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Final Report

Predictive Ecosystem Mapping (PEM) with Wildlife Habitat Interpretations to Support Oil and Gas Pre-Tenure Planning in the Muskwa - Kechika Management Area

Volume 1 - PEM

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Executive Summary

During the period of November, 2000 to March, 2002, EBA Engineering Consultants Ltd. (EBA) carried out a project on Predictive Ecosystem Mapping (PEM) with wildlife habitat interpretations (WHI) for the BC Ministry of Energy & Mines, Petroleum Lands Branch. During January to March, 2002, the project – referred to throughout this document as the "Muskwa PEM project" – was assembled and delivered in final form.

Work within this project focused on the production of 1:50,000 scale PEM and derivative wildlife suitability mapping for some 183 1:20,000 TRIM mapsheets in four Pre-Tenure Plan (PTP) Areas within the Muskwa-Kechika Management Area (MKMA). PEM with WHI was completed for a total area of approximately 1.2 million ha.

This Final Report documents the PEM (Volume 1) and WHI (Volume 2) components of the project.

PEM Mapping

PEM mapping was carried out within the four PTP areas in two manners:

- Within PTP Areas 1 and 2, the two most southerly PTP areas of the Muskwa PEM project, bioterrain mapping was initially conducted, and then, upon this base, the ecosystem mapping was completed using several input spatial datasets. For PTP Areas 1 and 2, the bioterrain mapping was constructed using a two-stage approach. First, terrain / landform units were identified, delineated and labelled onto 1:40,000 scale black and white photos. For the purposes of PEM and associated wildlife habitat suitability interpretations, bioterrain enhancements were then photo-interpreted and added, including drainage class, slope steepness class, geomorphological subclass and avalanche process subclass.

- Within PTP Areas 3 and 4, bioterrain mapping was not completed, but ecosystem mapping was conducted using the other same spatial datasets as for PTP Areas 1 and 2. Base units for mapping in PTP Areas 3 and 4 were derived polygons using slope and aspect from the digital elevation model (DEM). A very similar methodology, aside from the use of bioterrain, was conducted for PTP Areas 3 and 4 as for PTP Areas 1 and 2, so results are closely comparable.

For all PTP Areas, PEM modeling was completed using several input spatial datasets. PEM depicts ecosystem (site series) patterns within different climatic units. Within the Study Area, there are 9 different climatic units ranging a lower elevation boreal forest unit to high elevation non-forested alpine tundra. Each climatic unit included a number of site series and other ecosystem units. Each ecosystem unit is further described using ecosystem site modifiers. Site modifiers are site-specific factors that can be directly related to management interpretations of different site series. These include factors such as aspect, soil texture and certain specific soil terrain features.

Bioterrain and PEM databases and maps were produced through a sequence of:

- Project initiation and input data assessment;
- Photo-typing, photo-to-map transfer, and GIS database / map production for bioterrain (PTP Areas 1 and 2);
- Field verification sampling;
- PEM modeling and interpretation; and,
- Final GIS database / map production.

Methods followed and other specifications are detailed in Volume 1. The work conformed to provincial standards that were in place for PEM mapping (i.e., RIC 2000a, b) and standard conventions were followed throughout the process. Final PEM products were prepared in digital form, within a GIS.

Each stage of PEM map production was accompanied by a combination of internal and external quality control audits. The latter were conducted under the auspices of MSRM Provincial Correlation staff for PEM, and formal approvals and sign-offs at milestones were obtained.

Wildlife Habitat Interpretations

The goal of the wildlife component was to produce WHI's, basically habitat suitability interpretations, for ten featured wildlife species: grizzly bear, moose, caribou, Rocky Mountain elk, plains bison, Stone sheep, mountain goat, American marten, fisher and Bay-breasted Warbler.

In addition to habitat suitability mapping, this project undertook a synthesis of known wildlife values for the Study Area, including the results of a wildlife experts workshop, wildlife habitat assessments and incidental observations.

Wildlife habitat suitability ratings define the relative importance of mapped ecological units to wildlife populations. Habitat suitability mapping provides a basis to evaluate the effects of development on wildlife habitat. It identifies areas that provide regionally and/or provincially significant habitat and places the loss or modification of habitat into a local and regional context. When combined with current known animal distributions, interpretations can also be made on potential avenues or opportunities for range expansion.

We developed species-habitat models that relate each species' life requisites to the attributes of the ecosystem units present in the Study Area. Each model is based on scientific literature, previous studies in the region, our own field data collection, additional field observations, and expert opinion. Ratings tables were generated using a linear model that contains the key attributes of ecosystem units. An automated approach using a relational database was used to assign ratings to each possible ecosystem unit in the Study Area.

Based on the 1:50,000 PEM outputs, WHIs were produced in digital form.

There are strong resource development pressures upon the MKMA, particularly with respect to oil and gas exploration and potential oil and gas industrial developments. The information derived from this PEM and wildlife habitat suitability investigation will be used to direct and inform higher-level resource management planning and operational activities within the MKMA.

Acknowledgements

The project was conducted by EBA Engineering Consultants Ltd. (EBA), with the involvement of staff from our Vancouver, Kelowna and Fort St. John offices. A number of people and agencies were involved in various stages of the work, and the report authors would like to acknowledge their contributions.

Staff of Ministry of Energy & Mines (MEM), Petroleum Lands Branch played a crucial role in this project, providing overview direction and ongoing input. Principal contact for EBA staff during the first half of the project was Deborah Johnson, and during project completion phases, Graeme McLaren.

Other provincial staff with ongoing involvements were Anne Murphy (GIS Specialist, MSRM, Fort St. John), Craig Delong (Regional Ecologist, Ministry of Forests (MoF), Prince George Forest Region, Prince George), Del Meidinger (Provincial Ecologist, MoF Research Branch, Victoria) and Marvin Eng (Landscape Ecologist, MoF Research branch, Victoria).

Correlation and quality assurance roles were also critical to the completion of this project, and the following provincial staff provided important support with these aspects:

- Deepa Filatow (Bioterrain Specialist, MSRM, Victoria) correlated the bioterrain mapping and the bioterrain components of the digital database

- Ted Lea (Vegetation Ecologist, MSRM, Victoria) and Craig Delong (Regional Ecologist, Ministry of Forests (MoF), Prince George Forest Region, Prince George) jointly correlated the ecosystem units and mapping

- Calvin Tolkamp (Wildlife Specialist, MSRM, Victoria) and Rod Backmeyer (Wildlife Biologist, MSRM, Fort St. John) correlated the wildlife habitat interpretations

- Tim Brierley (MSRM, Victoria) and Terry Gunning (MSRM, Victoria) undertook, respectively, the spatial and non-spatial database correlation activities for data components of the project.

The Muskwa PEM project was overseen and managed throughout by the following three individuals:

- Richard Sims, who managed the project, organized project staff, and supervised the completion of all aspects.

- John Grods, who technically managed and coordinated the assembly of all input data layers, knowledge base development and testing, application of the PEM modeling and final map production.

- Jeff Matheson, who technically managed and coordinated the wildlife habitat interpretations, analyses and wildlife-related reporting.

These three were ably assisted throughout by a dedicated team of professionals, who worked on important components of the project. We are pleased to acknowledge the following EBA staff for their contributions towards the completion of the Muskwa PEM:

- Wayne Darlington, Karen Warrendorf and Christine Curry who helped with the initial logistics and background information gathering during the critical start-up phases of the project.

- Ksenia Barton (sub-consultant), Jack Dennett, Polly Uunila, Damian Powers (sub-consultant) and Sheldon Helbert, who provided biological expertise, and assisted John Grods and Jeff Matheson in carrying out the summer field data collection program for the project.

- Bill Nalder and Mike Waberski of EBA Waberski-Darrow’s Fort St. John office for their ongoing involvement in terms of local support and liaison throughout the project

- Wayne Darlington, Karen Warrendorf, Jon Brydges, York Law, Peter Graham, Jeff Kruys, Michael Nivens and Steven Kraetzer, for their invaluable assistance with GIS-based activities, including input data management, PEM modeling and map production for the project.

- Polly Uunila, Jack Dennett and Jennifer Shypitka (sub-consultant), who conducted bioterrain field annotation and office-based photo-typing.

- Damian Power (sub-contractor) and Michael Nivens who assisted Jeff Matheson with the construction of habitat ratings tables and the application of these to wildlife interpretations

- Vin Campbell (sub-consultant) and Karen Warrendorf for their assistance with satellite remote sensing data analysis

The assembly of the Final Report (Vol. 1 and 2) was undertaken collaboratively. Richard Sims and John Grods wrote and edited the PEM Final Report (Vol.1), with inputs from several others at EBA. John Grods and Wayne Darlington completed ecosystem factsheets / expanded ecosystem legends. The WHI portion of the Final Report (Vol. 2) was prepared and edited by Jeff Matheson.

Funding support for this project was provided by British Columbia's Ministry of Energy and Mines.

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1. INTRODUCTION

During the period of November, 2000 to March, 2002, EBA Engineering Consultants Ltd. (EBA) carried out a project on Predictive Ecosystem Mapping (PEM) with wildlife habitat interpretations (WHI) for the BC Ministry of Energy & Mines, Petroleum Lands Branch. During January to March, 2002, the project – referred to throughout this document as the “Muskwa PEM project” – was assembled and delivered in final form.

Work within this project focused on the production of 1:50,000 scale PEM and derivative wildlife suitability mapping for some 183 1:20,000 TRIM mapsheets in four Pre-Tenure Plan (PTP) Areas within the Muskwa-Kechika Management Area (MKMA). The total area mapped using the PEM procedures described in this document is about 1.2 million ha.

This Final Report documents the PEM (Volume 1) and WHI (Volume 2) components of the project.

1.1. Background

The Muskwa-Kechika Management Area (MKMA) is a remote wilderness area in northeastern BC and is one of the few remaining vast, intact and largely unroaded areas south of the 60th parallel. The area is composed of 1.58 million hectares of provincial parks and protected areas surrounded by 4.78 million hectares of special resource management areas (for more information see http://www.luco.gov.bc.ca/nrockies/home.htm).

In order to direct potential resource development, a landscape-level planning approach is being applied in Pre-Tenure Planning (PTP) areas within the special resource management areas. The Muskwa PEM is a key background mapping activity for that planning, and – as described in this Final Report – provides critical information on the land base in terms of terrain, ecosystems and wildlife habitat. The results of the Muskwa PEM are being used directly in pre-tenure planning and decision making (EBA Engineering Consultants Ltd., 2001a, 2001b).

The Muskwa PEM project was conducted over a 19 month period by EBA. The project was undertaken to address the requirements of landscape-level pre-tenure planning at a scale of 1:50,000 in the Muskwa-Kechika Management Area (MKMA). The general approach and activities for the project were outlined in EBA’s original Technical Work Plan for the Muskwa PEM (EBA 2001a).

The Year 1 Progress Report documented the progress for the project during the first 6 months. (EBA 2001b) Year 1 of the Muskwa PEM project consisted of the period from project start-up in mid-November, 2000 to March 31, 2001. During the start up period, effort was focused toward the initiation of the project, the capture and reconciliation of East Slope Mapping Project and bioterrain typing of new areas.

During the second phase of the work, during April 2001 to March, 2002, the remaining digital capture of map materials, for use as input data, was completed. Field data collection was conducted. Project knowledge bases were assembled and tested, the input data were assembled for pilot test areas and the final PEM models were tested and iteratively refined. Final reporting, quality assurance and other activities were conducted so as to complete the project by 31 March, 2002.

Bioterrain typing of new areas, not covered by the East Slope Mapping or other existing bioterrain mapping (e.g., as exists for the NE Burn area, the Besa-Prophet TEM area (Anon. 1999) or the Dunedin TEM area) was completed.

An important factor in the accuracy of a PEM map is the quality of the BGC Zone / Subzone / Variant mapping. For the entire project area, the provincial-level BGC mapping was refined or localized to a 1:50,000 scale sing the provincial BCG localization procedure (Eng and Meidinger 1999). This was conducted in close cooperation with provincial Research Branch staff, and used expert opinion, field verification data, existing BCG linework and TRIM elevational data to complete a re-contouring procedure to derive refined lines. These were used as a key input into the PEM process.

1.2. Ecosystem Mapping Methodologies

Within BC, ecosystem mapping follows standardized methodologies, and the usefulness of ecosystem mapping for a range of resource management applications is well recognized.

Terrestrial Ecosystem Mapping (TEM) is the precursor to PEM in BC. TEM has been conducted within BC since the early 1990's and is well established as a tool for identifying and mapping ecosystem units (Banner et al., 1996; Britton et al., 1996, Resources Inventory Committee 1998a, 1998b). TEM has been completed with in a large number of provincial TRIM sheets, particularly in southern coastal and interior BC.

In the northern parts of the province, because of the more extensive management approaches that are followed, the costs associated with field data collection which is a major component of a TEM's cost, and given the generally lower quality of available input databases, PEM is a more appealing alternative. PEM tends to be less expensive than TEM, and is more readily extended over a large and remote area, and where ground plot sampling is conducted in a more directed or selected manner.

Like TEM, PEM is based, in large part, upon the Biogeoclimatic Ecosystem Classification (BEC) system (e.g., see Meidinger and Pojar 1991; Delong et al. 1990, 1994). During the late 1990's and 2000-2002, a limited number of PEM projects have been completed throughout the province, using standardized protocols and methodologies, including integrated quality assurance and project correlation components.

Efficiencies arising from PEM as an approach revolve around the use of existing information or data that is already in place, and the obvious cost-effectiveness of building upon existing sources. As well, because there is a defined set of algorithms involved in PEM derivation, there is a repeatable process, which can be replicated or updated in future, should more information or better quality sources become available.

1.3. Objectives

The project's principal objective was to undertake PEM and associated wildlife habitat mapping according to Resource Inventory Committee (RIC) standards (Resource Inventory Committee 2000a, 2000b). It was understood that the inventory outputs of the work would be directly incorporated into the MKMA's resource management and planning activities within the Muskwa PEM's four PTP Areas.

Resource planning and management in northern environments needs the best possible inventory data, so that informed decisions can be made. Within the 4 PTP Areas, there are some particular concerns about preserving critical wildlife habitats, particularly with respect to grizzly bear, moose, caribou, Rocky Mountain elk, plains bison, Stone sheep, mountain goat, American marten, fisher and Bay-breasted Warbler. Consequently, the current 1:50,000 scale PEM project provides valuable baseline information for some 183 1:20,000 mapsheets within the Muskwa TSA.

Several sub-objectives were also outlined at the outset of the project, and were summarized in EBA's original Technical Plan for the project (EBA 2001a). These include:

- Confirm or adjust locations of Biogeoclimatic (BGC) Zonal / Subzonal / Variant boundaries within the Study Area;

- Refine existing Site Series units and their descriptions, and define / describe previously unclassified ecosystem units, particularly within the Engelmann Spruce-Subalpine Fir Parkland (ESSFp), and AT Zones; and,
- Develop spatially-referenced baseline biophysical information so that it can assist higher level management analysis and decision-making (such as, longer-term wildlife management scenarios, or spatial estimation of potential site productivity within the Study Area.

The goal of the wildlife component was to produce habitat suitability interpretations for ten featured wildlife species: grizzly bear, moose, caribou, Rocky Mountain elk, plains bison, Stone sheep, mountain goat, American marten, fisher and Bay-breasted Warbler.

To undertake the habitat suitability interpretations (Volume 2), look-up tables and GIS-based algorithms were developed, tested and applied based upon habitat values determined from literature reviews, expert opinion, field data collection and other observations. In addition to habitat suitability mapping, the project provides a synthesis of known wildlife values for the Study Area, including the results of aerial surveys, wildlife habitat assessments, incidental observations.

The project resulted in outputs that directly address biodiversity conservation issues within the Muskwa PEM Study Area, an area known to have high wildlife values.

1.4. Report Layout

Volume 1: PEM is composed of three main sections:

- Section 1 provides an overview of the project, including general context related to the project's objectives, scope and organization, and the Study Area's physiographic and biotic components.
- Section 2 describes the methodology and approach followed to complete PEM and wildlife interpretation deliverables. It also documents conventions used in the mapping.
- Section 3 describes the ecosystem units applied in the PEM mapping. It includes a set of photographs showing a range of ecosystem conditions, and also the project's Expanded Legend which lists all ecosystems visited, described and classified within the Study Area.

A complete set of final PEM digital databases is also associated with this Final Report.

1.5. Study Area

As already noted, the Muskwa PEM Study Area occurs as four Pre-Tenure Plan (PTP) Areas. The extent of these areas are shown in Figure 1. The Study Area is located within the Southern Interior Mountains Ecoprovince; Southern Rocky Mountain Trench, Western Continental Ranges, and Northern Columbia Mountains Ecoregions; Upper Fraser Trench (UFT), Northern Park Ranges (NPK), and Caribou Mountains (CAM) Ecosections (Anon., 1998).

Overall the Study Area covers 1,216,570 ha. It lies east of the Continental Divide and within the arctic watershed. The area is mainly drained by the Liard River, Peace River and their major tributaries, which, in the project areas, include the Graham, Halfway, Muskwa, Dunedin, Racing and Toad Rivers. The areas are located within the Peace Foothills, Missinchinka Ranges, Muskwa Plateau, Muskwa Foothills and Eastern Muskwa Ranges Ecosections and are covered by the Alpine Tundra, Spruce-Willow-Birch, Boreal White and Black Spruce, and Engelmann Spruce-Subalpine Fir Biogeoclimatic Zones (BGC).

For planning purposes, the MKMA is divided into additional broad planning areas referred to as Resource Management Zones (RMZs). Within the Study Area the distribution of RMZs is described in Section 1.6.

Figure 1. Muskwa PEM Study Area

The Study Area includes elements of three forested BEC Zones: the Engelmann Spruce-Subalpine Fir (ESSF), the Boreal White and Black Spruce (BWBS) and the Spruce-Willow-Birch (SWB) Zones.. Lower elevations within the Study Area generally fall within the BWBS, and are comprised mostly of the BWBSmw2, BWBSwk2 and BWBSdk2 Subzones and a minor component of BWBSmw1. Higher elevations mainly consist of the ESSFmv4 and SWBmk Subzones, as well as a variety of ESSFmvp4 Parkland, SWBmks Scrub and Alpine Tundra (AT BEC Zone) vegetation community types. There are a variety of wetlands and non-forested communities which occur throughout the Study Area.

The Study Area is located east of the Rocky Mountains of the Rocky Mountain Foothills and Rocky Mountains Physiographic Region. Lower elevations within the Study Area are within the BWBS Zone and are dominated by medium textured gravelly fluvial materials featuring mostly Orthic Dystric Brunisols and glacio-lacustrine materials featuring mostly Brunisolic Gray Luvisols. Zonal sites within the ESSF are dominated by Dystric Brunisols. In this Zone, morainal materials dominate and are usually gravelly loam textured. The bedrock geology of the Study Area is mostly dominated by foliated sedimentary rocks – chiefly Mesozoic age.

1.6. PTP Area Descriptions

The final Study Area, as shown in Figure 1, is composed of four PTP Areas. Brief descriptions of each area are provided in Sections 1.6.1 to 1.6.4.

1.6.1. PTP Area 1

PTP Area 1 (Figure 2) extends over 234,149 ha. Elevation ranges from 860m in the valley bottom to 2660m in the northwestern portion of the area.

PTP Area 1 includes the Besa-Halfway-Chowade RMZ and Graham North RMZ. The most common BEC Subzones are ESSmv4, AT and SWBmk, which together account for 71% of the area (Table 1)

The Halfway, Chowadee and Cypress River drainages are located on the northern portion of PTP Area 1, and they all drain to the east away from the Foothills. The Graham River drains the southern portion of PTP Area 1, flowing southward into the Peace River.

Table 1. Coverage (ha, %) of BEC Subzones for PTP Area 1.

Subzone	Hectares	Percent of PTP Area 1
AT	55117.3	23.54%
BWBSmw 1	1022.1	0.44%
BWBSwk 2	23525.9	10.05%
ESSFmv 4	83063.6	35.47%
ESSFmvp4	18369.3	7.85%
SWB mk	28803.3	12.30%
SWB mks	24247.4	10.36%
Total	234149.3	

1.6.2. PTP Area 2

PTP Area 2 (Figure 3) covers 150,848 ha. Relative to the other three PTP Areas, elevation ranges are the least extreme within PTP Area 2; they range from 500 m in lower landscape positions to, in the foothills along the eastern extent of the area, up to 1760 m.

The Muskwa West RMZ and Muskwa River Corridor RMZ both occur within PTP Area 2. The BWBSmw2 BEC Subzone is widespread within PTP Area 2 and extends over 95% of the area (Table 2)

Portions of the Prophet, Muskwa, Ghato, Tucudi and Tetsa River drainages are located on the east half of of PTP Area 2, in the boreal plains. A portion of this Study Area edges into the Muskwa foothills to the east.

Table 2. Coverage (ha, %) of BEC Subzones for PTP Area 2.

Subzone	Hectares	Percent of PTP Area 2
BWBSmw 2	143410.1	95.07%
SWB mk	7390.1	4.90%
SWB mks	48.3	0.03%
Total	150848.6	

1.6.3. PTP Area 3

PTP Area 3 (Figure 4) is the largest of the four PTP Areas, and extends over some 435,107 ha. Elevation ranges between 420m in the northern portions of the study along the Liard Valley and 2380m of the central Rockies along the western edge.

PTP Area 3 is associated with the Stone Mountain RMZ, Toad River Corridor RMZ, Eight Mile / Sulphur RMZ, and Alaska Highway Corridor Enhanced RMZ. The SWBmk and BWBSmw2 BEC Subzones are the most predominant Subzones within PTP Area 3 and together account for 84% of the area (Table 3). About 1.3% of total area (5675 ha) is occupied by water.

Sulphur and Eight Mile Creek, which are both tributaries to the Toad and Racing River drainages, are located across the northeastern half of the Study Area.

Table 3. Coverage (ha, %) of BEC Subzones for PTP Area 3.

Subzone	Hectares	Percent of PTP Area 3
AT	22399.3	5.15%
BWBSdk 2	31135.1	7.16%
BWBSmw 2	149585.2	34.38%
SWB mk	216068.4	49.66%
SWB mks	15918.7	3.66%
Total	435107.0	

Figure 2. PTP Area 1.

Figure 3. PTP Area 2.

Figure 4. PTP Area 3.

Figure 5. PTP Area 4.

1.6.4. PTP Area 4

PTP Area 4 (Figure 5) extends over some 396,466 ha. This elevational ranges from 660 m along the valley bottom of the Racing River, up to 2840 m, in the central Rockies Range.

PTP Area 4 is associated with the Churchill RMZ and the Alaska Highway Corridor Enhanced RMZ (i.e., Tone Mountain to Muncho Lake). Alpine Tundra and SWBmk together cover 89% of the area (Table 4). About 1.4% (5,414 ha) of the area is water (lakes and rivers), and 5.1% (20,215 ha) is glacial ice.

PTP Area 4 includes the Toad River and Racing River drainages, which are located within the central Rocky Mountains.

Table 4. Coverage (ha, %) of BEC Subzones for PTP Area 4.

Subzone	Hectares	Percent of PTP Area 4
AT	213278.5	53.79%
BWBSmw 2	6223.1	1.57%
SWB mk	140872.0	35.53%
SWB mks	36092.9	9.10%
Total	396466.6	

1.7. Physiography and Soils

1.7.1. Bedrock Geology and Topography

All four study areas are located on the eastern side of the Rocky Mountains. PTP Area 2 and the eastern portions of PTP Areas 1 and 3 are located within the Rocky Mountain Foothills Physiographic Region (Holland, 1976). PTP Area 4 and the western portions of PTP Areas 1 and 3 are located in the Muskwa Ranges of the Rocky Mountains Physiographic Region (Holland, 1976). The spine of the Northern Rockies trend from the northwest to the southeast.

The portions of PTP Areas 1 and 4 that lie within the Muskwa Ranges are generally underlain by Devonian and Permo-Carboniferous - aged limestones (Holland, 1976, Journeay et al, 2000a, Journeay et al, 2000b). Along the height of land in these two study areas, volcanic bedrock may be found, such as, tuff, breccia and basalt (Journeay et al, 2000a, Journeay et al, 2000b). The most rugged terrain with the greatest relief of the four study areas can be found within the Muskwa Ranges of PTP Areas 1 and 4. In PTP Area 4, elevations range from about 4000 ft along the Toad and Racing Rivers to as high as 10,500 ft at the height of land. In PTP Area 1, elevations range from about 4000 ft along the Halfway, Cypress and Chowade Rivers to about 7700 ft at the height of land.

The portion of PTP Area 3 that lies within the Muskwa Ranges is generally underlain by Devonian and Permo-Carboniferous - aged limestones and soft Upper Devonian and Lower Triassic shales (Holland, 1976, Journeay et al, 2000a). The most rugged portion of this area is underlain by limestone and elevations range from 2680 ft at Muncho Lake to 7675 ft at the height of land. The areas underlain by the shales are more subdued with rounded ridge-tops. Here elevations range from 2500 ft along the Toad River to as high as 6400 ft at the height of land.

PTP Area 2 and the portions of PTP Areas 1 and 3 that lies within the Rocky Mountain Foothills are underlain by sedimentary rocks, primarily of Mesozoic age (Holland, 1976, Journeay et al, 2000b). In PTP Area 1, elevation ranges from about 3000 ft to as high as 7500 ft. In Areas 2 and 3, elevations range from about 2000 ft to 5000 ft.

Potential differences in weathering characteristics in the rock types mapped in the four areas are worth noting. Characteristics of bedrock, such as mineral composition and structure, determine the shape and texture of its weathered material. These characteristics influence the shape and size of clasts, and the matrix texture of colluvium and till. Sedimentary rocks typically fracture along bedding planes to create pebble-sized rubble and slabs. These rock types weather into the particle sizes that the rocks are composed of, for example sandstone would tend to weather to sand and siltstone would tend to weather to silt. Volcanic bedrock breaks down into rubble and blocks, which weather into silt and clay.

1.7.2. Landscape Evolution and Deposition of Surficial Materials

The present physiography dates back several hundred million years ago (Paleozoic) when plate tectonics thrust and uplifted shallow sea sediments onto the western margin of the North American continent. This created mountain ranges (the Rocky Mountains) oriented in a northwest-southeast direction. Erosion from the newly uplifted mountains deposited alluvial sands, mud and gravel along the eastern front of the mountains. Ongoing thrusting pushed these alluvial sediments to create the Rocky Mountain Foothills (Yorath, 1990).

During the maximum of the most recent glaciation (Fraser Glaciation) which occurred about 14,500 year ago, 3 glacier systems met over the Study Areas; the Collideran Ice Sheet from the west, the Laurentide Ice Sheet from the east and a locally coalesced system of Rocky Mountain valley glaciers (Mathews, 1980). Over the Study Areas, the Collideran and valley glaciers flowed generally in an eastern direction and the Laurentide Ice Sheet flowed generally in a westward direction. The easterly and westerly flowing ice masses met approximately along the eastern edge of the Rocky Mountain Foothills (Mathews, 1980). During the Pleistocene, the fronts of these ice sheets appear to have alternately overlapped, and there were ice-free periods in a narrow band along the Rocky Mountain Foothills and the area immediately to the east (Mathews, 1980).

During the Pleistocene glaciations, all but the highest peaks were buried by the Collideran Ice Sheet and the Rocky Mountain valley glaciers (Fulton, 1989, Holland, 1976, Mathews, 1980). At elevations located above the major ice masses, late-stage alpine and cirque glaciation eroded and shaped many of the highest peaks (Holland, 1976).

Glaciers deposited morainal (till) sediments from the ice base and margins and till melted out of stagnating ice. These deposits are commonly found blanketing gentle to moderately steep hillslopes within the Study Areas. Till typically consists of a fine-grained matrix (particles <2 mm) that surrounds and supports clasts (particles >2 mm) of a variety of sizes, shapes and rock types. Till characteristics, such as texture (particle sizes) and consolidation (or bulk density), vary according to specific processes of deposition by glacier ice (e.g., subglacial vs.

supraglacial tills). These deposits can be highly variable and gradations in texture and consolidation can vary over short distances.

Deglaciation occurred between about 14,000 and 11,000 years ago. Deglaciation was by downwasting so that the uplands emerged from beneath the ice while tongues of ice remained in the valley bottoms. Downwasting ice often forms characteristic subglacial and ice-marginal landforms on gentle surfaces, such as eskers, kames, and meltwater channels. Drainages were blocked, and ice-dammed lakes formed, as a result of the retreating ice. The largest of these lakes recorded are located east and southeast of the four Study Areas.

Glaciofluvial materials consist of sand and gravel with small quantities of finer material and are potential sources of aggregate. These deposits are commonly found along the margins of the valley bottoms within the Study Areas. Sorting and bedding characteristics are variable depending on the mode and site of deposition. Gravels range from unsorted to well-sorted and bedding can range from absent to well-defined. Glaciofluvial deposits are loose (uncompacted) and clasts tend to be more subrounded than subangular. Ice-contact deposits may have distorted bedding, slump structures and faults as a result of settling and collapse due to the melting of supporting ice. Ice contact deposits may also contain lenses of fine-textured glaciolacustrine sediments and coarse-textured ablation till. Beds in raised deltas are inclined up to 22°, and indicate the frontal slopes of depositional landforms.

Glaciolacustrine materials consist of fine sediments that accumulated in ice-dammed lakes. Large areas of these sediments are not mapped within the four Study Areas. Fine sand, silt, and clay ("rock flour") initially produced by glacial abrasion were transported to the lakes by meltwater streams. Finer sediments tend to remain suspended in the lake for long periods before slowly settling to the lake bottom. Glaciolacustrine sediments typically consist of interlayered silt, clay, and fine sand. Dropstones from melting ice that range in size from pebbles to boulders may be embedded in the finer material. This material is generally moderately to highly cohesive, depending on the percentage of clay, and is slowly permeable to impermeable. Beach sediments tend to be sands and gravels that are loose and porous.

During post-glacial times, processes have re-worked some glacial sediments and weathered bedrock to redistribute them as colluvium and fluvial sediments. Streams and rivers have downcut into glacial deposits and bedrock creating terraces, benches, and steep-sided scarps.

Colluvial materials have accumulated during post-glacial time as a result of gravity-induced slope movement such as soil creep and landslides. Colluvium is commonly found blanketing the steeper slopes in the Study Areas. The physical characteristics of colluvium are closely related to its source and mode of accumulation. Four processes generally create colluvial deposits. These are: rockfall from bedrock bluffs, soil creep in weathered bedrock, mass movement processes in gullies (debris flows and debris slides) and rock slumps and rockslides. Talus slopes often form below bedrock bluffs from accumulated rockfall. Talus is typically loosely packed rubble or blocks with little interstitial silt and sand near the surface, and is rapidly or well drained. Colluvial veneers and blankets develop where weathered bedrock has been loosened and moved downslope by gravitational processes such as soil creep. The characteristics of this colluvium closely resemble those of the material it was derived from. It is loosely packed and usually well drained. Colluvial fans and cones form at the base of steep gullies due to deposition by debris flows. These deposits are generally compact, and sorting may range from poorly sorted to well sorted. The deposit may or may not be matrix-supported and the matrix is usually sand. Deep-seated slumps and slides in bedrock and surficial materials result in hummocky, irregular colluvial deposits. Rock slump and slide deposits contain blocks and rubble with little or no interstitial silt and sand.

Streams have deposited fluvial gravels in post-glacial time. Floodplains are common along valley bottoms, and fluvial fans are common at the base of tributary valleys. These sediments are loose, non-cohesive and highly porous and permeable. Associated landforms, such as floodplains and parts of fans that are close to stream-level, have high water tables and are moderately to imperfectly drained. Floodplains are subject to periodic inundation during high flows. Fluvial terraces stand above present day creek-levels.

1.8. Ecoregions

The Ecoregion classification system is a hierarchical classification of physiographic units. These units are based on a five-level, nested, classification of landscapes which are relatively homogeneous or consistent for significant wildlife habitat features at each. (Demarchi 1996). It has some commonality and overlap with the Biogeoclimatic Ecosystem classification (Meidinger and Pojar 1991), but it is a broader, more physiographically-based classification. More than one BGC climatic unit is typically included within each of the lowest Ecosection mapping units that exist within the Study Area.

Three Ecoprovinces comprise the Study Area: Northern Boreal Mountains, Sub-Boreal Interior, and Taiga Plains. The Study Area is located within the Northern Canadian Rocky Mountains, Central Canadian Rocky Mountains, Muskwa Plateau, and Hyland Plateau Ecoregions. Within the Study Area, these consist of the following Ecosections: Eastern Muskwa Ranges (EMR), Muskwa Foothills (MUF), Misinchinka Ranges (MIR), Peace Foothills (PEF), Muskwa Plateau (MUP), and Hyland Highland (HYH). Distribution of these Ecosections within the four PTP Areas are shown in Figures 2 to 5.

The Sub-Boreal Interior Ecoprovince is found in the southern extents of PTP Area 1, predominantly in the Graham, Cypress and Chowade River drainages. Further defined by the Central Canadian Rocky Ecoregion and Peace Foothills Ecosection. Climate is prevailing westerly Pacific air with low moisture content in a strong rain shadow affect.

The Northern Boreal Mountains Ecoprovince is found in the northern portion of PTP Area 1, the eastern edge of PTP Area 2, the western portion of PTP Area 3 and all of PTP Area 4. Within this Ecoprovince, Pacific air is prevailing with a great reduction in moisture; this results in some areas becoming seasonally very dry. Winter is frequented by Arctic air outbreaks. Rugged relief leads to complex surface temperature patterns. Snow accumulations typically decrease eastward into the foothills.

The Taiga Plains Ecoprovince is found in the eastern portions of PTP Areas 2 and 3, exclusively in the Muskwa Plateau. The climate is continental with Arctic air masses that are sustained for long durations in winter. The position of the Ecoprovince in summer is typically between Pacific and Arctic air masses, and this tends to result in frequent periods of cloud and unstable weather. This lowland area typically increases in snow accumulation, as one proceeds westward from the foothills.

1.9. Biogeoclimatic Units

Ecosystem mapping in BC, including PEM, is conducted according to a three-level hierarchy of units. The two upper levels of classification – the “Ecoregion / Ecosection Classification” and the “Biogeoclimatic Ecosystem Classification” (BEC) – together provide the broader ecological context for PEM. More locally-occurring ecosystem units are then delineated, described and mapped at finer levels.

The BEC system is a hierarchical ecosystem classification system in which units are delineated based upon an integrated treatment of climate, vegetation and site (topography). Broad Biogeoclimatic (BEC) units or zones are based on regional similarities determined under the classification system. British Columbia is divided into 14 various BEC Zones and four of these BEC Zones are found within the Muskwa - Kechika PEM study, namely the Alpine Tundra

(AT), Englemann Spruce – Subalpine Fir (ESSF), Spruce-Willow-Birch (SWB), and Boreal White and Black Spruce (BWBS) Zones (Meidinger, 1991). Characteristics of these four Zones within the Study Area are considered further in Sections 1.9.1 to 1.9.4.

Local climates within BEC Zones are somewhat variable along southern to northern gradients, from wetter coastal to drier interior situations and are also influenced by local terrain features. On this basis, they are further subdivided into Subzones and Variants. There are a total of nine Subzones / Variants within the Study Area (Table 5), since both ESSF and SWB are represented by two Subzones and the BWBS is represented by four:

- AT
- SWBmk and SWBmks
- ESSFmv4 and ESSFmvp4
- BWBSdk2, BWBSmw1, BWBSmw2 and BWBSwk2

1.9.1. Alpine Tundra (AT)

Generally, Alpine Tundra (AT) occurs above 1800 m. The climate in this Zone is cold, windy, snowy and characterised by low growing season temperatures and a very short frost-free period. Most precipitation falls as snow. By definition, the AT is treeless.

Alpine vegetation is dominated by shrubs, herbs, bryophytes, and lichens. Many areas in the AT are dominated by rock, snow and ice. Common shrubs in the Study Area are scrub birch and various willows (Pojar and Stewart 1991b).

1.9.2. Spruce Willow Birch (SWB)

The Spruce Willow Birch (SWB) Zone is the most northerly subalpine Zone in BC (Pojar and Stewart 1991a). The climate is characterised by long, cold winters and brief, cool summers. Winter cold spells can be broken by Chinook winds. Mean annual precipitation is 460 to 700 mm, with 35-60% occurring as snowfall (Meidinger and Pojar 1991). Generally open, low vigour, forests are dominated by white spruce, subalpine and lodgepole pine. Aspen and Black spruce occur occasionally at lower elevations.

SWBmk is the largest Subzone / Variant found in all four PTP Areas. In PTP Area 1, SWBmk is restricted to the northern reaches above the Half Way River. This area is affected by southern influences from the ESSF Zone that extends upwards from Williston Lake.

1.9.3. Engelmann Spruce – Subalpine Fir (ESSF)

The Engelmann Spruce – Subalpine Fir (ESSF) Zone is the uppermost forested zone in three-quarters of the interior of BC. In the Rocky Mountains, it occurs below the Alpine Tundra Zone. Growing seasons as cool and short and winters are long and cold. Most precipitation falls as snow and snow depths are deep.

The Graham Moist Very Cold ESSF (ESSFmv4) occurs primarily in the Muskwa Range of the Rocky Mountains. Climax forests are dominated by Engelmann spruce and subalpine fir. However, fire occurs more frequently in this Variant and a large proportion of stands are dominated by lodgepole pine. Mixtures of lodgepole pine and black spruce also occur on poor sites at lower elevations (DeLong et al., 1994).

1.9.4. Boreal White and Black Spruce (BWBS)

The Boreal White and Black Spruce (BWBS) zone occurs as an extension of the Great Plains (Alberta Plateau) continental climate into the northeastern corner of BC. The Zone occupies the lower elevations of the main valleys west of the northern Rocky Mountains. The climate of this Zone is characterised by short growing seasons, long, very cold winters with frequent outbursts of arctic air masses. Annual precipitation averages between 330 and 570 mm with 35-55% of this falling as snow. The ground freezes deeply for a large part of the year and discontinuous permafrost is common in the northeastern parts of the Zone. White spruce, trembling aspen, lodgepole pine, black spruce, balsam poplar, tamarack, subalpine fir and paper birch are major tree species found in the BWBS. Forest fires are frequent, maintaining most of the forests in various structural stages (Meidinger and Pojar 1991). True climax forests are largely unknown in the BWBS, as few stands have escaped fire for several hundred years (Delong et al. 1991).

The Liard BWBSdk (BWBSdk2) occupies the lower elevations of all of the major river valleys within the northern reaches of PTP Area 3, mostly below 1000m elevation. The BWBSdk2 disappears at a somewhat lower elevation within most upper drainages, since is typically under the influence of cold air ponding from the Terminus Range. The SWBmk bound upper elevations of this Subzone.

The Peace BWBSmw (BWBSmw1) is exclusive to PTP Area 1 and occupies the lower reaches of the Chowadee River below 1000m elevation. This Variant has a drier and cooler growing season, warmer and moister winter than the Fort Nelson Variant to the north. It is bounded at upper elevations by the BWBSwk2.

The Fort Nelson BWBSmw (BWBSmw2) is the largest boreal Subzone in the study and can be found in PTP Areas 2, 3 and 4. This Variant occupied the lower eastern elevational reaches of the study below 1030m elevations. This Variant is bounded at upper elevations by the SWBmk.

The Graham BWBSwk (BWBSwk2) is found exclusively in the lower elevations of the Half Way, Chowadee, and Graham River drainages in PTP Area 1. Typically it is found associated with the lower reaches of most drainages, with the exception of the Chowadee River which is bounded by the BWBSmw1. The BWBSwk is bounded in the upper elevation by BWBSwk2.

Table 5. Summary of characteristics of Biogeoclimatic Subzones / Variants within the Muskwa PEM Study Area.

BEC Zone	Subzone/ Variant	Elevation (m)	Description
BWBS	dk2 – Liard dry cool	600 to 950 *	Climax zonal forests are comprised of White Spruce with a dominantly feathermoss understory. Seral stands containing pine and aspen are very common.
BWBS	mw1 – Peace moist warm	600 to 1000 *	Zonal sites are found with a mix of White Spruce, Lodgepole Pine and Apsen is extensive throughout the Zone.
BWBS	mw2 – Fort Nelson moist warm	600 to 1030 *	Climax zonal forests are dominated by a mix of White and Black Spruce and Aspen with a strong feathermoss component in the understorey.
BWBS	wk2 – Graham wet cool	600 to 1030 *	Climax zonal forests are comprised of White Spruce with a dominantly feathermoss understory. Seral stands containing pine and aspen are very common.
ESSF	mv4 – Graham moist very cold	1000 to 1600 *	Zonal climax vegetation is a mixed overstory of Engelmann spruce and Sub-alpine fir, frequently dominated by *Rhododendron* in the understory.
SWB	mk – moist cool	800 to 1600 *	Zonal climax forests consists of mixed White Spruce and Sub-alpine fir forests, with scrub birch

BEC Zone	Subzone/ Variant	Elevation (m)	Description
			and shrub willow present in the understory.
SWB	mks – moist cool scrub	1500 to 1900*	The parkland is transitional between high elevation forest Zones and the non-forested alpine tundra Zone. Characterized by lush forb-alpine grass communities, in association with shrub willow and krummholz vegetation (mostly Sub-alpine fir).
ESSF	mvp4 – Graham moist very cold parkland	1500 to 1900*	The parkland is transitional between high elevation forest Zones and the non-forested alpine tundra Zone. Characterized by lush forb-alpine grass communities, in association with shrub willow and krummholz vegetation (mostly Sub-alpine fir).
AT	(not applicable)	Above 1800*	AT is an upper-elevation treeless area characterized by a harsh climate and a very short growing season. Zonal vegetation is dominated by lush mixed forbs and alpine grasses at lower elevations, while at higher elevations, conditions for growth are more limiting and support a less vigorous mix of sedges, dwarf shrubs, forbs and alpine grasses.

Wildlife habitat characteristics of each of the BEC Subzones / Variants in the Study Area are described further in Volume 2.

1.10. Ecosystem Units

Site series (or "ecosystem units". when they have an unassigned site series number) are the most common units used to describe ecosystems within a BEC Subzone / Variant. They are defined as the potential community of vegetation, found at late seral or climax stage on a given site. These unique vegetation assemblages characterize a relatively specific nutrient and moisture potential for each site. The nutrient and moisture potential, in turn, are determined by the examination and evaluation of a number of site parameters.

Using the most recent site series list from the provincial warehouse ftp site for approved ecosystems, ftp://ftp.env.gov.bc.ca/dist/wis/tem/mapcodes_nov2001.xls, listed a possible 245 potential ecosystem units that could be associated with the four PTP Areas. This list includes forested and non-forested ecosystems assembled from many different projects and investigations within the general vicinity of the Study Area.

A relatively small number (57) of site series have been approved by the Regional Ecologist, as ecosystem units that have an assigned number classification (ie 01, 02, 03,..). All of these are forested ecosystems. The remaining ecosystem units in the list are approved by the Regional Ecologist for mapping. Many of these, also, exist as duplicated descriptions or as a larger-scaled mapping entity than was appropriate for the current project, given the focus on units that could be mapped at a 1:50,000 level.

The final list for the Muskwa PEM consists of 121 ecosystem units, all of which are included in the original group of 245 possible ecosystem units. Some of the units in the final list were condensed from different mapping projects that used more than one convention or map codes for essentially the same ecosystem unit. A number of other aggregations were applied to wetland units and other smaller ecosystems that represented discrete areas on the landscape, and which would be difficult to differentiate from one another and map at 1:50,000. A few aggregations were conducted to conform to a generic PEM unit that existed within the provincial site series list.

The final list included 57 forested ecosystem units, 58 non-forested units that were mainly shrub or herb dominated, and 6 non-vegetated ecosystems. Ecosystem units associated with each BEC Subzone within the Study Area are described in detail in the Expanded Legend (Section 3.2).

1.11. Disturbance

Natural and human disturbance has an ongoing influence upon terrestrial ecosystems occurring throughout the Muskwa PEM Study Area. Landscape-level natural disturbances include forest fires and wildfires, effects of snow loads / snow packs, avalanches, river flooding and erosion, insect and pest damage, and a variety of other mostly localized effects.

The effects of some more pervasive disturbances, like recurring wildfire, help to perpetuate diversity of vegetation pattern, and the occurrence – across the landscape – of a mosaic of successional stages. Extensive recent burns have occurred on some larger south-facing slopes along the Cypress River within PTP Area 1 and as well Sulphur Creek within PTP Area 3, particularly within the BWBSmw2 and SWBmk. Most of these wildfires are at least two to three decades old, and extensive regeneration has occurred over time. There have also been more limited burns on north-facing slopes of the West Toad Rivers within PTP Areas 4.

Seasonal flooding and localized erosion appears to occur regularly within the wide valley bottom associated with the lower Racing and Toad Rivers. There are flat river terraces, braided channel features and occasional oxbows along the Muskwa River. In contrast, there are very narrow valley bottom in West Toad and upper Racing Rivers, and no visible signs of significant floodplains.

There are many widespread and large avalanche chutes within the Muskwa PEM Study Areas, particularly within PTP Areas 3 and 4, because of the considerable relief, steep slopes, and high snow loads. Slowly melting snow in the deposition zones at lower end of chutes typically create lush vegetation conditions that persist right into the summer. These chutes are important for a number of wildlife species, most importantly Grizzly bear.

In terms of human effects, there are limited visible signs throughout the four PTP Areas. Roads are limited in accessing a few utility corridors occur within the general vicinity. Remote guide outfitting camps are scattered throughout the MKMA and are mostly accessed by air or horseback. There are few disturbances associated with recreation and tourism activities because of the remoteness of the area, and the controlled manner of access that exists. However, winter back-country activities, particularly snowmobile use at higher elevations, may have caused some minor damage to higher elevation meadows, in particular.

Presently within the four PTP areas, some evidence of oil and gas exploration activities is visible, but it is relatively minor. There are some very limited occurrences of seismic lines in the eastern extents of PTP Areas 1 and 2. Seismic lines can create corridors for animal movement, or for winter access for snowmobiles.

2. ECOSYSTEM MAPPING METHODOLOGY

In Section 2, the project's methodology for ecosystem mapping is described. A schematic overview of the main components involved in the Muskwa PEM's methodology is provided in Figure 6.

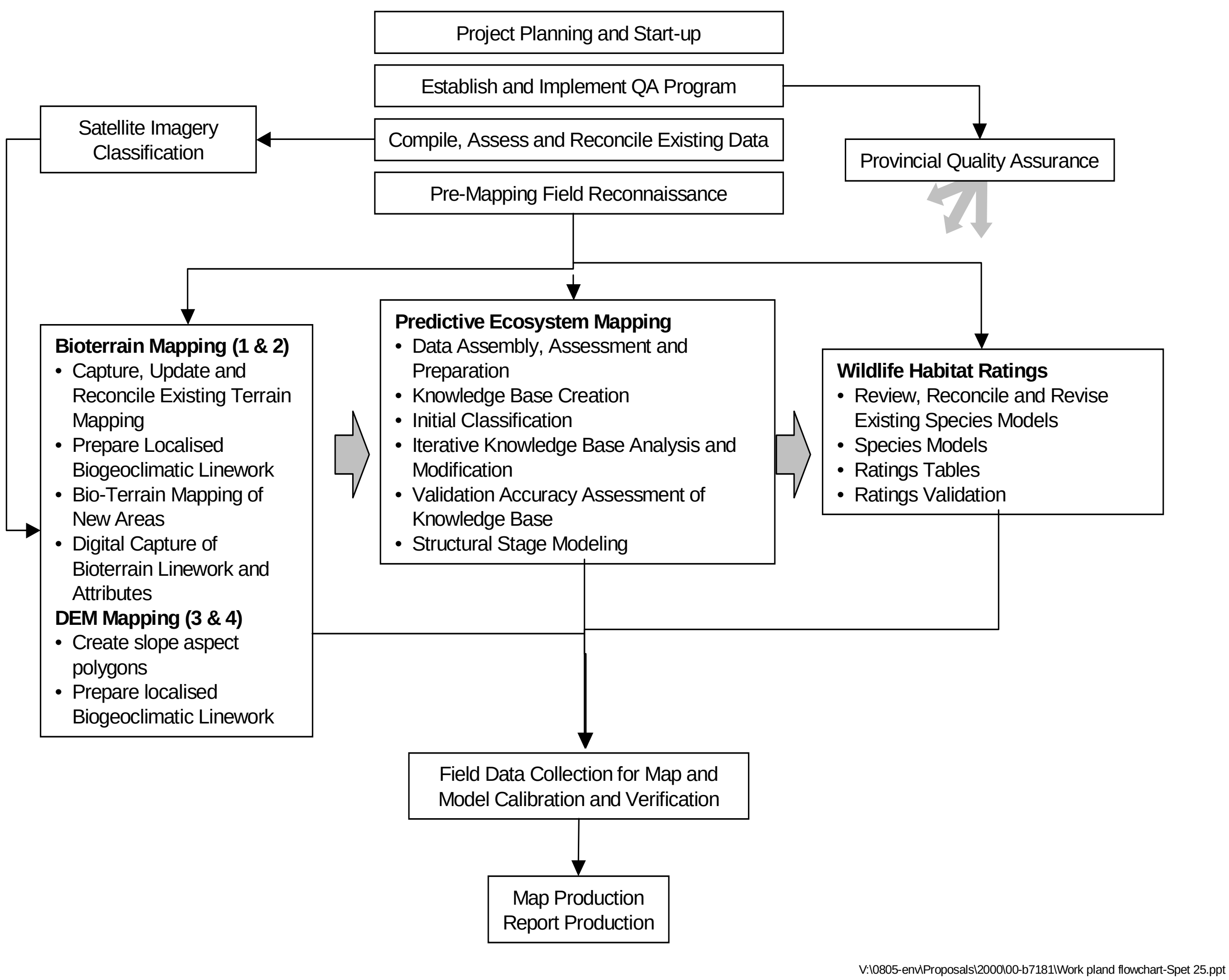

Figure 6. Main Components of the Muskwa PEM Project's Methodology.

2.1. Organization of PEM Input Databases and Knowledge Base

2.1.1. General Approach

As noted in Section 1, ecosystem mapping at 1:50,000 scale has been conducted for the Muskwa PEM Study Area. The approach follows guidelines outlined in several PEM methodology documents (e.g., Moon, 1999; RIC 2000a, 2000b) but PEM methodology is project-specific to a degree, based upon the datasets that are employed and the techniques of GIS-assisted modeling that are adapted to the task. There is no single standardized and universally accepted methodology for PEM.

The approach for the Muskwa PEM was based on EcoGEN PEM modeling software (Meidinger et al., 2000, Jones and Meidinger 2000; http://www.for.gov.bc.ca/research/ecogen/) and involved a methodology that attempted to use the most reliable and consistent data input sources that could be obtained.

Some key aspects of the Muskwa PEM's procedure are:

- There was a lack of consistent spatial coverages over the whole Study Area. This necessitated some divergence of methodology between PTP Areas 1 and 2 versus 3 and 4. Initially, EBA undertook the project with the East Slope Capability Mapping in mind as a bioterrain base and fill in holes where required. Upon examination of the mapping product, the East Slope Mapping was deemed unusable, and consequently it was not used as a primary input database. Because photo-interpreted bioterrain was already in production for most of PTP Area 1 and 2, this activity was expanded to provide complete coverage of "new bioterrain" for these areas. The PEM modeling methodology subsequently used this data layer as a central component in the modeling process.

- For PTP Areas 3 and 4, where relief was a major characteristic of the landscape, the information content of the DEM was felt to bring considerable information to the modeling process, and so – with manual derivation of a bioterrain beyond the project's scope and budget – it was decided to follow a "more automated procedure" using DEM-derived indices of slope, aspect and inferred moisture as a central component in the PEM modeling process.

- There was a need for the integration of a number of different types of spatial input data sources. A substantial effort in the Muskwa PEM project involved data assembly from many sources and past projects. EcoNGen required that all of the input databases be set up as flat file systems so that relational databases (forest cover, plot information, etc…) could be constructed. Effort was required to integrate, quality test and integrate the spatial data so that it was accurate spatially and thematically. This required a combination of GIS effort, field based data gathering, photo and image interpretation and expert opinion review and testing.

- It was recognized that classified and interpreted Landsat 7 TM imagery would serve as a valuable input data source for the PEM modeling. Satellite imagery was used as a key input data source for the PEM. Satellite remote sensing data was used to update land cover information, assist with the seamless interpretation of photo flightline information, as a secondary/confirmatory input in the overall modeling of structural stages, and as a visual backdrop for the presentation of some project results.

- Collected field data and expert opinion was a valuable aspect to help verify the PEM modeling outputs and to direct the ecosystem derivations and wildlife habitat interpretations. The PEM knowledge base and associated knowledge table for each BGC Zone / Subzone / Variant was iteratively checked and revised as new layers were added and as new PTP Areas were processed. New runs of the knowledge base were adjusted and improved, and checked against independent field data, as the modeling effort proceeded.

- The existing broad-scale (1:250,000) BCG lines were inadequate for the planned level of 1:50,000 resolution for the PEM project. As a result, new localized BCG lines had to be prepared early in the project, so that they could serve as a main stratifier for the PEM modeling activity. The newer localized BGC lines were developed in conjunction with MoF Research Branch staff (Marvin Eng and Del Meidinger) using approaches and tools developed by MoF (REF). The new BCG lines also incorporated newly described Subzones associated with the SWBmks (a scrub Subzone that is analogous to parkland).

- An iterative approach to generation of the PEM outputs was a critical part of the PEM modeling methodology. A small pilot area was delineated early in the project, and this representative area – located within PTP Area 2 – was used to first test each step of the process, so that computational time was not wasted as various PEM inputs were integrated in a number of different ways to determine an optimum methodology. After the pilot area studies had provided some information on a possible best approach, only then was it applied to the larger PTP Areas. When applied over the more extensive landbase, there were still numerous instances where additional iteration was required, to fine tune or adjust parameter effects upon the range of conditions that existed throughout the four PTP Areas.

- The EcoGen PEM modeling tool (www.for.gov.bc.ca/research/ecogen/ , see also Meidinger and Jones 2001, Jones et al. 2001) was used to develop the knowledge base and apply it to the spatial data that was assembled for the Muskwa PEM project. EcoGen was developed by the MoF Research Branch and has been successfully used in several PEM projects as the means of incorporating ecological relationships so that PEM outputs can be created.

- Additional tools were developed in-house to assist the process of iteratively validating and testing the accuracy of the Knowledge Base. These tools were created in various forms, including ArcInfo AMLs, Arcview procedures, Visual Basic programs, Access and Excel formulae, and ER Mapper routines. They were developed to speed up processes and overall, improve the quality and accuracy of Muskwa PEM outputs.

2.1.2. Input Data Quality

EBA recognized that there was a range of quality involved in the various databases and information sources used in the Muskwa PEM. Because of the northerly location of the project area, its considerable size, and the limited numbers of past projects within and around the general area, the approach for the PEM modeling required that all available and useful data and information from past studies be incorporated into the project whenever possible. While many of the critical input data sources were considered important for the PEM modeling, none of them were originally collected or assembled with such a rigorous spatial application in mind.

In some cases, there was considerable effort required by the project team to bring data up to a level where it could be imported or adapted, and then used effectively. As outlined in EBA's Input Data Report (EBA 2001b), it was important to undertake a proper review of inputs be documented for reliability and quality, in order to ensure that the inputs were best suited for the task (Moon 1999a, 1999b; Sims and Matheson 1999, 2000). The provincial PEM standards (RIC 2000a, 2000b) outline that input data must be considered in terms of a range of criteria, and that this process should guide their use in PEM modeling. There is also a "PEM meta-data capture tool" that is currently under development by MELP (T. Gunning, MELP, pers. comm.) which should further help in the "screening in" of candidate datasets for use in provincial PEMs.

In the data compilation, assessment and review process outlined in Muskwa PEM's Work Plan (EBA 2001a) and Input Data Report (EBA 2001b), the data were assigned among three categories, based upon the project team's assessment of each dataset's potential level of input into the Muskwa PEM:

1. *Primary Data Sources* are directly involved in the PEM process as outlined under the PEM standards (RIC 2000a). Primary data sources are of principle concern in terms of the Muskwa PEM's overall content and quality.

2. *Secondary Data Sources* are not directly used in the knowledge tables, modeling or map production, but they provide data and information that is of direct relevance to the PEM modeling, and/or they are used directly to support key decisions regarding the ways that primary data sources are handled.

3. *Tertiary Data Sources* are supplementary to the project, and typically involve project materials that are from adjacent or nearby geographies or which are regional in scale. While they don't provide directly useable inputs for the Muskwa PEM, they still represent important contextual or regional data, or information of significant general relevance to the project.

The project's data tracking list (Appendix B) provides an overall summary of all datasets and information sources that have been identified-to-date for the Muskwa PEM. The tracking table includes a ranking (Primary, Secondary, Tertiary) for each data source that relates to the anticipated level of use it will receive in the PEM modeling.

As the work proceeds, the tracking list (Appendix B) will be regularly updated. The ranking for individual data sources is subject to change, as the PEM modeling process dictates.

2.1.3. Primary Data Sources

There were 12 primary input data sources currently identified for the Muskwa PEM project (Table 6). As already noted, primary data sources are those key information sources that directly contribute either linework (e.g., existing or new bioterrain mapping, forest cover mapping) or key frameworking concepts for the attribution of polygon contents (e.g., the provincial BCG site series list).

Two of the Muskwa PEM's primary data sources (Table 6: Items 1, 2) serve to establish the overall base-mapping and principal cartographic extents for the Muskwa PEM project. Three other primary data sources (Items 3, 4, 5) are required to accurately define the physical extents of the four PTP areas. Two primary data sources (Items 6, 7) define the basis for mapping entities, while two others (Items 8, 9) are directly involved in the definition of map entities. Four primary sources (Items 1, 2 10, 13) are involved in creating the fundamental polygon attribution within the PTPs.

There are a variety of attributes associated with each of the primary data sources. Selected attributes were used to populate the Muskwa PEM models. Table 7 summarizes, for a range of selected attributes, the "relative" overall quality / reliability we encountered with each attribute.

Attributes that were expected to have a higher overall quality / reliability (Table 8) were selected for PEM analyses. For example, surficial materials are attributes that are contained in the East Slope, Dunedin TEM and New Bioterrain primary data sources, but the latter two sources were considered to be of considerably higher overall quality / reliability. For the geographic extents that these latter sources cover, the Muskwa PEM analyses used these higher quality data.

As already noted, the East Slope mapping was not used as a primary data source. The East Slope mapping outputs were subjected to a quality review process that found many apparent inaccuracies, incomplete polygon linework, un-attributed polygons, and several other types of errors. Because the original typed photographs could not be located, the data shortcomings could not be corrected nor could an independent quality assessment procedure be applied to determine project-level quality. The original basemapping for the East Slope outputs was also NAD27 National Topographic Series mapping and without the photos to assist with the transfer of the linework to a new base, or for any alternative photo to map transfer, there were additional concerns regarding positional accuracy.

Table 6. Primary data sources for the Muskwa PEM Project.

ITEM NO.	NAME	DESCRIPTION	FORMAT	COVERAGE	REFERENCE [5]	DEPT [6]	SCALE [7]	COMP. DATE [8]
1	TRIM	Provincial base maps	Digital	Complete	TRIM published specifications	Land Data BC	1:20 000	1995
2	DEM	Gridded Digital Elevation Model, 25m resolution	Digital	Complete	GRIDDED DEM published specifications	Land Data BC	1:20 000	1995?
3	MKMA Boundaries	Project Area Boundaries for the MKMA	Digital	Complete	N/A	LUCO	1:20 000	2001
4	Pre-Tenure Plan Lines	Pre-Tenure Planning Boundaries	Digital	Complete	N/A	OGC	1:20 000	2000
5	Protected Areas Boundaries	Legal boundaries for northern parks	Digital	Complete	?	LUCO	1:20 000	2001
6	Localized BGC Linework	Provincial calibrated BGC linework	Digital	Complete	Eng and Meidinger 1999 http://www.for.gov.bc.ca/research/TEMalt/bigbec.pdf	MoF	1:20 000	2002
7	Forest Cover	Forest Coverage Mapsheets	Digital	Complete	Ministry of Forests, Resources Inventory Branch, Inventory Manual, Forest Classification	MoF	1:20 000	1997?
8	Site Series	Current Provincial List of Site Series	Digital	Complete	http://www.elp.gov.bc.ca/rib/wis/tem/provincial.htm	MELP	N/A	2001
9	Wetland Units	WREC standards	Digital	Complete	RIC standards	MoF	N/A	

ITEM NO.	NAME	DESCRIPTION	FORMAT	COVERAGE	REFERENCE [5]	DEPT [6]	SCALE [7]	COMP. DATE [8]
10	New Bioterrain	Bioterrain photo-typing, conducted to fill in portions of the Muskwa PEM project area	Digital	Complete	EBA Engineering, following RIC (1998, 2000a, 2000b) standards for PEM data capture	EBA-compilation, OGC-custodian	1:50 000	2001
11	Dunedin TEM	Complete files on Dunedin TEM	Digital	Partial study	RIC (1998) TEM data capture standards http://www.elp.gov.bc.ca/rib/wis/tem	MELP	1:50 000	1999
13	Satellite Imagery	Landsat 7 (multispectral) satellite images, dated 1999 and 2000	Digital	Complete	Published federal standards (CCRS) for satellite data preprocessing and preparation (Radarsat International Inc.)	EBA / MEM	~20m pixels	1999, 2000

Table 7. Attributes associated with input data sources for the Muskwa PEM Project.

Attribute	East Slope Capability	Dunedin TEM	MK- PEM New Bioterrain	Forest Cover	Satellite Imagery	Localized BGC Linework	TRIM
Surficial materials	L	H	H	Nil	?	-	-
Surficial expression	L	H	H	-	?	-	(M)[1]
Drainage	L	M	M	-	?	-	-
Geomorphological Process	-	H	H	-	?	-	-
Slope Position	L	-	H	-	-	H	?
Slope Gradient	L	L	H	Nil	-	-	H
Aspect	L	-	H	Nil	-	-	H
Tree species	-	-	-	M	(L)[2]	-	-
Tree species percent	-	-	-	L	(L)[2]	-	-
Crown Closure	-	-	-	M	(L)[2]	-	-
Non-forest descriptor	-	-	-	L	(L-M)[2]	-	-
Non-productive descriptor	-	-	(H)[3]	M	(M)[2]	-	(M)[3]
Stand age	-	-	-	M	(L)[2]	-	-
Stand height	-	-	-	M	(L)[2]	-	-
Stems per hectare	-	-	-	M	-	-	-
BGC Subzone	L	H	-	L	-	M	-

L, M, H, ? – Low, Moderate, High, Unknown.
[1] Only a portion of the expressions listed in Howes and Kenk (1997) can be derived from this database.
[2] To be determined, pending completion of the satellite analyses; anticipate that only limited classes of certain attributes (e.g., coniferous, mixed, deciduous classes for forested conditions) may be possible.
[3] On-site symbols and water features (e.g., swamp).

2.1.4. Secondary Data Sources

There were 83 additional data sources that were considered as "secondary" in that they were important contributors of information to the Muskwa PEM, but not fundamental in defining polygon boundaries or attributes. A list of these attributes is provided in Appendix A.

Approximately 6,000 ground plots from previous field studies in and around the Muskwa PEM project area have been identified (Table 9). These ground plot data was used to verify BCG line placement that was produced by the localisation process. Plot data was used to "ground-truth" polygon linework and attributing throughout the Muskwa PEM. Existing plot data was also used to help satellite image analysis work, the checking of photo-interpretation characters for bioterrain mapping, and spot-checking of the quality of other input data sources.

Table 8. Notes regarding input data quality of individual attributes for the Muskwa PEM Project.

PROJECT	ATTRIBUTE	NOTES REGARDING DATA QUALITY
East Slope Capability Mapping	General	• Project was completed in 1992 under broader standards and conventions presently in place • NTS basemap was used, so there are mismatches introduced when shifted to a TRIM base • Broad scale, and precision and accuracy are lower • Unfortunately, the air photos with original linework are missing, so cross-checks and updates are significantly hampered by this • Some lines incomplete, some polygon contents unlabeled, lack of overall QA and questions re consistency across the whole of the project area (work completed by 3 different contractors and there appear to be some differences among areas in terms of detail, completeness, etc...)
	Surficial Material	• Complex mapping entities (i.e., C represents Cb, Cv or Cbv) • Large polygons, with generalized labels
	Surficial Expression	• Built into complex mapping entity as previous example
	Drainage	• Not directly associated to polygon, broad range inferred in mapping entity
	Slope Position	• Size of polygons large • Position is annotated, but accuracy is unknown
	Slope Gradient	• Size of polygons are large • Mapped gradients are very generalized, accuracy unknown
	Aspect	• Large polygons with various aspects • Aspects, slope positions and gradients all based on NTS contours, so they are generalized and are not in sync with TRIM contours / DEM
	BGC	• Poor quality hard copy maps, based on a transfer process (unknown) that was not highly accurate • Lines are discontinuous in portions of mapsheets, and are not digital

PROJECT	ATTRIBUTE	NOTES REGARDING DATA QUALITY
Dunedin TEM	Surficial material Surficial Expression Geomorphology	• Mapped to newer TEM standards under current TEM provincial QA processes • Some inconsistencies observed with wrong site series in some BCG Subzones so some concern regarding accuracy; more investigation required • Date of photos older, quality of original airphotos not ideal, scale of photos 1:50K to 1:60K
	Drainage	• Difficult to determine from photo interpretation • Associated with polygon, and not with individual attributes within complex polygon
	Slope Gradient	• Few modifiers used in project • Some concerns regarding the consistency of use of modifiers within the project
	BGC	• Good accuracy on a local scale, tied to TRIM and suitable for checking the localised BCG • BCG lines generally follow polygon borders (not vice versa) and so are not smoothed as in some TEM projects • Overall context with regional BCG conditions may not be complete
Besa-Prophet TEM	Surficial Materials Surficial Expression Geomorphology Slope Position Slope Gradient Aspect	• Mapped to newer TEM standards under current TEM provincial QA processes • Orthorectified process may have resulted in possibly higher spatial accuracy • Some inconsistencies observed with wrong site series in some BCG Subzones so some concern regarding accuracy; more investigation required • Date of photos older, quality of original airphotos not ideal, scale of photos 1:50K to 1:60K, however satellite image data were used to help update the mapping
	Drainage	• Difficult to determine from photo interpretation • Associated with polygon, and not with individual attributes within complex polygon
	Non-Productive Descriptor	• On site symbols are included for swamp, cliff, etc… • Consistency of use of modifiers within the project unknown

Table 9. Existing ground plots for the Muskwa PEM Project.

Source	#'s	PTP-1	PTP-2	PTP-3	PTP-4	Current Status for PEM Input	Year Obtained
Besa TEM	482	0	0	0	0	Complete	1998
Dunedin TEM	951	0	0	350	0	Complete	1998
East Slope[1]	272	0	?	?	?	Incomplete	1991
Akie TEM	3192	0	0	0	0	Complete	1997
NE Burn TEM	114	0	5	0	0	Complete	1995
Smith-Vents TEM	828	0	0	0	0	Complete	1996
Mackenzie Wetlands (TEM)	56	0	0	0	0	Complete	1997
Liard Hotsprings TEM	100	0	0	0	0	Incomplete	1996
Range	9	2	0	0	0	complete	?
Total No. of Plots	6004						

[1] Digital transfer of the plot data from the East Slope mapping project (Anon. 1992) is not yet completed, and total numbers per PTP area are not yet calculated (the majority of the East Slope plots are outside the Muskwa PEM project area, but within the immediate vicinity).

2.1.5. Tertiary Data Sources

Some 35 additional sources of information (including data from adjacent areas, regional level mapping, etc…) were also identified as part of the initial information gathering activity for the Muskwa PEM project. These various sources of information were consulted and used to generally provide background context for the project, but were not used directly in the PEM modeling (Appendix A).

2.2. GIS-Based Modeling and Integration

As noted earlier, PEM involves the integration of many input databases, using a standardized modeling procedure. In the previous section (Section 2.1), the key input data layers and their overall quality for the Muskwa PEM were generally discussed. A subsequent task was to regenerate these individual inputs within a common layer (i.e., a “flat file”) so that the information was available for EcoNGen to use as input. This was a critical step for the GIS modeling and integration process.

Each input layer was linked to an established base layer. The base layer was established as the fundamental set of polygon building blocks upon which the PEM mapping would be based. For example, for PTP Areas 1 and 2, the photo-interpreted bioterrain mapping was established as the base layer. For PTP Areas 3 and 4,following a review of all available input databases and an evaluation of their overall quality, the base layer was created from a coverage of slope/aspect derivative polygons that were themselves derived from DEM input data.

The process involved in the preparation of individual input data layers is described below. The use of these layers followed a step-wise process, whereby selected data from a range of input data layers could be attributed and tagged to the base layer.

The PEM model construction is described in detail in Section 2.6.1, but involved a selection procedure that was closely tied to the project’s internal quality assurance. This selection procedure was an iterative one, where data was selected, and then tested in terms of it effect upon the information content of the evolving PEM map. Each step of testing included an evaluation of the suitable stage of introduction of each data element. If this evaluation indicated that a suitable information contribution was made, the data was accepted as a data contributor to the model and it was incorporated into the PEM algorithm.

PEM analyses were based upon data from the input data layers described in the following sections (Section 2.2.1 to 2.2.6).

2.2.1. Bioterrain

Initial preparation of this layer was minimal since this was the established base layer for input in PTP Areas 1 and 2. Following RIC (1998a, b) standards, bioterrain was completed as a photo interpretation procedure. Digital capture and photo to map transfer was also carried out in accordance with RIC (1998b, 2000a, b) standards. TEM conventions for bioterrain were followed (RIC 1998a, b).

Based upon discussions that were held among the Muskwa PEM mappers, and provincial correlation and MEM staff during project planning stages, it was decided that two modifications would be made to the conventional bioterrain mapping approach. These involved some additional effort for the photo-interpreters, but it was felt that the information content was important to obtain as a PEM model input.

- Two user-defined attributes related to drainage and aspect determination were created and filled in as the work was conducted. As the photo-interpretation proceeded, each bioterrain decile within a polygon was assigned to a drainage class and final ecosystem aspect modifier was derived for the polygon.

2.2.2. Satellite

LANDSAT Satellite imagery was obtained and used for the Muskwa PEM project, to provide critical information on land cover features. The analytical methodology used to process and interpret the imagery is outlined in Section 2.3.

To prepare the imagery for use within the PEM modelling, it was necessary to convert the classified raster data to vector format. Raster imagery could not be used directly within EcoGEN and in conjunction with bioterrain coverages that were stored in vector mode.

A raster to grid conversion was conducted on the interpreted satellite image data. Using a filter over each PTP Area (and allowing for an edge overlap buffer area), the raster to vector conversion was conducted, holding the original classification assignment within each rasterized polygon. This created a large but unaltered / filtered set of polygons. As an example, PTP Area 4 contained over 6 million polygons that were on average about 0.2 ha in size. Once converted to vector mode, these polygons were further processed using a dissolve process to merge similar adjoining classified polygons into larger more manageable units.

Due to the resulting size of the converted satellite image databases, each PTP Area was classified and handled for processing separately.

2.2.3. Forest Cover

Provincial 1:20,000 forest cover maps files were provided by MSRM for use in the Muskwa PEM project. Forest cover mapping was provided on a tiled (per TRIM mapsheet) basis, with separate non-spatial data (i.e., layers and history) included as a large flat file. Most of the forest cover maps dated from 1997, and so there were some limitations to the data source (as discussed in the Input data Quality evaluations (EBA 2001a) The forest cover mapping did, however, contain key information on forest cover features, dominant forest tree species and other key pieces of information that were considered to be very important for the PEM modeling.

When the mapsheets were aggregated into an overall seamless coverage for use in the project, there were numerous inconsistencies that arose due to poor edge matching of the original data. Repairs and corrections, to eliminate these problems, were undertaken on a mapsheet by mapsheet basis. As the work continued, these mis-matches were individually resolved and eliminated from the database.

Forest cover attributes deemed suitable for use in the PEM process were then selected and tested using an internal quality assurance procedure. Selection was based on two important criteria of reliability and consistency based on field plots. The tree species proved to be the best attribute from forest cover as an indicator of presence. Tree heights, age, crown closure, non-productive attributes were selected but deemed limited in meeting the criteria. Selected attributes that were selected for use were then imported into EcoNGen and used in the PEM modeling.

2.2.4. DEM

TRIM-based Digital Elevation Model (DEM) data on a 25 m grid provided spatial data for several key inputs to the PEM modeling process. For all PTP Areas, the initial data quality assessment conducted by EBA showed that the DEM provided considerable information content with respect to slope, aspect and moisture (Sections 2.2.4.1 to 2.2.4.3). As well, it was recognized that the DEM was a key spatial database for completing the Biogeoclimatic (BCG) line localization activity (Section 2.2.5).

- The DEM involved some large data blocks and represented some considerable processing requirements. Seamless DEM blocks were prepared from input TRIM data (1:20,000 scale) for the four PTP Areas. To minimize edge effects during the processing of individual PTP Areas, sub-blocks were prepared that included a 1 to 5 km buffer around the periphery of the each PTP Area. The four DEM "grids" were then assembled so that slope, aspect and moisture analyses could be undertaken (as outlined in the following sections).

2.2.4.1. Slope

Slope was calculated for each DEM grid for all PTP Areas. The grid point calculations per PTP Area numbered upwards of 6 million points. Using a similar approach to that followed for the rasterized satellite data, the grid-point coverage was converted to vectors for each PTP Area.

The slope class calculations were developed in consultation with local wildlife ecologists and MEM contacts. In particular, to help identify high quality sheep and mountain goat habitat, it was determined that steeper slope classes than those normally captured using RIC (1998a, b) TEM slope classes were desirable.

As a result, in addition to the slope class of w and k (excluding the aspect portions), steeper q and z classes were also defined, and these were further subdivided into 10 degree increments (also excluding aspect portion). These user-defined classes were delineated during the slope derivation work, and the new user-defined classes were labelled as:

- z (46 to 55 degrees)
- z1 (56 to 65 degrees)
- z2 (66 to 75 degrees)
- z3 (76 to 85 degrees) and,
- z4 (greater than 86 degrees).

Once thsee initial vectorized slope grids were derived, as outlined above, a GIS based "dissolve process" was conducted to combine all adjoining polygons of identical slope class. The resultant slope vector map was used as an initial basis for slope in the PEM modeling.

Subsequent pilot area testing, however, indicated that the slope coverage produced in this way resulted in polygons input layer produced polygons that were unnecessarily small and numerous for the PEM modelling. To remedy this, an additional processing step was carried out to collapse polygons and filter out "noisy" small polygons that were less than 25 ha in size. This effectively eliminated many small polygons, while at the same time maintaining the overall integrity of the slope derivation process. Over much of the PTP Areas, smoother polygon units that were ultimately more intuitive were obtained with the dissolve process.

It was necessary to complete one additional round of revisions, however. While the dissolve process improved the overall slope interpretation, the steeper upper slopes tended to become over generalized. At this point, the process was reversed somewhat, some additional rulesets were developed, and the sequence of dissolves was changed so that a “top down” process was applied over the landscape to determine slope class, with steepest slopes removed first.

Two conclusions were drawn:

1. Steeper slope classes were small in size averaging less than 5 ha. and a 25 ha tolerance for a polygon dissolve effectively over generalizes the gentler slopes at the upper elevations.

2. A “top down” sequencing of the slope class calculation was needed in conjunction to the lower size tolerances for steeper slopes. This sequencing procedure preserved the smaller steep slope class of polygons while amalgamating the gentler slopes into larger polygons.

PTP Areas 1 and 2 slopes were assigned using by dropping the derived slope mapping, as described above, onto the polygon linework for bioterrain. Slopes were determined based upon the predominant slope class, calculated on a percent area basis, within each bioterrain polygon.

2.2.4.2. Aspect

For aspect, the DEM data was processed within a GIS, in a similar derivation process to that described above for slope. As for slope, the DEM grid was used, with its 1 to 5km buffer around the perimeter of each PTP Area, in order to eliminate any edge effects.

Aspect was assigned to either warm (136^o to 285^o) or cool (286^o to 135^o), in accordance with RIC (1998a, b) standards for ecosystem mapping. As was done for slope, a dissolve process was undertaken to combine vector polygons into larger coherent units. Because only a 2-class map was being produced, it was not necessary to test different sequences of dissolves, as was required for slope, but it was necessary to test several different minimum sizes so that the dissolve process was done in an optimal manner. In particular for PTP Areas 3 and 4, where topographic relief was more pronounced, several iterations were done to determine minimum size tolerances. The optimal minimal size, for PTP Areas 3 and 4, was determined to be 20 ha. Aspect was calculated in PTP Areas 1 and 2 as slope by dropping the derived aspect values into the bioterrain polygons as a percent area basis.

The subsequent steps to create base polygons in PTP Areas 3 and 4 was to combined the final slope and aspect layers, as described in Section 2.7. (Data Assembly). PTP Areas 1 and 2 slope and aspect layers were calculated directly into the bioterrain base layer and was considered complete.

2.2.4.3. Moisture

In BC's BEC system, nutrient and moisture regimes are two main ecological gradients that are used to position site series in relation to one another within a given BEC Subzone / Variant (Anon 1990). Calculation of moisture ranges provides information in the PEM modelling to narrow the focus of most likely ecosystems.

A GIS modelling tool for the derivation of soil moisture was recently developed as part of SINMAP (Pack et al. 1998a, b, 2001; also see http://moose.cee.usu.edu/sinmap/sinmap.htm). SINMAP is a GIS-based and automated spatial tool for the derivation of slope instability ratings for a geographic area. It uses DEM-based grided data as input, and as part of the modelling process that it conducts, there is an automated procedure for defining soil moisture on the basis of topographic input data.

For the Muskwa PEM, four moisture classes – wet, moist, fresh and dry – were derived. It was determined that this 4-class moisture assignment was appropriate for the Muskwa PEM's level of resolution and input data quality. As described in Section 2.6.1, the choice of only four moisture classes also served to focus the EcoGEN process towards a few most likely ecosystem choices on a given edatopic grid, thus limiting the amount of lumping and combining that was required during that part of the processing

The initial output for the moisture spatial interpretation was a raster grid similar to slope and aspect. This grid was subsequently converted to vectors and dissolved into the four moisture classes. No further processing was required until the moisture layer was incorporated into the base layers, as described in the Data Assembly section (Section 2.6.1).

2.2.5. Localised BGC

The Biogeoclimatic (BCG) linework that defines the position of BEC boundaries is a fundamental input layer for PEM. For EcoGEN to proceed through its analyses, for example, BCG linework is needed as an initial input. Previously-existing BGC lines for the Study Area were derived at a smaller resolution than the final mapping product so they were of insufficient resolution for the current project.

To remedy this, EBA worked with MoF Research Branch staff to derive new localised BGC lines for the Muskwa PEM general area. To establish the regional patterns properly, the BCG linework was generated for an area that was considerably larger than the four PTP Areas.

An initial knowledge base was created by EBA and provided to MoF in early 2001, using the surrounding previous TEM projects as elevation guides for the newer localised lines. Original field-annotated BGC maps were also provided by Del Meidinger, who had aerial truthed the BCG line locations several years earlier. These field maps provided some valuable spot confirmations of the positions of BCG boundaries, for example, along several valley walls within the Study Area.

The first draft linework for new localised BGC lines was prepared by MoF Research Branch staff in June 2001, so that it could be carried into the field by crews, as they completed the project's field work. After the field session, several adjustments and minor improvements were identified to MoF so that a second iteration of the linework could be prepared. This was carried out, and final localized BCG lines were completed for the Study Area and surroundings in February, 2002.

Some minor shortcomings were identified with the February 2002 linework, even though there had been a few iterations. Along the Alpine – Parkland boundary there were some areas that required adjustment but, because of timing issues, the adjustments were completed within the PTP Areas by EBA using a manual approach.

2.2.6. TRIM

TRIM water features were extracted and used in the PEM map generation, so that water features conformed to standard basemapping conventions in TRIM. This step followed RIC standard for water feature inclusion in PEM products (RIC 2000a, b). Extracted features included all double-banked rivers and lakes that existed within TRIM.

Glaciers from TRIM were also used in conjunction with the satellite image classification to confirm the presence and spatial extent of perennial ice. This procedure supported satellite classification distinctions between early seasonal snow and ice.

2.3. Satellite Image Analysis

2.3.1. Preprocessing

Landsat 7 ETM imagery was obtained and prepared for the entire MKMA in early 2001 from Radarsat International (Figure 7). Images were initially examined using remote sensing analytical software (ER Mapper®). General characteristics of the 4 images are summarized in Table 10.

Using provincial standards (cf., Graeme Weir, Remote Sensing Specialist, MoF, pers. comm.), all four scenes were orthorectified using a TRIM-based DEM assembled by EBA The seamless DEM coverage was prepared with a 25m ground cell and TRIM vectors of water features and roads.

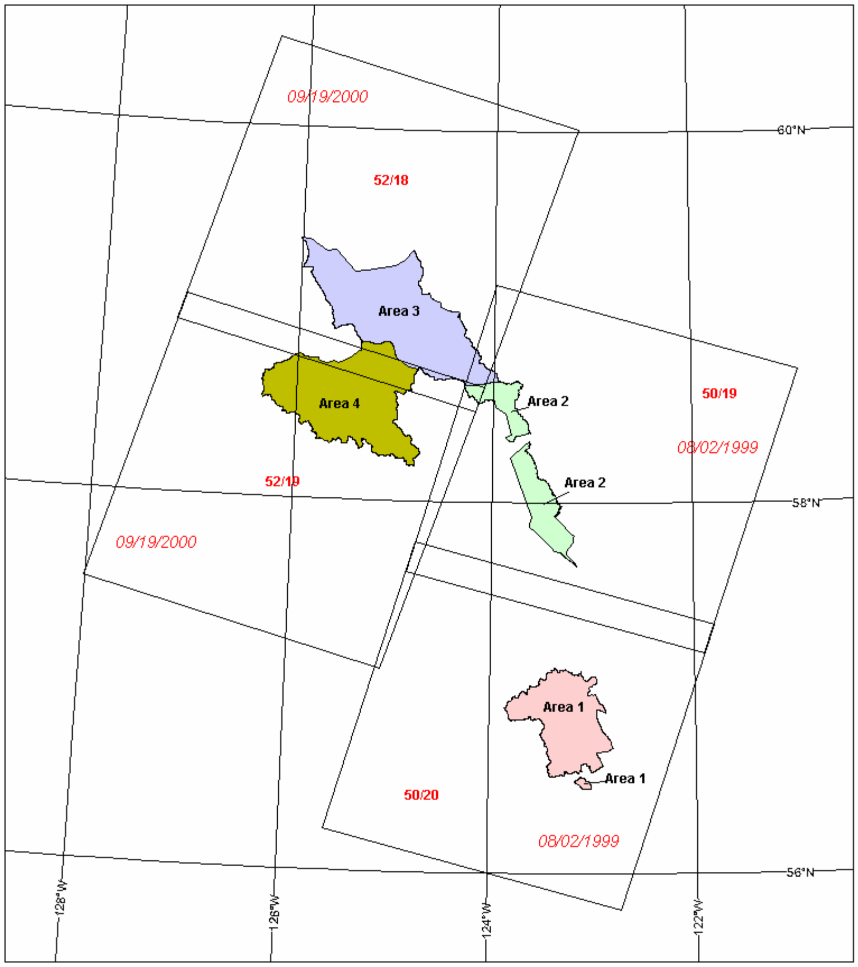

Figure 7. Extents of four Landsat 7 ETM scenes used in Muskwa PEM, overlain on four PTP Area.

Table 10. Landsat 7 ETM imagery used in The Muskwa PEM project.

Path/Row	Acquisition Date	Notes
50/19	August 2, 1999	excellent scene, little or no cloud
50/20	August 2, 1999	excellent scene, little or no cloud
52/18	September 19, 2000	some cloud, haze in north section
52/19	August 2, 1999	extensive thin cloud in south

The images were then cut to the PTP Area boundaries, but with the addition of a 1 km buffer around the perimeter of each to eliminate edge effects in the analyses. All image data outside of each PTP Area was “nulled”, by setting all pixel values to zero. This ensures the subsequent classification pertains only to the area in question.

Imagery was appropriately mosaicked, where PTP Areas extended across imagery. PTP Area 1 was found entirely from the August 2, 1999 scene, 50/20 shown in Figure 8. Satellite August 2, 1999 scene 50/19 includes all of PTP Area 2 and a southern portion of PTP Area 3 is shown in Figure 9. PTP Area 3, shown in Figure 10, was cut from the September 19, 2000 scene, 52/18. The southeast corner of Area 3, that lying outside scene 52/18, is not included in the image subset as it was included in the Area 2 image subset. PTP Area 4, shown in Figure 11, was mosaicked from the September 19, 2000 scenes, 52/18 and 52/19. No complicating factors were encountered during the procedure to assemble and process the images.

In Figure 8, the false color composite of bands 5, 4, and 3 (RGB) displayed the following features:

- cyan - light blue represents ice and snow
- deep purple represents rock (bedrock, talus, bare soil)
- dark green represents coniferous forest
- light bright green represents deciduous growth and,
- the strong red tones represent additional rock and soil varieties.

Prior to classification a simple haze correction, known as dark object subtraction, for each scene that was applied after orthorectification and summerized in Table 11. The DN (digital numbers) indicated were determined by plotting the DN's of band 7 (Y axis) vs. each of bands 1 to 5 (X axis) and picking the X intercept of a straight line passing though the DN scatterplot.

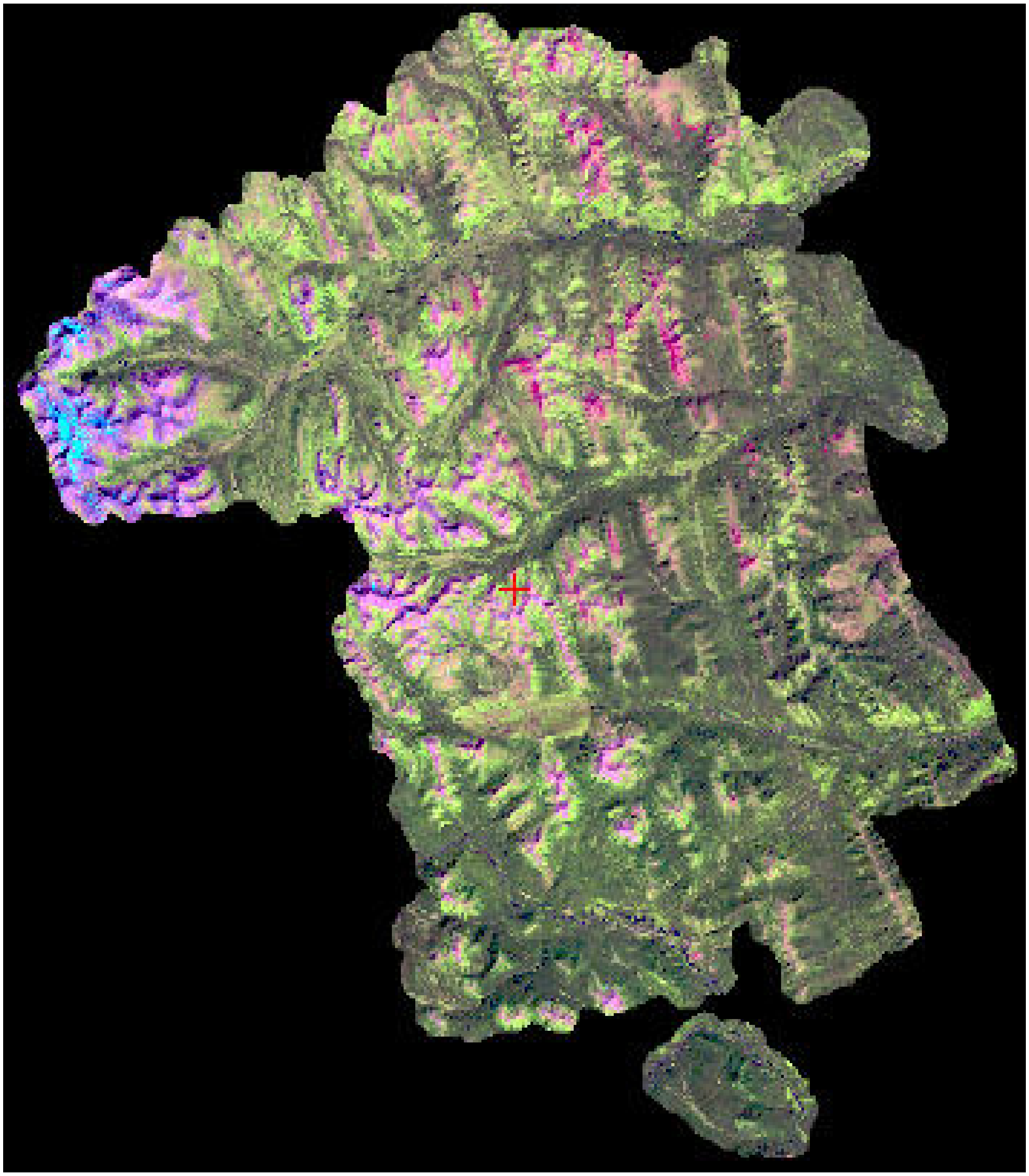

Figure 8. PTP Area 1. Composite of bands 5, 4, 3 (RGB) with a 1 km buffer and associated null values on outlying portions of the grid

Figure 9. PTP Area 2, includes southeast corner of Area 3.

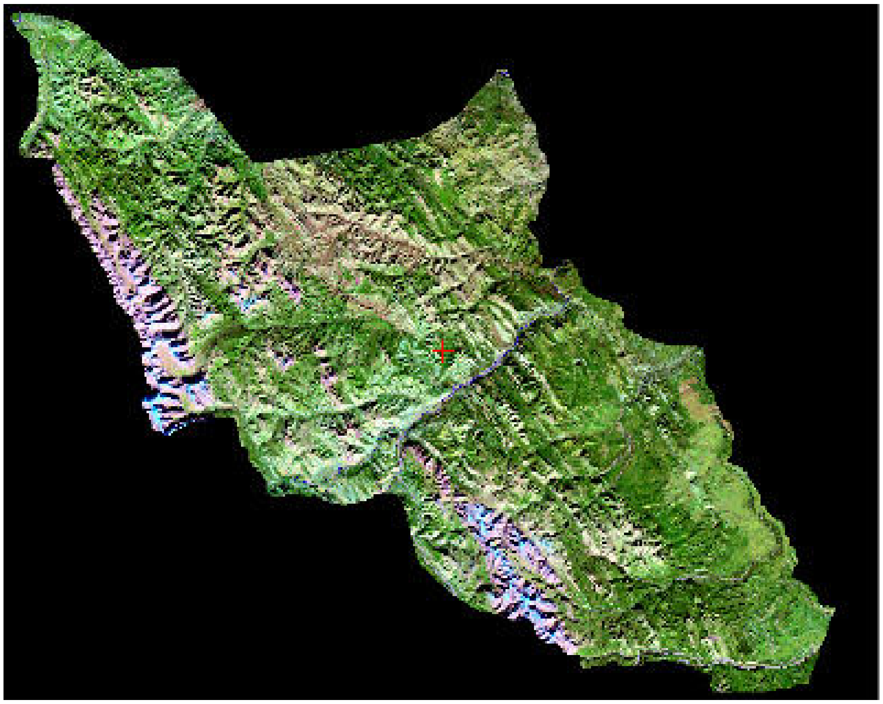

Figure 10. PTP Area on 3 scene 52/18, without southeast corner included on previous image for PTP Area 2.

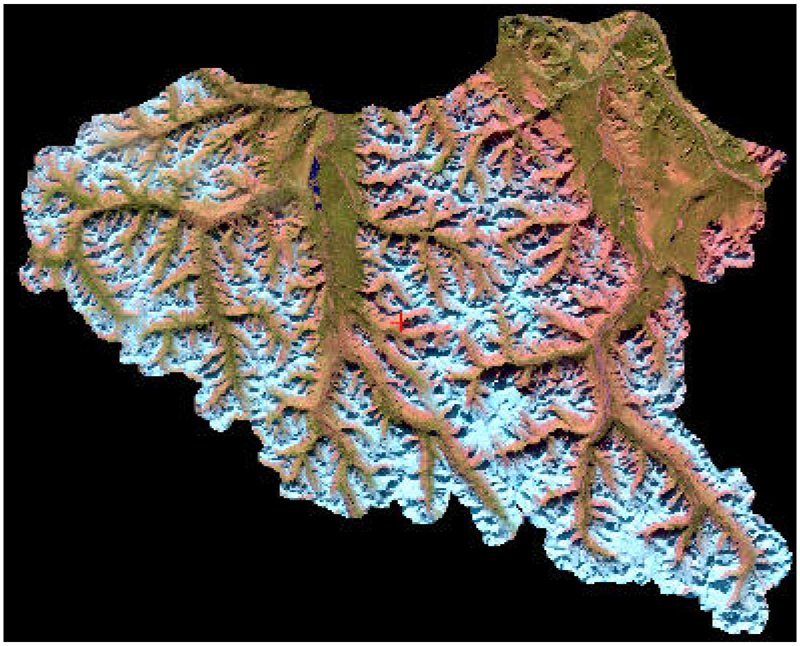

Figure 11. PTP Area 4 mosaicked from the September 19, 2000 scenes, 52/18 and 52/19.

Table 11. Summarizes simple corrective DN haze subtraction.

	Subtractive DN haze correction					
Path/Row	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
50/19	-44	-20	-12	-1	0	0
50/20	-43	-21	-13	-1	0	0
52/18	-37	-18	-9	-5	0	0
52/19	-37	-18	-9	-5	0	0

2.3.2. Image Classification

The goal of the Landsat ETM classification work was determined after pre-processing and test classifications were conducted within different parts of the imagery datasets. The following main cover classes were focused upon, to create a final useful input database to the PEM process:
Main cover classes were:

- ice and snow
- rock
- water
- shrub (leafed and/or coniferous
- herb (meadows)
- forested (leafed and/or coniferous)
- grass
- wetlands or bogs

Unsupervised classification techniques were chosen due to lack of sufficient knowledge as to the vegetation species present and their location. It was considered that an unsupervised classification could distinguish the general vegetative types.

The Landsat sensor record reflectance over a ground cell or pixel of 30 x 30 meters. The reflectance returned to the sensor is the average value of all the cover types occupying a ground cell.

The basic approach of the unsupervised technique for the Muskwa PEM was to first identify the clearly separable or distinguishable cover types including ice, snow, rock and water, and then remove these classes from further classification iterations by masking them out.

There was no purpose in distinguishing between ice and snow in these August and September images and these classes are grouped together. The rock class includes bedrock, talus will little or no vegetation and gravel along stream courses. The spectral reflectances of rock and gravel are very similar and unlikely to be distinguished with a 30 m sampling ground cell. In most cases water is easily distinguishable on satellite imagery, basically due to its zero reflectance in the short-wave infrared (SWIR). However, in the Muskwa project area it proved very difficult to separate water from shadows, both having little or no SWIR reflectance. Many tarns are located in north-facing cirques and lie in shadows. Due to the inability of the spectra to separate water and shadows, and compounded by the situation that some waterbodies were carrying appreciable sediment loads that confused the analytical technique it was decided to map waterbodies and watercourses using the TRIM vector information, presumably from a superior spatial resolution base.

The example of the classification processing described below is that for PTP Area 1. Similar procedures were followed for the other areas.

- An unsupervised IsoData classification assigning 29 classes (approximately 2 to 3 times as many as were to be expected) was run on ETM bands 1 to 5 and 7.

- The product of the classification is a new image channel in which classified pixels have a DN equal to their class number, in this case 1 to 29.

- The next step was to aggregate all the ice/snow classes into Class 0b and rock classes into Class 0a. Bitmaps were then generated for both these, which were then combined. The complement of this bitmap of ice/snow plus rock then becomes the operational mask or bitmap under which additional processing is applied.

- A second unsupervised IsoData classification assigning 10 classes was run on the ETM bands 1 to 5 and 7, but only under the operational mask generated above.

The initial results of this classification work in PTP Area 1 are shown in Table 12. The initial cover assignment was based on the project team's familiarity with Cordilleran mountains.

Table 12. Overview of Landsat-based cover classes and associated processing for PTP Area 1.

Area 1 Class	Initial Cover Assignment	Note regards subsequent processing or assignment
0a	aggregate of rock classes	
0b	aggregate of ice/snow classes	
1	water, shadows, dark conifers	repeat IsoData routine, assign 2 classes; 1a and 1b
1a	dark coniferous forest	
1b	water, shadows	
2	dark conifers	
3	coniferous forest with deciduous component	
4	deciduous forest with coniferous component	
5	deciduous forest	
6	shrub	
7	shrub	
8	herb on ridges, bog in stream channels	
9	alpine shrub	
10	alpine shrub	

Class 1, as described in Table 12, was an assemblage of mixed cover types; water, water in shadows, dark coniferous forest and shadowed forest. This class was isolated and a third IsoData classification run assigning two classes to see if the water/shadows could be separated from the shadowed and dark forest. The results were deemed satisfactory for this exercise and Class 1 was divided into Class 1a (dark coniferous forest) and Class 1b (water/shadows).

Subsequent to the initial field work by EBA, the Landsat classification was reexamined to iteratively improve it. Representative areas of original classes were visited in the field and notes were collected to help improve the selection of training areas. Based on the field results, the cover type designation of some of the initial classes were revised.

Some efforts were expended in comparing field sample locations with the unsupervised classification results. The main problems were field locations that coincided with the boundary between two classes or that were sited in shadows or relatively small areas of a particular class.

2.3.3. Incorporation of Imagery Cover Classes into the PEM

After the satellite imagery was classified into broad categories using a supervised classification process, a raster to vector conversion was conducted, as described in Section 2.7.

Due to the resulting size of the converted satellite image databases, each PTP Area was classified and handled for processing separately.

2.4. Derivation of Bioterrain from Air photos

2.4.1. Pre-Typing of Aerial Photos for Bioterrain

For PTP Areas 1 and 2, bioterrain mapping was conducted as described in this part of the Final Report.

For PTP Areas 1 and 2, pre-typing of 1:20,000 b&w panchromatic stereo-photos was undertaken. The initial step involved the "boxing" of alternate (odd-numbered) photos, and the set up of indexed sets of photo-flightline sets. Following this, stereoscopes were used to view photos so that the AT and ESSFp Subzone lines could be delineated (as per RIC Standards (RIC 1998a, b)). As this portion of the work proceeded, the marked-up photos showing these initial AT and ESSFp lines were sent to MSRN for auditing. As required, any necessary modifications were then undertaken.

A PEM bioterrain "working legend", as well as schematic landscape/terrain/ecosystem profiles and photo-typing keys were all developed to help guide the photo-typing.

2.4.2. Post-Field Edits and GIS Transfer of Bioterrain Linework and Labels

Following field work within PTP Areas 1 and 2, bioterrain units were revised as necessary. The most significant edits involved resolution of final bioterrain labels and boundaries, based on field-checking.

GIS analysts working on the Muskwa PEM project were provided with map legends for all bioterrain units. They used these legends to then develop editing checks for photo-typing errors and for errors in the transfer of line work and polygon labels from aerial photographs.

Edited aerial photographs were photocopied and the original typed aerial photographs were digitally transferred from photos to maps, using Maps3D software to complete a monorestitution process. Transcription errors in both line work and polygon labeling were dealt with, in a final round of air photo reviews by the photo-interpreters. The most frequently encountered errors were line work that wasn't completely closed-off within polygons, and labeling errors associated with edge matching of aerial photos.

Final edited bioterrain datasets were then reviewed by MSRM staff, and used directly in the PEM modeling activities.

2.4.3. Bioterrain Labels

Standard procedures for bioterrain were followed, as outlined in the PEM Standards (RIC, 1998a, b, 2000a, b).

The bioterrain terrain classification system was specifically developed to provide an inventory of the terrain features in the landscape and to show their distribution, extent and location (Howes and Kenk, 1997). The data is described on maps by the use of symbols, which are conducive to computer digital storage, management and processing. The symbol sequence describes the following terrain characteristics: texture and type of surficial material, surface expression, geomorphological processes, and qualifiers.

When bioterrain is conducted as a component of PEM, Bioterrain Map Symbols are composed of a sequence of letters where each letter defines a specific characteristic. The position of the letters in the sequence typically then augments the information described by the letter grouping (Figure 11).

geomorphological process

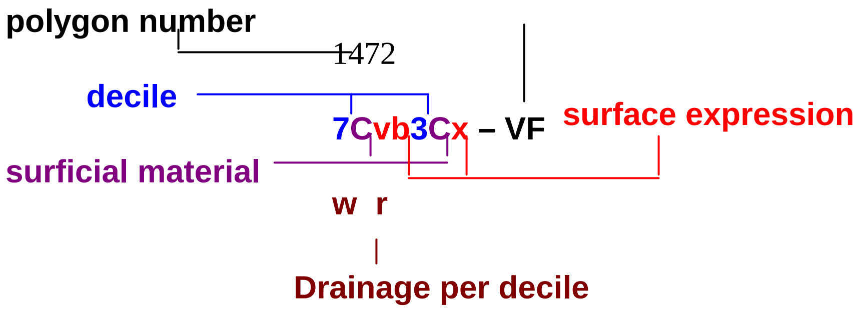

Figure 12. Bioterrain map symbols and map label format.

2.5. Field Sampling

During the startup of the project, the project team participated in an initial familiarization visit (during march, 2001) to the Study Area. Impressions developed following this overview of the area, and augmented by our previous knowledge of the general ecology and landscape, and additionally based upon discussions with MSRM, MEM and MOF contacts, provided the foundation for the development of a formal field sampling plan prior to summer 2001.

PEM field data collection was conducted within all 4 PTP Areas, during July and August, 2001. Field access was by helicopter. Field reconnaissance was undertaken in two field sessions:

- The July, 2001 field session focused on PTP Areas 1 and 2, with a field crew of 6 specialists, including bioterrain personnel.

- The August, 2001 field session focused on PTP Areas 3 and 4, and the crew of 4 specialists was smaller (bioterrain specialists were not involved).

- Deb Johnson accompanied EBA crews for portions of both field sessions and provided project input, as well as local knowledge regarding fire history, related wildlife and other studies in portions of the Study Area, and additional perspectives on wildlife habitat.

PEM data collection included the judicious use and placement in the field of different types of field point sample plots; this is also to be supplemented, according to RIC standards (1998a, b, 2000a, b) with ground and air based transect notes. The PEM field sample plot types used in this project included ground-based GIFs (Ground Inspection Form plots) and PEM Air / Ground Calls.

GIFs involve a somewhat less rigorous data collection effort; there is somewhat less detailed vegetation and soils information collected than within a full plot and no coarse woody debris assessment. GIF plots were installed as a photo-typing calibration aid and as a tool to verify PEM assignments. Because of the poorly known nature of Climatic Subzone boundaries and the existence of large areas of unclassified ecosystem boundaries within the Study Area, GIFs were mainly installed to help clarify boundary locations and transitions.

PEM Air / Ground Calls were brief area-based sample descriptions that were acquired mainly from the air, during the helicopter overflights. A limited number were also established from vista locations on mountainsides. These plots were used as a calibration tool for the PEM assignments, and a large number of PEM air / ground call plots (1,773) were installed as part of the Muskwa PEM field work.

Total numbers of field plots established for the Muskwa PEM are summarized in Table 13.

Table 13. Overall numbers of full, visual and air/ground call plots established for the Muskwa PEM project.

Plot Type	PTP Area 1	PTP Area 2	PTP Area 3	PTP Area 4	Total
Ground Inspection (GIF) Plots	17	7	70	7	101
PEM Air / Ground Call Plots	280	91	837	565	1773
Total PEM Plots (All Plot Types)	**297**	**98**	**907**	**572**	**1874**

A small proportion, about 15% (290) of the plots established, were set aside for use in verifying the final assignments made by the PEM modeling process. These plots were randomly selected out of the entire database of plots. These plots were not used in the PEM model adjustments, but were applied at the end of the PEM modeling activity, once the final PEM outputs were submitted for Provincial correlation.

During the field session a range of objectives were established. One was distribution of plots with regards to size and the extent of each Subzone in all four PTP Areas. A greater number of plots were established into PTP Areas 3 and 4 needing higher PEM model refinements. An attempt was also made to establish plots in most ecosystem units.

The overall quality of plot data was considered to be good. GPS positioning was carried out with precision GPS instruments. Plot data collection was conducted by experienced staff, most of whom had worked in or near the Study Area in the past. Care was taken in the installation of PEM air / ground calls in particular, since there were a large number established, and since their positioning and ecosystem unit assignment, in particular, needed to be collected accurately.

Post-field, Microsoft Access© was used as a database entry tool for all PEM plot data.

2.6. Knowledge Table Construction

As indicated earlier in this document, EcoGEN was chosen for the inference software in the project. It is an additive model based on a flat file input linked by multiple internal tables to select the proper BGC Subzone and ecosystems for prediction.

During the project a newer version of EcoGEN 1.0c was released by Ministry of Forest and quickly adapted for use into this project. Advantages of the newer version were in the table output formats and some bug fixes in the earlier version. A complete overview of this application is found in “EcoNGen 1.0c” (Anon 2001).

2.6.1. Ecosystems

Early on the in the project blank knowledge tables were created for each BGC Subzone with all potential ecosystem units, as identified in the provincial site series list. At this point the site series and eco tables in EcoGEN were ready to be linked to a PARAM table and populated. The philosophy here was to identify attributes individually early on in the PEM process that would contribute to a successful model.

Simultaneously, as the base polygons were being constructed from all inputs the ecosystem knowledge tables were constructed. Knowledge tables were then created for each input layer in all PTP Areas. Creation of multiple tables for each PTP Area was to deal with the variability found within the entire PEM Study Area. Tables were then tested on each layer at every step in the data assembly phase to identify the best attributes and optimal model.

Two key issues were identified at an early stage and then resolved. One involved attributes from different inputs producing confounding interpretations. For example, forest cover may indicate a coniferous forest, while satellite image would be rock. The other issue involved the difficulty of selecting specific ecosystems with the current set of attributes. This resulted in the amalgamation of some ecosystems to correctly classify them, such as many sedge fen types could not be distinguished and lumped into broad generic PEM units.

At the final data assembly stage, only minor adjustments were needed to produce optimal results. Appendix B provides Subzone knowledge tables for each PTP Area.

2.6.2. Structural Stages

Structural stage knowledge tables were also constructed on a Subzone – PTP Area basis. Using the ecosystem outputs from the previous section, structural stages could then be predicted more reliably. There were a selected few potential structural stages best suited for the ecosystem, and so this information was used to help calibrate the structural stage assignment algorithm. For example, a non-vegetated ecosystem unit such as rock could only exist as a structural stage 1, so there was a limitation placed upon rock being assigned any other structural stage.

Appendix C shows the corresponding structural stage knowledge tables for all Subzones.

2.7. Data Assembly

Once individual inputs were asssembled, as described in Section 2.2, inputs were organized for inputed into EcoGEN. Two proceses were maintained, one for PTP Areas 1 and 2, and the other, for PTP Areas 3 and 4.

2.7.1. PTP Areas 1 and 2

The process followed to assemble data for PTP Areas 1 and 2 is described in Figure 13.

Bioterrain was completed in PTP Area 1 and later for PTP Area 2. Localised BGC lines were also intersected with bioterrain to create the base layer for EcoGEN modelling. Small slivers (i.e., less than 5.0 ha) were created in this process, but were removed by dissolving them to adjacent larger polygons. The process followed for this was similar to that for PTP Areas 3 and 4 (see Section 2.7.2).

A subsequent step involved intersecting water features. Lakes and Rivers polygons derived from TRIM were intersected into the base layer.

As described for PTP Areas 3 and 4 (see Section 2.7.2), a regioning process was completed to incorporate satellite and forest cover information into the bioterrain base. Files were flattened to help eliminate noise from smaller polygons as well as to create a set of binary attributions as was required by EcoGEN.

2.7.2. PTP Areas 3 and 4

The process used to assemble the data for PTP Areas 3 and 4 is diagrammatically shown in Figure 14.

Slope was selected as the initial input data layer to build the base layer for PTP Areas 3 and 4. The aspect layer was intersected into slope. This created a large number of small polygons, many of them under a hectare in size. To eliminate smaller polygons, a tolerance of 5.0 ha was used to remove aspect lines and replace these splinters back into the original slope polygons.

Lakes and Rivers polygons derived from TRIM were then intersected into the base. Next, localized BGC lines were imported into the newly created base for PTP Areas 3 and 4. This created a final polygon base for the EcoGEN process.

The final process before the inputs were ready for EcoGEN was to incorporate the satellite, forest cover, TRIM and moisture data into the current polygon base. This was completed is by

Figure 13. Carto graphic model PT Areas 1 and 2

Figure 14. Carto graphic model PT Areas 3 and 4

“regioning” (using ArcInfo processing tools) so that the information from one input is placed within a base set of polygons, and proportionally assigned. Through GIS modeling the information from the source input (satellite, FC, Moisture polygons) is overlaid onto the base input (Slope/Aspect polygons) and attributes are transferred into (i.e., regioned into) the base polygons form the source polygons. This transfer calculates the percent by area overlap from the original source into the base of all attributes selected.

The regioned resultant was processed further to “flatten” the data file for EcoGEN. All attributes inside the resultant base polygons were added together, based on area. A final resultant for the transferred attributes was then created in two forms, by area and percent of the base polygon.

This regioning process creates what we termed “noise” inside the base polygons. Attributes from source polygons that would only spatially intersect a very small portion of the resultant base polygon would be included in the attribute transfer. A simple method was used to eliminate much of this noise by subsequently cleaning the resulting spatial coverage to eliminate attributes that occupied less than 10 to 15% coverage within a polygon. The extent of this noise was entirely dependent upon the nature of the input database.

Satellite, Forest Cover and TRIM attributes were placed in a common flat file. This presented a range of options to have the EcoGEN model proceed. While we tested a variety of methods, the simplest convention, which was usually selected first, was to convert the desired attributes into a binary approach of presence (1 for present and 0 for absent). This further flattened the source input into a data set easily usable in EcoGEN.

Initial runs in EcoGEN all produced acceptable results. Smaller polygons were better suited to one ecosystem as an output. Larger polygons were not. Moisture as an input was converted into a decile structure inside the base polygons based on percent area. This approach for incorporating moisture spatial data helped to adequately capture additional information content that was associated with ecosystem complexes within larger polygons.

2.8. PEM Reliability Determinations

2.8.1. Overall PEM Map Reliability

Immediately following the field season, a subset of about 15% (290) of the field plots were formally set aside. These plots were to serve, later, as a basis for independent reliability checking. As described by Meidinger (2001), sufficient plots were reserved so that a quality assurance level 3 (with a confidence level of 0.90) could be conducted. The set-aside plots were not used in delineating the localised BGC lines, or in any aspect of the PEM modelling or knowledge table construction.

For various reasons, a number of the plots were eliminated from the reliability analysis. About 24% (55) of the plots were mis-located because of the final positioning of the localised BGC lines, and so these had to be set aside. This issue arose because summer, 2001 field plots were established using first draft localised BCG lines. When newer versions of the lines were completed in February, 2002, there were some significant changes, in particular to the SWBmks and ESSFmvp4 boundaries. This resulted in a number of the reliability plots losing their formal link to a defined BEC Subzone / Variant.

An additional number of plots were, in advance, culled from the verification dataset because they represented very locally-occurring ecosystem units that would not be reasonably identifiable at the scale of mapping. Plots that were installed within very small polygons, for example less than 5 ha in size, were rejected from the reliability checking.

The final set of plots for map reliability determination was an independent set of 147 independent reliability plots for the four PTP Areas (Table 14). It is believed that the reliability plot set provided a sufficient base to independently test the PEM model’s overall resolution and thematic accuracy.

Table 14. Reliability Plot Allocations for the Muskwa PEM. Results are shown for each PTP Area, based upon localised BEC Subzones.

	Area 1	Area 2	Area 3	Area 4
AT	4/4		5/5	14/20
ESSFmv4	4/6			
ESSFmvp4	-			
SWBmk	3/4	-	15/22	19/20
SWBmks	-	-	-	-
BWBSmw1	5/6			
BWBSmw2		5/6	22/34	3/4
BWBSwk2	6/8			
BWBSdk2			6/8	
Total	78%	83%	70%	66%

The results provide an overall evaluation of potential accuracy of the final PEM outputs. As expected, given the additional effort placed upon bioterrain mapping in PTP Areas 1 and 2, overall higher accuracies (78 and 83%, respectively) were achieved.

There are some remaining gaps in the assessment of reliability, however. There is a very low population of plots from ESSFmvp4 parkland and SWBmks scrub Subzones. Many of the original plots for these were eliminated in the culling out process, given that some of the eocsystem units occur in a very localized manner. The total area covered by SWBmk and SWBmks is not extensive within the Study Area, and it is mostly confined to the northwestern extent of the Study Area, however these units as well have few reliability plots to base any interpretation on.

The “real test” of PEM outputs occurs when spatial products are used to generate plausible and realistic interpretations. In the case of the Muskwa PEM, the wildlife interpretations developed and described in Volume 2 of this Final Report provide considerable evidence that the output maps provide useful mapped details on a range of wildlife species.

Table 15 provides an overall summary of the thematic and spatial characteristics within the Muskwa PEM Study Area.

Table 15. Summary of the thematic and spatial characteristics of PEM map products for PTP Areas 1 and 2 versus PTP Areas 3 and 4.

Feature	PTP Areas 1 and 2	PTP Areas 3 and 4
Thematic precision	• Medium?	• Medium?
Thematic accuracy	• High	• Medium to High
Spatial accuracy	• Designed for use at 1:50,000.	• Designed for use at 1:50,000.
Spatial Resolution	• Minimum mapped area is 10 to 15 ha	• Minimum mapped area is 10 to 15 ha
Relative Cost	• More costly (because of bioterrain photo-interpretation)	• Less costly.

2.8.2. Input and Output Data Quality

2.8.2.1. Input Data Quality

Input data quality for the Muskwa PEM was addressed when the Input Dat Quality Report was assembled in March, 2001. At that time, it was indicated that some further evaluations of input data quality would be conducted. With the wrap up of the project, it was possible to use the independent plot database to also test and evaluate the thematic accuracy of individual input data elements.

Tables 16 to 18 summarize the results of the determination of initial input data quality for some of the following attributes used in the PEM modelling.

In PTP Areas 1 and 2 the initial inputs used in the modelling was derived from the bioterrain and Forest Cover. Attributes were tested in the format used in the modelling process. For example Forest Cover tree species was tested by presence within the original forest cover polygon and not on percentage. Surficial materials were tested in conjunction with surficial expression as predominately found in the knowledge tables to reflect the PEM modeling.

In PTP Areas 3 and 4 attributes were derived from the DEM and Forest Cover. Instead of drainage as found from bioterrain, moisture was developed from the DEM and used. Forest cover was done as in PTP Areas 1 and 2 by indicating a presence within the original FC polygons.

Table 16. Input Data Quality Determinations for the Muskwa PEM's Four PTP Areas Using Independent Data

PTP Area 1				
	slope	151	227	67%
	aspect	110	154	71%
	Drainage	132	201	66%
	Surf/exp	86	154	56%
	FC species	80	112	71%
PTP Area 2				
	slope	40	63	63%
	aspect	9	34	26%
	drainage	34	53	64%
	Surf/exp	23	51	45%
	FC species	34	57	60%
PTP Area 3				
	slope	54	102	53%
	aspect	49	115	43%
	FC species	12	22	55%
	moisture	29	52	56%
PTP Area 4				
	slope	44	92	48%
	aspect	68	98	69%
	FC species	21	47	45%
	moisture	25	30	83%

2.8.2.2. Output Data Quality

During the data assembly of the inputs attributes from other layers beyond the base layers were integrated into the base. This required some generalization of inputs, as they were regioned into the base layer.

Table 17 illustrates the final input layer reliability prior to EcoGen modeling. Notice the base layers and regioning layers do not appreciably change, with the exception of the slope and aspect base from PTP Areas 3 and 4.

Table 17. Output Data Quality Determinations for the Muskwa PEM's Four PTP Areas Using Independent Data

PTP Area 1				
	slope	151	227	67%
	aspect	110	154	71%
	drainage	132	201	66%
	Surf/exp	86	154	56%
	FC species	80	112	71%
PTP Area 2				
	slope	40	63	63%
	aspect	9	34	26%
	drainage	34	53	64%
	Surf/exp	23	51	45%
	FC species	34	57	60%
PTP Area 3				
	slope	58	102	57%
	aspect	86	115	75%
	FC species	12	22	55%
	moisture	29	52	56%
PTP Area 4				
	slope	45	92	49%
	aspect	71	98	72%
	FC species	21	47	45%
	moisture	25	30	83%

Due to the multiple number of variations attempted for many inputs, it would be difficult to reflect accurately all input iterations. Many iterations resulted in poorer desired results and were not carried through the process to adequately be tested. What can be reported is the overall change for two of the base inputs found in PTP Areas 3 and 4, slope and aspect. Table 18 shows the differences found in the initial individual input layers

Table 18. Comparison of Initial and Final Output Data Quality for Slope and Aspect Calculations for PTP Areas 3 and 4

PTP Area 3		initial	final	plots	% change
	slope	54	58	102	4%
	aspect	49	86	115	32%
PTP Area 4					
	slope	44	45	92	1%
	aspect	68	71	98	3%

2.8.2.3. PEM Map Output

The quality of the modelling process for output was tested against the remaining plots not set aside for Reliability purposes. These plots were used to adjust the knowledge table against the inputs to achieve the best overall desired output. The following tables 19 to 22 show the final output results for each PTP Area on a per Subzone basis.

Tables in Appendix D illustrate the predicted ecosystems by PTP Area and Biogeoclimatic Subzone.

Results are similar to what was seen in the reliability where the modelling process itself lowered the overall results. Attributes inside polygons from various inputs layers gave conflicting information for the additive selection process of the model or they were simply not available for selection. A second factor in the results was the plot itself. Many of the smaller ecosystems were part of larger polygons.

Table 19. PTP Area 1 PEM Output Results

BGC_UNIT	entity	Plot Numbers	Output Agree	Percent Agree
AT	AW	1	0	0%
AT	CL	4	3	75%
AT	GL	1	1	100%
AT	MA	10	9	90%
AT	RO	5	5	100%
AT	TA	8	8	100%
AT	WV	5	0	0%
BWBSmw1	AM	1	0	0%
BWBSmw1	SH	3	3	100%
BWBSwk2	BH	4	1	25%
BWBSwk2	BL	3	0	0%
BWBSwk2	BW	2	0	0%
BWBSwk2	FB	5	0	0%
BWBSwk2	LA	1	1	100%
BWBSwk2	LL	2	0	0%
BWBSwk2	RO	1	1	100%
BWBSwk2	SC	4	1	25%
BWBSwk2	SH	6	6	100%
BWBSwk2	SM	17	8	47%
BWBSwk2	SW	10	3	30%
ESSFmv4	BT	5	2	40%
ESSFmv4	CL	1	1	100%

BGC_UNIT	entity	Plot Numbers	Output Agree	Percent Agree
ESSFmv4	FB	3	2	67%
ESSFmv4	FH	3	1	33%
ESSFmv4	FR	19	12	63%
ESSFmv4	LA	2	2	100%
ESSFmv4	LC	2	0	0%
ESSFmv4	RH	6	1	17%
ESSFmv4	RO	5	1	20%
ESSFmv4	WA	9	1	11%
ESSFmvp4	AW	1	0	0%
ESSFmvp4	FR	3	1	33%
ESSFmvp4	MA	2	1	50%
ESSFmvp4	TA	1	0	0%
ESSFmvp4	WA	4	3	75%
SWBmk	ME	1	1	100%
SWBmk	SB	2	1	50%
SWBmk	SC	1	1	100%
SWBmk	SS	1	1	100%
SWBmk	SW	1	1	100%
SWBmks	AW	1	0	0%
SWBmks	SC	3	2	67%
SWBmks	SK	2	2	100%
SWBmks	WM	1	0	0%
		172	87	51%

Table 20. PTP Area 2 PEM Output Results

BGC_UNIT	entity	CountOfentity		CountOfagree
BWBSmw2AM		15	13	87%
BWBSmw2BB		10	5	50%
BWBSmw2BK		7	3	43%
BWBSmw2BL		14	6	43%
BWBSmw2BS		7	5	71%
BWBSmw2BW		5	2	40%
BWBSmw2FE		1	0	0%
BWBSmw2ME		3	0	0%
BWBSmw2RI		2	2	100%
BWBSmw2RO		1	0	0%
BWBSmw2SH		11	7	64%
BWBSmw2WB		3	1	33%
SWBmk	SL	1	0	0%
		80	44	55%

Table 21. PTP Area 3 PEM Output Results

BGC_UNIT	entity	CountOfentity		CountOfagree
AT	ME	1	0	0%
AT	AW	9	5	56%
AT	MA	9	5	56%
AT	RO	51	48	94%
AT	WV	3	0	0%
BWBSdk2	BF	5	4	80%
BWBSdk2	BL	10	4	40%
BWBSdk2	BT	2	0	0%
BWBSdk2	FE	1	0	0%
BWBSdk2	LA	1	1	100%
BWBSdk2	RI	1	1	100%
BWBSdk2	RO	2	0	0%
BWBSdk2	SH	6	3	50%

	BGC_UNIT	entity	CountOfentity		CountOfagree
BWBSdk2	SM		22	14	64%
BWBSdk2	WV		2	0	0%
BWBSmw2	AM		58	47	81%
BWBSmw2	BB		3	0	0%
BWBSmw2	BK		48	26	54%
BWBSmw2	BL		34	15	44%
BWBSmw2	BS		8	3	38%
BWBSmw2	BW		16	3	19%
BWBSmw2	CL		2	2	100%
BWBSmw2	FE		4	0	0%
BWBSmw2	LA		2	2	100%
BWBSmw2	RI		4	4	100%
BWBSmw2	RO		6	2	33%
BWBSmw2	SH		47	31	66%
BWBSmw2	SS		1	0	0%
BWBSmw2	TB		3	0	0%
BWBSmw2	TH		4	0	0%
BWBSmw2	WB		7	0	0%
SWBmk	AW		8	1	13%
SWBmk	CL		1	0	0%
SWBmk	FE		6	2	33%
SWBmk	LA		2	2	100%
SWBmk	MA		3	0	0%
SWBmk	RO		28	15	54%
SWBmk	SB		43	5	12%
SWBmk	SH		7	4	57%
SWBmk	SK		120	77	64%
SWBmk	SL		72	31	43%
SWBmk	SS		2	2	100%
SWBmk	SW		12	4	33%
SWBmk	WA		2	0	0%
SWBmk	WH		2	1	50%
SWBmk	WM		10	1	10%
SWBmk	WV		1	0	0%
SWBmks	AW		8	2	25%
SWBmks	BS		1	0	0%
SWBmks	MA		4	1	25%
SWBmks	RO		3	2	67%
SWBmks	SB		2	0	0%
SWBmks	SH		1	1	100%
SWBmks	SK		3	0	0%
SWBmks	SL		1	0	0%
SWBmks	SS		1	0	0%

	BGC_UNIT	entity	CountOfentity		CountOfagree
SWBmks	WA		1	0	0%
SWBmks	WM		2	0	0%
SWBmks	WV		3	0	0%
			721	371	51%

Table 22. PTP Area 4 PEM Output Results

	BGC_UNIT	entity	CountOfentity		CountOfagree
AT	ME		1	0	0%
AT	AW		17	11	65%
AT	CL		10	9	90%
AT	GL		6	5	83%
AT	LA		2	2	100%
AT	MA		30	21	70%
AT	RO		73	65	89%
AT	WV		4	1	25%
BWBSmw2	AM		4	2	50%
BWBSmw2	BB		2	0	0%
BWBSmw2	BK		4	3	75%
BWBSmw2	BL		5	5	100%
BWBSmw2	BS		1	0	0%
BWBSmw2	FE		2	0	0%
BWBSmw2	RI		2	2	100%
BWBSmw2	SH		2	2	100%
SWBmk	AW		2	1	50%
SWBmk	CL		1	1	100%
SWBmk	LA		3	3	100%
SWBmk	PL		3	0	0%
SWBmk	RI		15	11	73%
SWBmk	RO		10	6	60%
SWBmk	SB		22	6	27%
SWBmk	SH		13	12	92%
SWBmk	SK		45	28	62%
SWBmk	SL		18	7	39%
SWBmk	SW		28	9	32%

	BGC_UNIT	entity	CountOfentity		CountOfagree
SWBmk	WA		1	1	100%
SWBmk	WB		1	0	0%
SWBmk	WM		1	0	0%
SWBmk	WV		10	1	10%
SWBmks	AW		1	0	0%
SWBmks	BS		12	9	75%
SWBmks	CL		1	0	0%
SWBmks	FB		2	0	0%
SWBmks	MA		1	0	0%
SWBmks	RO		5	3	60%
SWBmks	SB		2	0	0%
SWBmks	SK		3	0	0%
SWBmks	WV		8	5	63%
			373	231	62%

2.9. PEM Deliverables

Map production included both map legend development and the preparation of digital maps. PEM product deliveries for the Muskwa PEM project include digital data delivered to the Ministry of Sustainable Resource Management's ftp site.

Hard copy maps for the Muskwa PEM were *not* prepared as part of the final deliverables.

The following tables (Table 23 to 30) provide a summary of the data files that were assembled and produced as part of the overall project.

Table 23. Input Digital Files for the Muskwa PEM Area 1 (Graham / Halfway).

File Type	Files Name
Spatial Data File	graham_bioterrain.e00 graham_pem_input.e00 graham _sat_initial.zip graham _sat_interim.zip graham _satd.e00 Lbgc_ graham.e00 graham _fc1.e00 graham_plots.e00

Table 24. Output Digital Files for the Muskwa PEM Area 1 (Graham / Halfway).

File Type	Files Name
Spatial Data File	lecp_mk1.e00 leci_mk1.e00 lbgc_mk1.e00
Non-Spatial Data File	lecp_mk1.dbf lecp_mk1.pem lecp_mk1.meta muskwa_prj.dbf lbgc_mk1.dbf linp_mk1.dbf lpro_mk.dbf mk1_userdef.dbf
Legend and Expanded Legend Files	muskwa_exp_legend.xls muskwa_legend.doc

Table 25. Input Digital Files for the Muskwa PEM Area 2 (Muskwa West).

File Type	Files Name
Spatial Data File	mwest_bioterrain.e00 mwest _pem_input.e00 mwest _sat_initial.zip mwest _sat_interim.zip mwest _satd.e00 Lbgc_ mwest.e00 mwest _fc1.e00 mwest_plots.e00

Table 26. Output Digital Files for the Muskwa PEM Area 2 (Muskwa West).

File Type	Files Name
Spatial Data File	lecp_mk2.e00 leci_mk2.e00 lbgc_mk2.e00
Non-Spatial Data File	lecp_mk2.dbf lecp_mk2.pem lecp_mk2.meta muskwa_prj.dbf lbgc_mk2.dbf linp_mk2.dbf lpro_mk.dbf mk2_userdef.dbf
Legend and Expanded Legend Files	muskwa_exp_legend.xls muskwa_legend.doc

Table 27. Input Digital Files for the Muskwa PEM Area 3 (Sulphur / 8 Mile).

File Type	Files Name
Spatial Data File	sulphur_input.e00 sulphur_sat_initial.zip sulphur_sat_interim.zip sulphur_sat.e00 lbgc_sulphur.e00 sulphur_fc1.e00 sulphur_moist.e00 sulphur_aspect.e00 sulphur_slope.e00 sulphur_plots.e00

Table 28. Output Digital Files for the Muskwa PEM Area 3 (Sulphur / 8 Mile).

File Type	Files Name
Spatial Data File	lecp_mk3.e00 leci_mk3.e00 lbgc_mk3.e00
Non-Spatial Data File	lecp_mk3.dbf lecp_mk3.pem lecp_mk3.meta muskwa_prj.dbf lbgc_mk3.dbf linp_mk3.dbf lpro_mk.dbf mk3_userdef.dbf
Legend and Expanded Legend Files	muskwa_exp_legend.xls muskwa_legend.doc

Table 29. Input Digital Files for the Muskwa PEM Area 4 (Churchill).

File Type	Files Name
Spatial Data File	church_input.e00 church _sat_initial.zip church _sat_interim.zip church _sat.e00 lbgc_ Churchill.e00 church _fc1.e00 church _moist.e00 church _aspect.e00 church _slope.e00 church_plots.e00

Table 30. Output Digital Files for the Muskwa PEM Area 4 (Churchill).

File Type	Files Name
Spatial Data File	lecp_mk4.e00 leci_mk4.e00 lbgc_mk4.e00
Non-Spatial Data File	lecp_mk4.dbf lecp_mk4.pem lecp_mk4.meta muskwa_prj.dbf lbgc_mk4.dbf linp_mk4.dbf lpro_mk.dbf mk4_userdef.dbf
Legend and Expanded Legend Files	muskwa_exp_legend.xls muskwa_legend.doc

3. DESCRIPTION OF ECOSYSTEM UNITS

Section 3 provides background information on the ecosystem units that were used as a basis for PEM mapping. Conventions for names, associated descriptions and other features follow recommended TEM and PEM standards (RIC 1998a, b, 2000a, b).

Some background context is provided in Section 3.1, and each ecosystem unit that was mapped within the Muskwa PEM Study Area is then listed and summarized in a tabular "expanded legend" in Section 3.2.

3.1. Ecosystem Unit Photographs

Colour photos and associated captions (Plates 1 to 10) relating the to Muskwa PEM project are presented on the following pages. These photos were acquired during the summer, 2001 field program.

Photos and captions provide general context regarding common ecosystems and ground features within the Muskwa PEM Study Area. Ecosystem units named in the captions are further described in Section 3.2.

DCP_0353.JPG

Plate 1. A small sedge fen found in PTP 3 in the upper elevations of SWBmk (plot 214). Very poorly drained collecting sites found in depressions along the landscape are good moose habitat.

DCP_0404.JPG

Plate 2. A north facing slope in the SWBmk PTP Area 3 in the foreground is typically the SL (Sw – Willow – Crowberry) sites where soils maybe frozen for most parts of the year (plot 244). Background is a westerly facing slope of a regenerating burn. Two Grizzly yearlings and a Martin were seen in the vicinity.

0009.jpg

Plate 3. Woodpecker sign found in the Halfway River drainage PTP Area 1 lower elevations of the SWBmk. (Plot 003)

DCP_0415.JPG

Plate 4. Rich fluvial site in the north western portion of PTP Area 3 SWBmk (plot 238). A mixed forest dominated by spruce and cottonwood is subjected to periodic flooding and material deposition.

DCP_0252.JPG

Plate 5. Looking north along the Racing River in the northern PTP Area 4 illustrates the transition from SWBmk into SWBmks and then finally Alpine Tundra in the foreground on a gentle slope.

DCP_0295.JPG

Plate 6. Typical steep valleys found in PTP Area 4 along the upper Toad River. Open gravel bars along the valley floors with narrow bands of forest adjacent on the lower slopes are common. Willow units are then typically above on the steeper shallow soils.

DCP_0414.JPG

Plate 7. Water Sedge Fen in the fore ground of fairly large size found in PTP Area 3 near the Liard River in the lower SWBmk (Plot 239). Surrounded by short willows and then moving up slope into the forested communities in the adjacent area provides good habitat moose.

0012.jpg

Plate 8. PTP Area 2 was predominantly BWBSmw2 and this site illustrates a typical BW3bC. Fairly poorly drained organics with a high willow and moss layers while the tree layer is very poorly developed. Frequent fire events are common in this Subzone also suppressing any development of a canopy layer.

DCP_0349.JPG

Plate 9. XX Creek road in PTP Area 3 is one of a few accesses by road into the Muskwa Kechika leading to a communications tower in the Alpine Tundra. This common high elevation ecosystem MA (Mountain avens – Arctic Lupine) is found on shallow soils.

DCP_0515.JPG

Plate 10. An old growth SH (Spruce –Horsetail) ecosystem found in PTP Area 3 along a tributary to the Dunedin River.

3.2. PEM Expanded Legend

An expanded legend for the Muskwa PEM project is provided in Appendix E, as a colour-coded table originally constructed in Microsoft Excel®. The legend summarizes key descriptive information about the ecosystem units that were encountered in the field (during field plot descriptions) and/or were identified as part of the air photo interpretation activities for the project.

Note: The expanded legend provides a full listing of all ecosystem units that were mapped as part of the Muskwa PEM – among other variables, it provides the BEC unit, site series number, ecosystem unit code and the ecosystem unit name.

Entries in the table are provided according to BEC Subzone/Variant (generally organized from upper elevation to valley bottom), with sections colour-coded as follows:

- AT – light brown;
- SWBmk – olive,
- SWBmks – gold,
- ESSFmvp4 – dark yellow;
- ESSFmv4 – yellow,
- BWBSdk2 – dark green,
- BWBSmw1 – green,
- BWBSmw2 – lime green,
- BWBSwk2 – light green.

For each ecosystem unit, the site series number (i.e., from the Prince George BEC field guides (Delong 1996, Delong et al. 1990, 1994)) is provided where it exists (otherwise this entry is left blank and “00” is assumed). The structural stage symbol (as used for PEM mapping) and the corresponding ecosystem unit name are identified.

The vegetation description in Appendix E is compiled in part from the field plot data, using VENUS and VTAB sorting functions to create abbreviated lists of dominant and indicator species associated with the unit. Where no plots were encountered for a structural stage that was likely to have occurred, then a plant list was extrapolated based on our best ecological knowledge.

Other columns summarize, for each ecosystem unit, associated ecological conditions (terrain, assumed typical situation, typical soil moisture regime, common site modifiers). The Region and Project name are listed, as per standard conventions for a PEM Expanded Legend.

4. CLOSURE

Respectfully submitted,

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March 31, 2002

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APPENDICES

Appendix A. Input Data Sources

Appendix B. Knowledge Bases Ecosystems

Appendix C. Knowledge Bases Structural Stages

Appendix D. Table(s) summarizing area coverages of ecosystem units, according to each PTP Area.

PTP Area 1

BEC	% of total	% of bec	SITEMC_S1
AT	0.73%	3.54%	AW
AT	3.51%	16.94%	CL
AT	0.00%	0.02%	FE
AT	0.20%	0.96%	FL
AT	0.09%	0.43%	GL
AT	0.01%	0.03%	LA
AT	8.60%	41.48%	MA
AT	0.21%	1.00%	ME
AT	0.00%	0.01%	RI
AT	0.02%	0.10%	RO
AT	7.11%	34.30%	TA
AT	0.25%	1.19%	WV
BWBSmw1	0.05%	11.55%	AM
BWBSmw1	0.04%	8.13%	BT
BWBSmw1	0.00%	0.09%	LA
BWBSmw1	0.06%	12.95%	RI
BWBSmw1	0.29%	65.23%	SH
BWBSmw1	0.01%	2.06%	SO
BWBSwk2	0.58%	5.77%	BH
BWBSwk2	0.58%	5.83%	BL
BWBSwk2	0.16%	1.64%	BW
BWBSwk2	0.00%	0.02%	CL
BWBSwk2	0.02%	0.24%	FE
BWBSwk2	0.03%	0.28%	LA
BWBSwk2	0.03%	0.31%	LL
BWBSwk2	0.03%	0.32%	ME
BWBSwk2	0.32%	3.21%	RI
BWBSwk2	0.38%	3.76%	SC
BWBSwk2	2.42%	24.15%	SH

BWBSwk2	4.98%	49.75%	SM
BWBSwk2	0.47%	4.71%	SW
ESSFmv4	11.01%	31.02%	BT
ESSFmv4	0.61%	1.71%	CL
ESSFmv4	0.52%	1.48%	FB
ESSFmv4	0.10%	0.29%	FE
ESSFmv4	1.30%	3.68%	FH
ESSFmv4	16.77%	47.24%	FR
ESSFmv4	0.01%	0.03%	LA
ESSFmv4	1.36%	3.83%	LC
ESSFmv4	0.16%	0.45%	ME
ESSFmv4	0.36%	1.03%	RH
ESSFmv4	0.02%	0.06%	RI
ESSFmv4	3.26%	9.19%	WA
ESSFmvp4	0.18%	2.30%	AW
ESSFmvp4	0.21%	2.74%	CL
ESSFmvp4	0.00%	0.03%	FE
ESSFmvp4	3.74%	47.62%	FR
ESSFmvp4	0.07%	0.84%	LC
ESSFmvp4	0.02%	0.26%	ME
ESSFmvp4	0.32%	4.03%	RH
ESSFmvp4	0.00%	0.01%	RO
ESSFmvp4	0.04%	0.50%	TA
ESSFmvp4	3.27%	41.67%	WA
SWBmk	0.11%	0.86%	CL
SWBmk	0.13%	1.04%	FB
SWBmk	0.42%	3.37%	FE
SWBmk	0.04%	0.30%	LA
SWBmk	0.14%	1.14%	ME
SWBmk	0.63%	5.13%	PL
SWBmk	0.05%	0.40%	RI
SWBmk	7.75%	62.91%	SB
SWBmk	0.01%	0.06%	SC
SWBmk	0.54%	4.35%	SH
SWBmk	0.51%	4.11%	SK
SWBmk	0.40%	3.23%	SL
SWBmk	0.07%	0.56%	SS
SWBmk	0.52%	4.21%	SW
SWBmk	0.67%	5.44%	WA
SWBmk	0.01%	0.07%	WH
SWBmk	0.35%	2.80%	WM
SWBmks	0.42%	3.23%	AM
SWBmks	0.08%	0.61%	AW
SWBmks	0.40%	3.08%	BS
SWBmks	0.40%	3.03%	CL
SWBmks	0.29%	2.21%	FE
SWBmks	0.00%	0.01%	LA

SWBmks	0.89%	6.77%	MA
SWBmks	1.10%	8.39%	PL
SWBmks	0.00%	0.00%	RI
SWBmks	0.00%	0.02%	RO
SWBmks	1.22%	9.31%	SB
SWBmks	0.13%	1.01%	SC
SWBmks	0.38%	2.89%	SH
SWBmks	5.43%	41.33%	SK
SWBmks	1.24%	9.41%	SL
SWBmks	0.15%	1.10%	SW
SWBmks	0.18%	1.38%	TA
SWBmks	0.75%	5.69%	WA
SWBmks	0.05%	0.37%	WM
SWBmks	0.02%	0.15%	WV

PTP Area 2

BEC	% of total	% of bec	MC
BWBSmw2	19.23%	20.23%	AM
BWBSmw2	27.40%	28.82%	BB
BWBSmw2	8.68%	9.13%	BL
BWBSmw2	11.97%	12.59%	BS
BWBSmw2	3.50%	3.68%	BW
BWBSmw2	14.78%	15.55%	KH
BWBSmw2	1.33%	1.40%	LL
BWBSmw2	0.87%	0.91%	RI
BWBSmw2	0.05%	0.05%	RO
BWBSmw2	5.14%	5.41%	SH
BWBSmw2	1.88%	1.98%	TH
BWBSmw2	0.24%	0.25%	WB
SWBmk	0.11%	2.32%	CL
SWBmk	0.00%	0.05%	FE
SWBmk	0.02%	0.41%	KI
SWBmk	0.01%	0.27%	PL
SWBmk	1.96%	39.94%	SB
SWBmk	0.06%	1.14%	SC
SWBmk	0.10%	2.12%	SH
SWBmk	0.74%	15.02%	SK
SWBmk	1.57%	32.05%	SL
SWBmk	0.00%	0.00%	SS
SWBmk	0.11%	2.28%	SW
SWBmk	0.03%	0.54%	WA
SWBmk	0.05%	0.95%	WH
SWBmk	0.14%	2.91%	WM
SWBmks	0.00%	2.83%	BS

SWBmks	0.01%	16.91%	CL
SWBmks	0.01%	27.52%	MA
SWBmks	0.01%	22.32%	PL
SWBmks	0.00%	2.30%	SK
SWBmks	0.00%	5.12%	SL
SWBmks	0.01%	23.00%	WM

PTP Area 3

BEC	% of total area	% of bec	SITEMC_S1
AT	0.94%	16.98%	AW
AT	0.88%	15.87%	CL
AT	0.01%	0.18%	KH
AT	0.00%	0.00%	LA
AT	0.42%	7.60%	MA
AT	3.27%	59.04%	RO
AT	0.02%	0.33%	WV
BWBSdk2	1.11%	14.49%	BF
BWBSdk2	0.80%	10.43%	BL
BWBSdk2	0.01%	0.12%	BT
BWBSdk2	0.00%	0.03%	LA
BWBSdk2	0.21%	2.73%	LC
BWBSdk2	0.03%	0.37%	ME
BWBSdk2	0.09%	1.15%	RI
BWBSdk2	0.01%	0.15%	RO
BWBSdk2	0.74%	9.65%	SH
BWBSdk2	4.37%	56.80%	SM
BWBSdk2	0.31%	4.06%	SW
BWBSdk2	0.00%	0.02%	WM
BWBSmw2	13.25%	45.01%	AM
BWBSmw2	0.02%	0.07%	BB
BWBSmw2	6.33%	21.50%	BK
BWBSmw2	2.63%	8.93%	BL
BWBSmw2	2.33%	7.92%	BS
BWBSmw2	1.03%	3.49%	BW
BWBSmw2	0.01%	0.02%	CL
BWBSmw2	0.01%	0.05%	FE
BWBSmw2	0.01%	0.05%	LA
BWBSmw2	0.05%	0.17%	LL
BWBSmw2	0.04%	0.14%	ME
BWBSmw2	0.96%	3.28%	RI
BWBSmw2	0.10%	0.34%	RO
BWBSmw2	2.63%	8.94%	SH
BWBSmw2	0.03%	0.10%	WB
SWBmk	0.33%	0.62%	AW

SWBmk	0.05%	0.10%	CL
SWBmk	0.00%	0.00%	FB
SWBmk	0.21%	0.40%	FE
SWBmk	0.05%	0.10%	LA
SWBmk	1.14%	2.13%	ME
SWBmk	1.55%	2.91%	PL
SWBmk	0.28%	0.52%	RI
SWBmk	2.82%	5.27%	RO
SWBmk	3.88%	7.27%	SB
SWBmk	2.20%	4.11%	SH
SWBmk	16.88%	31.60%	SK
SWBmk	12.34%	23.10%	SL
SWBmk	5.12%	9.58%	SS
SWBmk	2.78%	5.20%	SW
SWBmk	1.03%	1.92%	WA
SWBmk	0.01%	0.02%	WH
SWBmk	2.75%	5.15%	WM
SWBmks	0.79%	20.35%	AW
SWBmks	0.01%	0.38%	BS
SWBmks	0.09%	2.37%	BV
SWBmks	0.02%	0.49%	CL
SWBmks	0.00%	0.04%	KI
SWBmks	0.00%	0.06%	LA
SWBmks	1.76%	45.20%	MA
SWBmks	0.00%	0.10%	PL
SWBmks	0.00%	0.01%	RI
SWBmks	1.12%	28.60%	RO
SWBmks	0.00%	0.02%	SB
SWBmks	0.00%	0.00%	SH
SWBmks	0.05%	1.17%	SK
SWBmks	0.00%	0.02%	SL
SWBmks	0.02%	0.51%	WA
SWBmks	0.02%	0.48%	WM
SWBmks	0.01%	0.21%	WV

PTP Area 4

BEC	% of total area	% of bec	SITEMC_S1
AT	9.18%	17.02%	AW
AT	4.23%	7.85%	CL
AT	5.10%	9.45%	GL
AT	0.02%	0.03%	KH
AT	0.07%	0.13%	LA
AT	18.00%	33.39%	MA

AT	0.01%	0.02%	ME
AT	0.01%	0.02%	RI
AT	16.52%	30.64%	RO
AT	0.78%	1.44%	WV
BWBSmw2	0.47%	30.24%	AM
BWBSmw2	0.12%	7.35%	BK
BWBSmw2	0.40%	25.46%	BL
BWBSmw2	0.03%	2.00%	BW
BWBSmw2	0.00%	0.02%	FE
BWBSmw2	0.00%	0.12%	LA
BWBSmw2	0.00%	0.07%	LL
BWBSmw2	0.00%	0.04%	ME
BWBSmw2	0.10%	6.50%	RI
BWBSmw2	0.44%	27.92%	SH
BWBSmw2	0.00%	0.28%	WB
SWBmk	0.05%	0.13%	AW
SWBmk	0.19%	0.54%	CL
SWBmk	0.06%	0.17%	FB
SWBmk	0.53%	1.48%	FE
SWBmk	0.11%	0.30%	LA
SWBmk	0.44%	1.23%	ME
SWBmk	0.24%	0.69%	PL
SWBmk	1.03%	2.90%	RI
SWBmk	0.85%	2.39%	RO
SWBmk	3.51%	9.85%	SB
SWBmk	3.86%	10.85%	SH
SWBmk	9.40%	26.40%	SK
SWBmk	2.97%	8.33%	SL
SWBmk	4.57%	12.85%	SS
SWBmk	1.12%	3.15%	SW
SWBmk	2.78%	7.81%	WA
SWBmk	0.32%	0.90%	WH
SWBmk	3.57%	10.03%	WM
SWBmks	0.00%	0.01%	AM
SWBmks	0.62%	6.95%	AW
SWBmks	3.36%	37.69%	BS
SWBmks	0.07%	0.81%	BV
SWBmks	0.15%	1.67%	CL
SWBmks	0.00%	0.01%	FE
SWBmks	0.01%	0.07%	KI
SWBmks	0.00%	0.04%	LA
SWBmks	2.04%	22.86%	MA
SWBmks	0.01%	0.09%	PL
SWBmks	0.03%	0.38%	RI
SWBmks	1.08%	12.15%	RO
SWBmks	0.02%	0.18%	SB
SWBmks	0.04%	0.50%	SH

SWBmks	0.33%	3.70%	SK
SWBmks	0.04%	0.48%	SL
SWBmks	0.10%	1.10%	SS
SWBmks	0.02%	0.18%	SW
SWBmks	0.02%	0.26%	WA
SWBmks	0.53%	5.99%	WM
SWBmks	0.44%	4.88%	WV

Appendix E. Muskwa PEM Expanded Legend.