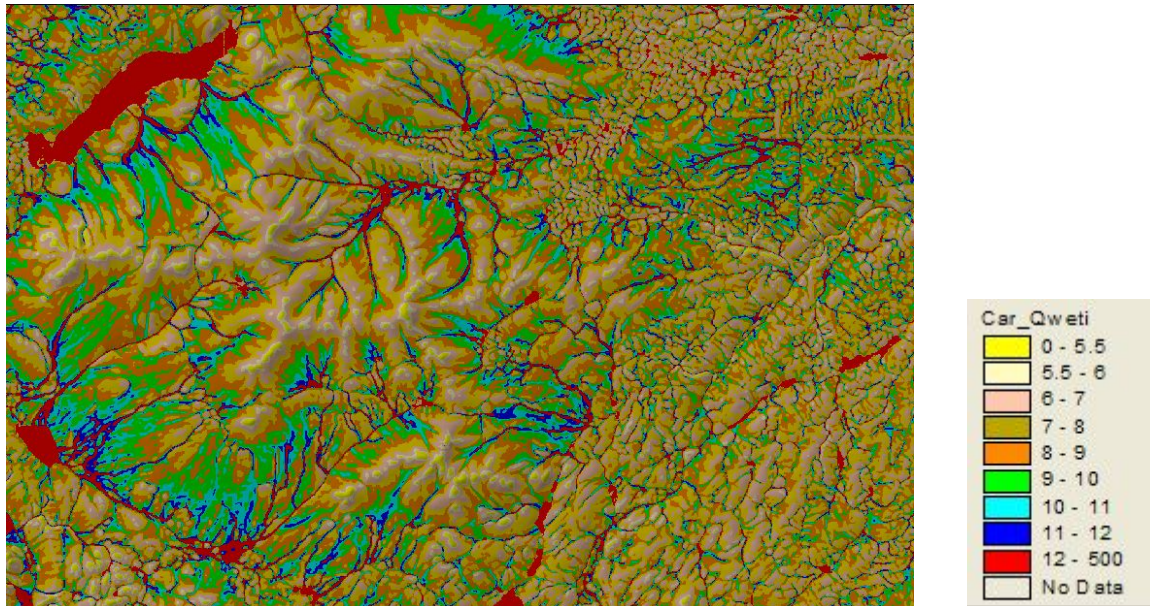
Figure 22 Illustration of the input variable Quinn Wetness Index for an area in the Cariboo

The derivative called wetness index (Qweti) is also commonly referred to as compound topographic index (CTI). It is meant to provide an indication of relative moisture condition (wetness or dryness) associated with the accumulation of surface and near-surface runoff of rainfall and snowmelt. It is less effective at identifying areas of elevated moisture that arise from accumulations of sub-surface moisture (e.g. high water tables) or from hydrogeological controls such as seepage from bedrock seams or artesian conditions. This derivative is used in the LMES DSS procedures to approximate the concept of moisture regime as expressed by such terms as xeric, mesic and hygric. The LMES DSS rule bases elect not to use these exact terms in order to avoid confusion between the precise definitions of terms such as xeric and the fuzzy, imprecise definitions associated with the classes of Qweti defined for use in the LMES DSS procedures.

Fuzzy classes defined to approximate concepts of relative moisture status (Table 14) are based on defining ranges of the variable Qweti that correspond with a conceptual understanding of the spatial pattern exhibited by different classes of moisture regime in the landscape.

The derivative Qweti is computed using an algorithm described by Quinn et al., (1991) that is implemented in the LMES program FormMapR as documented in MacMillan et al., (2000). Qweti is calculated by simply dividing the log of diffuse upslope area (LnQarea) described above by the mean slope computed from a central grid cell into all 8 of its adjacent neighbors (or fewer neighbors if the cell is located at the edge or corner of a data matrix). The conceptual underpinning of the derivative Qweti is quite simple. Basically, the notion is that surface water is less likely to run off from level terrain than from more steeply sloping terrain. Surface runoff is more likely to slow down and accumulate in areas of low slope gradient and is more likely to continue to run off down-slope in areas of steeper slopes. Thus, for any cell with a given diffuse upslope area (LnQarea) the relative likelihood of being wet (e.g. the wetness index) will be higher for a cell with a low slope (level) than for a cell with a high slope (steep). The equation for wetness index is Qweti = (LnQarea/Tan b). Dividing LnQarea by the slope expressed as a tangent (Tan b) results in larger values for wetness index for cells with a small slope and smaller values of wetness index for cells with a high slope gradient.   Ergo, level areas are projected to be wetter and steep areas projected to be drier for any given value of diffuse upslope area (LnQarea).

Table 14. Listing of relative moisture regime attribute classes defined using Quinn wetness index

No.	file_in	attr_in	class_out	model_no	b	d		No.	file_in	attr_in	class_out	model_no	b	d
9	formfile	QWETI	VDry	5	5.8	0.2		1	formfile	QWETI	Not_Wet	5	10.5	0.5
10	formfile	QWETI	VDry2SlDry	5	7.8	0.2		2	formfile	QWETI	Dry	5	10.0	0.5
11	formfile	QWETI	Dry	1	6.8	0.2		3	formfile	QWETI	Dry_WI	5	5.0	0.5
12	formfile	QWETI	Dry2SlDry	1	7.0	1.0		4	formfile	QWETI	VDry	5	6.0	0.2
13	formfile	QWETI	Sl_Dry	1	9.0	0.5		5	formfile	QWETI	Dry2SlDry	1	7.0	1.0
14	formfile	QWETI	Dry2Med	1	7.5	1.5		6	formfile	QWETI	Sl_Dry2Med	1	7.0	1.5
15	formfile	QWETI	Med_WI	1	8.5	1.0		7	formfile	QWETI	Dry2Med_WI	1	7.0	2.0
16	formfile	QWETI	Sl_Wet	1	10.0	0.9		8	formfile	QWETI	Dry2Med	1	7.5	1.5
17	formfile	QWETI	SLWet2Wet	1	11.0	0.6		9	formfile	QWETI	Dry2SlWet	1	7.5	2.0
18	formfile	QWETI	Wet	1	11.5	0.5		10	formfile	QWETI	VDry2SlDry	5	7.8	0.2
19	formfile	QWETI	Wet2V_Wet	4	12.5	0.5		11	formfile	QWETI	Sl_Dry_WI	5	8.5	0.5
								12	formfile	QWETI	Med_WI	1	8.5	1.0
								13	formfile	QWETI	Med2SlWet	1	8.5	1.0
								14	formfile	QWETI	Rel_Dry	5	9.0	0.5
								15	formfile	QWETI	Sl_Dry	1	9.0	0.5
								16	formfile	QWETI	Med2Sl_Wet	1	9.2	1.2
								17	formfile	QWETI	Wet2V_Wet	4	9.5	0.5
								18	formfile	QWETI	Rel_Wet	4	9.5	0.5
								19	formfile	QWETI	Sl_Wet	1	9.7	0.9
								20	formfile	QWETI	Sl_Wet2Wet	1	9.7	2.0
								21	formfile	QWETI	SLWet_Wet	4	9.8	0.5
								22	formfile	QWETI	Moist	1	10.0	2.0
								23	formfile	QWETI	SLWet2Wet	1	11.3	1.0
								24	formfile	QWETI	Wet	4	12.5	0.5

The derivative Quinn wetness index (Qweti) provides a useful measure of relative moisture regime for different portions of the landscape. The continuous variation in the value computed for Qweti can be partitioned into fuzzy classes that approximate soil moisture regime classes used to establish the defining conditions for Site Units in the keys and edatopic grids of published Field Guides.

As with the variable LnQarea used in its computation, Qweti tends to display a spatial pattern in which values increase smoothly and monotonically in progressing down-slope from crest to valley or depression (see Figure 22). Green, blue and red colors are indicative of assumed increasing levels of near surface moisture in Figure 22 while light yellow to brown colors are associated with drier moisture regimes.

The inference is that conditions become increasingly moister in progressing from high ridges into low valleys. In other words, water is assumed to run downhill and to accumulate in more level down-slope landform positions. The actual situation may not always be this simple; however the variable Qweti does provide a very useful measure of potential relative moisture regime (as well as relative landform position). Other spatial inputs (such as parent material texture) can be used to modify the basic assumption that moisture conditions become wetter in lower and flatter landform positions but, on the whole, this assumption proves to be useful and workable.

Readers are cautioned that the types and numbers of classes and the threshold values (b and d) used to establish the range of values associated with each wetness class can, and do, differ for different LMES DSS attribute rule files defined for different "classification zones". The class definitions listed in Table 14 are meant to provide an illustration of the concepts only and do not provide comprehensive documentation of all classes and all class limits used in all LMES DSS attribute rule files. The KB rules listed in Table 14 left are a copy of rules defined for the MS xv subzone while the list on the right identifies all concepts defined using the variable Quinn wetness index in any KB rule base defined for use in the Cariboo.

In the case of the input variable Qweti described here, the units of measure are not significant in any absolute sense. It is the relative values that are important. The variable Qweti is computed for 25 m by 25 m pixel entities and values of Qweti apply to each individual pixel entity. In general terms the relative moisture regime classes defined using Qweti can be considered to be ordered classes, insofar as each class is defined to be conceptually wetter or drier than its adjacent classes.

3.2.3 Slope Gradient (Slope) as a measure of slope steepness

This terrain derivative is computed from the 25 m DEM data using the LandMapR program FormMapR. It is used as a measure of slope steepness in the LMES DSS procedures (Figure 23).
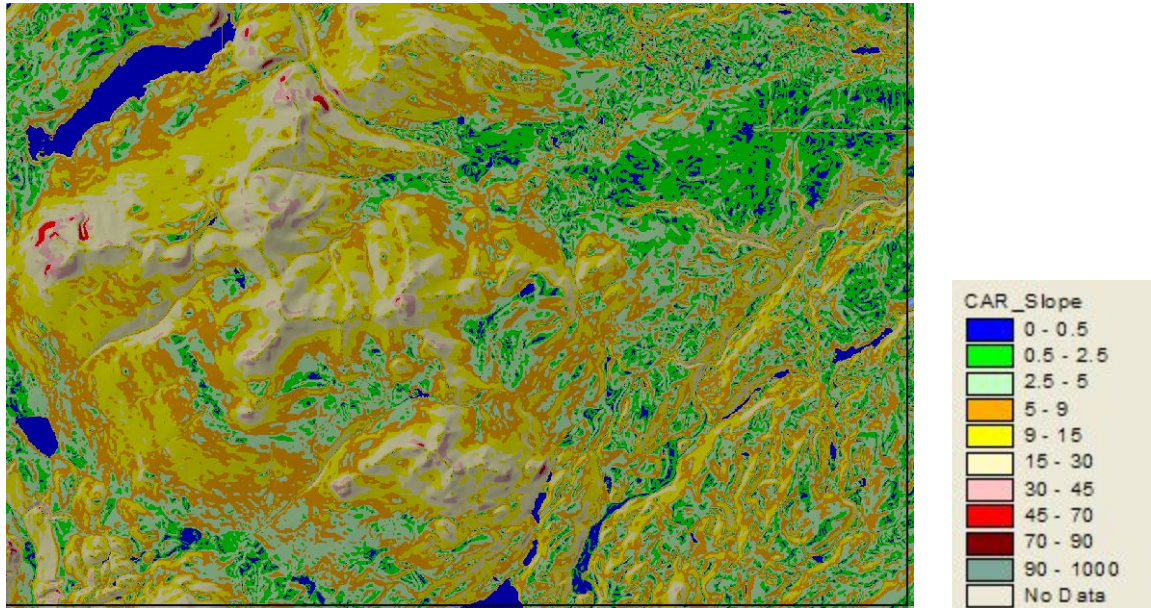
Figure 23. Illustration of the input variable Slope Gradient for an area in the Cariboo

Slope gradient (Slope) is used as either a definitive or descriptive criteria for virtually every Site Unit defined for use in the former Cariboo Forest Region. Site Units are regularly defined as occurring on a specified range of slopes, with some Site Units confined to steep slopes and others confined to gentler slopes. Slope gradient is therefore a key input layer used in the LMES DSS procedures. However, except when used to identify steeply sloping warm (SW) or cool (NE) aspect slopes, slope gradient is seldom assigned a high weighting factor in the LMES DSS procedures. Slope gradient is used to define a fairly consistent set of fuzzy classes that describe relative slope steepness using cognitive terms (Table 16).

Table 15. An example of an attribute rule file that defines fuzzy classes of slope steepness

No.	file_in	attr_in	class_out	model_no	b	d
20	formfile	SLOPE	Steep	4	30.0	2.0
21	formfile	SLOPE	SlopeLT05	5	5.0	1.0
22	formfile	SLOPE	SlopeLT10	5	10.0	1.0
23	formfile	SLOPE	SlopeLT20	5	20.0	1.0
24	formfile	SLOPE	SlopeLT30	5	30.0	1.0
25	formfile	SLOPE	SlopeGT05	4	5.0	1.0
26	formfile	SLOPE	SlopeGT10	4	10.0	1.0

Fuzzy classes of slope gradient are given cognitive class names such as Steep or SlopeLT05 (slope less than 5%). The Slope Attribute is represented by the fuzzy attributes as listed in Table 16 in the column named class_out. The unit of measurement used is percent slope computed as metres of rise divided by metres of run (m/m) times 100 (to convert to percent). Slope is computed along the plane of inclination (aspect) computed for a 3x3 window around a 25m x 25m pixel. Slope describes the pixel entity. The Slope attribute describes data that can be considered to be grouped into ordered classes.

3.2.4 Rotated Slope Aspect (New_Asp) as a measure of slope orientation

This terrain derivative is computed from the 25 m DEM data using the LandMapR program FormMapR. It is used as a measure of slope orientation (or exposure) in the LMES DSS procedures.

Slope aspect (New_Asp) (Figure 24) is used mainly to distinguish sites that exhibit warm (SW-facing) or cool (NE-facing) aspects from other sites that are not strongly influenced by aspect. In general, the main requirement was to be able to differentiate steep warm (SW) aspects and steep cool (NE) aspects. However, a few Site Units were defined in terms of occurring on gentle NE or gentle SW aspects.
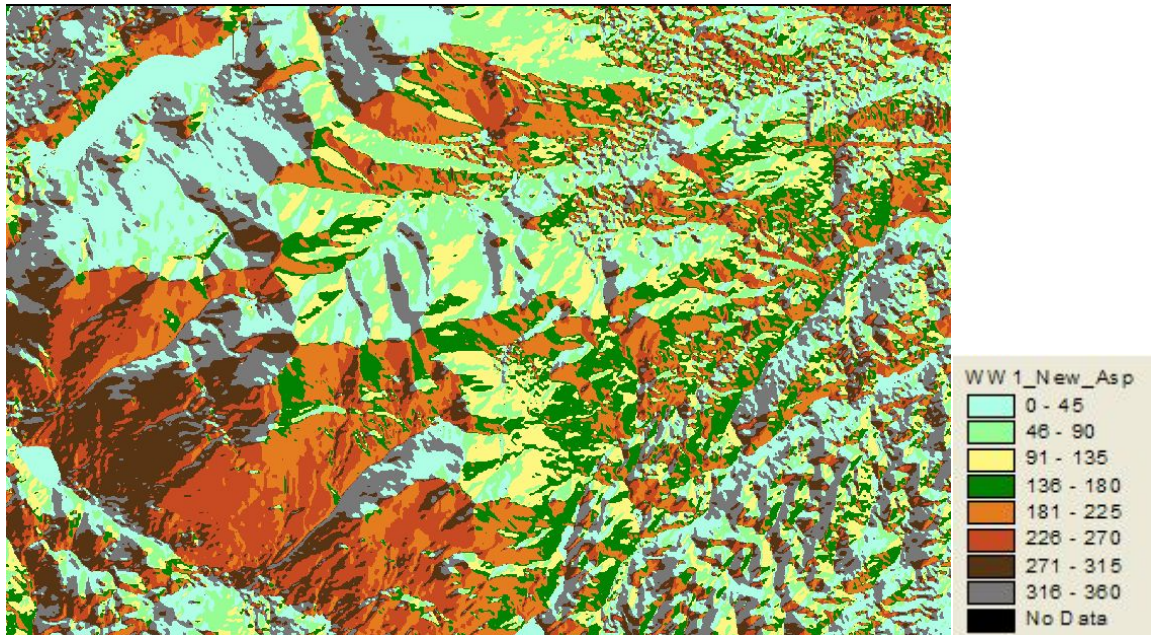
Figure 24. Illustration of the input variable for rotated (NEW) Aspect for an area in the Cariboo

The original numerical values computed for aspect (Aspect) were subjected to a counter-clockwise rotation of 45 degrees to create a slightly different variable that is here called New_Asp (Table 16). The new aspect variable (New_Asp) was required to help address a difficulty in using the original, un-rotated values for aspect to define fuzzy classes for NE aspect and SW aspect. Aspect is a circular variable with a value of zero (0) at north progressing to 360 degrees when one arrives back at north. The LMES DSS procedures for computing fuzzy classes need numerical data to exhibit a continuous, somewhat normal, distribution about a central value (b) in order to be applicable. This required distribution did not exist about the desired central values of 45° (NE) and 225° (SW) for the original, un-rotated calculations of aspect. By rotating the original values of aspect by 45° in a counter-clockwise direction, the value for New_Asp at 270° became equal to 0° (and also 360° of course) while the value for New_Asp at 0° became equal to 45° and the value for New_Asp at 45° became 90°. This made it possible to treat the value of New_Asp that occurred at 45° (e.g New_Asp - 90°) as a central value that had 90° of aspect to its left (counter-clockwise) and 90° of aspect to its right (clockwise). Thus a value of New_Asp of 90° could be treated as having a 100% likelihood of having a NE aspect with likelihood of having a NE aspect decreasing continuously to zero in both the counter-clockwise direction (at New_Asp = 0) and the clockwise direction (at New_Asp = 180). A similar result was obtained that permitted definition of a SW aspect centered on a value of New_Asp of 270°, which in reality is located at 225°. This re-orientation of the original aspect calculations was a kind of mental gymnastics required to respond to the fact that aspect is a circular variable that is not easily used for computing fuzzy measures of orientation in its original form.

The derivative Aspect is computed using an algorithm described by Eyton (1991) that is implemented in the LMES program FormMapR as documented in MacMillan et al., (2000). The algorithm of Eyton (1991) differs from most algorithms used to compute aspect in GIS systems in that it uses numerical procedures to fit an aspect plane exactly to the 9 cells in a 3x3 window. Most other algorithms use analytical techniques that fit a second or third order polynomial surface to the 9 elevation values in a 3x3 window and compute the first derivative of the polynomial surface to determine aspect. LMES elected to implement the Eyton (1991) algorithm in the FormMapR program after judging the results obtained using the numerical methods of Eyton (1991) to be more robust and stable than those obtained using more commonly used analytical algorithms. The original raw values of aspect (stored in a field named Aspect) were translated into the new variable New_Asp by applying a counter-clockwise rotation of 45° as described above.

Table 16. An example of an attribute rule file that defines fuzzy classes of slope orientation (aspect)

No.	file_in	attr_in	class_out	model_no	b	d
1	formfile	NEW_ASP	NE_Aspect	1	90.0	45.0
2	formfile	NEW_ASP	NNE_Aspect	1	90.0	22.0
3	formfile	NEW_ASP	NW_Aspect	1	23.0	22.0
4	formfile	NEW_ASP	SE_Aspect	1	158.0	22.0
5	formfile	NEW_ASP	SW_Aspect	1	270.0	45.0

Initially, only two fuzzy classes of slope orientation were defined for use in the LMES DSS procedures (Table 16). These classes were named NE_Aspect and SW_Aspect. As their names imply, these two classes represent the likelihood that any given cell will exhibit an orientation that is deemed to be NE or SW. A cell with an aspect of 45° (New_Asp of 90°) will have a likelihood of being considered to have a NE aspect of 100%. This likelihood will decrease to 50% at values for New_Asp of 45° and 135° in the counter-clockwise and clockwise directions respectively. Similarly, a value of New_Asp of 270° (in reality a true aspect of 225°) will have a likelihood of being considered to have a SW aspect of 100% that decreases to 50% at values for New_Asp of 225° and 315° in the counter-clockwise and clockwise directions respectively.

The LMES approach of rotating aspect 45° counterclockwise achieves the same overall effect as the Beers aspect transformation (Beers et al., 1966) which ranges from 0-200 and assigns a value of 0 to a grid cell that faces SW and 200 to a grid cell that faces NE, with 100 assigned to both NW and SE. The intent in both cases is to be able to differentiate SW from NE orientations.

Towards the end of the Cariboo PEM project, there was a need to define the slightly narrower classes of NNE_Aspect, NW_Aspect and SE_Aspect listed in Table 16. These were only needed for use in 1 BGC unit (BG xh3) in which a particular Site Series was defined as only occurring on a narrow NNE aspect.

The slope orientation attribute (New_Asp) is represented by the fuzzy attributes listed in Table 16 in the column named class_out. The unit of measurement used is degrees (note however that absolute values have been changed by a counter-clockwise rotation of 45°). Slope aspect is computed along the plane of inclination (aspect) computed for a 3x3 window around a 25m x 25m pixel. Slope aspect describes the pixel entity. The slope aspect attribute (New_Asp) describes data that can be considered to represent nominal classes of NE, NNE, NW, SE and SW aspect.

3.2.5 Percent Z to Stream (PctZ2Str) as a measure of relative landform position

This terrain derivative is computed from the 25 m DEM data using the LandMapR program FormMapR. It is one of two derivatives (the other being log of diffuse upslope area – LnQarea) that are commonly used as measures of relative landform position in the LMES DSS procedures (Figure 25).
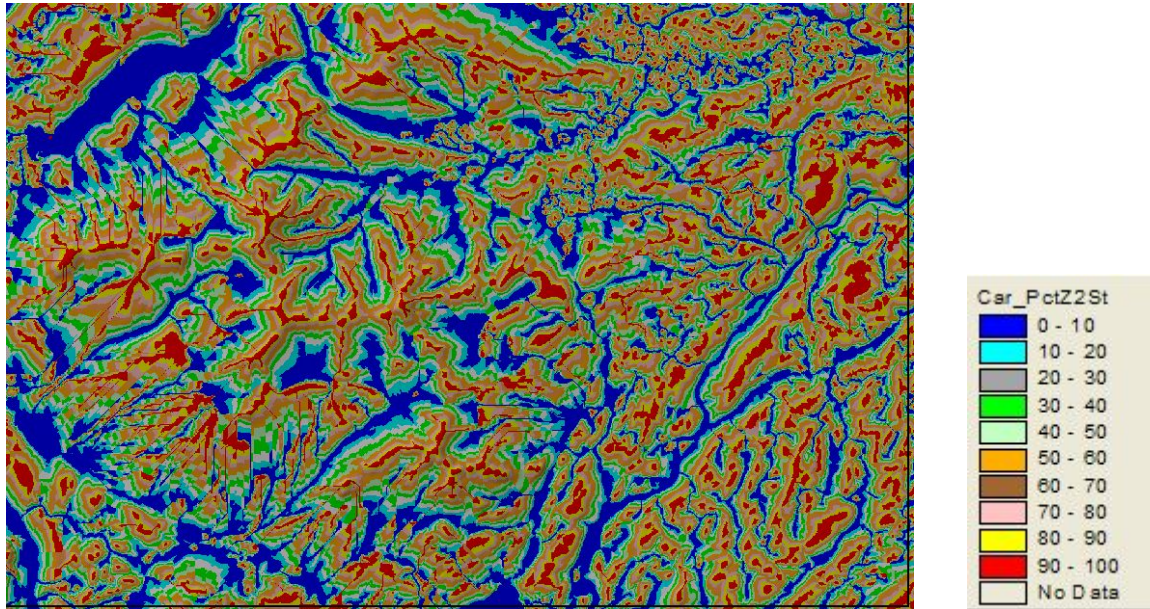
Figure 25. Illustration of the input variable Percent Z to Stream (PctZ2St) for an area in the Cariboo

This derivative is used to approximate the concept of relative landform position as expressed by such terms as crest, upper-slope, mid-slope, lower-slope, toe-slope and depression. Due to irregularities in the spatial pattern exhibited by this variable, it was not usually used in defining the highest (crest) and lowest (valley) relative landform positions (see Table 15). These two relative landform positions were generally approximated using a second terrain derivative (LnQarea) that exhibits a smoother, and less fragmented, spatial pattern in the vicinity of crests and valleys (Table 13).

Table 17. Listing of relative landform position attribute classes defined using Percent Z to Stream

No.	file_in	attr_in	class_out	model_no	b	d
1	formfile	LNQAREA	Crest	5	7.5	0.5
2	relzfile	PCTZ2ST	Crest2Mid	1	60.0	20.0
3	relzfile	PCTZ2ST	Up2Mid	1	50.0	30.0
4	relzfile	PCTZ2ST	Mid2Low	1	30.0	20.0
5	relzfile	PCTZ2ST	Low2Toe	1	12.0	10.0
6	relzfile	PCTZ2ST	Toe	1	6.0	4.0
7	relzfile	PCTZ2ST	Toe2Valley	1	4.0	2.0
8	formfile	LNQAREA	Valley	4	13.0	0.5

The derivative PctZ2Str is computed following procedures documented in MacMillan et al., (2000). The basic approach is relatively simple and can be summarized as follows. Firstly, flow directions and flow paths are computed for simulated surface water flow in both the down-slope and upslope directions using the LandMapR program FlowMapR. Once flow paths are established for fully integrated flow, each cell in a DEM is visited and the flow path from that cell is followed down-slope until flow arrives at a cell that is recognized to be a channel cell. A channel cell is simply any cell that has an upslope area count that is greater than a user assigned minimum threshold value. For most project areas, a threshold value of 900 upslope cells was used to classify cells as channel (or divide) cells.

Once flow has arrived at a channel cell, several useful measures can easily be computed. These include the vertical change in elevation between the originating grid cell and the grid cell classified as a stream channel (Z2St), the horizontal as-the-crow-flies distance from the originating cell to the stream channel cell (L2St) and the total flow path distance from the originating cell to the stream channel cell (N2St).

The process is then repeated using flow upslope from every cell in a DEM until flow reaches a cell that has been classified as a ridge or divide cell. Upslope flow directions and flow paths are computed using exactly the same algorithms as used for down-slope flow, with the difference being that the algorithms are applied to an inverted DEM. Inverting the DEM causes upslope flow from each cell to be treated as if it were down-slope flow. Ridges or divides are simply channels in the inverted DEM. The same threshold value of 900 cells was used to recognize ridge cells in the flow paths computed from the inverted DEM. Following simulated paths of flow upslope from each grid cell yields calculations of Z2Div, L2Div and N2Div that are the upslope equivalents of the previously described measures of Z2St, N2St and L2St.

These measures of absolute distance from each cell to the nearest channel (St) and ridge (Div) cells to which it is connected by defined paths of simulated surface flow can easily be converted into measures of relative slope position. In the case of the variable PctZ2St the calculation is simply computed as PctZ2St = (Z2St/(Z2Div+Z2St))*100. Multiplying by 100 causes the measure to be expressed as an integer number between 0 and 100 which is interpreted as percent vertical distance upslope relative to the total change in elevation from divide to channel (Z2Div+Z2St). A value of 0% upslope places a cell in a stream channel, a value of 100% upslope places a cell on a local crest or ridge top, while a value of 50% is taken to represent a mid-slope position.

Unlike most conventional PEM projects in BC that utilize EcoGen or ELDAR software to apply PEM knowledge bases, the LMES DSS approach does not define and use a single, consistent set of classes with fixed class boundaries for each class of each input layer. Instead, the LMES DSS procedures can define different classes, with different class boundaries and different ranges of values for each input variable in each different LMES "classification region". This has the advantage that the types and numbers of classes and the class boundaries can be adjusted for each and every defined "classification region".

In the case of the variable PctZ2Str that is used to approximate relative slope position classes, this means, for example, that the definition for where the boundary for a class called a toe slope will occur can be adjusted to move the location of where in the landscape a toe slope is recognized "up" or "down" slope as required in order to achieve the best possible fit between the Regional Ecologist's perception of where in the landscape a toe slope entity may be expected to occur, in a specific region, and where the toe slope entity is predicted to occur using the LMES classification rules. Similarly, some BGC units may contain Site Units that are defined as occurring in very specific landform positions such as, for example, gently sloping lower slopes, while other zones may have only a few Site Units and may not need to differentiate landform position to this level of detail. Therefore, the LMES DSS procedures are set up to permit different numbers and types of landform position classes to be defined for each BGC unit (and for each "classification region" within a zone). The list of slope position classes defined for a particular sub-zone or classification region is therefore not fixed and can vary according to the need to recognize different classes of landform in different areas.

In Table 15 each class of each attribute (in this case the attribute is relative slope position) is given a name that is meant to convey some cognitive meaning such as, for example, Crest2Mid for a crest to mid-slope position. This class name appears in the column labeled class_out. The classes defined for use in the LMES DSS procedures are fuzzy classes and do not have hard, fixed class boundaries, such as are usually used in other PEM software programs. Fuzzy classes are computed by applying a fuzzy classification model (model_no) to any numerical input variable that is selected to define the class. In the case of relative landform position, the input variable(s) selected to represent the concept of relative landform position are named LNQAREA and PCTZ2STR. The LMES attribute rule file (Table 15) tells the LMES program FacetMapR which input file to look in (in_file) to find the required input data and which field in the input file (attr_in) contains the data required to define the fuzzy class.

Fuzzy attribute classifications are computed according to 3 different types of fuzzy models (model_no). A type 5 model computes a one tailed curve of the LESS_THAN variety. In Table 15 any cell with a value for LNQAREA that is LESS THAN the index value (b) will be computed to have a likelihood of being a crest of 100%. The other important column in Table 14 is the one labeled (d). This column contains a number for computing what is termed the crossover value. The crossover value is a measure of the difference (d) in value from the index value (b) at which the likelihood that an input value belongs to the defined class is 50%. Thus, in Table 14, a value of LNQAREA of $7.5 + 0.5 = 8.0$ would be computed as having a 50% likelihood of being classified as being a crest. Values of LNQAREA between 7.5 and 8.0 would have a likelihood of being a crest of between 50% and 100% while values of LNQAREA that are greater than 8.0 would have a likelihood of being a crest of less than 50% decreasing to zero.

A type 4 model is a one tailed model of the GREATER-THAN variety. That is all values of the input variable that are GREATER THAN the user selected value of (b) are considered to have a 100% likelihood of being the defined class (the Valley class in Table 14). The crossover value of $13.0 - 0.5 = 12.5$ is the value at which the likelihood of being considered to occur in a valley is 50%. All input values less than 12.5 are considered to have a likelihood of being classed as a valley of less than 50%.

The most commonly used fuzzy model in the LMES DSS procedures is the two-tailed type 1 model. This model defines a kind of bell curve with a single peak and two tails that decrease in value symmetrically from the peak. The peak value is the user selected value for (b). This is the value of the input variable at which the likelihood of belonging to the defined class is 100%. The computed likelihood value drops off in both directions and reaches 50% at the two crossover values of (b+d) and (b-d). In the case of crest2mid b+d is $60+20 = 80$ while b-d is $60-20 = 40$. Thus a value of PCTZ2ST of 40% will be computed to have a likelihood of being in a crest to mid slope landform position of 50% as will a value of 80% upslope while a value of PCTZ2ST of 60% will be computed to have a 100% likelihood of belonging to this class.

The attribute for relative landform position is therefore represented by two different input variables, namely LNQAREA and PCTZ2ST. Classes for the attribute of relative slope position are not fixed and different types and numbers of classes can be defined for each unique "classification region". Each class in each "classification region" can be defined using different threshold values (b and d) that will define a different range of input values over which the pertinent input variable will be considered to have a high likelihood of belonging to a particular fuzzy attribute class.

Readers are reminded that the types, numbers and definitions of fuzzy classes of relative relief are not constant and may vary in the attribute rule tables (arule*xxxx*) created for any given "classification region". The classes of relative relief presented in Table 14 simply provide an example of one set of relative relief classes defined for one "classification region". Different types and numbers of classes of relative relief may be defined for other "classification regions".

In the case of the input variable PCTZ2STR described here, the units of measure are dimensionless units of percent. Relative relief is relative, not absolute, and the percent that any given cell is considered to be upslope is a function of the height that that cell is above a stream channel relative to the total change in elevation (Z) from divide to channel. Relative relief is computed for 25 m by 25 m pixel entities and values of relative relief apply to each individual pixel entity. In general terms the defined classes of relative relief can be considered to be ordered classes, insofar as each class is defined to occur conceptually above or below adjacent defined classes in an ordered topographic sequence.

3.2.6 Percent Z to Pit (PctZ2Pit) as a measure of relative height above base level

This terrain derivative (PctZ2Pit) was computed from the 25 m DEM data using the LandMapR program FormMapR (Figure 26).

It is used very rarely as a secondary measure of relative height above a local base level in the LMES DSS procedures. It was defined for use in only a single BGC unit (SBPSmc) and even there, it ended up not being used to any great effect. It was intended to help differentiate local valleys or channels that were sloping and high above the base level of the main river channel from portions of the landscape that were at or near the base level of the main channel of the Fraser River. In the end, the distinction was not useful or needed and the different classes predicted using it were amalgamated into a single class. The presence of this variable as an orphan in the LMES DSS attribute rule bases is simply due to the fact that it was easier to leave it in the rule bases and not use it than it was to remove it from the rule bases and revise the rules.
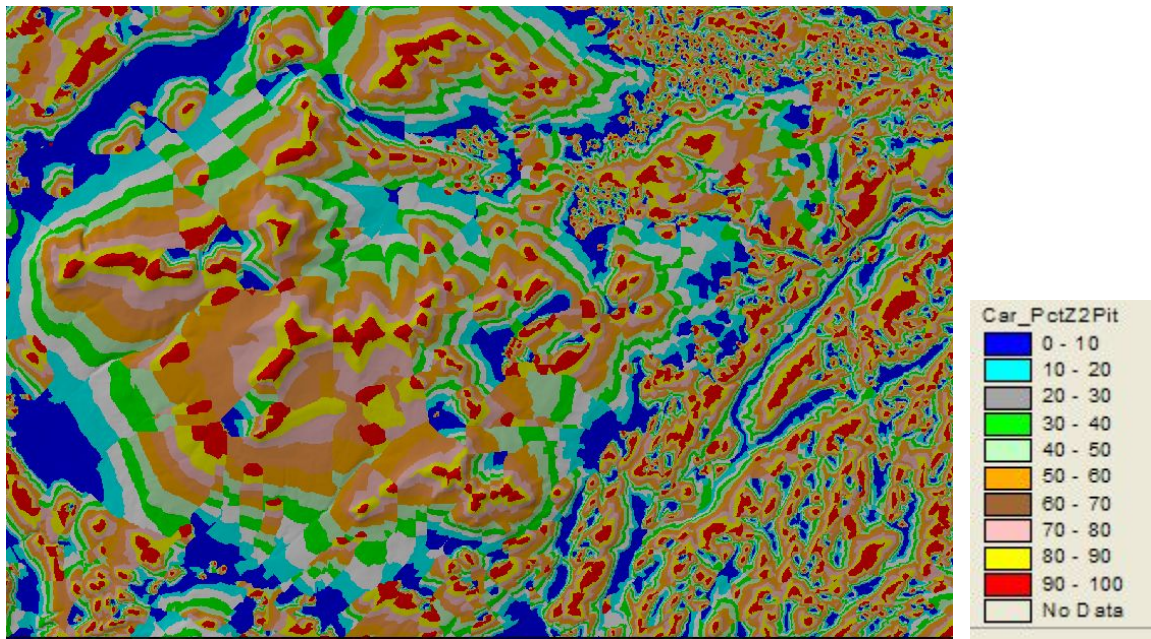
Figure 26. Illustration of the input variable Percent Z to Pit (PctZ2Pit) for an area in the Cariboo

In the example provided below (Table 21) grid cells would be considered to be high above local base level if they were centered around a value of PctZ2Pit of 30 (or more) while they would be considered to be relatively near local base level if they were centered around a value of 12% upslope (e.g. from 2-22% upslope). This was not a very important LMES DSS input data layer.

Table 18. An example of an attribute rule file that defines fuzzy classes of near base and above base

No.	file_in	attr_in	class_out	model_no	b	d
1	relzfile	PCTZ2PIT	Above_Base	1	30.0	20.0
2	relzfile	PCTZ2PIT	Near_Base	1	12.0	10.0

In the case of the input variable PCTZ2STR described here, the units of measure are dimensionless units of percent. Relative relief is computed for 25 m by 25 m pixel entities and values of relative relief apply to each individual pixel entity. In general terms the defined classes of relative relief can be considered to be ordered classes, insofar as each class is defined to occur conceptually above or below adjacent defined classes in an ordered topographic sequence.

3.2.7 Manually interpreted measures of soil depth (Depth)

This input layer (Figure 27) was described in a previous section that documented the input data used in the preparation of the LMES "classification zone" files.
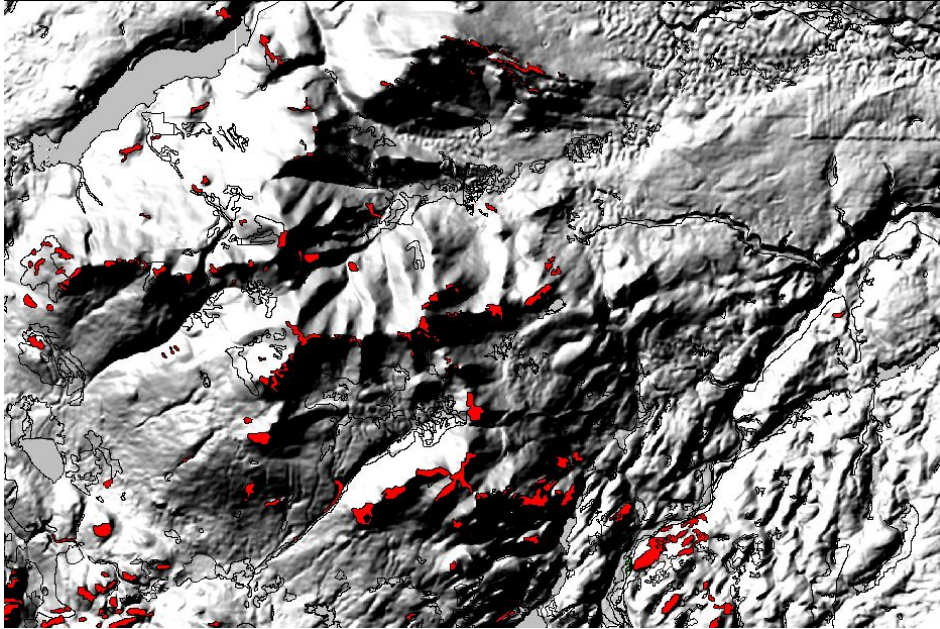
Figure 27. Illustration of the input variable Depth to Bedrock (Depth) for an area in the Cariboo

The manually interpreted codes for depth to bedrock were inserted into a field named Depth in the LMES file named ID#Geo for each tile of each individual project area. These codes (documented in Table 6) were basically used to identify areas that had been manually interpreted as being shallow to bedrock (< 20 cm). Such areas appear in Figure 27 in red, while all areas that are not red are assumed to have a depth to bedrock of greater than 50 cm. Areas mapped as shallow had a very high likelihood of being predicted to be occupied by shallow, dry ecological classes.

In some BGC units, the Regional Ecologist was not convinced that all areas manually interpreted as shallow were, in fact, shallow. In such areas, the weight placed on the input variable depth was reduced and shallow areas needed to also exhibit other conditions indicative of drier than normal environments (e.g. low wetness index, strong convexity) before they were predicted to be occupied by a drier than mesic ecological class.

Table 19. An example of an attribute rule file that defines fuzzy classes of shallow and deep

No.	file_in	attr_in	class_out	model_no	b	d
29	geofile	DEPTH	Deep	4	95.0	5.0
30	geofile	DEPTH	Shallow	5	49.0	1.0

In the case of the input variable depth described here, the units of measure are general estimates of depth in cm. Depth was mapped manually and then converted into 25 m by 25 m pixel entities and values of depth assigned to each individual pixel entity. In general terms the defined classes of depth can be considered to be ordered classes.

3.2.8 Manually interpreted measures of parent material texture (Texture)

This input layer (Figure 28) was described in the previous section that documented the input data used in the preparation of the LMES "classification zone" files.
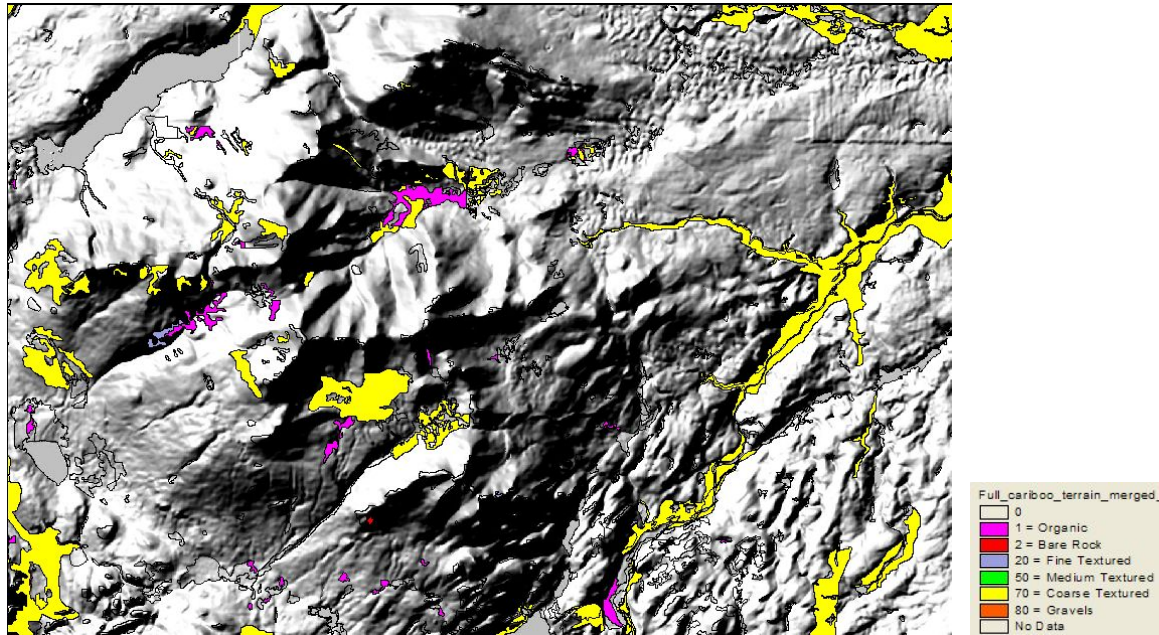
Figure 28. Illustration of the input variable Parent Material Texture for an area in the Cariboo

In addition to being used to prepare the classification zone files, the manually interpreted codes for depth to bedrock were inserted into the LMES file named ID#Geo for each tile of each individual project area. The value codes used to identify parent material texture (Figure 28) were often included in the Fuzzy KB rule bases used to define ecological entities. Organic areas (code 1) were often identified as being occupied by a very wet, organic, ecological class. Areas of bare tock (code 2) were treated as shallow (< 20 cm) for most purposes but were occasionally mapped out separately as simply bare rock. Areas mapped as fine textured (code 20) were often associated with the presence of alluvial or lacustrine materials and with moister than normal ecological classes. Areas mapped as coarse textured (codes 70 and 80) were usually used to define separate classification zones in which only coarse textured ecological classes were defined (Table 20).

Table 20. An example of an attribute rule file that defines fuzzy classes for parent material texture

No.	file_in	attr_in	class_out	model_no	b	d
30	geofile	TEXTURE	Coarse	4	60.0	5.0
31	geofile	TEXTURE	Med2Crs	4	40.0	20.0
32	geofile	TEXTURE	Medium	1	50.0	20.0
33	geofile	TEXTURE	Fine	5	31.0	20.0
34	geofile	TEXTURE	Organic	1	1.0	1.0

In the case of the input variable texture described here, the units of measure are general estimates of texture classes of the parent material. Texture classes were mapped manually and then converted into 25 m by 25 m pixel entities and values of texture codes were assigned to each individual pixel entity. In general terms the defined classes of texture can be considered to be ordered classes on a scale of 0 to 100.

3.2.9 Manually interpreted identification of seepage areas (Seepage)

The seepage input layer was described in the previous section that documented the input data used in the preparation of the LMES "classification zone" files. Seepage areas (Figure 29) were mapped manually by TFIC and JMJ interpreters.
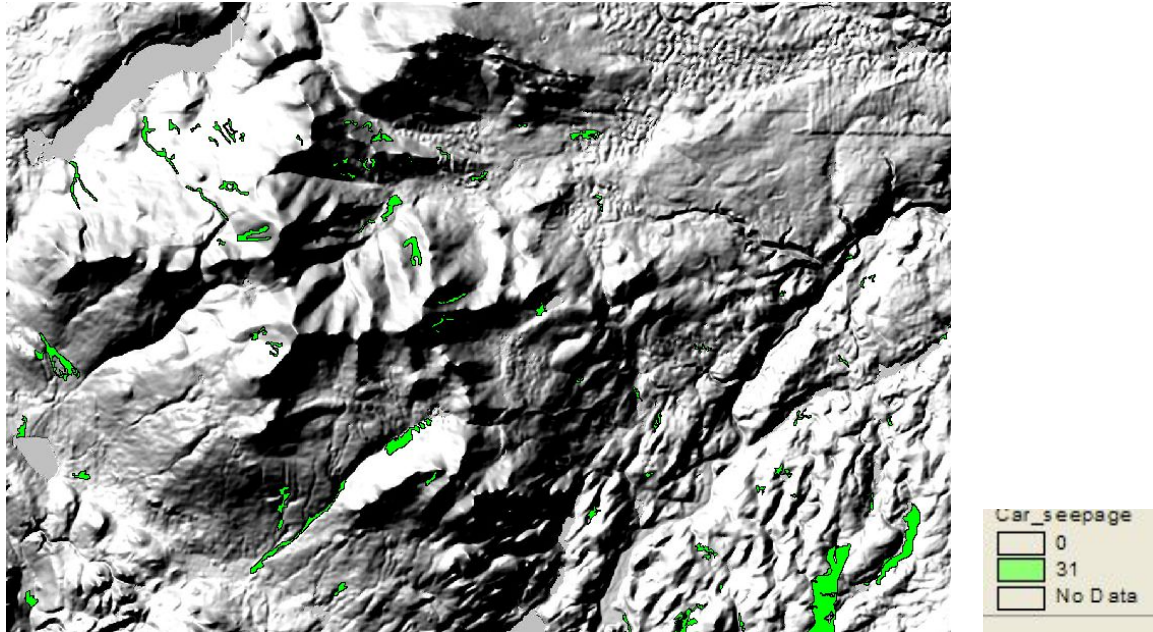
Figure 29. Illustration of the manually mapped SEEPAGE input variable for an area in the Cariboo

In addition to being used to prepare the classification zone files, the manually interpreted codes for depth to bedrock were inserted into the LMES file named ID#Geo for each tile of each individual project area. The only Fuzzy classes defined using the seepage input layer were those that recognized the presence or absence of seepage (Table 21).

Table 21. An example of an attribute rule file that defines fuzzy classes for seepage

No.	file_in	attr_in	class_out	model_no	b	d
1	geofile	SEEPAGE	Hi_Seep	4	0.9	0.1
2	geofile	SEEPAGE	No_Seep	5	0.0	0.1

Seepage areas represented an attempt to utilize manual visual interpretation to identify locations that appeared to be moister than would normally be expected for a given landform position. In most cases, interpreters identified areas that would normally have been expected to be occupied by normal mesic ecological classes but that were slightly wetter than normal for some reason or other. Some drift occurred in the interpretation of seepage areas by different contractors over the course of the full Cariboo PEM project. In later stages, it was not uncommon for interpreters to delineate seepage polygons in areas that would normally have been predicted to be quite moist by the LMES modeling procedures.

In the case of the input variable seepage described here, the units of measure are general estimates of presence or absence of seepage. Seepage classes were mapped manually and then converted into 25 m by 25 m pixel entities and the 31 seepage code was assigned to any affected pixel entity. In general terms the defined classes of seepage can be considered to be a single binary class on a scale of 0 or 1.

3.2.10 Vertical Distance to Stream (Z2St) as a measure of height above local stream level

This terrain derivative (Z2St) (Figure 30) was computed from the 25 m DEM data using the LandMapR program FormMapR. It is used as a measure of absolute height above a local base level in the LMES DSS procedures. More specifically, Z2St was used to help distinguish high ridges and knolls from lower ridges and knolls.
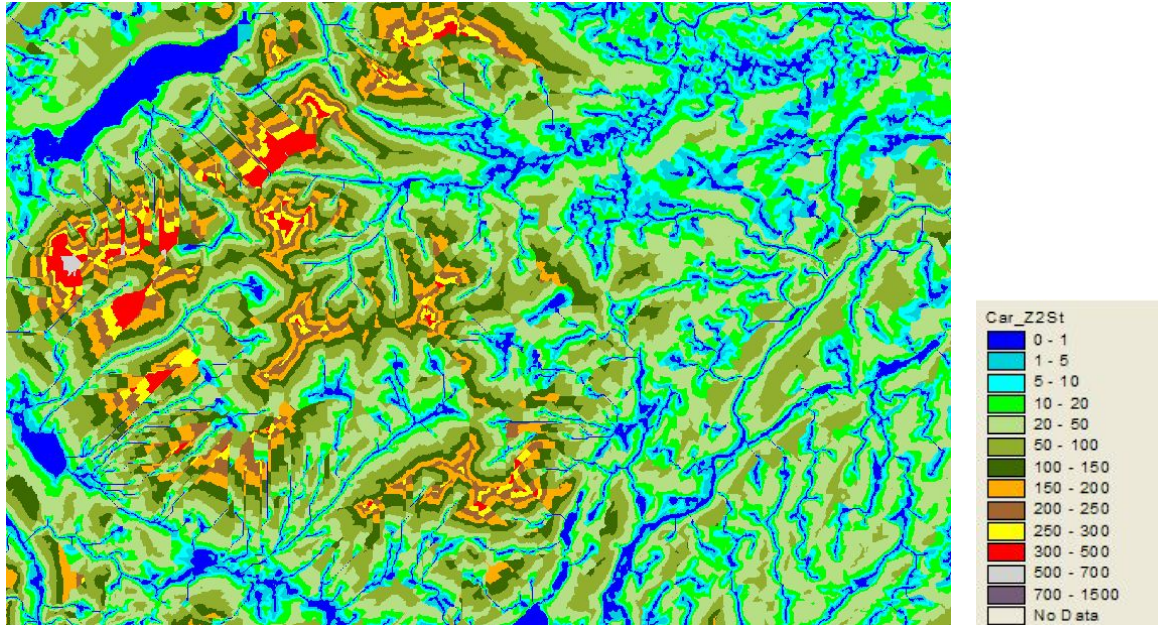
Figure 30. Illustration of the input variable distance to Stream (Z2St) for an area in the Cariboo

Vertical distance to stream (Z2St) was used as a secondary input variable to help distinguish whether a particular ridge or knoll was large and significant or smaller and less significant (Figure 30). This was the only use to which this input variable was put. Ridges higher above local base level than some specified absolute vertical distance (usually around 40 m) were considered to be high ridges that might have a higher likelihood of developing drier conditions associated with drier Site Units that occurred principally on the tops of higher ridges and knolls. Local base level was considered to be the elevation of the nearest stream channel to which a grid cell was connected by a defined path of simulated surface flow. Ridges or knolls that were less than the specified absolute height above local base level were considered to be less likely to be occupied by drier than normal Site Units (see Table 12).

Table 22. An example of an attribute rule file that defines fuzzy classes of high ridge and low knoll

No.	file_in	attr_in	class_out	model_no	b	d
39	relzfile	Z2St	Hi_Ridge	4	40.0	5.0
40	relzfile	Z2St	Low_Knoll	5	35.0	5.0

The variable Z2St was computed by the FormMapR program using an algorithm that has been documented by MacMillan et al., 2002 whose operation is summarized elsewhere in this report. The variable Z2Str was only used to help distinguish high ridges from lower knolls so that the tops of higher ridges could be associated with drier than normal moisture conditions and sub-mesic Site Units.

In the case of the input variable Z2St described here, the units of measure are metres above a local base level defined by a stream channel. Absolute relief is computed for 25 m by 25 m pixel entities and values of absolute relief apply to each individual pixel entity. Values of Z2St are used to define ordered classes.

3.2.11 Vertical Distance to Pit (Z2Pit) as a measure of height above local base level

This terrain derivative (Z2Pit) (Figure 31) was computed from the 25 m DEM data using the LandMapR program FormMapR. It is used as a measure of absolute height above a local base level in the LMES DSS procedures.
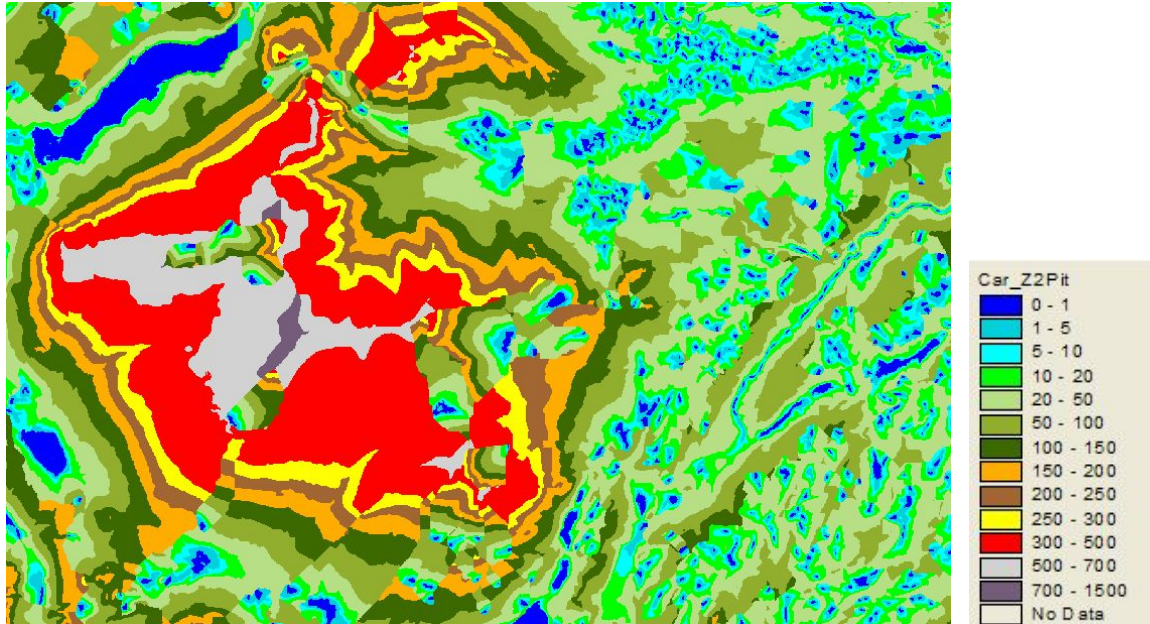
Figure 31. Illustration of the input variable distance to pit (Z2Pit) for an area in the Cariboo

Vertical distance to pit (Z2Pit) was used as a secondary input variable to help distinguish high and low benches and to differentiate areas that were located within valleys from those that were not (Table 23). This was the only use to which this input variable was put. Local base level was considered to be the elevation of the nearest pit or depression centre to which a grid cell was connected by a defined path of simulated surface flow. This input layers was not widely used.

Table 23. An example of an attribute rule file that defines fuzzy classes of high ridge and low knoll

No.	file_in	attr_in	class_out	model_no	b	d
1	relzfile	Z2Pit	Hi_Bench	4	25.0	5.0
2	relzfile	Z2Pit	Low_Bench	5	15.0	5.0
3	relzfile	Z2PIT	Not_Valley	4	20.0	5.0
4	relzfile	Z2PIT	In_Valley	5	15.0	5.0

The variable Z2Pit was computed by the FormMapR program using an algorithm that has been documented by MacMillan et al., 2002 whose operation is summarized elsewhere in this report. The variable Z2Pit was only used occasionally to help distinguish low from high benches and valleys from not valleys.

In the case of the input variable Z2Pit described here, the units of measure are metres above a local base level defined by a local depression bottom. Absolute relief is computed for 25 m by 25 m pixel entities and values of absolute relief apply to each individual pixel entity. Values of Z2Pit are used to define ordered classes.

3.2.12 Vertical (Z2Wet) and Horizontal (L2Wet) Distance to Wetland as measures of proximity to wetlands

These terrain derivatives were computed from the 25 m DEM data using a custom modification of a component of the LandMapR program FormMapR. They are used in the LMES DSS procedures as measures of positional context to identify cells located "near to" identified wetlands or water bodies.

These two measures were first computed for the Canim Lake PEM project in response to suggestions made by the Regional Ecologist. The Regional Ecologist was concerned with predictions that saw mesic, or even drier, Site Units predicted to occur right up to the margins, or edges, of wetlands and bodies of open water. The Regional Ecologist asked if there was not some mechanism by which low-lying areas located in close proximity to areas already mapped as being non-forested wetlands or open water might be differentiated.

LMES suggested that low-lying areas near the margins of wetlands or bodies of open water could be identified by computing two terrain derivatives that measured the vertical height of each cell above the nearest cell identified as a non-forested wetland or open water to which it was connected by a path of simulated surface flow (Z2wet) as well as the horizontal distance from each cell to the first cell mapped as wetland or open water (L2Wet) (see Table 24).

The two new variables named Z2Wet and L2Wet were computed by making a slight adaptation to an existing LMES program named Calc_RelZ. The original program was used to compute the variables Z2St, Z2Pit and so on described elsewhere in this report. This program was modified to flow down from each cell in a DEM, following a pre-defined path of simulated surface flow, until it encountered a target cell that had been manually interpreted as either non-forested wetland or open water. Immediately upon encountering the first target cell, the program identified the location and elevation of the target cell and used this information to compute the vertical change in elevation between the originating cell and the target cell (Z2Wet) as well as the horizontal, as-the-crow-flies distance from the originating cell to the target cell (L2Wet).

These two new measures provided a capability to identify cells that were located both close to a previously mapped wetland or water body in terms of horizontal distance and close to the elevation of the wetland or water body in terms of vertical height above the wetland or water body. Cells that were close to wetlands or water bodies in both the vertical and horizontal contexts were considered to have a higher than normal likelihood of being occupied by Site Units that were slightly, to significantly, wetter than mesic.

Table 24. An example of an attribute rule file that defines fuzzy classes of distance to wetland

No.	file_in	attr_in	class_out	model_no	b	d
35	geofile	L2Wet	WetL_LT200	5	100.0	50.0
36	geofile	Z2wet	WetZ_LT05	5	1.0	0.5

LMES defined a special class of low-lying buffer regions that occurred around the margins of wetlands or bodies of open water. This special class was recognized in virtually every BGC unit and was usually described as being occupied by one or more Site Units that were wetter than mesic. The class was defined as being "near to" a mapped wetland or lake in terms of both horizontal (WetL_LT200) and vertical (WetZ_LT05) distance.

The actual threshold values used to establish what constituted close to a wetland in both the horizontal and vertical dimensions can, and do, change from one BGC unit to another. Values used to define close to in the horizontal sense (WetL_LT200) varied from a low of 50 m to a high of 200 m. Values used to define close to in the vertical sense (WetZ_LT05) varied from a low of 0.5 m to a high of 5 m. It was necessary to use different threshold values for these variables in different BGC units in order to be able to respond to differences in topography and in how different scales of topography affected the size and extent of the predicted buffer zones.

3.2.13 Buffered Distance to meadows and non-productive brush (N2Wet)

The measure named N2Wet was computed using a simple linear buffer command in ArcView 3.2. This measure is not one that is normally computed or used by the LMES DSS programs and procedures. The measure N2Wet was computed and used ONLY in the Quesnel and West Quesnel PEM project areas in response to suggestions made by the Regional Ecologist. This input variable was NOT USED any other portions of the Cariboo PEM project area.

The Regional Ecologist had observed that many areas mapped as non-productive brush or meadows on the manually interpreted map of material texture, depth and exceptions were brush or meadow instead of being non-forested wetlands because they were underlain by coarser textured materials than normal (sands and gravels). The underlying coarser textured materials tended to be somewhat more freely drained and to hold moisture less well and for shorter periods than in similar areas underlain by less coarse textured materials. Consequently areas of brush or meadow developed where one might normally expect to find non-forested wetlands developing. The Regional Ecologist further noted that many of these same areas of non-productive brush or meadow had sandy margins and were affected by frequent frosts associated with accumulation of cold air drainage. The map of material texture, depth and exceptions had, unfortunately, not identified these areas of brush and meadow as being associated with coarse textured parent materials. Additionally, LMES had not prepared manually digitized maps to identify the margins of areas of brush and meadow as having a higher than normal frost hazard. The Regional Ecologist indicated that the sandy, frosty margins of these areas of non-productive brush or meadow were highly likely to be occupied by Site Series that were not representative of normal, mesic conditions but that were characterized by cool, frosty conditions and, also, frequently by coarser than normal parent material textures.

These observations by the Regional Ecologist were made during a modeling workshop held February 23-27, 2004. This did not leave very much time to find and implement a suitable solution to address the concerns raised by the Regional Ecologist. The quickest solution was simply to compute a linear buffer of fixed dimensions around the margins of all areas mapped as non-productive brush or meadow. LMES computed a linear buffer of 100 m horizontal distance using the buffer capability in ESRI's ArcView 3.2. This linear buffer was converted from a vector representation to a grid representation using the Save-As-Grid function in ArcView. The resulting 25 m grid had dimensions and extent identical to that of the source DEM and all other grid data sets defined for use in the Quesnel PEM project. The grid had a value of 100 for all cells that lay within a 100 m horizontal distance of an area of non-productive brush or meadow as mapped by TFIC and a value of 0 for all other cells. This grid was exported from ArcView 3.2 as a binary FLT export file. The FLT file was then converted into a DBF table and the resulting column of data in DBF format was copied into a field named N2Wet in the LMES defined geofile DBF table. The name N2Wet is not truly meaningful as it was simply a field that had been computed by a previous program, had then not been used and so was available for use.

Table 25. An example of an attribute rule file that defines a fuzzy class of sandy fringe

No.	file_in	attr_in	class_out	model_no	b	d
38	geofile	N2Wet	Sand_Fringe	4	100.0	1.0

The new variable N2Wet was used exclusively to define a fuzzy attribute named Sand_Fringe (Table 25). This fuzzy attribute was, itself, used exclusively to identify specific Site Units that occurred within a sandy fringe surrounding the margins of manually mapped areas of non-productive brush or meadow. The LMES DSS procedures treat all input variables as if they were continuous and treat all output classes as if they were represented by a continuous range of fuzzy likelihood values. In this particular case, however, the input data value was effectively a Boolean class of 0 = not within 100 m of a meadow or non-productive brush and 100 = within 100 m of a meadow or non-productive brush. The fuzzy model (4) applied to this input layer also produced what was effectively a Boolean (either/or) result class with likelihood of being considered to belong to a sandy fringe being either 0 or 100 with no intermediate values.

3.2.14 Plan curvature (Plan) as a measure of local convergence or divergence

This terrain derivative (Plan) (Figure 32) was computed from the 25 m DEM data using the LandMapR program FormMapR. It was used as a secondary measure to differentiate convergent forms associated with potential accumulation of moisture and finer textured alluvial materials in hollows and draws in areas of coarse textured parent materials from divergent forms associated with drier and coarser conditions.
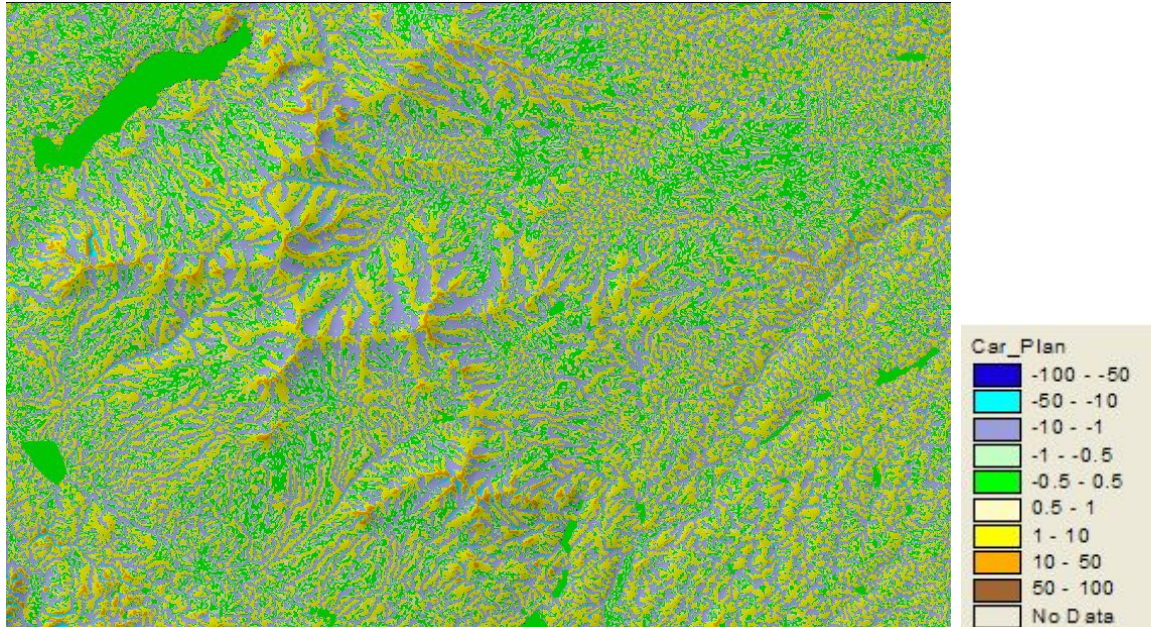
Figure 32. Illustration of the input variable plan curvature (Plan) for an area in the Cariboo

This terrain derivative was only used rarely in creating fuzzy KB rules. It was really used as an experiment to investigate whether local surface shape (convexity versus concavity) could be more effective in differentiating potentially wetter hollows and draws from drier spurs and ridges in areas of coarse textured materials. The experiment worked reasonably well, so the experimental rules were retained and used in the place of rules that would normally have used the wetness index variable (Qweti) to differentiate wetter hollows from drier spurs.

Table 26. An example of an attribute rule file that defines fuzzy classes of convex and concave across

No.	file_in	attr_in	class_out	model_no	b	d
1	formfile	PLAN	Concave_a	5	-1.0	1.0
2	formfile	PLAN	Concave_A	5	-2.0	0.5
3	formfile	PLAN	Convex_a	4	0.0	1.0
4	formfile	PLAN	Convex_A	4	-1.0	0.5

The derivative plan curvature (PLAN) is computed using an algorithm described by Eyton (1991) that is implemented in the LMES program FormMapR as documented in MacMillan et al., (2000). In the example provided (Table 26) grid cells would be considered to be convex in the across slope direction if they exhibited values for the variable PLAN of 0 to -1.0 or greater while they would be considered to be concave in the across slope direction if they exhibited values of -1.0 to -2.0 or smaller. This input data layer (PLAN) was not used in many definitions and is not considered to be a key input layer.

3.2.15 Profile curvature (Prof) as a measure of down slope curvature

This terrain derivative (Prof) (Figure 33) was computed from the 25 m DEM data using the LandMapR program FormMapR. It was used as a secondary measure to differentiate concave portions of the landscape associated with potential deceleration of surface flow and accumulation of moisture and finer textured alluvial materials in toe slopes from convex portions of the landscape associated with drier conditions.
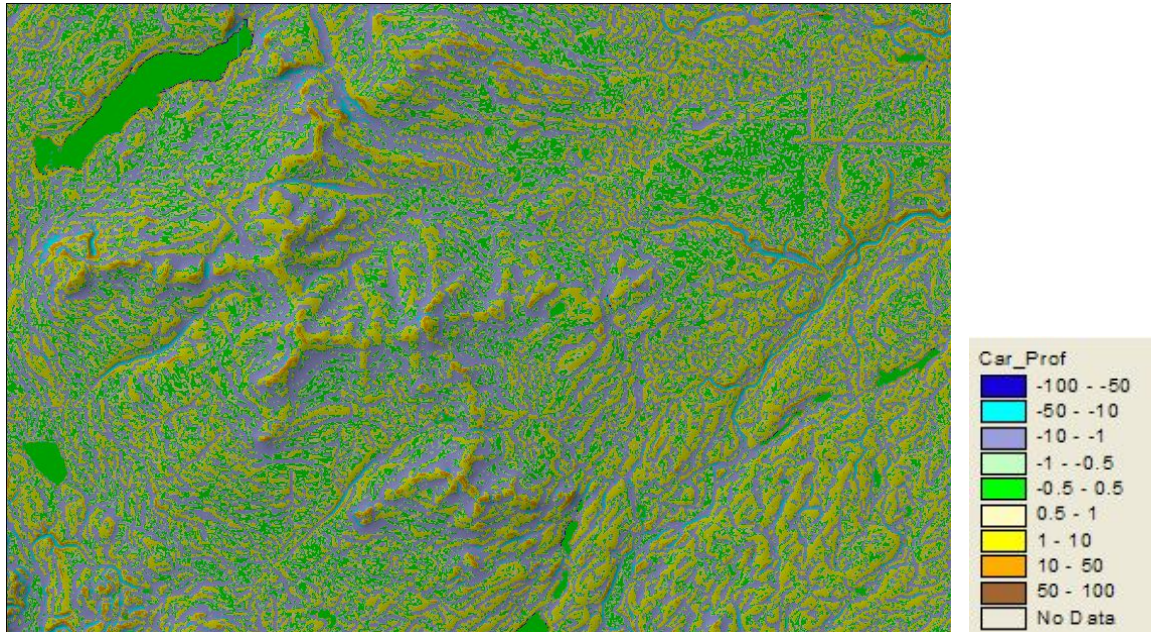
Figure 33. Illustration of the input variable profile curvature (Prof) for an area in the Cariboo

This terrain derivative was only used rarely in creating fuzzy KB rules. It was used to help define concave gullies in grassland areas. Otherwise, this variable was not widely used.

Table 27. An example of an attribute rule file that defines fuzzy classes of concave down slope

No.	file_in	attr_in	class_out	model_no	b	d
1	formfile	PROF	Concave	5	-2.0	1.0

The derivative profile curvature (PROF) is computed using an algorithm described by Eyton (1991) that is implemented in the LMES program FormMapR as documented in MacMillan et al., (2000). In the example provided (Figure 33) grid cells would be considered to be convex in the down slope or profile direction if they exhibited yellow to brown colors while they would be considered to be concave in the down slope direction if they exhibited green to blue colors. This input data layer (PROF) was not used in many definitions and is not considered to be a key input layer.

One of the reasons why this variable was not widely used was its tendency to reflect artifacts and local noise in the DEM source data. Hard edges and straight lines visible in Figure 33 indicate areas where joining of DEM tiles produced abrupt breaks in the elevation data that are picked up, and magnified, by the calculations of profile curvature. Another common artifact of calculations of profile curvature is the appearance of alternating bands of convexity and concavity in the down slope direction. Such bands are a common artifact that is often referred to as paddy-terraces. This artifact arises from the influence of regularly spaced contour lines in procedures used to interpolate a regular gridded DEM from the initial point elevation data.

LandMapper Environmental Solutions Inc.   69
7415 118 a Street NW, Edmonton, AB, T6G 1V4
(780) 435-4531
email: bobmacm@telusplanet.net

3.2.16 Elevation (Elev) as an indication of local altitude related climatic conditions

This input layer (Elev) (Figure 34) is a direct representation of elevation above mean sea level as portrayed by the original 25 m DEM data. Elevation was used as an input to Fuzzy classification rules in a few instances in which ecological classes (Site Units) were defined as occurring over a specified range of elevations.
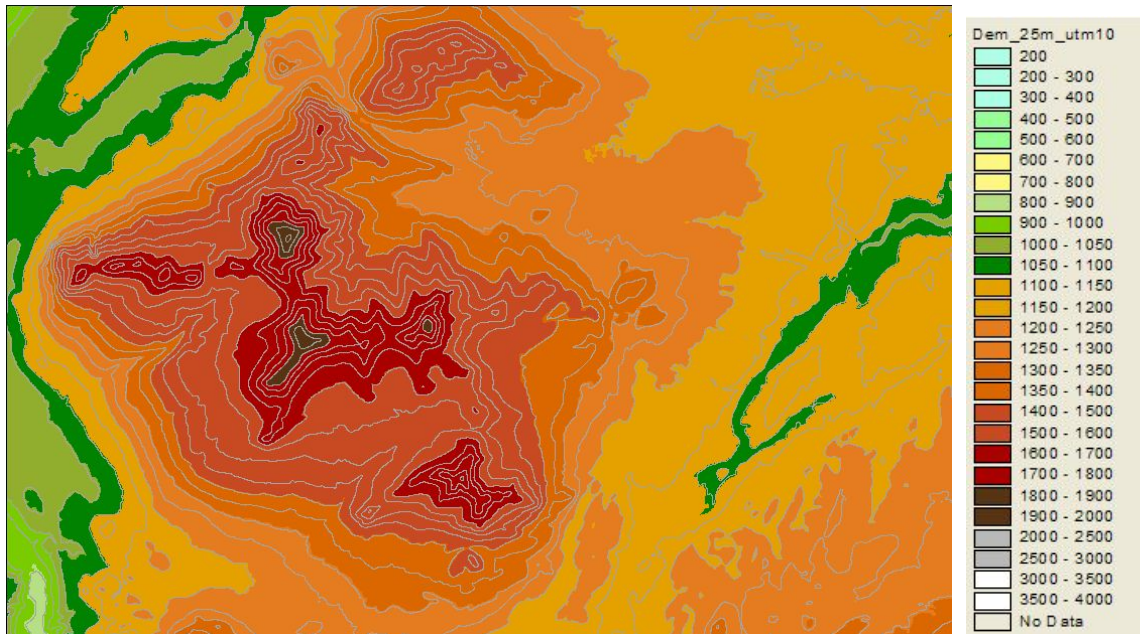
Figure 34. Illustration of the input variable elevation (Elev) for an area in the Cariboo

From Table 28, it can be seen that elevation was used to define fuzzy classes that were greater than 1800 m, greater than and less than 1450 m and greater than and less than 950 m. These were the only uses of the elevation data directly to define Fuzzy KB rules. In most of these cases, the value of elevation used was likely selected to represent an elevation above or below which frosty cold conditions had been observed to commonly occur. As such, elevation was used here as a surrogate for temperature and frost regimes.

Table 28. An example of an attribute rule file that defines fuzzy classes based on elevation

No.	file_in	attr_in	class_out	model_no	b	d
1	geofile	ELEV	GT1800	4	1820.0	20.0
2	geofile	ELEV	GT1450	4	1450.0	50.0
3	geofile	ELEV	Z_GT_950	4	975.0	25.0
4	geofile	ELEV	LT1800	5	1780.0	20.0
5	geofile	ELEV	LT1450	5	1400.0	50.0
6	geofile	ELEV	Z_LT_950	5	925.0	25.0

In the case of the input variable elevation (ELEV) described here, the units of measure are metres above mean sea level. Elevation is reported for 25 m by 25 m pixel entities and values of elevation apply to each individual pixel entity. Values of Elevation are used to define what effectively become binary or Boolean classes defined as greater than or less than some specified elevation.

3.2.17 Band 3 Digital Number as an indication of type and density of land cover

This input layer (B3) (Figure 35) was only used as an input to Fuzzy classifications for areas included in the original Quesnel PEM and in the immediately adjacent portions of the West Quesnel and West Williams Lake PEMs. It was used to infer the type and density of land cover in non-forested areas.
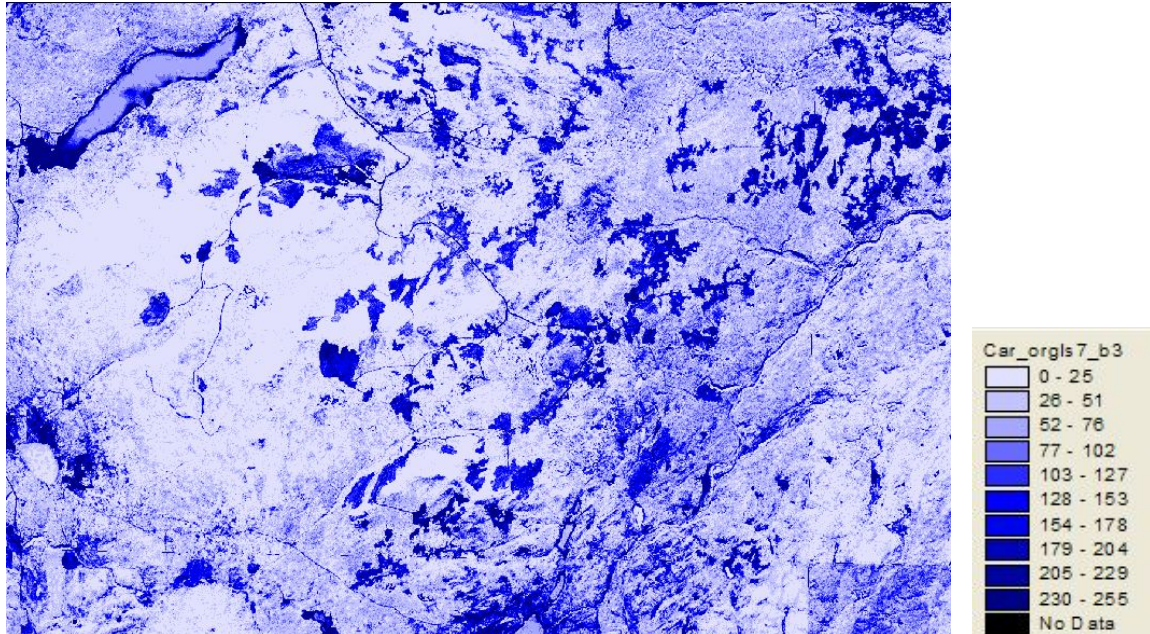
Figure 35. Illustration of the input variable LandSat Band 3 (B3) for an area in the Cariboo

As can been seen in Table 29, the raw digital number of Band 3 of the original LandSat false color composite mosaic was interpreted to infer the type and density of land cover. This was effectively a level slice operation in which different ranges of the raw Band 3 data were associated with different levels of land cover. Low digital numbers were associated with continuous and dense forest cover. High values of band 3 digital numbers were associated with areas of bare soil while slightly high values (150-200) were associated with grass of thin forest cover. This approach worked well in very restricted areas and under very restricted circumstances. As the PEM project progressed, the method of utilizing the satellite image data changed and all bands of data were used to define land cover classes that then acted as classification zones (see section 3.1.5).

Table 29. An example of an attribute rule file that defines fuzzy classes based on LandSat Band 3

No.	file_in	attr_in	class_out	model_no	b	d
1	geofile	B3	Bare	4	215.0	5.0
2	geofile	B3	No_FC	4	200.0	5.0
3	geofile	B3	Grassed	1	175.0	35.0
4	geofile	B3	Thin_FC	1	170.0	30.0
5	geofile	B3	Mod2Hi_FC	5	135.0	5.0
6	geofile	B3	Low_Brush	1	110.0	30.0
7	geofile	B3	Mod_FC	1	100.0	40.0
8	geofile	B3	Treed	5	75.0	5.0
9	geofile	B3	Heavy_FC	5	50.0	10.0

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3.2.18 Other inputs computed from combinations of original input layers

The LMES DSS procedures automatically compute four fuzzy attributes that do not appear in any LMES DSS fuzzy attribute rule tables. These four fuzzy attributes are computed by multiplying the fuzzy values computed for NE_Aspect and SW_Aspect (Table 16) by fuzzy values computed for the fuzzy slope classes of Steep and SlopeLT20 respectively (Table 15). The products that result from this multiplication provide numerical measures of the relative likelihood that a cell will exhibit one of four conditions of interest. These are given the names Steep_NE, Steep_SW, Gentle_NE and Gentle_SW respectively.

The intent of multiplying the fuzzy likelihood values for slope steepness by the fuzzy attribute values for slope orientation is to create a new compound measure that identifies conditions where the cell is BOTH steep (or gentle) AND has a strong orientation in one of the two directions of interest (NE or SW). The LMES DSS procedures use a weighted mean approach to compute the fuzzy likelihood of membership in each predicted Site Unit class. A high value for only one of slope steepness (Steep) or preferred slope orientation (NE_Aspect or SW_Aspect) might be enough to produce a high mean value for likelihood that a cell belonged to a Site Unit defined as occurring on a steep NE or SW slope. By multiplying the two separate fuzzy likelihood values together, only cells that are BOTH steep AND have a preferred orientation end up having a high likelihood of being classified into a Site Unit defined as being both steep (or gentle) and NE-facing (or SW-facing). It was determined that, in some instances, recognition of Site Units that occurred preferentially on steep (or gentle) slopes with a prominent NE (or SW) orientation was improved by utilizing the four compound measures described above. These measures acted as more powerful constraints that restricted the recognition of steep NE or Steep SW slope facets to just those cells that were both steep and SW (or NE).

The four compound variables described above are always computed by the FacetMapR program and are always computed using the same formula. However, the threshold value used to define the Steep and gentle fuzzy attribute classes can, and does, change from one BGC unit to another. Therefore the absolute values computed for these four compound measures will change depending upon the threshold value used to define steep in any given classification region.

4.0 Description of the LMES DSS procedures for applying fuzzy logic calculations

Section 2.0 provided a brief overview of the LMES DSS procedures. Section 3 described the input data layers produced and used in the LMES DSS PEM modeling process. This section (4) describes, in greater detail, how the various input layers were combined and analyzed to convert input data layers into output classifications.

The LMES DSS procedures use a combination of hard (Boolean) and soft (Fuzzy) logic and a combination of manually and automatically prepared input data layers. Most manually prepared input data layers are analyzed using Boolean logic while most of the layers prepared through automated analysis of digital data sets (e.g. the DEM) are analyzed using Fuzzy logic.

It is useful to introduce here the concepts of *criteria* and *constraints* in describing how the logic of the LMES DSS procedures is developed and applied.

Criteria are considerations that, when analyzed, cause a phenomena or classification to be judged to be somewhat more or less likely to occur. Computationally, *criteria* are treated as numerical values between 0 and 100 that are used, in combination with other criteria, to compute weighted numerical averages for the likelihood that a given condition or classification will exist. *Criteria* can raise or lower the likelihood that a given condition can be expected to occur and the final weighted average computed using them can be either larger or smaller in value than any single criteria used in its calculation. The Fuzzy logic components of the LMES DSS procedures treat most input layers as *criteria*.

Constraints are considerations that severely limit or restrict any given outcome. Computationally, *constraints* are treated as quotients in a multiplication process. The numerical values of two or more constraints are multiplied by one another to compute a resulting number that is a product of their multiplication. The resulting output value can never be larger than the smallest of the input constraint values. Thus, if a calculation involved two constraints, one with a value of 90 and a second with a value of 60, the resulting value (60*90 = 54) cannot be larger than the smallest of the inputs (60). Constraints can therefore be seen to be powerful considerations that can strongly affect the likelihood value of any predicted outcome. *Binary constraints* are a special class of constraints that can have values of only 0 and 1. With binary constraints a particular outcome can either occur (1) or not occur (0). Most of the manually prepared input maps in the LMES DSS procedures are used as binary constraints in computations that make use of Boolean logic, rather than Fuzzy Logic.

As previously discussed in section 2.0, the LMES DSS procedures first partition an entire map area into smaller "classification regions". A "classification region" is a sub-division of a BGC unit. Each BGC unit can be subdivided into many sub-divisions (see Section 3.1.6 and Table 11) based on considerations of physiography (e.g. high or low relief), local climate (frosty or not frosty), land cover and parent material texture (coarse or not coarse). All possible combinations of classification regions are not always present in every BGC unit. The input data layers used to create these "classification region" maps were mostly prepared manually. The logic used to produce the classification region maps is Boolean logic that treats each input layer as a binary constraint (0/1) in deciding whether a given cell belongs to a classification region or does not.

All non-forested ecological spatial entities were also mapped directly using manual visual interpretation. Boolean logic was used to compute whether a particular non-forested ecological entity occurred (1) or did not occur (0) at any given location. These non-forested ecological entities tended to exhibit clear, well defined, hard boundaries that were readily observable by human interpreters and that were amenable to direct manual delineation and to analysis using Boolean logic.

Fuzzy logic was only used to predict the spatial pattern of distribution of forested ecological spatial entities (Site Units). These forested ecological entities tend to have much less clear, or well defined, boundaries that are not always immediately obvious to human interpreters. Also there are many more forested than

non-forested spatial entities and consequently many more sites to identify and more boundaries to locate. Recognition and delineation of forested ecological spatial entities (Site Units) is therefore well suited to procedures that use Fuzzy logic for automated feature recognition. Fuzzy logic can accommodate the fuzziness that is inherent in the difficulty of deciding where to place boundaries between different forested ecological entities whose recognition and classification is subjective and not always obvious. Automated fuzzy logic procedures are also more rapid and more economical than equivalent manual procedures and more flexible than automated procedures that use Boolean logic or other less flexible classification methods.

The following sections describe how the Fuzzy logic procedures used to predict the likelihood of occurrence of the forested ecological entities (Site Units) work. It is assumed that the Boolean logic procedures used to define and map the "classification regions" and to map the non-forested ecological entities using manual visual interpretation require no further elaboration.

4.1 Concepts and computational strategies underlying the Fuzzy logic approach

The LMES DSS procedures apply Fuzzy logic in a two step sequence. In the first step, Fuzzy logic is used to convert numerical input data (both classed and continuous) into integer values that are referred to as "fuzzy attributes".   Fuzzy attributes are defined in a DBF attribute rule file that is always assigned a name beginning with "arule", to which is appended a number that identifies the "classification region" (e.g. subdivision of a BGC unit) in which the rule applies. In the second step, fuzzy attributes are used to define and calculate "fuzzy classes" of ecological entities (here Site Units). Rules for defining "fuzzy classes" of Site Units are stored in a second DBF rule table that is always assigned a name beginning in "crule", to which is to which is appended a number that identifies the BGC sub-zone in which the rule file applies.

4.2.1 Fuzzy attributes and fuzzy attribute rule tables

Fuzzy attributes express the degree to which a given value of a given input variable approximates a semantic concept such as wetness or relative landform position that is used to define a Site Series class. A semantic concept is simply a word such as "crest" or "dry" that is used to describe a condition believed to be definitive for a given ecological class (Site Unit) of interest. Simple equations are used to convert raw continuous or classed input variables into numbers that range from 0 to 100. These integer numbers express the likelihood that a particular value of a given input variable matches or meets the central concept for a fuzzy semantic construct such as being in a "crest" position or being "dry". The more closely an input variable matches the defined central concept, the higher the integer value computed for the fuzzy likelihood that the input value represents that fuzzy concept. In the LMES approach, a value of 100 expresses complete agreement with a defined fuzzy concept while a value of 0 expresses complete disagreement.

The LMES procedures permit up to 40 different "fuzzy attributes" to be defined based on any available input variables. A guiding principal, however, is that it is best to use as few input variables as possible to define as few fuzzy attribute concepts as possible. In all cases, the standard approach is to define the minimum number of fuzzy attributes that are absolutely necessary to express all the concepts embodied in the definitions of all Site Units listed for any given BGC unit. New "fuzzy attributes" based on new input variables are only defined if the initial set of minimum "fuzzy attributes" is found to be unable to effectively classify all required Site Unit classes. In modeling, this is known as the *"principal of parsimony"*. Any model should attempt to produce reliable outputs using as few input variables and as few operations as possible. Models that contain large numbers of input variables that are subjected to a large number of operations rapidly become very difficult to interpret and to control. It becomes difficult to understand interactions between variables and to predict and control the interactions. If the LMES DSS rule bases appear incredibly simple, this is by design. The underlying philosophy is always to try to achieve a reasonable classification result using the fewest possible input variables to define the fewest possible number of "fuzzy attributes".

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4.2.2 Fuzzy classes and fuzzy class rule tables

The second step in the LMES procedures involves defining and computing "fuzzy classes" expressed as a linear average of a number of "fuzzy attributes". Up to 30 different "fuzzy classes" can be defined in terms of any number of combinations of "fuzzy attributes" within any given "classification zone".

Each "fuzzy class" in the LMES DSS procedures is meant to represent a unique combination of both hard and fuzzy attributes that collectively define (and spatially locate) a unique "landscape situation" or "environmental setting". A unique situation or environmental setting identifies a particular set of conditions within which a particular Site Series (or combination of Site Series) can be expected to occur. In the first instance, each unique setting has the following hard (Boolean) attributes.

   a) It occurs within a defined BGC unit;
   b) It occurs within a particular class of relief, physiography or land cover within that subzone; and
   c) It occurs within an area classified as being either predominantly coarse textured or not coarse textured.

These conditions are defined and spatially located by reference to the map of "classification regions" and are treated as Binary constraints. Within each "classification region" the Fuzzy logic rules define (and spatially locate) compartments or facets of the landscape that may be thought of as components of a defined toposequence. A toposequence is simply a partitioning of the continuum that occurs from the top (at a drainage divide or hilltop) to the bottom (at a stream channel or depression) into a series of discrete segments or facets that have the following principal characteristics:

   a) A characteristic relative landform position or range of landform positions (e.g. crest, toe, etc)
   b) An implied relative drainage regime (e.g. dry, medium or wet)
   c) A characteristic range of slope gradients (not always a definitive characteristic)
   d) A characteristic range of exposure or orientation (e.g. aspect – not always a defining characteristic)
   e) Any of a number of other specific attributes that establish contextual position in the landscape (e.g. adjacency to wetlands or open water, presence of seepage or a high water table, elevation above local base level).

The partitioning of the landscape continuum into a limited number of discrete compartments, each with a defined range of characteristics or attributes, provides a capability to associate a single, most probable, Site Series (or a range of likely Site Series) with each defined partition or environmental setting. Each compartment, or environmental setting, is defined with a view to capturing a particular set of environmental conditions that is consistent with the definition of a particular Site Unit in the relevant ecological Field Guide. Each unique environmental setting is defined using only those hard constraints and fuzzy criteria that are essential and definitive for its recognition. The defining criteria are meant to directly parallel the definitions for each ecological entity (Site Units) provided in the relevant ecological Field Guides and to capture the knowledge and beliefs encapsulated in the keys, Edatopic grids, landscape profile diagrams and textual descriptions of the Site Units in the Field Guides. In cases where there is confusion about the definition of a particular Site Unit in the Field Guide, the Regional Ecologist was consulted and his interpretation of the correct definition was accepted and implemented.

The "fuzzy classes" for ecological spatial entities (Site Units) are defined in the crule file. Each class is defined as a linear combination of "fuzzy attributes" that are considered to be definitive of the class. The LMES programs read in the crule file to determine how many "fuzzy classes" to define in any given area, what "fuzzy attributes" to use to define each class and what label to give to a cell that is determined to be best represented by a given "fuzzy class". The likelihood that a given cell belongs to a defined "fuzzy class" is computed by multiplying the value of each listed "fuzzy attribute" for that cell by a weighting factor that specifies the relative importance that a particular "fuzzy attribute" is assumed to exert in terms of the overall definition of the class.

Fuzzy class membership values are thus computed as the sum of Fuzzy Attribute(n)*Attribute Weight(n) for n = 1 to the total number of attributes used to define the class. The values for Attribute Weight(n) are normalized to sum to 1.0 before being applied in the above equation, so all resulting values for "fuzzy class" membership also range from 0 to 100 as is the case with the "fuzzy attribute" input values themselves. A value between 0 and 100 is computed for "fuzzy class" membership for every possible "fuzzy class" listed in the relevant crule file. In the implementation of the LMES DSS program used in the Cariboo PEM, only one final class code is recorded for each grid cell. This class code represents the "fuzzy class" with the highest computed fuzzy likelihood value for that cell. Other implementations of the LMES DSS program store the value for the fuzzy likelihood of every possible class for every grid cell. However, this represents a very large overhead in terms of data storage and disk read/write time and so is not used for very large data sets such as in the Cariboo PEM.

Different fuzzy class and fuzzy attribute rule files are read in for each "classification region" within each BGC unit. In the initial LMES PEMs, it was determined that it was beneficial to define and apply rules for up to 10 different "classification regions" within each BGC sub-zone. This was partly because different types of landforms were observed to require different sets of rules (that defined different classes) or different threshold values for the same rules (that defined the same classes but used different boundary values) because of differences in size, scale or composition of the landform features. Another reason for different rule sets was that some areas, particularly areas of coarse textures soils, exhibited different Site Units classes in the same landform positions relative to other more "normal" areas.

The BGC classification was observed to be, in fact, a hierarchical classification, in which certain classes of Site Units only occurred in certain specific areas defined in terms of either material texture (coarse versus non-coarse) or relative relief (e.g. high versus lower relief).

4.3 Description of the LMES work spaces for defining rule bases

The two rule bases required to define and compute "fuzzy attributes" and "fuzzy classes" using the LMES LandMapR rules need to be created, applied, evaluated and revised for each "classification region" within each BGC unit. It was determined that construction and revision of the two rule bases could be streamlined and facilitated by incorporating copies of both rule bases into a combined "work space" for each unique "classification region". These "work spaces" were created in Microsoft Excel in order to benefit from the capabilities of Excel for copying, pasting and editing columns of codes and numbers.

For the Cariboo PEM, a different Excel file was created for each of the 55 different BGC units included in the PEM. The Excel file for each BGC unit contained up to 10 different workspaces, one workspace for each of up to 10 different "classification region" sub-divisions that could occur in each BGC unit. Rules were created to define "fuzzy attributes" and "fuzzy classes" for each of up to 10 possible "classification regions" in each of the BGC sub-zones found in the former Cariboo Forest Region.

In some cases, rules do not vary between "classification regions" within a given BGC unit. In other cases, the rules for "fuzzy classes" remain identical, but the rules for defining "fuzzy attributes" change in order to use different threshold values to change the definition of concepts such as slope position to accommodate changes in the values of key input variables (e.g. wetness index and log of upslope area) that occur in areas of different topography (e.g. longer slopes with higher upslope accumulation areas).

4.3.1 Reading and interpreting the "fuzzy attribute" rule tables

Each "fuzzy attribute" rule table (see Table 30) contains 11 columns of data as described below. A different "fuzzy attribute" rule table is constructed for each and every "classification region" in each and every different BGC unit. It is neither possible nor desirable to review all fuzzy attribute rule tables constructed for the Cariboo PEM in this document.

Table 30. An example of a LMES DSS fuzzy attribute rule file

sortorder	file_in	attr_in	class_out	model_no	b	b_low	b_hi	b1	b2	d
1	formfile	LNQAREA	Crest	5	7.50	7.50	7.50	0.00	8.00	0.50
2	relzfile	PCTZ2ST	Crest2Mid	1	60.00	60.00	60.00	40.00	80.00	20.00
3	relzfile	PCTZ2ST	Up2Mid	1	50.00	30.00	75.00	20.00	80.00	30.00
4	relzfile	PCTZ2ST	Mid2Low	1	30.00	20.00	50.00	10.00	50.00	20.00
5	relzfile	PCTZ2ST	Low2Toe	1	12.00	5.00	20.00	2.00	22.00	10.00
6	relzfile	PCTZ2ST	Toe	1	6.00	3.00	9.00	2.00	10.00	4.00
7	relzfile	PCTZ2ST	Toe2Valley	1	4.00	2.00	6.00	2.00	6.00	2.00
8	formfile	LNQAREA	Valley	4	13.00	13.00	13.00	12.50	50.00	0.50
9	formfile	QWETI	VDry	5	5.80	5.80	5.80	0.00	6.00	0.20
10	formfile	QWETI	VDry2SlDry	5	7.80	7.80	7.80	0.00	8.00	0.20
11	formfile	QWETI	Dry	1	6.80	6.80	6.80	0.00	7.00	0.20
12	formfile	QWETI	Dry2SlDry	1	7.00	6.50	7.50	6.00	8.00	1.00
13	formfile	QWETI	Sl_Dry	1	9.00	9.00	9.00	8.50	9.50	0.50
14	formfile	QWETI	Dry2Med	1	7.50	6.50	8.50	6.00	9.00	1.50
15	formfile	QWETI	Med_WI	1	8.50	8.50	8.50	7.50	9.50	1.00
16	formfile	QWETI	Sl_Wet	1	10.00	10.00	10.00	9.10	10.90	0.90
17	formfile	QWETI	SLWet2Wet	1	11.00	11.00	11.00	10.40	11.60	0.60
18	formfile	QWETI	Wet	1	11.50	11.50	11.50	11.00	12.00	0.50
19	formfile	QWETI	Wet2V_Wet	4	12.50	12.50	12.50	12.00	50.00	0.50
20	formfile	SLOPE	Steep	4	30.00	30.00	100.00	30.00	100.00	2.00
21	formfile	SLOPE	SlopeLT05	5	5.00	0.00	5.00	0.00	5.00	1.00
22	formfile	SLOPE	SlopeLT10	5	10.00	0.00	10.00	0.00	10.00	1.00
23	formfile	SLOPE	SlopeLT20	5	20.00	0.00	20.00	0.00	20.00	1.00
24	formfile	SLOPE	SlopeLT30	5	30.00	0.00	30.00	0.00	30.00	1.00
25	formfile	SLOPE	SlopeGT05	4	5.00	5.00	100.00	5.00	100.00	1.00
26	formfile	SLOPE	SlopeGT10	4	10.00	10.00	100.00	10.00	100.00	1.00
27	formfile	NEW_ASP	NE_Aspect	1	90.00	90.00	90.00	0.00	180.00	45.00
28	formfile	NEW_ASP	SW_Aspect	1	270.00	270.00	270.00	180.00	360.00	45.00
29	geofile	DEPTH	Deep	4	95.00	95.00	95.00	90.00	900.00	5.00
30	geofile	DEPTH	Shallow	5	49.00	49.00	49.00	0.00	50.00	1.00
31	geofile	TEXTURE	Med2Crs	4	40.00	40.00	40.00	40.00	100.00	5.00
32	geofile	TEXTURE	Medium	1	50.00	50.00	50.00	30.00	70.00	20.00
33	geofile	TEXTURE	Fine	5	31.00	31.00	31.00	0.00	30.00	1.00
34	geofile	TEXTURE	Organic	1	1.00	1.00	1.00	0.90	1.10	0.01
35	geofile	L2Wet	WetL_LT200	5	100.00	100.00	100.00	0.00	150.00	50.00
36	geofile	Z2wet	WetZ_LT05	5	1.00	1.00	1.00	0.00	1.50	0.50
37	geofile	SEEPAGE	Hi_Seep	4	0.90	0.90	0.90	0.90	10.00	0.10
38	geofile	N2Wet	Sand_Fringe	5	3.00	3.00	3.00	2.00	4.00	1.00
39	relzfile	Z2St	Hi_Ridge	4	40.00	40.00	40.00	35.00	999.00	5.00
40	relzfile	Z2St	Low_Knoll	5	35.00	35.00	35.00	0.00	40.00	5.00

Column 1, "No", is used to sort the rows in the rule file into a consistent sequential order each time the rules are read into the LMES DSS program. This ensures that all rules that pertain to a specific "fuzzy attribute" are read in together in a contiguous fashion.

Column 2, "file_in" identifies to the LMES DSS program the name of the file in which the input data required to compute a particular "fuzzy attribute" is located. All input data are located in DBF format tables and this column identifies the name of the table in which the required input data reside.

Column 3, "attr_in" identifies the name of the field (or column) in the source DBF table that contains the input data that is to be used to compute the required "fuzzy attribute". As can be seen in Table 15, the same input variable (e.g. QWETI) can be used to define a large number of "fuzzy attributes". All of the codes used to identify input variables in the column "attr_in" were described in a previous section.

Column 4, "class_out" identifies a variable name to assign to the current "fuzzy attribute" being defined. Fuzzy attribute names such as "Crest" or "VDry2SlDry" are meant to provide meaningful, cognitive labels that can be associated with concepts used to define Site Unit ecological classes.

Column 5, "model_no" identifies the type of fuzzy model calculation to use to convert the value of the input variable into an integer number between 0 and 100 that represents the likelihood that the input value meets the criteria used to define the current "fuzzy attribute" of interest. There are 5 defined model types, but only model numbers 1, 4 and 5 were used for the Cariboo PEM (see Figure 4 and Section 2.3.1).

Model 1 is essentially a normal or bell curve. It has a central value that defines its peak (b) at 100% likelihood and a regular curving decline in likelihood value whose rate of decline is controlled by the value assigned for dispersion (d) later in the table. Model 4 is a one-tailed curve that is essentially a greater than (>) statement. In Table 30, any value greater than the value identified in the column labeled "b" will have a likelihood of meeting the "fuzzy attribute" condition of 100 and any value less that this will have a smaller likelihood value. The rate of decline in "fuzzy attribute" likelihood is again controlled by the value assigned for dispersion in the column labeled "d". Model 5 is another one-tailed curve that is equivalent to a less than (<) statement. Any value less than the value identified in the column labeled "b" will have a likelihood of meeting the "fuzzy attribute" condition of 100 and any value greater that this will have a smaller likelihood value.

Column 6, "b" contains a critical value that identifies the value of the relevant input variable at which the fuzzy likelihood of fully meeting the condition required for full membership in the fuzzy class (e.g. a likelihood of 100) is met. For two-tailed bell curves, this value is equal to the value that defines the top of the bell curve. For one-tailed curves, it defines the value for which any value of the input variable that is greater than (model 4) or less than (model 5) this value will result in a fuzzy likelihood if 100.

Column 7, "b_low" defines a value that is not used by any of the fuzzy calculation models employed in the current exercise.

Column 8, "b_hi" defines a value that is not used by any of the fuzzy calculation models employed in the current exercise.

Column 9, "b1" defines a value that is not used by any of the fuzzy calculation models employed in the current exercise.

Column 10, "b2" defines a value that is not used by any of the fuzzy calculation models employed in the current exercise.

Column 11, "d" identifies a critical value termed the dispersion index. This value determines the "spread" of the bell curve, or expressed otherwise, the rate of decline in the likelihood value from its high of 100 at the value identified by the column "b". The dispersion value (d) is the difference from the central value (b) in whatever measurement units are being used, at which the likelihood of meeting the criteria defined for the "fuzzy attribute" declines to ½ the maximum likelihood (50).

Taking the data for "Crest" in Table 30, a cell will have a likelihood of 100 of being a "crest" if it has a value for LNQAREA of 7.5 or less. It will have a value for likelihood of being a "crest" of 50 if the value for LNQAREA is 7.5 + 0.5 = 8.0. Values of LNQAREA of greater than 8.0 will have a likelihood value of being a "Crest" of something less than 50.

4.3.2 Reading and interpreting the "fuzzy class" rule tables

The "fuzzy class" rule table (Table 31) contains 5 columns of data as described below.

Column 1, "f_name" contains a user assigned alpha-numeric code that identifies the particular instance or "environmental setting" being defined. Some Site Units only occur in a single unique "environmental setting". More frequently, several different "environmental settings" may have to be defined to capture all the locations in which a particular Site Unit may occur. This column may contain any combination of letters or numbers up to a total of 10 characters. This column provides a means of identifying (and creating definitions for) as many different instances of a particular Site Unit as there are unique conditions under which it may occur. It is very common to observe that a single given Site Unit may be defined in such a way that it can occur on several very different landform positions depending upon other factors (e.g. moisture status, aspect, seepage, soil texture). This column permits the creation of definitions for multiple instances of a single Site Unit and permits this separate recognition to be maintained in the final output maps (if desired). Codes used in column 1 should be unique and should not repeat for other entities.

In the particular example presented in Table 31, the first conceptual entity defined is identified as H8302r in the column f_name. This entity (H8302r) is meant to define a dry, shallow crest in an area of high relief (H) in a BGC unit identified by the number 83 (SBPSmk) that is occupied mainly by Site Series 02 that occurs only on shallow, rocky ridge tops (r). The f_name codes therefore try to be cognitive.

Column 2, "fuzattr" identifies a list of "fuzzy attributes" used to identify the defining characteristics of each unique "environmental setting" or "situation". A "fuzzy class" may be defined by as many "fuzzy attributes" as are required to achieve a reasonable classification result. Each "fuzzy attribute" has a value between 0 and 100 that is computed prior to computing the "fuzzy class" value by following the rules contained in the previously described "fuzzy attribute" table. The codes or names selected to identify "fuzzy attributes" are meant to be cognitive and to provide a reader with some idea of the semantic construct (e.g. relative landform position or relative moisture status) that the code is intended to represent. Thus an attribute of "Low2Toe" is intended to convey the idea that the "situation" currently being defined can occur anywhere from a lower to toe slope in terms of landform position. Similarly, the attribute "SlWet2Wet" is intended to convey the idea that the unique "situation" will occur where moisture conditions range from slightly wet to wet. These terms have an approximate correlation with the formal terms such as mesic used to define moisture status in the Field Guides, but different words have been used to avoid the possibility of confusing the relatively defined "fuzzy attributes" with formally defined classes and concepts.

Column 3, "attrwt" identifies the relative weight to be associated with the "fuzzy attribute" currently being read in when computing the overall fuzzy likelihood that a grid cell belongs to the class (unique situation) currently being defined. Any value can be assigned for an attribute weight for a given "fuzzy attribute". All attribute weights are summed and then normalized to add up to 1.0 before being applied by the LMES DSS equations used to compute fuzzy class membership, so it is not necessary for the attribute weights to sum to 100 or to any other number.

Only the relative values are important in computing weights. In practice, however, it is convenient to have all weights for a given class sum to 100. It is also convenient to ensure that all classes have roughly equal weights assigned to a given "fuzzy attribute". ***If unequal weights are assigned to the same "fuzzy attribute" for different classes, one class may be calculated to be more likely to occur just because of the difference in relative attribute weight and not because of a real difference in physical conditions.*** Maintaining a proper balance of weights is one of the reasons why it is important to avoid using too many different input variables and too many different "fuzzy attributes" when defining "fuzzy classes". The more input variables and "fuzzy attributes" that are defined; the more difficult it becomes to balance weights and to be aware of the interactions from multiple inputs and of the possible outcomes from unbalanced weights.

Table 31. An example of a LMES DSS Fuzzy class rule table

f_name	fuzattr	attrwt	facet_no	f_code	f_name	fuzattr	attrwt	facet_no	f_code
H8302r	Crest	30	1	8302	H8316L	Mid2Low	30	9	8301
H8302r	VDry	30	1	8302	H8316L	Dry2SlDry	30	9	8301
H8302r	SlopeLT30	10	1	8302	H8316L	SlopeGT20	10	9	8301
H8302r	Med2Crs	10	1	8302	H8316L	Med2Crs	20	9	8301
H8302r	Shallow	40	1	8302	H8316L	Deep	10	9	8301
H8302r	Hi_Ridge	10	1	8302	H8361L	Mid2Low	30	10	8361
H8342r	Crest	30	2	8342	H8361L	Med_WI	30	10	8361
H8342r	VDry	30	2	8342	H8361L	SlopeLT20	20	10	8361
H8342r	SlopeLT30	10	2	8342	H8361L	Med2Crs	10	10	8361
H8342r	Med2Crs	10	2	8342	H8361L	Deep	10	10	8361
H8342r	Deep	20	2	8342	H8306L	Low2Toe	30	11	8306
H8342r	Hi_Ridge	10	2	8342	H8306L	Sl_Wet	30	11	8306
H8341r	Crest	30	3	8342	H8306L	SlopeLT20	20	11	8306
H8341r	VDry	30	3	8342	H8306L	Med2Crs	10	11	8306
H8341r	SlopeLT30	10	3	8342	H8306L	Deep	10	11	8306
H8341r	Med2Crs	10	3	8342	H8316t	Low2Toe	30	12	8301
H8341r	Deep	20	3	8342	H8316t	Dry2Med	30	12	8301
H8341r	Low_Knoll	10	3	8342	H8316t	SlopeGT20	20	12	8301
H8303s	Crest2Mid	30	4	8303	H8316t	Med2Crs	10	12	8301
H8303s	VDry2SlDry	30	4	8303	H8316t	Deep	10	12	8301
H8303s	Steep_SW	20	4	8303	H8306t	Toe	30	13	8306
H8303s	Med2Crs	10	4	8303	H8306t	SLWet2Wet	30	13	8306
H8303s	Deep	10	4	8303	H8306t	SlopeLT10	20	13	8306
H8343s	Crest2Mid	30	5	8343	H8306t	Med2Crs	10	13	8306
H8343s	VDry2SlDry	30	5	8343	H8306t	Deep	10	13	8306
H8343s	Gentle_SW	20	5	8343	H8307s	Valley	30	14	8307
H8343s	Med2Crs	10	5	8343	H8307s	Wet2V_Wet	30	14	8307
H8343s	Deep	10	5	8343	H8307s	SlopeGT05	20	14	8307
H8305n	Crest2Mid	30	6	8305	H8307s	Med2Crs	10	14	8307
H8305n	VDry2SlDry	30	6	8305	H8307s	Deep	10	14	8307
H8305n	Steep_NE	20	6	8305	H8307f	Valley	30	15	8307
H8305n	Med2Crs	10	6	8305	H8307f	Wet2V_Wet	30	15	8307
H8305n	Deep	10	6	8305	H8307f	SlopeLT05	20	15	8307
H8315n	Crest2Mid	30	7	8315	H8307f	Medium	10	15	8307
H8315n	VDry2SlDry	30	7	8315	H8307f	Deep	10	15	8307
H8315n	Gentle_NE	20	7	8315	H8378m	WetZ_LT05	50	16	8307
H8315n	Med2Crs	10	7	8315	H8378m	WetL_LT200	50	16	8307
H8315n	Deep	10	7	8315	H8366s	Hi_Seep	80	17	8366
H8301m	Up2Mid	30	8	8301	H8366s	Med2Crs	20	17	8366
H8301m	Dry2SlDry	30	8	8301	H8308o	Organic	99	18	8308
H8301m	SlopeLT30	20	8	8301					
H8301m	Med2Crs	10	8	8301					
H8301m	Deep	10	8	8301					

Column 4, "facet_no" is a rather innocuous, but important column. The LandMapR program used to compute output classes (FacetMapR) sorts each classification rule file by the value stored in this field prior to reading and executing the classification rules. This sorting was implemented to ensure that all rules that pertain to a given output class are contiguous in the file and are read in together in one continuous sequence. If the integer value that is stored in this column gets corrupted and all "fuzzy attributes" required to define a specific output class are not labeled with the same integer number, the rules will be read in incorrectly and the resulting classification will be suspect and incorrect.

Column 5, "f_code" is the integer label or code that the program attaches to each "fuzzy class" that is defined and computed. This integer code is the main value used to identify the most likely classification assigned to each grid cell upon completion of all fuzzy likelihood calculations for each cell. In the Cariboo PEM, these codes identify two main numbers. The first two digits (in the hundreds and thousands places) record a code used to identify the BGC unit for which the rules apply and within which they will be read and implemented. Each of the BGC units in the Cariboo PEM map area was assigned a unique integer identifier ranging from 34 to 99. The last two digits in this field are an integer key used to identify a particular unique "environmental setting" or "landscape situation". Often, this integer number is the same as the Site Series number as used in the Field Guide. In other cases, the 2 digit number may have been devised to identify a combination of 2 different Site Series thought to be likely to occur within that particular "landform situation". In a few cases, the 2 digit integer number has no cognitive meaning and was simply selected because it was unique and had not been used to identify any other defined "situations".

Each unique "environmental setting" code (e.g. 8302) can be associated with a prediction of the dominant Site Series considered most likely to occur within it, as well as with predictions of proportions of minor to significant inclusions of other Site Series. LMES presents these predictions as a separate legend or look-up table (See Part B MacMillan et al., 2008b).

Please note again that, with one single exception, all LMES PEM entities defined for use for the entire Cariboo PEM map area have been treated as if they describe simple "pure" entities that consists entirely of a single dominant ecological class.

The Project Technical Monitor (Dr. David Moon) was responsible for developing and applying the procedures used to assess the LMES PEM maps for accuracy. In the initial PEM projects (PEM Pilot, Canim Lake PEM and Quesnel operational pilot)), he assessed the accuracy of the LMES PEM maps with PEM entities treated as both simple and complex map units. When treated as simple map units, each entity was considered to be occupied 100% by the dominant ecological class described to occur within the entity. When treated as complex map units, each entity was considered to be occupied by up to three different ecological classes that occurred in specified proportions within the extent of each PEM entity. In no case did the analysis of field accuracy traverse data demonstrate statistically significant improved accuracy for complex versus simple map units. Complex map entity descriptions did achieve slightly greater accuracy for the Canim and Quesnel PEMs but this increase was marginal and not statistically significant.

The project technical monitor recommended that all LMES PEM entities be described as simple map units composed entirely of a single dominant ecological class. He observed that listing of associated sub-dominant Site Units for small polygons (< .5 ha) was inappropriate to the scale of variation in ecological classes observed on most traverses. He also noted that polygon accuracy on small polygons was very low.

Treating all PEM entities as simple map units has several distinct advantages, in addition to producing equally accurate estimates of the proportions of ecological classes in any given area. Firstly, the process of assessing accuracy is greatly simplified when each map entity is considered to be composed 100% of a single dominant ecological class. The accuracy assessment calculations do not have to compute proportions of proportions when comparing observed to predicted extents of ecological classes. Secondly, the resulting maps tend to be much easier for clients to use and interpret. End users should be aware that these units are not pure but the scale and distribution of the sub-dominant classes is such that managing for anything but the dominant class would be impractical. In addition, accuracy of the proportional estimates is not verified.

5.0 Attribute Definitions

Attribute definitions are provided below in Table 32 as per Table 6 in *The Standards for Predictive Ecosystem Mapping – Inventory Standard Version 1.0* (RIC, 1999).

Because the LMES DSS procedures employ fuzzy logic and classify mainly continuous input variables into different numbers and types of fuzzy classes, it is not possible to construct an attribute definition table that corresponds exactly to those constructed to report on attributes used as input to traditional PEM modeling programs such as ELDAR and EcoGen. Table 32 is an attempt to provide a close approximation to the normal attribute definition tables required by the standards that assume attributes will be defined in a manner similar to that done for EcoGen or ELDAR.

Table 32. Attribute Definitions

Attribute	Attribute Code	Attribute Type	Data Format
BEC subzone	Zone	Categorical	Number(4)
Depth to bedrock	Depth	Categorical (0/1)	Number(3)
P.M. Texture	Texture	Categorical	Number(3)
Seepage areas	Seepage	Categorical (0/1)	Number(2)
Lakes and water	Lake	Categorical (0/1)	Number(2)
Non-forested wetlands	Wetland	Categorical (0/1)	Number(2)
Meadows	Meadow	Categorical (0/1)	Number(2)
Pastures	Pasture	Categorical (0/1)	Number (2)
Non-productive brush	Brush	Categorical (0/1)	Number(2)
Avalanche track	Avalanche	Categorical (0/1)	Number(2)
Urban/Anthropogenic	Disturbed Land	Categorical (0/1)	Number(2)
Gravel Bar	Gravel Bar	Categorical (0/1)	Number(2)
Talus Slopes	Talus	Categorical (0/1)	Number(2)
Grassland	Grassland	Categorical (0/1)	Number(2)
Relative Slope Position	LnQarea	Fuzzy Classes	Number(3)
Relative Moisture Regime	Qweti	Fuzzy Classes	Number(3)
Slope gradient	Slope	Fuzzy Classes	Number(3)
Aspect	New_Asp	Fuzzy Classes	Number(3)
Exposure (slope x aspect)		Fuzzy Classes	Number(3)
Relative Slope Position	PctZ2Str	Fuzzy Classes	Number(3)
Position relative to base level	PctZ2Pit	Fuzzy Classes	Number(3)
Vertical distance to channel	Z2St	Fuzzy Classes	Number(9)
Vertical distance to base level	Z2Pit	Fuzzy Classes	Number(9)
Vertical distance to wetland	Z2Wet	Fuzzy Classes	Number(9)
Horizontal distance to wetland	L2Wet	Fuzzy Classes	Number(9)
Horizontal distance to NP brush	N2Wet	Fuzzy Classes	Number(3)
Across slope (Plan) curvature	Plan	Fuzzy Classes	Number(9)
Down slope (Profile) curvature	Prof	Fuzzy Classes	Number(9)
Elevation above mean sea level	Elev	Fuzzy Classes	Number(9)
Digital Number for Band 3	B3	Fuzzy Classes	Number(3)

The attribute heading describes the LMES variable, identified under the heading attribute code, that is used to record and store data values pertaining to the identified spatial attribute.   All of the manually prepared input layers are recognized to be categorical even though some (depth and texture) are treated as if they were continuous in some of the LMES DSS analysis procedures. Most of the manually prepared categorical variables are of the binary (0/1) type, meaning that they are used to recognize the presence (1) or absence (0) of a single class of spatial entity. Most of the manually prepared attributes listed in Table 32 may, in fact, be regarded as a particular class of the manually prepared map of classes of exception areas.

All but one of the series of attributes described as being fuzzy classes are based on terrain derivatives computed automatically from the 25 m TRIM II DEM supplied by Meridian Mapping Ltd. The only digital input not computed from the DEM was the raw digital number for band 3 of the false color satellite image that was used as an input to Fuzzy procedures for only a few Subzones in the original Quesnel PEM map area.

All of the original terrain derivatives are numerical data with continuous distributions. These continuous distributions are partitioned into fuzzy classes through application of fuzzy attribute classification rules contained in fuzzy attribute rule files that are a key element of the LMES DSS procedures. Fuzzy classes are somewhat different from hard, Boolean classes in that they do not have exact, crisp, hard boundaries. Fuzzy classes can have overlapping definitions and overlapping boundaries and class membership is expressed as a value between 0 and 100.

6.0 Attribute Value Codes

As discussed above, the LMES DSS procedures are not directly comparable to those used for traditional PEM projects in BC. As such, Table 33 below is only an approximation of tables for conventional PEMs.

Readers are reminded that the types, numbers and definitions of fuzzy classes presented in Table 33 are not constant and may vary in the attribute rule tables (arule*xxxx*) created for any given "classification region". The classes presented in Table 18 simply provide an example of one set of classes defined for one notional "classification region". Different types and numbers of classes of may be defined for other "classification regions".

Because the LMES DSS method does not use classes of input layers commonly used in other types of PEM approaches (e.g. EcoGEN or ELDAR), there are no existing PEM standards that can be referred to as can be done for EcoGEN or ELDAR. Consequently, Table 33 instead refers to the appropriate section of this report to identify the location where each class concept is described and documented.

Table 33. Examples of Typical Fuzzy Attribute Value Codes

Attribute Code	Attribute Class	Attribute Value Description	Reference to Appropriate Reference or Standard
LNQAREA	Crest	< 7.5 – 8.0	Section 3.2.1 and 3.2.5 – Log of upslope area and Percent Z 2 Stream as measures of relative landform position. Note: Threshold values and ranges for fuzzy attributes vary from one "classification zone" to the next and not all zones have the same fuzzy attribute classes
PCTZ2ST	Crest2Mid	60% +/- 20% (40-80%)	
PCTZ2ST	Up2Mid	50% +/- 30% (20-80%)	
PCTZ2ST	Mid2Low	30% +/- 10% (20-40%)	
PCTZ2ST	Low2Toe	12% +/- 10% (2-22%)	
PCTZ2ST	Toe	6% +/- 4% (2-10%)	
PCTZ2ST	Toe2Valley	4% +/- 2% (2-6%)	
LNQAREA	Valley	> 13.0 - 0.5	
QWETI	VDry	< 6.0 + 0.2	Section 3.2.2 – Quinn wetness index as a measure of relative moisture regime. Note: Threshold values and ranges for fuzzy attributes vary from one "classification zone" to the next and not all zones have the same fuzzy attribute classes
QWETI	VDry2SlDry	< 7.8 + 0.2	
QWETI	Dry	6.5 +/- 1.0 (5.5 – 7.5)	
QWETI	Dry2SlDry	7.0 +/- 1.0 (6.0 – 8.0)	
QWETI	Sl_Dry	9.0 +/- 0.5 (8.5 – 9.5)	
QWETI	Dry2Med	7.5 +/- 1.5 (5.0 - 9.0)	
QWETI	Med_WI	8.9 +/- 1.0 (7.9 - 9.9)	
QWETI	Sl_Wet	9.0 +/- 0.8 (8.2 - 9.8)	
QWETI	SLWet2Wet	11.5 +/- 0.8 (10.7 – 12.3)	
QWETI	Wet	11.0 +/- 0.5 (10.5 – 11.5)	
QWETI	Wet2V_Wet	> 12.0 – 0.5	
SLOPE	Steep	> 30% - 2% (> 28%)	Section 3.2.3 – Slope gradient as a measure of slope steepness. Note: Threshold values and ranges for fuzzy attributes vary from one "classification zone" to the next and not all zones have the same fuzzy attribute classes with the same ranges as listed here.
SLOPE	SlopeLT05	< 5% + 1% (< 6%)	
SLOPE	SlopeLT10	< 10% + 1% (< 11%)	
SLOPE	SlopeLT20	< 20% + 1% (< 21%)	
SLOPE	SlopeLT30	< 30% + 1% (< 31%)	
SLOPE	SlopeGT05	> 5% - 1% (> 4%)	
SLOPE	SlopeGT10	> 10% + 1% (> 11%)	
SLOPE	SlopeGT20	> 20% + 1% (> 21%)	
NEW_ASP	NE_Aspect	90° +/- 45° (45° - 135°)	Section 3.2.4 – Rotated slope aspect as a measure of slope orientation
NEW_ASP	SW_Aspect	270° +/- 45° (225° - 315°)	
Slope*Aspect	Steep_NE	Steep * NE_Aspect (Fuzzy values)	Section 3.2.18 – Slope times aspect as a measure of steepness and orientation.
Slope*Aspect	Steep_SW	Steep * SW_Aspect (Fuzzy values)	
Slope*Aspect	Gentle_NE	SlopeLT20 * NE_Aspect (Fuzzy)	
Slope*Aspect	Gentle_SW	SlopeLT20 * SW_Aspect (Fuzzy)	
DEPTH	Deep	> 95 cm – 5 cm (> 90 cm)	Section 3.2.7 – The TFIC prepared map of parent material texture, depth and exception classes.
DEPTH	Shallow	< 60 cm + 1 cm (< 61 cm)	
TEXTURE	Coarse	> 60 - 5 (> 55%)	Section 3.2.8 – The TFIC prepared map of parent material texture, depth and exception classes. Note: not all classes were defined for all zones and class ranges may change from zone to zone.
TEXTURE	Med2Crs	> 40 - 5 (> 35%)	
TEXTURE	Medium	50% +/- 20% (30% - 70%)	
TEXTURE	Fine	< 31% + 1% (< 32%)	
TEXTURE	Organic	1% +/- 0.01%	
L2Wet	WetL_LT200	< 100 m + 50 m (< 150 m)	Section 3.2.12 – Horizontal (Z2Wet) and Vertical (L2Wet) distance to wetland as measures of proximity to wetlands.
Z2wet	WetZ_LT05	< 1.5 m + 1.0 m (< 2.5 m)	
N2Wet	Sand_Fringe	> 0 (binary 0/1 class)	Section 3.2.13 – Buffered distance to meadows and non-productive brush (N2Wet)
SEEPAGE	Hi_Seep	> 0 (binary 0/1 class)	Section 3.2.9 – The TFIC prepared map of parent material texture, depth and exception classes.
Z2St	Hi_Ridge	> 40 m - 5 m (> 35 m)	Section 3.2.10 – Distance Z to Stream (Z2St) as a measure of absolute height above stream level
Z2St	Low_Knoll	< 35 m + 5 m (< 40 m)	
Z2Pit	High_Bench		Section 3.2.13 – Distance Z to Pit (Z2Pit) as a measure of absolute height above local base level
Z2Pit	Low_Bench		
PCTZ2PIT	Near_Base	12% +/- 10% (2%-22%)	Section 3.2.6 – Percent Z to Pit (PctZ2Pit) as a measure of relative height above base level
PCTZ2PIT	Above_Base	30% +/- 20% (10% - 50%)	
PLAN	Convex_A	-1.0 - 0.5 (> -1.5)	Section 3.2.14 – Plan curvature (Plan) as a measure of local convergence or divergence.
PLAN	Concave_A	-2.0 + 0.5 (< -1.5)	
PROF	Concave	-2.0 + 1.0 (< -1.0)	Section 3.2.15 – Profile curvature (Prof) as a measure of local acceleration or deceleration of surface flow speeds.
ELEV	GT1800	1820 - 20 (> 1800)	Section 3.2.16 – Elevation (Elev) as a measure of elevation controlled local climate variation.
ELEV	GT1450	1450 - 50 (> 1400)	
ELEV	LT1800	1780 + 20 (< 1800)	
ELEV	LT1450	1400 + 50 (< 1400)	
B3	Bare	215 - 5 (> 200)	Section 3.2.17 – Band 3 Digital Number (B3) as a measure of type and thickness of vegetative cover.

7.0 PEM Entity Definitions

LMES has elected to prepare a separate listing and description of PEM entities for each TSA-specific PEM project area within the overall Cariboo PEM project area. In these separate reports, each and every unique numeric symbol that appears on the PEM grid maps prepared for a particular TSA is described and documented. Readers are directed to locate and review the PEM entity report for a specific TSA.

The LMES DSS procedures seek to locate and map what may be thought of as unique "environmental settings" or "situations". Each "situation" represents a unique combination of BGC unit, LMES physiographic class, land cover, parent material texture and topographic setting including consideration of relative landform position, moisture regime, aspect or exposure and other factors such as relative proximity to wetlands or open water and absolute or relative height above local base level. Since a given Site Series may be described in the relevant Field Guide(s) as occurring in several different environmental settings in a given BGC unit, the LMES DSS procedures were designed to permit recognition of as many different unique environmental settings as were necessary in order to predict the most likely spatial pattern of occurrence of each ecological class (Site Series) in each BGC unit. Consequently, in any given BGC unit, the LMES DSS procedures may define (and associate with a single defined Site Series class) anywhere from a single unique setting to many different environmental settings. LMES could easily have rolled-up all unique environmental settings predicted to be occupied by the same dominant Site Series, but that would have meant reducing the potential utility of the resulting PEM maps. LMES elected instead to identify each unique environmental setting using a unique numeric map code and to retain this unique integer map code in the final PEM map. LMES considers that there will be situations where it will be beneficial to be able to identify and interpret the individual unique environmental setting classes separately. In fact, the Regional Ecologist explicitly requested that many unique environmental settings be retained separately, even if they were predicted to include the same dominant Site Series, as slight differences in the composition and conditions within these unique environmental settings were of interest and use to him.

LMES has described each unique environmental setting or situation in terms of the dominant ecological class (Site Series or non-forested ecological entity) predicted to occur within the setting. In most cases, each setting was also recognized as being likely to contain a mixture of other ecological classes that were viewed as inclusions. The legend (or look-up table) for the each PEM map area identifies the dominant ecological class predicted to occur within each unique environmental setting and also lists estimated proportions for up to three ecological classes (including the dominant class) that might occur in specified proportions within each defined unique "environmental setting". The project technical monitor only evaluated the accuracy of the LMES predictions of dominant ecological class within each uniquely defined environmental setting. Final external accuracy assessment procedures indicated that the LMES PEM maps were of sufficient accuracy to meet provincial accuracy requirements when evaluated in terms of predicted dominant ecological class alone. The project technical monitor recommended against assessing the accuracy of the LMES predictions of proportions of ecological classes within each uniquely numbered environmental setting, as the simpler, initial maps that predicted a single ecological class for each uniquely numbered environmental setting were already sufficiently accurate for acceptance. It was judged that there would be no real benefit achieved by evaluating the proportions predicted for up to three ecological classes in each unique environmental setting.

Readers will observe that each unique environmental setting is identified by a unique integer ID number in the expanded legend (Unique Numeric ID) and that each unique numeric ID is associated with a Site Unit number and Site Unit alpha symbol that identifies the Site Series (or non-forested ecological class) predicted to occupy the dominant extent of each identified unique "environmental setting". LMES has included a relatively detailed comments section that attempts to explain the major characteristics of each unique environmental setting and the reasons why that setting was recognized, mapped and associated with a particular predicted Site Series or non-forested ecological class. The comments make the look-up table quite large for any BGC unit.

8.0 Summary and Conclusions

This report fully documents the procedures used by LMES to produce PEM maps for the entire extent of the former Cariboo Forest Region. The report identifies and documents all input data layers used in the preparation of the PEM maps. The report provides a comprehensive description of the hybrid (Boolean and Fuzzy) procedures used by LMES in the production of the PEM maps. The LMES Fuzzy logic procedures used to define "unique environmental settings" that are then associated with a predicted distribution of dominant and included ecological classes (Site Units) are described in complete detail. Separate reports present a complete list of PEM mapping entities for each TSA within the former Cariboo Forest Region, describe the characteristics of each entity and explain why each entity is believed to be likely to be occupied by the named dominant (and included) ecological classes (Site Units).

The LMES DSS procedures adopt a hybrid approach that uses direct manual visual interpretation and digitizing to map some ecological entities (mainly non-forested ecological entities) and automated feature extraction based on Fuzzy Logic to classify other ecological entities (mainly Site Series). This hybrid approach recognizes that it easier, faster and more economical to directly map what is easily visible and readily interpretable on available imagery and other digital data sets than it is to try to extract these features using automated procedures. Use of automated procedures (and fuzzy logic) is restricted to recognition and extraction of features that are so numerous, ambiguous, subjective or difficult to identify and delineate manually that automated procedures prove to be more reliable, accurate, faster and less expensive.
The LMES DSS approach to modeling the pattern of spatial distribution of forested ecological entities (Site Units) can be considered to offer a number of distinct advantages.

Firstly, the Fuzzy Logic Knowledge Bases (KBs) are extremely comprehensive, extremely compact and very effective at capturing and presenting ecological knowledge in a manner that is easy to review, easy to understand and easy to use. The LMES KBs only reference input data layers that can be thought of as providing effective approximations for the main concepts used in the Field Guides to define ecological entities. The LMES DSS procedures do not try to mine available digital data bases to seek out any and all patterns of spatial co-occurrence between input data layers and the desired output classes (Site Units) whether they are based on meaningful and interpretable relationships or just on fortuitous co-occurrence. Rather, the LMES DSS procedures critically examine the ecological knowledge that is encapsulated in the keys, landform profile diagrams, Edatopic grids and textual descriptions in the relevant ecological Field Guides to identify the key attributes that are definitive of each defined Site Unit. This examination has often revealed that some attributes that initially appear to be definitive are, in fact, simply descriptive. Such descriptive attributes often refer to conditions that are commonly associated with a particular Site Series but that do not absolutely have to occur in order to recognize the Site Series. The critical examination has occasionally revealed instances where the materials in the Field Guide were not complete and definitive, with definitions missing key criteria required to differentiate two or more Site Series. In such instances, the knowledge of the Regional Ecologist was consulted to obtain the missing criteria. In this sense, the LMES DSS Knowledge Bases (KBs) may be considered to have acted as a test, or evaluation, of the comprehensiveness, completeness and correctness of the ecological classification rules as presented in the published Field Guides. If LMES was able to capture and apply the ecological knowledge contained in the Field Guides accurately and effectively, then the knowledge, as presented in the Field Guides, was judged likely to be complete and correct. If LMES encountered difficulty in capturing and applying the ecological knowledge in the Field Guides, then that knowledge was judged likely to be incomplete or incorrect and to require further elaboration or correction.

Secondly, the LMES DSS approach applies the ecological knowledge extracted from the relevant Field Guides and other sources in a systematic, quantitative and formal manner that is reproducible, repeatable and can be updated. If one runs the same data through the same rules for the same area, one will always obtain the same results. Similarly, if one runs equivalent data for a different area through the same rules, one will obtain predictions for the new area that are identical in concept and spatial distribution to those obtained for the first area. If a particular rule in the K-Base does not appear to be producing the desired result, it can be altered and the procedures re-run using the revised rule without adversely affecting all of

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the areas where the initial rules worked well. And finally, the rules in the K-Base can be re-run against improved input data layers, should such layers become available, to produce an improved representation of the spatial distribution of the predicted output classes. The concepts behind the classes will remain the same, but the accuracy with which classes are located in space can be improved.

Thirdly, the LMES DSS procedures have been demonstrated to be as accurate, rapid and affordable as can realistically be expected given the current limitations of input data sets, ecological knowledge and the basic fact that nature is highly variable and inherently unpredictable with significant amounts of total variation occurring at scales and over distances that are below the level of resolution of most currently available input data sets. The LMES DSS procedures have now been evaluated as predicting Site Series composition at a level of accuracy of 65% or better for six different PEM projects.

Accuracy assessment data analyzed for the entire Cariboo PEM area indicated that the LMES DSS procedures have achieved a level of predictive accuracy in excess of the 65% minimum acceptable level of accuracy required by the provincial government if the maps are to be used to establish base case for Site Index and Annual Allowable Cut. The area-weighted average for exact overlap was 67.6% with a sample error of 2% at the 90% confidence level. The area-weighted average of acceptable overlap was 77.9% with a sample error of 2% at the 90% confidence level.

Results from four different replicated accuracy transects conducted in 2003 suggest that ecological experts on the ground, evaluating the exact same locations were not able to agree on exactly the same ecological classification at a rate greater than 65%. It is therefore unrealistic to expect any single ecological expert to agree with the classifications on a PEM map at a higher rate (>65%) than can be obtained by two or more experts classifying the same locations while viewing them on the ground.

The LMES DSS procedures have now been applied to very large areas in a relatively short time and have been used to produce PEM maps for from 2 to 5 million hectares per person-year. Limitations on the amount of area that could be classified in a single year were mainly due to restrictions imposed by rates at which key inputs for the LMES procedures could be produced (e.g. Big BEC maps and maps of material texture, depth and exceptions). A further limitation was introduced by the time and costs required to collect field transect data used in assessing and validating the accuracy of the PEM maps produced by the LMES DSS procedures. These accuracy assessment procedures are costly and it can take a long time to collect the necessary field transect data. There are limitations imposed by both the financial costs of collecting accuracy data and by the availability and maximum rates of progress of the experienced ecologists required to collect field transect accuracy data. In terms of cost, the LMES DSS procedures were applied for the entire extent of the former Cariboo Forest Region at a fixed cost of 10 cents per hectare. LMES did not raise the per hectare costs at all over the entire length of the Cariboo PEM project. The LMES PEM modeling costs of 10 cents per ha compare very favorably with costs for earlier PEM projects conducted by other contractors at costs that ranged from a low of 50 cents per hectare up to perhaps $1.50 per hectare.

The Cariboo PEM project provides information on the spatial pattern of distribution of forested and non-forested ecological entities for the entire extent of the former Cariboo Forest Region with no gaps or unmapped areas. The PEM maps are of acceptable accuracy and were produced at a relatively low cost and in a relatively short time. The raster (grid) PEM maps portray the distribution of different "environmental settings" which are associated with different dominant and included Site Units in a manner that provides a great deal of spatial precision (or at least of implied spatial precision). Relative to hand drawn maps of manually interpreted ecological spatial entities, the grid maps produced by the LMES DSS procedures locate and classify much smaller areas. They show where, in the landscape, the different environmental and ecological conditions are expected to occur and how, by inference, that variation is related to relative landform position and relative drainage regime.

The PEM maps produced using the LMES DSS methods are a lot like 3D block diagrams that capture and illustrate the spatial distribution of the heuristic concepts (beliefs) embodied in the definitions of Site Units in the relevant ecological Field Guides and classification systems. If these beliefs and rules are incorrect or

inconsistent, the LMES PEM maps will also be incorrect or inconsistent. If the input data sets used to apply the KB rules are inaccurate (e.g. do not portray the shape and orientation of the terrain correctly as it would be appreciated in the field) then the LMES PEM maps will again be incorrect at specific locations. In this case, the rules may still be correct and may produce acceptable results if improved input data sets are provided and the rules are re-run.

The virtue (and the criticism) of the LMES DSS procedures is that they directly capture and apply human beliefs as to how the landscape should be partitioned into different ecological classes. These beliefs are seldom 100% accurate and so maps that implement them cannot be expected to be 100% accurate. Factors other than those recognized in the formal definitions may alter the site conditions and site classification from what might be expected. The data layers used to portray or approximate the critical factors that control the spatial distribution of ecological classes are known to be incorrect and inaccurate at the scale of observation used to establish accuracy evaluations (10s of meters). The LMES DSS procedures are able to provide a very close approximation of the idealized (expected) spatial distribution of ecological spatial entities. It is unrealistic to expect that the actual distribution will always conform to some idealized expected distribution. The fact that the predicted distribution does conform to the distribution observed in the field for a significant proportion of evaluated sites (>65%) is highly encouraging.

Techniques for implementing predictive mapping are constantly improving and will continue to improve. Input data sets available for implementing predictive mapping are also improving and will continue to improve. Within the constraints imposed by currently available technologies and currently available input data sets, the PEM maps produced for the Cariboo PEM project area represent a successful application of available knowledge and technology to currently available input data sets.

The Cariboo PEM project produced PEM maps for over 8.2 million hectares of the former Cariboo Forest Region for a total final cost of less than $0.36 /ha over a period of five years. Final costs include all activities related to preparation of all input data layers, development and application of LMES DSS KB rules, collection and evaluation of internal quality control accuracy assessment data and internal and external project management and administration.   A more detailed breakdown of costs for each of the technical elements of the Cariboo PEM is presented in the project technical monitor's final report (Moon, 2008). Final assessments of accuracy confirm that all PEM maps did successfully achieve, and indeed exceed, the required minimum level of accuracy of 65%.

It is proposed that these results and this report represent a successful completion of a very large and challenging PEM project. We believe that we have conclusively demonstrated that it is possible to produce useful, effective and accurate maps of ecosystems for a very large area at an acceptable cost and within an acceptable period of time using the LMES DSS PEM modeling approach.

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10.0 Appendix A

A(1) Original program logic used to classify Bands 1, 2 and 3 digital numbers into 22 land cover classes

```
DO WHILE NOT EOF()
          DO CASE
                    CASE B1 <= 100
                              DO CASE
                                        CASE B3 > 200
                                                  REPLACE LC_CLASS WITH 10
                                        CASE B2 >= 55 AND B2 <= 100
                                                  DO CASE
                                                            CASE B3 <=40
                                                                      REPLACE LC_CLASS WITH 20
                                                            CASE B3 > 40 AND B3 <= 60
                                                                      REPLACE LC_CLASS WITH 11
                                                            CASE B3 > 60 AND B3 <=80
                                                                      REPLACE LC_CLASS WITH 12
                                                            CASE B3 > 80 AND B3 <=130
                                                                      REPLACE LC_CLASS WITH 13
                                                            CASE B3 > 130
                                                                      REPLACE LC_CLASS WITH 14
                                                  ENDCASE
                                        CASE B2 < 55
                                                  DO CASE
                                                            CASE B3 <=40
                                                                      REPLACE LC_CLASS WITH 21
                                                            CASE B3 > 40 AND B3 <=60
                                                                      REPLACE LC_CLASS WITH 16
                                                            CASE B3 > 60 AND B3 <=80
                                                                      REPLACE LC_CLASS WITH 17
                                                            CASE B3 > 80 AND B3 <=130
                                                                      REPLACE LC_CLASS WITH 18
                                                            CASE B3 > 130
                                                                      REPLACE LC_CLASS WITH 19
                                                  ENDCASE
                                        CASE B2 > 100
                                                  IF B3 >= 80 AND B3 <= 130
                                                            REPLACE LC_CLASS WITH 15
                                                  ELSE
                                                            REPLACE LC_CLASS WITH 22
                                                  ENDIF
                              ENDCASE
                    CASE B1 > 100 AND B1 <= 175
                              DO CASE
                                        CASE B2 <= 160
                                                  DO CASE
                                                            CASE B3 <= 160 AND B2 >= 100
                                                                      REPLACE LC_CLASS WITH 5
                                                            CASE B3 <= 160 AND B2 < 100
                                                                      REPLACE LC_CLASS WITH 9
                                                            CASE B3 > 160
                                                                      REPLACE LC_CLASS WITH 6
                                                  ENDCASE
                                        CASE B2 > 160
                                                  DO CASE
                                                            CASE B3 <= 200
                                                                      REPLACE LC_CLASS WITH 7
                                                            CASE B3 > 200
                                                                      REPLACE LC_CLASS WITH 8
                                                  ENDCASE
                              ENDCASE
                    CASE B1 > 175 AND B1 <= 220
                              DO CASE
                                        CASE B2 <= 170
                                                  REPLACE LC_CLASS WITH 1
                                        CASE B2 > 170
                                                  REPLACE LC_CLASS WITH 2
                              ENDCASE
                    CASE B1 > 220
                              DO CASE
                                        CASE B2 <= 210
                                                  REPLACE LC_CLASS WITH 3
                                        CASE B2 > 210
                                                  REPLACE LC_CLASS WITH 4
                              ENDCASE
          ENDCASE
          SKIP
ENDDO
```

A(2) Revised program logic used to classify Bands 1, 2 and 3 digital numbers into 22 land cover classes

```
DO WHILE NOT EOF()
        DO CASE
            CASE B1 <= 100
                DO CASE
                    CASE B3 > 200
                        REPLACE LC_CLASS WITH 10
                        && 10 => 50 Cores of Glaciers in Alpine
                        && Bright Cyan Color on LS Image
                    CASE B2 >= 55 AND B2 <= 100
                        DO CASE
                            CASE B3 <=40
                                REPLACE LC_CLASS WITH 20
                                && 20 => ?? Doesn't OCCUR??
                                && So Far I haven't encountered any
                            CASE B3 > 40 AND B3 <= 60
                                REPLACE LC_CLASS WITH 11
                                && 11 => 62 Thick Dark Green Trees in Shadow
                                && Very Dark Green Color on LS Image
                            CASE B3 > 60 AND B3 <=80
                                REPLACE LC_CLASS WITH 12
                                && 12 => 63 Very Thick Dark Green Trees in Shadow
                                && Dark Green Color on LS Image
                            CASE B3 > 80 AND B3 <=130
                                REPLACE LC_CLASS WITH 13
                                && 13 => 64 Very Bright Green Trees
                                && Mid to light purple color on LS Image
                            CASE B3 > 130
                                REPLACE LC_CLASS WITH 14
                                && 14 => 53 Glacier Core Ice in Shadow
                                && Bright Blue Color on LS Image
                        ENDCASE
                    CASE B2 < 55
                        DO CASE
                            CASE B3 <=40
                                REPLACE LC_CLASS WITH 21
                                && 21 => ?? None Occurs??
                                && So Far I haven't encountered any
                            CASE B3 > 40 AND B3 <=60
                                REPLACE LC_CLASS WITH 16
                                && 16 => 72 Very Dark Purple Trees (Shadow?)
                                && Purple on LS Image. Not much in Alpine
                            CASE B3 > 60 AND B3 <=80
                                REPLACE LC_CLASS WITH 17
                                && 17 => 71 Dark Purple Trees in Shadow
                                && Purple on LS Image. Not much in Alpine
                            CASE B3 > 80 AND B3 <=130
                                REPLACE LC_CLASS WITH 18
                                && 18 => 73 Dark Rock and Rubble in Alpine
                                && Greenish Purple on LS Image. Lots in Alpine
                            CASE B3 > 130
                                REPLACE LC_CLASS WITH 19
                                && 19 => 53 Glaciers in Shadow
                                && Dark Purple Blue on LS Image.
                        ENDCASE
                    CASE B2 > 100
                        IF B3 >= 80 AND B3 <= 130
                                REPLACE LC_CLASS WITH 15
                                && 15 => 65 Bright Green Trees
                                && Mid Green on LS Image. Def Green Vegetation
                        ELSE
                                REPLACE LC_CLASS WITH 22
                                && 22 => 11 Ice, Snow and Rock in Alpine
                                && Bright Mid Green below Alpine, Definitely Trees
                        ENDIF
                ENDCASE
            CASE B1 > 100 AND B1 <= 175
                DO CASE
                    CASE B2 <= 160
                        DO CASE
                            CASE B3 <= 160 AND B2 >= 100
                                REPLACE LC_CLASS WITH 5
                                && 5 => 61 Thick Green Trees and Brush
                                && Dark Green on LS Image, Definitely Trees
                            CASE B3 <= 160 AND B2 < 100
                                REPLACE LC_CLASS WITH 9
                                && 9 => 70 Dark Purple Trees in Shadow
                                && Dark Purple on LS Image, Could be Trees
                            CASE B3 > 160
                                REPLACE LC_CLASS WITH 6
                                && 6 => 51 Rock, Snow and Ice in Alpine
                                && Purple color on LS Image, Near edges of Glaciers
                        ENDCASE
```

```
CASE B2 > 160
            DO CASE
                        CASE B3 <= 200
                                    REPLACE LC_CLASS WITH 7
                                    && 7 => 40 Vigorous Brush, Forbs & Stunted Trees
                                    && Bright Light Green on LS Image, Not Bare, Brush?
                        CASE B3 > 200
                                    REPLACE LC_CLASS WITH 8
                                    && 8 => 52 Rock and Snow at edges of Glaciers
                                    && Cyan color on LS Image, Edges of glaciers
            ENDCASE
ENDCASE
CASE B1 > 175 AND B1 <= 220
            DO CASE
                        CASE B2 <= 170
                                    DO CASE
                                                CASE B2 <= 140
                                                            REPLACE LC_CLASS WITH 1
                                                            && 1 => 0 BARE to Sparse Heather Vegetation
                                                            && Lighter Pink colors on LS Image
                                                CASE B2 > 140
                                                            REPLACE LC_CLASS WITH 2
                                                            && 2 => 31 Low Shrubs and Grasses, Brush
                                                            && Very Light Green colors on LS Image
                                    ENDCASE
                        CASE B2 > 170
                                    DO CASE
                                                CASE B3 <= 200
                                                            REPLACE LC_CLASS WITH 2
                                                            && 2 => 31 Low Shrubs and Grasses, Brush
                                                            && Very Light Green colors on LS Image
                                                CASE B3 > 200
                                                            REPLACE LC_CLASS WITH 6
                                                            && 6 => 51 Rock, snow and ice in alpine
                                                            && Purple color on LS Image, Near edges of Glaciers
                                    ENDCASE
            ENDCASE
CASE B1 > 220
            DO CASE
                        CASE B2 <= 210
                                    DO CASE
                                                CASE B2 <= 160
                                                            REPLACE LC_CLASS WITH 3
                                                            && 3 => 10 Bare to slightly thicker vegetation
                                                            && Darker Pink colors on LS Image
                                                CASE B2 > 160
                                                            REPLACE LC_CLASS WITH 1
                                                            && 1 => 0 BARE to Sparse Heather Vegetation
                                                            && Lighter Pink colors on LS Image
                                    ENDCASE
                        CASE B2 > 210
                                    DO CASE
                                                CASE B3 > 200
                                                            REPLACE LC_CLASS WITH 4
                                                            && 4 => 20 Bright Bare Rock in Alpine
                                                            && Very Bright White Color on LS Image
                                                CASE B3 <= 200
                                                            REPLACE LC_CLASS WITH 2
                                                            && 2 => 31 Low Shrubs and Grasses, Brush
                                                            && Very Light Green colors on LS Image
                                    ENDCASE
            ENDCASE
ENDCASE
SKIP
ENDDO
```

A(3) Program logic used renumber 22 land cover classes into 18 classification zone numbers

```
DO WHILE NOT EOF()
            IF BEC_NO = 34 OR BEC_NO = 49 OR BEC_NO = 50
                        DO CASE
                                    CASE LC2_R8 = 1
                                                REPLACE ZONE_NO WITH (BEC_NO*100)+0
                                    CASE LC2_R8 = 2
                                                REPLACE ZONE_NO WITH (BEC_NO*100)+31
                                    CASE LC2_R8 = 3
                                                REPLACE ZONE_NO WITH (BEC_NO*100)+10
                                    CASE LC2_R8 = 4
                                                REPLACE ZONE_NO WITH (BEC_NO*100)+20
                                    CASE LC2_R8 = 5
                                                REPLACE ZONE_NO WITH (BEC_NO*100)+61
                                    CASE LC2_R8 = 6
                                                REPLACE ZONE_NO WITH (BEC_NO*100)+51
                                    CASE LC2_R8 = 7
                                                REPLACE ZONE_NO WITH (BEC_NO*100)+40
                                    CASE LC2_R8 = 8
                                                REPLACE ZONE_NO WITH (BEC_NO*100)+52
                                    CASE LC2_R8 = 9
                                                REPLACE ZONE_NO WITH (BEC_NO*100)+70
                                    CASE LC2_R8 = 10
                                                REPLACE ZONE_NO WITH (BEC_NO*100)+50
                                    CASE LC2_R8 = 11
                                                REPLACE ZONE_NO WITH (BEC_NO*100)+62
                                    CASE LC2_R8 = 12
                                                REPLACE ZONE_NO WITH (BEC_NO*100)+63
                                    CASE LC2_R8 = 13
                                                REPLACE ZONE_NO WITH (BEC_NO*100)+64
                                    CASE LC2_R8 = 14
                                                REPLACE ZONE_NO WITH (BEC_NO*100)+53
                                    CASE LC2_R8 = 15
                                                REPLACE ZONE_NO WITH (BEC_NO*100)+65
                                    CASE LC2_R8 = 16
                                                REPLACE ZONE_NO WITH (BEC_NO*100)+72
                                    CASE LC2_R8 = 17
                                                REPLACE ZONE_NO WITH (BEC_NO*100)+71
                                    CASE LC2_R8 = 18
                                                REPLACE ZONE_NO WITH (BEC_NO*100)+73
                                    CASE LC2_R8 = 19
                                                REPLACE ZONE_NO WITH (BEC_NO*100)+53
                                    CASE LC2_R8 = 20
                                                REPLACE ZONE_NO WITH (BEC_NO*100)+99
                                    CASE LC2_R8 = 21
                                                REPLACE ZONE_NO WITH (BEC_NO*100)+99
                                    CASE LC2_R8 = 22
                                                REPLACE ZONE_NO WITH (BEC_NO*100)+11
                                    OTHERWISE
                                                REPLACE ZONE_NO WITH (BEC_NO*100)+99
                        ENDCASE
            ENDIF
            SKIP
ENDDO
```