Towards the Establishment of Predictive Ecosystem Mapping Standards: A White Paper

1st Approximation

March, 1999

Under the Auspices of and Prepared for —
Terrestrial Ecosystem Mapping Alternatives Task Force
Resource Inventory Committee (RIC)

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1. Introduction

This White Paper has been prepared by the Terrestrial Ecosystem Mapping Alternatives Task Force for the purpose of helping the forestry and natural resources community obtain a more complete understanding of Predictive Ecosystem Mapping (PEM) approaches to forest resource inventory and, under what circumstances these methods can serve as useful alternatives, or be supplementary to conventional Terrestrial Ecosystem Mapping (TEM) products. Predictive ecosystem mapping approaches represent the prevailing form of TEM Alternatives being used in BC and are the principal focus of the White Paper. We define PEM as follows.

> ***Predictive Ecosystem Mapping* — a computer, GIS and knowledge based method to stratifying landscapes into ecologically-oriented map units based on the overlaying of existing mapped themes and the processing of the resultant attributes by automated inferencing software using a formalized knowledge base containing ecological–landscape relationships.**

The White Paper puts forth a first approximation PEM Framework of the main components, elements, features and interim protocols when considering or applying these alternative TEM techniques. This document also advances a set of definitions and discusses important emerging directions in ecologically-oriented mapping as they relate to PEM methods. Through common understanding, feedback and the subsequent refinement of the White Paper, PEM standards will be put in place through the Resource Inventory Committee (RIC).

Initially, it was hoped that a set of PEM standards could be established for use in fiscal 1999-2000. However, upon more detailed study of the issues surrounding PEM methods, the setting of standards was more complex than originally envisioned and therefore, premature. It was also important that sufficient time be allowed for review of the information contained in this paper and the companion detailed studies by both the immediate and broader TEM and resource inventory community. Your views on the concepts, assumptions and criteria are important and need to be understood and incorporated prior to setting a more structured standard with procedures, criteria and measures. Finally, in light of the relatively immature state and limited experience with PEM systems and methods, it was felt that a reasonable level of flexibility should continue to be allowed to encourage further innovation. Over the next few months it is proposed that efforts be focused on outstanding issues and in testing the evaluation frameworks. The implementation of appropriate PEM standards remains nevertheless, an important final goal with this Task Force directive.

The White Paper first provides some background information in Section 2 on the preceding work that has been undertaken and the present circumstances that have led to the preparation of this document. The appearance of PEM techniques in conjunction with the present fiscal environment in the province has created a heightened awareness among many resource professionals to fundamental resource inventory questions and the need for a greater streamlining of these efforts.

In Section 3, we provide context for and a summary of PEM approaches, related trends and their implications to resource inventories now and in the future. We also provide a set of working definitions and look at some of the advantages and disadvantages when applying predictive approaches to TEM.

An overarching, 1st approximation PEM Framework is outlined in Section 4. The PEM Framework comprises five main components, each of which contain key elements, features and other important related items. The five inter-related components are —

1. Client Requirements Assessment,
2. Input Data Quality Assessment,
3. Knowledge Base Assessment,
4. Output and Reliability Assessment, and
5. QC / QA Procedures and Standards.

Components 2, 3 and 4 are the topics of three detailed supporting studies that have been completed and are available under separate cover —

- *Problem Analysis on Data Quality Assessment Issues* by Dr. David Moon, CDT–Core Design Technologies Inc.,
- *Situation Analysis for Knowledge-Based Systems* by Dr. David Moon, CDT–Core Design Technologies Inc., and
- *Problem Analysis on Reliability, Quality Control and Validation of Predicitive Ecosystem Mapping (PEM)* by Dr. Richard Sims, and Jeff Matheson, R.A. Sims & Associates.

Findings from these studies, together with the Client Requirements Assessment and QC / QA Procedures and Standards components, constitute the PEM inventory "system". The PEM Framework will serve as a guiding and integrated structure for understanding PEMs and for completing the development of standards and procedures.

Section 5 concludes the White Paper by putting forward a set of recommendations for putting in-place an appropriate PEM standard by December 1999.

This White Paper is a working document. It puts forth a summary of much of the present understanding of predictive approaches to ecosystem or ecologically-oriented mapping. It also sets forth some general technical and business directions that are evident at this time. Our collective understanding will naturally evolve and change as further experience is gained and through the broader engagement and contribution of ideas from the resources inventory community. Again, the TEM Alternative Task Force welcomes these views.

With this process, the White Paper will naturally change through a series of approximations that will be made available on the Internet. Every effort will be made to make the resource inventory and resource management community aware of its existence and to encourage dialogue. Please share and discuss these ideas with your colleagues.

For those individuals who have contributed their thoughts already, we express our appreciation.

2. Background

2.1 Task Force Activities

The TEM Alternative Task Force was instituted in December 1997 in response to the work of a "TEM and TEM Alternatives Project Steering Committee" (see Section 2.1.1 below). The TEM Alternatives Task Force was formed with representation from Ministry of Forests and the Ministry of Environment, Lands & Parks (Headquarters and Regions), and the forest industry. The TEM Task Force presently has the following members —

Fern Schultz	BC Ministry of Forests, Victoria
Del Meidinger	BC Ministry of Forests, Victoria
Dave Clark	BC Ministry of Environment, Lands & Parks, Victoria
Bobby Love	BC Ministry of Forests, Smithers
Rob Stewart	BC Ministry of Environment, Lands & Parks, Smithers
Bill Beese	MacMillan Bloedel, Nanaimo
Frits Nijholt	Weldwood, Quesnel

The objectives of the Task Force are to further coordinate the development, testing, and documentation of "alternatives to TEM" and Predictive Ecosystem Mapping (PEM) approaches. These tasks are important and necessary precursors for the development of Resource Inventory Committee standards regarding the use of PEM approaches.

2.1.1 TEM and TEM Alternatives Project Steering Committee

In November 1997, the TEM and TEM Alternatives Project Steering Committee released their report titled "A Business Approach to Terrestrial Ecosystem Mapping (TEM) and TEM Alternatives" (Biggs et al. 1997). The report identified the value of TEM in providing information on ecosystem identification and mapping, and also the need to develop alternatives to TEM to address cost and time issues.

The recommendations from the committee report included the need to finalize standards for TEM and establish standards for TEM Alternatives for ratification by the Resources Inventory Committee. Selected recommendations[1] pertinent to the White Paper include —

- TEM and TEM Alternative methodologies be piloted together and comparative costs, outputs, inputs and potential applications evaluated prior to the development or adoption of standards for TEM Alternatives;
- as part of the implementation plan for TEM Alternatives, standards be published and information and training be provided to clients;
- before enabling TEM Alternatives, an adequate infrastructure must be provided by the custodian. The custodian must provide support for: development of a business strategy for TEM and TEM Alternatives; development and piloting TEM Alternatives;

1 Only key items are included and some have been paraphrased. Square Parentheses [ ] are added interpretation.

overseeing and undertaking data conversion/standardization; and warehousing, quality assurance, maintenance and distribution of incoming TEM and associated [TEM Alternatives] databases (in part, so that there can be some province-wide capabilities for roll-up and analyses);
- there needs to be further work done on TEM Alternatives in terms of understanding their potential and documenting their strengths and weaknesses;
- clients must clearly articulate project objectives and the use to which the data will be put [implications to input data quality considerations with PEM methods and to the level of interpretive decision risk];
- document existing TEM Alternatives (PEM) methodologies and standards, evaluate TEM Alternatives pilots and refine protocols;
- decide on TEM Alternatives to pursue and conditions under which they can be used [criteria]; and
- develop client educational materials and means of delivery of these materials — publish standards, disseminate information and develop and deliver training on standards.

2.1.2 TEM Alternatives Task Force Workshop January 1998

A one-day Task Force Workshop held in January, 1998 focused on understanding, scoping and identifying issues and a feasible set of activities that could be accomplished by March 31, 1998[2] regarding the documentation, piloting and evaluation of existing TEM Alternatives. Figure 1 shows an approximate sequence of activities that were identified as necessary to address the full extent of activities recommended in TEM / TEM Alternatives Report.

With reference to Figure 1, the Workshop concluded that —

1. Not all TEM Alternatives (globally) have been identified and evaluated (item 1); some further investigation of other systems might be useful, guided by clear selection criteria (item A);
2. The TEM Alternatives reviewed in the November 1997 report need further characterization (item 4); some misinterpretations have been reported; a consistent comparative framework for describing the different alternatives would help emphasize similarities and differences more easily and evaluate what approaches are most suited to what applications (item B);
3. There are only a few candidate TEM Alternatives (item 2) that are sufficiently developed and tested at this time that would likely qualify for the Short List (item 3); a set of minimum mandatory (and preferred) features (items A & B) might include:
    - well-documented procedures and assumptions, and a repeatable methodology,
    - use of a standard database structure, with meta data, for data input and result output facilities,
    - capability to handle BC resource inventory data sets,
    - use of a reasonably transparent and understandable knowledge base structure; relationship information exportable,
    - capability to generate standard cartographic[3] and report outputs,

[2] In response (mainly) to Action Item #3 of the November 1997 RIC report titled "A Business Approach to Terrestrial Ecosystem Mapping (TEM) and TEM Alternatives".
[3] ARC/INFO compatible

- documented minimum field calibration procedures with directed field sampling strategy, and
- objective methods for post-map reliability checking and reporting;

4. Comparative pilot studies of different TEM Alternatives (item 5) (along with traditional TEM) will require field sampling and a carefully thought-out study design, including post-mapping, objective sampling procedure (item D) to determine reliability; due to field season limitations, these studies cannot be completed before March 31, 1998;
5. Some TEM Alternative projects that have been completed, are presently in progress or are being planned might be augmented so that the results will contribute more directly to: completing the documentation of methodologies (item 4), structuring the evaluation framework (item B), and assessing alternative test locations (item C); and
6. An example operational inventory program Decision Tool (item 9) used in the Prince Rupert Region (draft) illustrated how different interpretive needs or issues can be assessed in terms of factors like nature of resource management issue, urgency, cost, existing inventory availability and inventory method and/or focus (see Appendix A).

2.1.3 PEM Activities 1998-1999

Following the initial work of the TEM Alternatives Task Force, a number of activities have transpired that are helping to address the recommendations from the TEM and TEM Alternatives Project Steering Committee report as well as issues and requirements identified in the TEM Alternatives Task Force workshop. Regrettably, due to time and budgetary constraints, not all issues have been addressed as fully as was hoped. As feasible, it was decided that the TEM Alternatives Task Force would work toward developing a general set of requirements for PEM models in areas such as data output formats, knowledge base documentation, evaluation criteria for TEM and TEM Alternatives, data preparation and edit, and infrastructure requirements to manage knowledge bases.

Fortunately, despite present fiscal restraints, a number of objectives have been introduced or appended to existing forestry initiatives such as the Enhanced Forest Management Pilot Projects (EFMPP) and Innovative Forest Practices Agreements (IFPA) programs. As well, a number of other related on-going activities are being followed and in some cases guided by the Task Force (please see Clark, 1998 for further details).

In June, 1998, the Standard for Terrestrial Ecosystem Mapping was updated and approved by RIC. This standard defines six options for mapping at scales between 1:20,000 and 1:50,000, characterized by the density of field inspections. The previous standard, suitable for landscape planning, is maintained as Level 4 (minimum of 1 field inspection per 100 hectares at 1:20,000). Two levels of lower survey intensity are presented as Level 5 and Level R (reconnaissance). Full characterization of the six Survey Intensity Levels is presented in Table 6.4 of the Standard for Terrestrial Ecosystem Mapping in BC (May 1998). The Standard for Terrestrial Ecosystem Mapping, is available at the following web site —

http://www.for.gov.bc.ca/ric/Pubs/teEcolo/tem/indextem.htm

A decision table was developed at the same time as a first approximation guide for resource managers and TEM proponents in deciding whether to use TEM or one of several TEM Alternatives for a given inventory requirement. This decision table is provided in Appendix B.

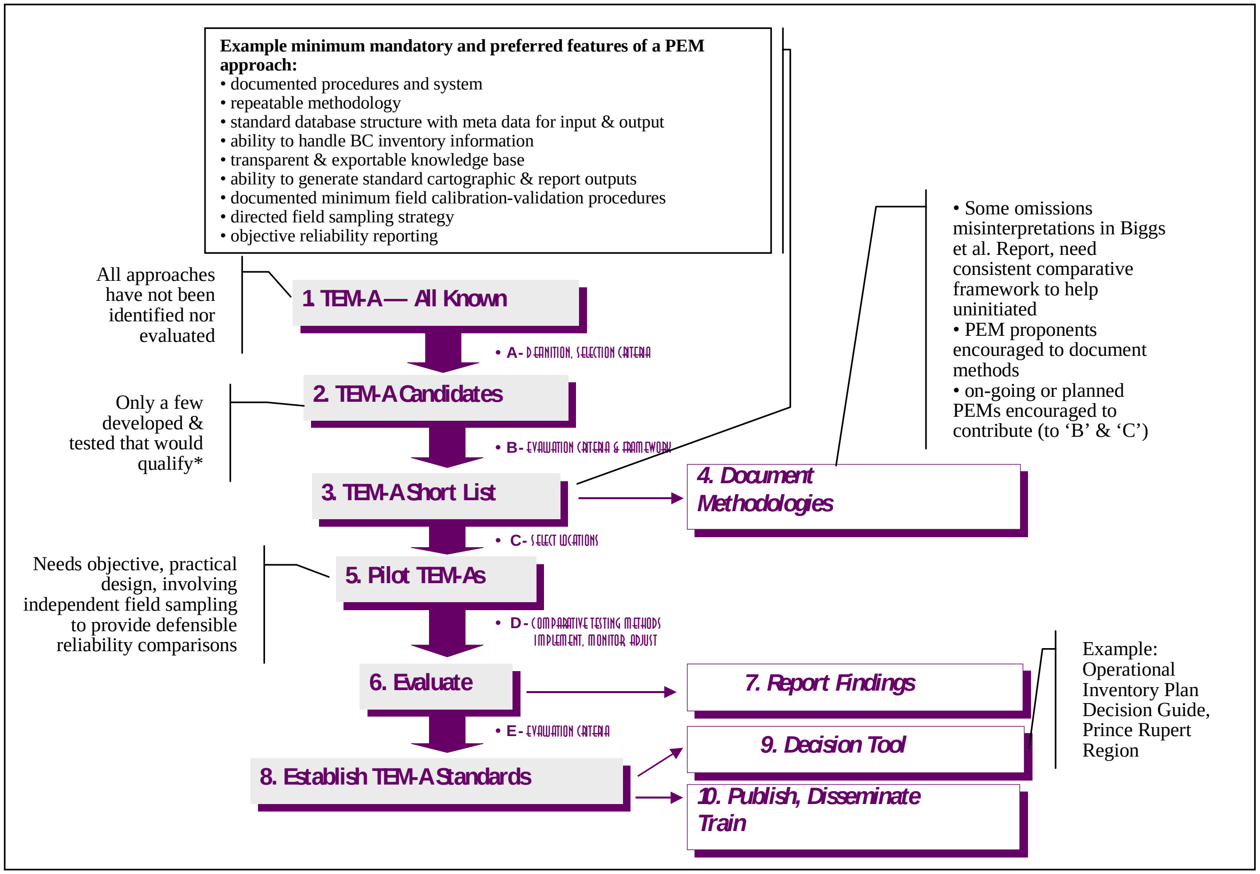

Figure 1. Workshop summary of TEM Alternatives Task Force, January 1998 (TEM–A means Terrestrial Ecosystem Mapping Alternatives).

2.1.4 Development of Predictive Ecosystem Mapping Framework to Support the Development of Standards

This present initiative[4], including this White Paper, has been focused principally on Predictive Ecosystem Mapping approaches in terms of —

- their continued but more structured evaluation,
- their future role in the TEM inventory program, and
- the formation of a PEM framework, principles with interim protocols and checklists as a basis for establishing PEM standards[5].

Specific objectives for this latest phase of the Task Force effort comprised three main components as outlined below (see also Figure 2). Components A and B4 were undertaken mainly by a Secretariat Team[6] on behalf of the TEM Alternatives Task Force. Component studies B1, B2 and B3 were coordinated by the Secretariat Team but were otherwise accomplished through the use of two expert consultants in these fields.

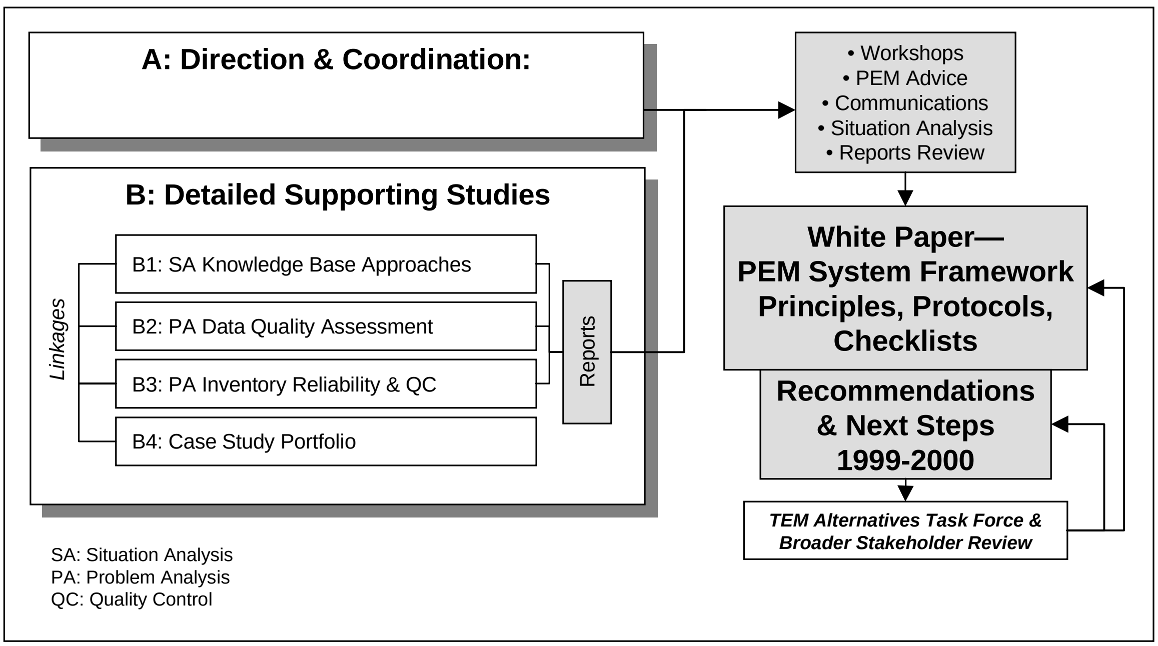

Figure 2. Development of Predictive Ecosystem Mapping System Framework, Principles, Protocols and Checklists to Support the Development of Standards.

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[4] Originally titled "Evaluation, Role & Development of Standards for Predictive Ecosystem Approaches to Terrestrial Ecosystem Mapping" (October 1998). For brevity the original objectives 'A' and 'C' have been merged.

[5] As noted in the Introduction, the original intent was to develop PEM standards, however this proved to be premature at this time.

[6] Dave Clark, Del Meidinger, Fern Schultz and Keith Jones

The objectives for this present initiative were —

A. **Direction & Coordination** — to coordinate a set of detailed supporting studies and create a forum for a more integrated TEM and TEM Alternatives program by developing an overarching PEM framework; establishing a set of guiding principles, interim protocols and checklists; and, preparing an evolving "White Paper" that brings many of these elements together. These coordinating functions, framework tools and White Paper are to help provide overall direction and guidance for managing PEM developments and PEM-based inventory projects during this transition period prior to the establishment of PEM standards. Serving as a form of transitionary "standards", the framework will aim to provide an understanding and structure to the present circumstances, while at the same time offer reasonable flexibility for continued evolution and innovation.

B. **Detailed Supporting Studies** — to undertake detailed supporting studies and integrated into this White Paper (A), to help establish a more thorough understanding and foundation for key components of a future TEM and TEM Alternatives inventory program. The detailed studies undertaken were —

B1. **Situation Analysis of Knowledge Based Systems** undertaken by David Moon of CDT–Core Decision Technologies Inc.

1. Identify, review and describe different types of knowledge base strategies and systems in the context of current PEM methods and other related modeling approaches. Include consideration of degree of integration (as a system), enabling technology, correlation function, version control, spatial and aspatial nature, temporal (successional) nature, import, export, update, transparency, allocation and logic tracing, etc.
2. Conduct interviews with current PEM developers and key government and industry information system staff regarding their thinking on present and future directions with the storage, access and sharing of knowledge (relationship information, models) in the broader context of corporate information systems, public access, public-private sector knowledge exchange
3. Undertake comparative analysis of findings: advantages, disadvantages, assumptions, implications, technology status, transparency, flexibility, adaptability, availability, enabling technology requirements, etc. Address what implications these findings might have on current and future PEM and TEM Alternatives standards.
4. Address relationships with task series B2 & B3; participate in coordination meeting among contributors in late January or early February, 1999.
5. Prepare final report and present findings to Secretariat Team by March 1, 1999.

B2. **Problem Analysis on Data Quality Assessment Issues** undertaken by David Moon of CDT–Core Decision Technologies Inc.

1. Describe and assess available input data types (annotated data dictionary, meta data overview) in relation to their use in PEM mapping; consider potential data overlaps or data redundancy.

2. Describe and assess data output requirements into various corporate (geographic) databases, textual output reporting formats and statistics, screen display views and hardcopy cartographic products, all in the context of PEM mapping approaches; consider output overlaps or redundancies.
3. Establishment of an initial set of pre-inventory (input) assessment guidelines in the use of PEM tools and how particular input gaps might be addressed more efficiently.
4. Address relationships with task series B1 & B3; participate in coordination meeting among contributors in late January or early February, 1999.
5. Prepare final report and present findings to Secretariat Team by March 1, 1999

B3. **Problem Analysis on Inventory Reliability, Quality Control and Validation** undertaken by Richard Sims of RA Sims and Associates

1. Identify (update), describe and review alternative methods for assessing land resource inventory map reliability in relation to quality control procedures and with respect to field and knowledge base calibration/validation methods used in both PEMs and conventional TEM. Include consideration of more recent studies and approaches used in the current PEM projects (e.g., Geomatics International study noted in Section 1.4 item #3).
2. Undertake a comparative analysis of findings: advantages, disadvantages, trade-offs and practical considerations (e.g., access, cost, rate of production), objectivity, sampling-stratification considerations, comparability of results, risk associated with incorrect interpretations or decisions being made, etc.; identify any unresolved issues relative to PEM.
3. Establish a set of alternative map reliability procedures, including a standard terminology, that addresses different classes of interpretive requirements (decision risk), recognizes practical field logistics, and incorporates these activities such that they are integral to the entire mapping, sampling, database development and reporting (tabular and map) process.
4. Address relationship with task series B1 & B2; participate in coordination meeting among contributors in late January or early February, 1999.
5. Prepare final report and present findings to Secretariat Team by March 1, 1999.

B4. **Compendium of Predictive Ecosystem Mapping Case Studies**[7].

[7] Case studies are under development at this time.

2.2 Summary of Current Situation

2.2.1 Predictive Ecosystem Mapping

Over the past few years, predictive ecosystem mapping approaches to resource inventory have come on the scene as an alternative to more conventional mapping and classification methods such as Terrestrial Ecosystem Mapping. This PEM information, as with TEM, is purported to support a wide range of resource planning needs ranging from broad-level planning such as Land and Resource Management Plans at a regional level to more detailed applications such as determining silvicultural options at the stand level. PEM initiatives, tested in different parts of the province and with varying techniques, have been driven by the need to obtain TEM-like information for more geographically extensive areas, more readily and more cost-effectively. With respect to inventory support, there has been a significant reduction in Forest Renewal BC funding for resource inventories over the past year. Lower funding levels remain and may be reduced further. This financial reality has created a stronger interest across the range of inventory stakeholders in understanding the potential of PEM approaches even more.

As noted in the Biggs et al. report (1997), it is felt that PEM approaches may have the potential to serve some of the needs being met by conventional TEM or other related map products. This situation has caused some degree of perplexity and confusion across the resource inventory community including — the main funding and technical oversight agencies (Forest Renewal BC, Ministry of Forests, Ministry of Environment, Lands & Parks); the TEM or PEM map providers; and the primary and secondary users of TEM or PEM products. Central to these PEM concerns and the opportunity are the following needs.

1. *From the client* (not only the TEM-PEM providers) — a clear articulation of the inventory requirement (specification).
2. *From the client* — a determination of a minimum reliability level that the inventory information should achieve, given the purpose of the inventory ('1').
3. *From the oversight agencies* — formulation of a mapping standard (procedures) that ensures the delivery of a product consistent with '1' and '2'.
4. *From the funding and oversight agencies* — defensible investment in inventory initiatives that provides good value for their intended purpose.

Figure 3 summarizes some of the key questions related to these needs from the perspective of primary and secondary users, the technical oversight agencies, the map providers and the funding agency. These needs and questions are central to the establishment of a standard, yet flexible, set of PEM mapping procedures which yield products of stated and acceptable reliability. These requirements are much the same for conventional TEM and many other inventory initiatives. The introduction of PEM techniques within the present fiscal environment however, has created a heightened cognizance of some fundamental resource inventory questions, many germane to the establishment of appropriate standards — interpretive purpose, reliability, quality, consistency, value, flexibility, extendibility, adaptability, training, capacity, inputs, analysis, outputs, storage, access, and sharing.

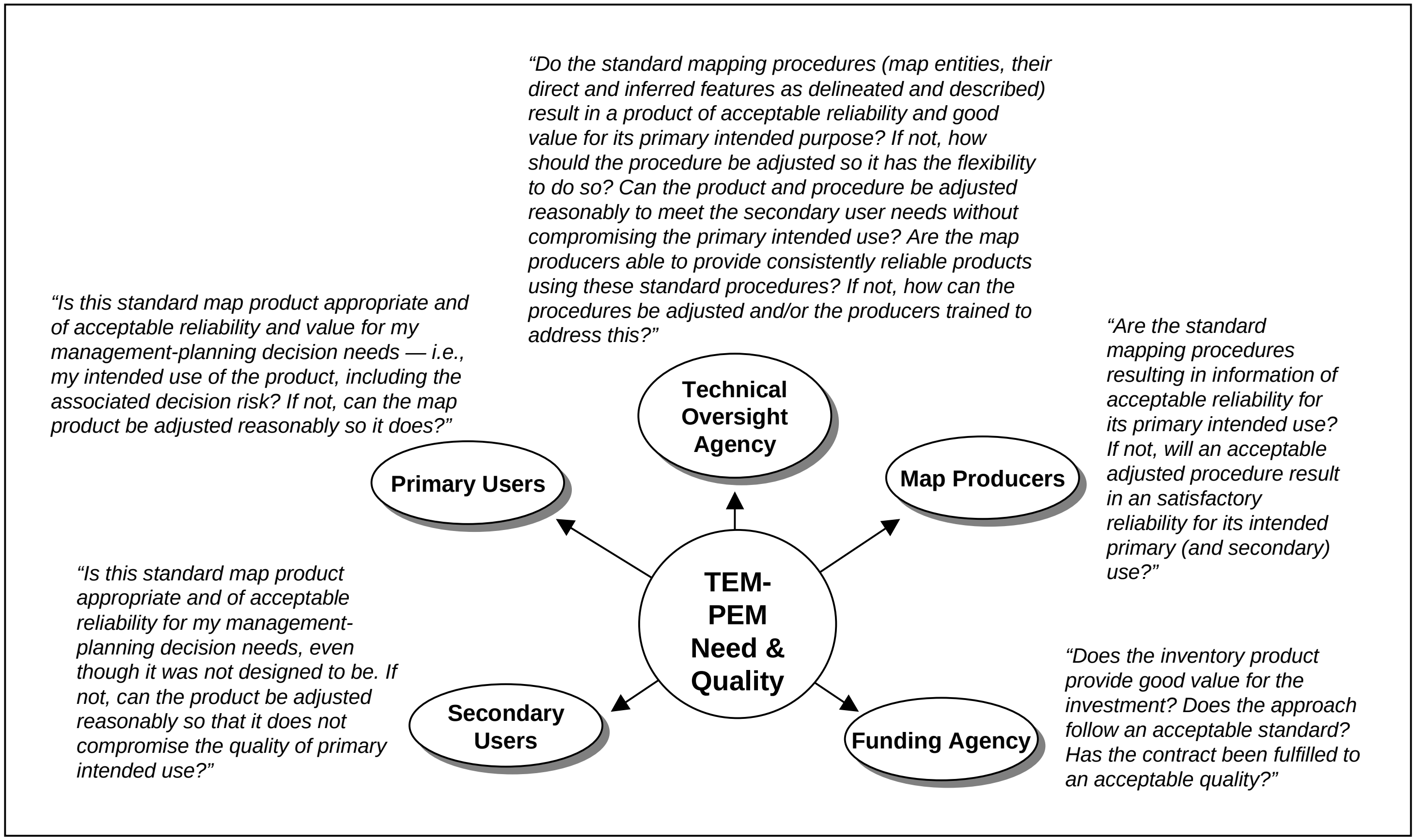

Figure 3. Key questions about TEM-PEM product need and quality from the perspective of primary and secondary users, technical oversight agencies, map providers and funding agency (modified after Sims 1999).

2.2.2 Broader Resource Inventory Rationalization

As mentioned above, the appearance of PEM techniques in BC in conjunction with the present fiscal environment has created a increased attentiveness among some to fundamental resource inventory questions. Having just come off a large pulse in inventory spending, many users, providers and resource agency staff are struggling with how to best handle the continued information demands to deal with the increasing complexity of contemporary resource management policies, regulations, guidelines, etc.

While ecologically-oriented resource inventories and planning approaches are far from new in British Columbia, it is evident that there is a growing need, and opportunity, to streamline existing efforts across the forestry and natural resources sector[8]. Done in a rational manner, this process should lead to greater efficiencies in many individual inventory activities. It should also provide natural resource managers with more focused access to the most appropriate and current forest and related land information for their decision and planning requirements. Such a rationalization process is seen by a number of knowledgeable professionals to be technically feasible and desirable. But, at the same time it is recognized there are institutional and cultural barriers equally as important to overcome.

Rationalizing and streamlining BC's resource inventory program is timely for a number of reasons, including —

- current government fiscal realities and the need to increase efficiency and reduce inventory overlap,
- changes in thinking from conventional timber inventory to the broader Vegetation Resource Inventory and its relationship, in turn, to Terrestrial Ecosystem and Bio-terrain Mapping objectives,
- a readily aging government demographic profile in which many experienced staff in resource inventory have left the public service or are soon to do so, and the need therefore, to capture and manage this limited and specialized knowledge,
- the advancement of a number of PEM techniques such as those reviewed by the Ministry of Environment, Lands & Parks (Clark 1996, 1997) and Biggs et al. (1997),
- the requirement across many natural resources and environmental sectors for sustainable, ecologically based management planning and the need for appropriate biophysical information to support these types of planning and business decisions,
- the growing geographic extent of GIS databases for many primary inventories, particularly TRIM and forest cover information,
- the increased use of computer-based modeling tools, particularly those with spatially explicit forecasting and assessment capability and their concomitant need for comprehensive multi-resource and multi-value primary input databases, and
- the maturity of corporate information systems, especially as they are able to facilitate greater data, information and knowledge sharing across government and private sector organizations.

Integral to any rationalization process should be the recognition that both resource inventories and resource planning processes are evolving from being relatively static and subjective processes to procedures that can be more dynamic and explicit. Further, this changing information and planning environment means that resource inventories are able to be more

[8] These perspectives have been gained in part from a Cursory Situation Analysis conducted as a part of the "Direction & Coordination" work outlined earlier in Section 2.1.4.

incremental, iterative and adaptive, relative to the financial and information resources available and the specific interpretative requirements of the resource manager (see Figure 4). Similarly, knowledge base tools ranging from simple spreadsheet procedures to more sophisticated expert systems, allow resource inventory and interpretive specialists to capture, apply and protect relationship knowledge and experience more objectively and consistently to land resource information across potentially large land areas.

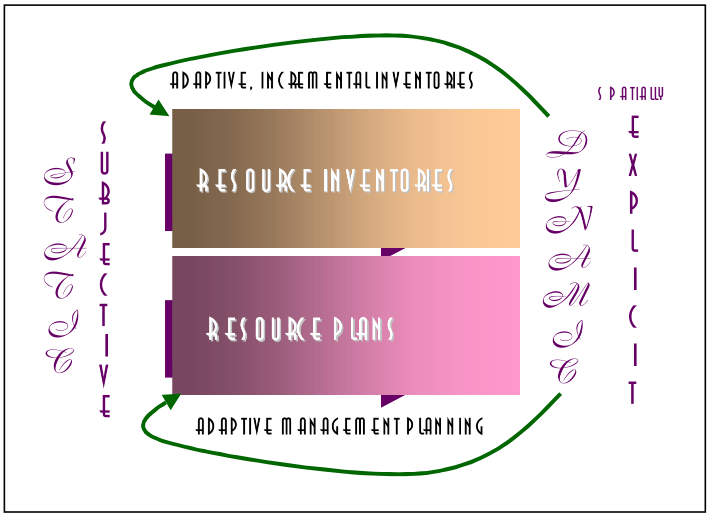

Figure 4. Ecological inventories and resource plans need to be flexible, explicit and be able to adapt to rapidly changing conditions and technologies.

Presently there are at least two proposals within government to review, document and rationalize the present inventory programs in BC —

- the formation of a "Forest Resources Inventory Council (FRIC)" being advocated by the Ministry of Forests and Ministry of Environment, Lands & Parks, and
- a "Corporate Inventory Assessment and Evaluation" proposed by the Land Use Coordination Office.

Proposed Forest Resources Inventory Council[9]

The proposed FRIC initiative has been advanced largely as a result of the findings of the April 1991 report of the Forest Resources Commission titled "The Future of Our Forests". This Commission found the current state of BC's resource inventories "woefully inadequate" and "fragmented and inconsistent". The Commission recommended that all inventories be standardized using compatible systems and that they should satisfy the needs of the resource user groups and be accessible. In response to the latter point, the Resource Inventory Committee was formed in the same year.

[9] Based on Terms of Reference, March 1, 1998.

Of particular interest to this White Paper, the Commission recommended that a common framework be developed to support all data essential to planning. To achieve these changes, it was further recommended that there be a complete redesign of how inventories of resources in BC are conducted.

FRIC's Vision is: cost effective, consistent and statistically reliable measurements of the quality, quantity, location and rate of change of the full range of BC's forest resources[10] required to meet strategic resource management objectives and ensure the sustainability of the forests.

Corporate Inventory Assessment and Evaluation[11]

This project proposal has been submitted to the Corporate Resource Information Initiative (CRII) for support in fiscal year 1999-2000. The project has two main objectives: 1) to review and document the current provincial delivery system of resource inventories, and 2) to undertake an analysis of this information and develop a number of recommendations to improve delivery in an environment of decreasing funding. With decreased funding levels, yet increasing information needs, existing systems need to be evaluated for their effectiveness, degree of duplication of effort and potential cost savings.

[10] Inventories of resources and values associated with forests and range including, without limitation, timber, water, wildlife, fisheries, recreation, botanical forest products, forage and biological diversity.
[11] Information provided by Don Howes, Manager, Land Inventory and Information, Land Use Coordination Office.

3. Predictive Ecosystem Mapping Approaches

3.1 The Resources Inventory Paradigm Shift

Conventional resource inventories, as we have known them for decades, are undergoing both a technical and business model paradigm shift[12]. The technical evolution is being driven by new capabilities for acquiring, processing, integrating and sharing resource information and knowledge digitally. It is enabled by various technologies like remote sensing, image processing, GIS, knowledge based systems and information networks. These changes are also occurring in response to new information demands of inventories on questions related to sustainability, ecosystem health and integrity and multi-scale, multi-rotation forest and environmental processes. The enabling technology suites of the emerging paradigm are allowing ecologists, natural resource specialists and resource managers to think of and work with information and knowledge in new ways that are less bounded necessarily, by classifications and traditional mapping conventions. At the same time, these analysis and modeling techniques provide a means to capitalize-on and lever much of our existing classification and mapping knowledge. Table 1 (top portion) compares and summarizes some of the key attribute features of the technical paradigm shift we are amidst.

Concurrent with the technical paradigm shift, we are also witnessing changes to long-standing inventory functions and business models. For example, over the last decade there has been change from timber-focused inventories to broader vegetation mapping programs[13]. There is also a trend towards greater data and information integration across inventory programs. Organizationally, the formation of the Resources Inventory Committee in 1991 was an important step in establishing standard inventory methods. With the present fiscal environment, a number of people are now looking at further opportunities for gaining efficiencies and greater information integration, guided by oversight bodies such as the planned Forest Resources Inventory Council noted in Section 2.2.2. The bottom half of Table 1 provides a comparative summary of some of the key attribute features of the business model paradigm shift we are witnessing with inventory institutions.

Clearly there is a broader opportunity over the next few years to synchronize these changing technical and business processes so that future resource inventories are strongly driven and specified by the business needs of the client while at the same time be organized within a broadly integrated inventory and information framework. This framework should be flexible, dynamic and multi-scale. It should also be designed so it is accessed easily, is network distributed, well-documented and indexed. It should be "filled" incrementally in relation to client priorities and the resources available.

[12] The term "paradigm" follows Kuhn's (1970) definition which refers to a broad explanatory concept that provides a foundation and structure for an entire field of scientific inquiry. In this instance, we are applying this concept to the technical and business approaches to ecological and other related resource inventory programs. Hudson (1992) discusses this use of paradigm for the case of soil survey.
[13] Some still feel that the vegetation features could be improved further however.

Table 1. Comparative summary of technical and business model features of resources inventory paradigm shift.

EXISTING and/or OLDER PARADIGM	EMERGING & FUTURE PARADIGM
Technical Evolution Features	
• Analog, static, rigid, inconsistent, inexplicit	• Digital, dynamic, revisable, consistent, explicit
• Classification-oriented	• Continuous-oriented
• Interpreted data-oriented — classes, ranks…	• Primary data oriented
• Polygon-oriented, scale inflexible	• Polygonization as required, scale flexibility, aggregation–decomposition capability
• Integrated entity concepts • Focus on classification sometimes over purpose	• Primary component inventories, less conceptual • Derivation & integration through modeling
• Expert dependent knowledge	• Knowledge capture & sharing, accelerated learning
• Field data intensive	• More “remote” data acquisition, directed field effort
• Discrete entity-oriented (polygon or class-based) interpretation	• Discrete & process-oriented (causal), spatially-explicit interpretations via modeling
Business Evolution Features	
• Large, expensive, inflexible, regular cycle, general purpose	• Priority focused, cost-effective, flexible, targeted as required, iterative, incremental
• Commodity focused (e.g., timber), single users	• Commodity and process oriented, multiple & some unknown users
• Long, onerous multi-year processes	• Short turn around from acquisition to interpretation
• Limited integration, overlap across agencies	• Integration across public, private & NGO organizations
• Learning through personal apprenticing	• Learning via captured, shared & managed knowledge
• Inventory for inventory sake in some cases	• Directed purpose-driven inventories & interpretation products
• Unique databases, not easily shared or distributed	• Common, shared, well-documented & distributed databases
• Fragmented, varied standards and quality	• Common but flexible standards, known reliability

3.2 Predictive Ecosystem Mapping Approaches

3.2.1 Introduction

Ecological classification systems provide a framework to organize and communicate our knowledge about the nature of physical and biotic features of landscapes. The fundamental premise is that future responses of forestland to management activities and natural events can be predicted — i.e., that similar forestland conditions respond in a similar manner to similar practices. Virtually all ecological land classifications (ELC) are built around the concepts of soil formation by Jenny (1941) and vegetation formation by Major (1954). Soil, vegetation, or ecosystem entities integrate the combined effects of climate, relief, parent material, organisms and time and function as meaningful entities in themselves, suitable for classification and interpretation (see upper portion of Figure 5). Classifications can also be considered the science of defining subsets of the universe in which a given process or processes act in a common manner (Williams 1988).

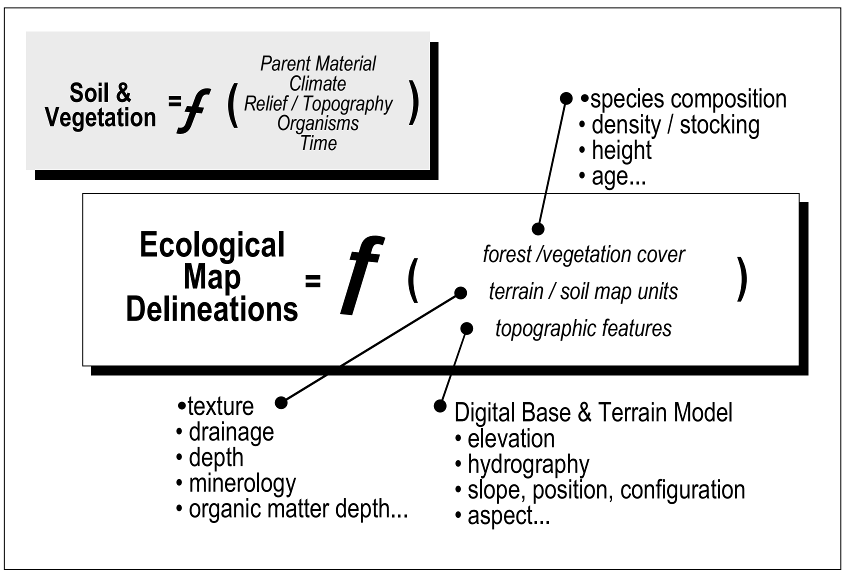

Figure 5. Ecosystem classification and current predictive mapping approaches are founded on analogous concepts of integration.

Predictive ecosystem mapping is an approach that stratifies the landscape into ecologically-oriented map units on the basis of combinations of existing mapped features, point information and knowledge about ecosystem–landscape relationships and their distribution pattern. In essence, many of the present PEM approaches take the concepts of Jenny and Major and apply them in a mapping context (see bottom portion of Figure 5). In other words, just as we approximate ecosystem types on the basis of relatively homogeneous landform–soil and vegetation features, we can likewise approximate ecological map delineations on the basis of the combined evidence of spatial themes like forest–vegetation cover, terrain–soil map units and derived topographic features from digital terrain models.

Within the context of the changing inventory paradigm described in Section 3.1, predictive ecosystem mapping approaches represent one expression of these next generation tools focused on characterizing ecological conditions locally and across larger landscapes (Jones 1993). PEMs have the potential to assist resource managers with the mapping of ecological conditions over extensive geographic areas using strategies that are consistent, explicit and dynamic (Jones 1993).

Existing ecological land classification systems represent a set of hypotheses about what we have observed about different ecological properties and how ecosystem entities are organized and related within a particular region. Ecosystem and other resource inventory maps (including legend information) similarly portray a set of hypotheses about how ecological conditions are distributed spatially across a map area. Consistent with the concept of dynamic resource inventories, PEM processes use, test and generate these classification (aspatial) and map (spatial) delineation hypotheses. On the spatial side, these processes can work with discrete polygonal input data sources or with more continuous raster or grid based input data sources.

Typically, we use an existing ecosystem classification system as an initial start — i.e., set of working hypotheses — for defining the predictive attributes and values of any already mapped land resource features such as species composition from a forest cover map or soil material from a soil map. When these mapped features are processed, by polygon or grid cell records, through the PEM knowledge base, they are assigned a likelihood of membership (a prediction) to an ecological class. Some polygons or grid cells may not be assigned because of shortfalls in either the source input map data or with the knowledge base — e.g., oversights during the creation of the knowledge base or true mapped feature combinations that represent “holes” in the existing classification. Whatever the case, PEM processes provide a mapped feature-oriented approach to testing and refining ecological land classification systems. With more objective analysis of geographically referenced information, they also can lead to new knowledge of the landscape complex being managed. They can also provide inventory and natural resource specialists with greater insight into some of the more important and controlling biophysical processes that work within and across these various nested geographical hierarchies — biogeoclimatic units, watersheds, physiographic regions, etc.

3.2.2 Definitions—TEM Alternatives & PEM

Paralleling the recent TEM thrust over the last few years, a number of specialists throughout the province and elsewhere have been investigating several similar but alternative approaches to this form of inventory. In using the term “alternatives” therefore, we have meant alternatives to the present standard and procedures for undertaking a TEM inventory project — i.e., the RIC TEM standard (RIC 1998).

The present TEM standard follows closely the union of two mapping methodologies used in BC (Mitchell et al., 1989 and Demarchi et al. 1990 as cited in Banner 1996). These approaches in turn have drawn upon and integrated a number of long-standing classification and mapping concepts and conventions that stem back to the Biogeoclimatic Ecosystem Classification (BEC) program of the BC Ministry of Forests (e.g., Krajina 1969, Pojar et al. 1987, and Meidinger and Pojar 1991), the biophysical classification and mapping program of the Ministry of Environment, Lands & Parks and elsewhere in Canada (e.g., Hills et al. 1973, Lacate 1969, Demarchi et al. 1990) and the Canadian Soil Survey program (e.g., McKeague 1976, CSSC 1978, ECSS 1987).

These alternative approaches for the most part have attempted to provide a TEM-like map product in that they have aimed to provide clients with an ecosystem inventory of biogeoclimatic units and site series (and often structural stage), but without having to undertake the full set of RIC TEM procedures. The reason for investigating these alternatives has been driven largely by an interest in reducing TEM inventory costs and in addressing a shortfall in mapping capacity in the market place, particularly when funding and demand for these inventories was high. The shortfall in capacity was also creating a concern that quality TEM products could not be delivered within a timeline to meet demand (see Biggs et al 1997 for further details). Since the preparation of the Biggs et al. report, both funding (and demand) for TEM has declined.

Predictive ecosystem mapping approaches represent the prevailing form of TEM alternatives being used in BC. There are other alternative forms that are not map focused. For example, the Operational Adjustments to Site Index (OASIS) approach uses an objective sampling method that allows for an apportioning of site series over the region of sampling.

With the above discussion as background, the following working definition is advanced for TEM Alternatives —

> ***TEM Alternatives:*** **alternative procedures to the RIC Terrestrial Ecosystem Mapping standard, that produce inventory or information products with similarities to TEM products or that provide similar interpretive value.**

TEM Alternatives are normally aimed at reducing inventory costs over traditional approaches. TEM Alternatives can include a wide range of techniques from annotation of existing single map inventories using supplementary point, mapped, relational or inferential information to more substantial predictive ecosystem software modeling systems. Predictive Ecosystem Mapping methods are a form of TEM Alternative and are the principal topic of this White Paper.

The following working definition is advanced for predictive ecosystem mapping —

> ***Predictive Ecosystem Mapping:*** **a computer, GIS and knowledge based method to stratifying landscapes into ecologically-oriented map units based on the overlaying of existing mapped themes and the processing of the resultant attributes by automated inferencing software using a formalized knowledge base containing ecological–landscape relationships.**

PEM tools cover a wide range of techniques from GIS overlay with informal interpretation and adjustment of relationship information to detailed, automated analysis of digital elevation models, images and directed polygon aggregation techniques — i.e., many of the technical features listed in the right hand column of Table 1.

3.2.3 The TEM & PEM Spectrum — Is It Necessarily an Either/Or?

Figure 6 illustrates the spectrum of ecosystem mapping approaches ranging from simple re-interpretations or enhancements of a single inventory theme (bottom of the triangle) to highly intensive site-specific or on-site field and mapping efforts (top end of the triangle). Each of the approaches across this spectrum has strengths and weaknesses, as annotated on the figure and discussed briefly below. The four core approaches in the spectrum are described below (modified after Downing et al. 1998).

Single-theme inventories — Single-theme inventory approaches are unable to reveal much information about the finer details of ecological structure. A pure pine stand on a dry south-facing slope, for example, is the same as a pure pine stand on moderately drained undulating till based on forest cover overstory characteristics alone, but site conditions, and hence stand growth potentials and probable successional pathways, are markedly different. While this approach is inexpensive, it may not be particularly cost-effective if it provides ambiguous ecological information.

GIS Overlay & 'If-Then' Logic — Approaches based on a GIS overlay of existing information (e.g., a forest cover map and a slope/aspect coverage) and the subsequent application of "if-then" logic are practical if the classification rules are simple and the total number of attributes being assessed is small. However, these approaches rapidly become intractable as information complexity increases. For example, consider a conditional logic scheme to identify five different ecosystem types using three different cover classes for five key overstory species and fifteen different slope and aspect combinations. This scheme would require at least 225 if-then statements to cover the range of possible combinations in a most detailed (worst) case situation. Moreover, every time the classification changes, the logic statements would have to be modified, and assigning an explicit probability to a prediction is difficult.

Predictive Ecosystem Mapping —Broadly speaking, most PEMs involve aspects of all of the above approaches. PEM, as a form of TEM Alternative, combines some of the elements of conventional ELC, such as field checking and the involvement of expert ecologists, along with some of the elements of single-theme approaches or simple GIS overlay approaches.

Standard TEM — Standard TEM approaches can provide a good quality landscape stratification for both timber and non-timber resources. The method is based on photo-interpretation and considerable field checking. The quality of the TEM product is highly dependent on the expertise and experience of the mapper. This type of inventory is, however, relatively expensive and can take considerable time to complete properly. Once a mapping project is underway or completed, changes to the mapping model criteria are difficult and expensive to deal with. Applying consistent mapping approaches across a map area are a continual quality control and correlation challenge.

As mentioned above, the various PEM methods being tested and used in BC are focused on modeling site series or ecosystem units using existing digital inventory sources such as forest cover, Vegetation Resources Inventory (VRI), topography (TRIM), biogeoclimatic, and/or terrain, with a minimum of additional field sampling or verification.

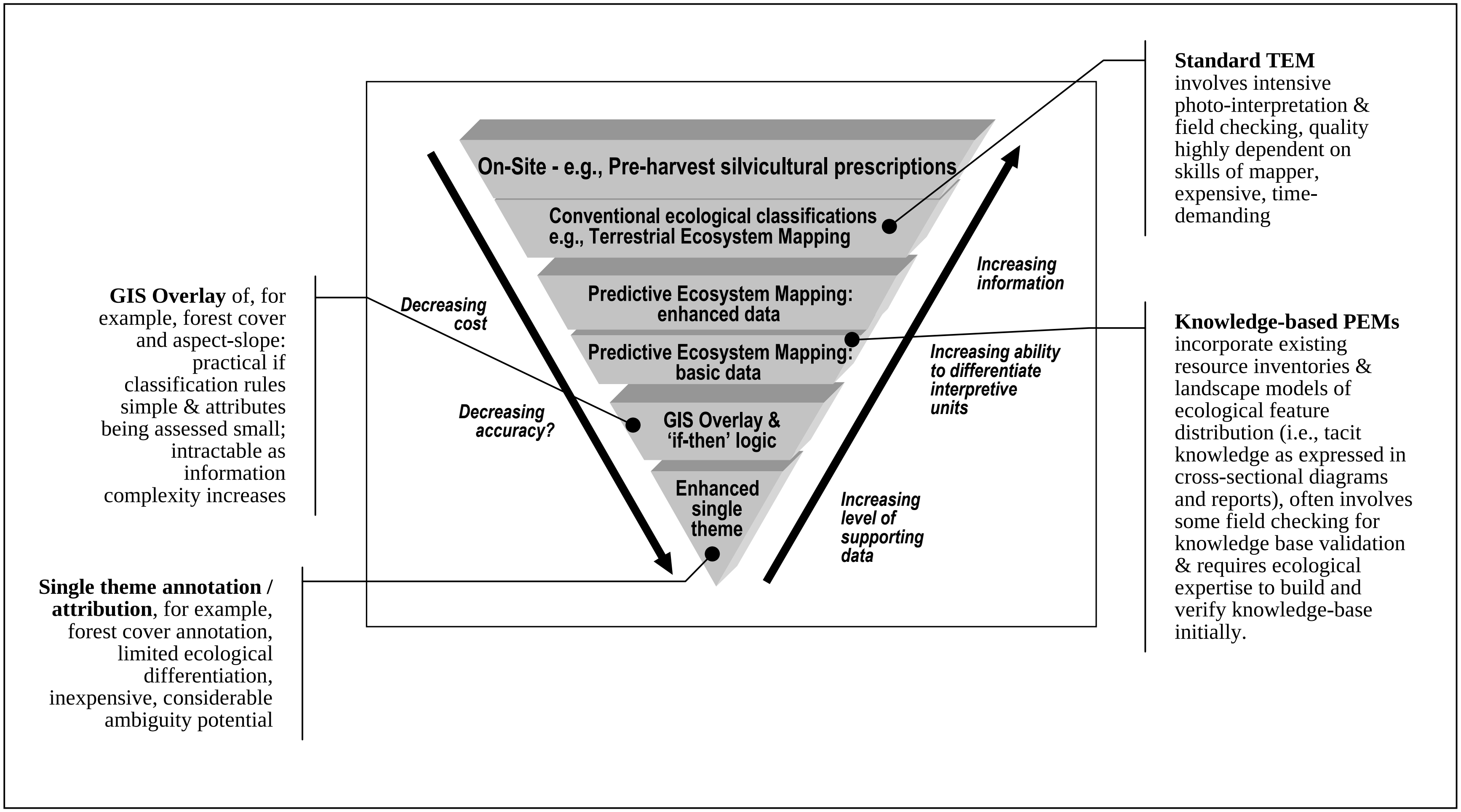

Figure 6. Spectrum of ecological mapping approaches ranging from simple re-interpretation of single themes inventories to intensive on-site methods (modified after Downing et al. 1998).

PEM methods can be consistent with and complementary to traditional TEM procedures. Undoubtedly however, there may be trade-offs between cost, resolution and accuracy. These trade-offs must always be measured against the intended use of the information. PEM inventory systems by their very nature can provide greater consistency with mapping protocols and also offer the potential for increasing production rates and building capacity. They also have the potential, by virtue of being digital, to become a more integral and amendable component of corporate information and knowledge base systems. Over time, PEM approaches and conventional TEM methods will likely converge in the form of a more integrated and flexible set of RIC TEM standards (see Figure 7). Section 5 discusses these options further.

In light of these potential PEM benefits, the opportunity for broader resources inventory rationalization and corporate information directions, **it is probably appropriate to think of PEM approaches as some of the digital building blocks of an integrated resource inventory and information framework and system.** They have the potential of providing the incremental steps towards a more enduring characterization of the land base, particularly for the more permanent physiographic elements that control many physical and biological phenomena — e.g., landform-terrain-soil facets (MacMillan and Pettapiece 1997, 1998).

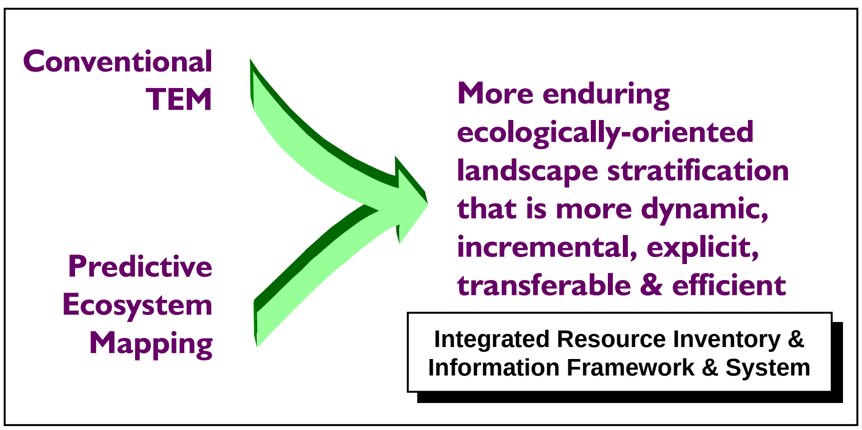

Figure 7. Over time, PEM approaches and conventional TEM methods will likely be complementary and converge in form.

With reference to Table 1, it is important to note that most PEMs being used in BC do not have all of the technical features listed on the right hand column of the table. Some PEMs are working towards having some of these features. Table 2 provides a brief summary of some of main features of PEMs being used in BC. Most of the current PEM approaches bridge the old and the new resource inventory paradigms (see Figure 8). In this respect, they have been designed to capitalize on the existing and older inventories and their associated knowledge representation systems (e.g., classification field guides, map legends, map labels, reports), while taking advantage of more structured and automated inferencing tools (e.g., expert systems), GIS databases and GIS overlay functions. In other words, **the present generation of PEM tools focus on translating existing classification strategies, mostly in analog form, into more structured and explicit knowledge-base tools.** The essence of most of the "knowledge" that is stored is about class property relationships (e.g., relationships between vegetation,

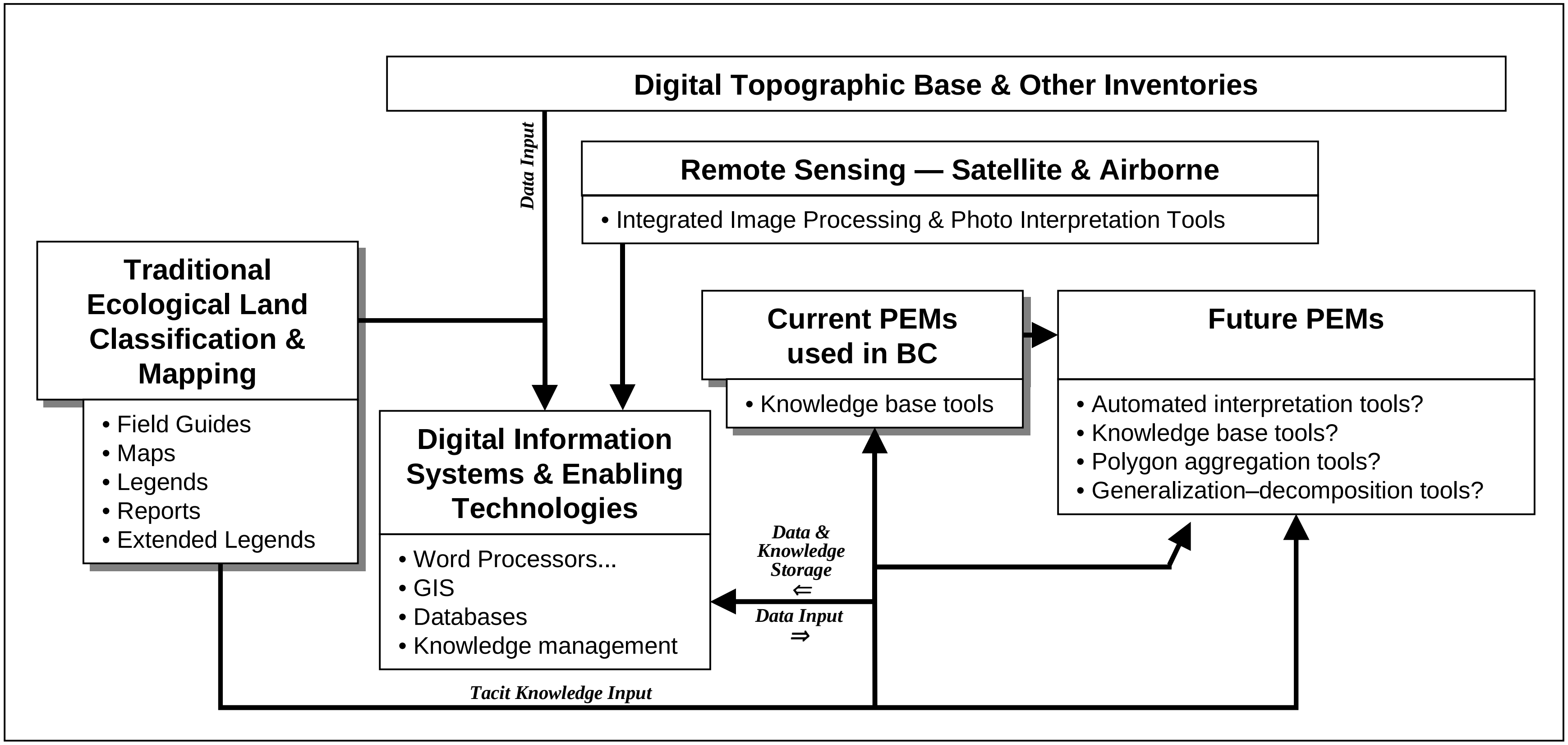

Figure 8. Current PEM approaches bridge the old and the new resource inventory paradigms.

Table 2. Summary of some of the main features of PEMs being used in BC.

Product* or Project Name	Status	Knowledge Base Approach & Key Features	Future Development Plans	Contact
ELDAR*	• Version 1.0 released with documentation and support • available commercially through 2 service providers	• automated inferencing using formalized KB shell • evidence (belief values) and rules based inferencing user-definable hierarchy, attributes, names & values • process tracing & reporting • KB verification tools • GIS & DBMS independent	• multi-sensor primary data acquisition and automated interpretation of vegetation & digital elevation data for higher quality primary data • automated terrain-soil segmentation from DTM using geo-morpho-metric modeling • automated interpretation & polygonization for tree-stand inventory	• Advanced Systems Applications, Alberta Research Council, 403-210-5330 (mulder@arc.ab.ca) • Timberline Forest Inventory Consultants, Prince George, 250-562-2628 (rjv@tfic.bc.ca) • Taiga Pacific Limited, Prince George, 250-563-2920 (angusm@mag-net.com)
EcoGen*	• Beta version being tested on five pilot areas • Will be a publicly available model package	• EcoPrep includes data preparation tools for GIS layers, e.g., TRIM features, large-scale BGC, FIPWiz, etc. • GIS and DBMS independent automated inferencing using KB shell (EcoNGen) • accepts any digital GIS inputs • "simple" system for coding KB	• Version 1.0 release by October 1999 • Interpretive models for yield analysis (EcoYield), • wildlife capability & suitability (EcoWild), and • preliminary identification of rare ecosystems (EcoRare)	• Del Meidinger - 250-387-6688 (Del.Meidinger@gems2.gov.bc.ca) • Bobby Love - 250-847-7517 (Bobby.Love@gems7.gov.bc.ca) • Allen Banner - 250-847-7431 (Allen.Banner@gems1.gov.bc.ca) • Colleen Jones - 250-847-1341 (shamaya@mail.bulkley.net)
VRIEM*	• Method development in progress. • Supporting analysis application under development.	• Site series defined in terms of VRI and other attribute values. • knowledge base built from relationship between input attributes and site series. • Rules and processes applied to generate ecosystem labels. Spatial GIS pre-processing occurs before separate development of the ecosystem label (data base analysis) with the output label again readable into a GIS.	• Methodology V1 documentation. • Method and supporting application fine tuning and testing on several project areas. • Methodology V2 release • Application release. • Links into initiatives for VRI-based Habitat Mapping, and important areas (ecosystems and habitat) mapping.	• Ron Kot - 250-387-9758 (rkot@fwhdept.env.gov.bc.ca) • Alex Inselberg - 250-838-2141 (inselber@noif.ncp.bc.ca)
OASIS	• currently being run through Timber Supply Review process for Bulkley TSA	• mapless, simple random sampling approach to improve yield estimates for timber through ecosystem-based productivity data. • may be useful as an independent data set for the evaluation of spatial ecosystem inventories	• Evaluation of the use of OASIS in Bulkley TSR process • generate report and paper • Field handbook and facilitator's handbook to permit application in new areas.	• Bobby Love - 250-847-7517 (Bobby.Love@gems7.gov.bc.ca)

Product* or Project Name	Status	Knowledge Base Approach & Key Features	Future Development Plans	Contact
Merritt TEM/PEM hybrid	• 50% of area is photointerpreted; 25% is digitised • PHSPs and existing ecological samples are being prepared for use in knowledge base • Regional Ecologist is doing analysis to localize BGC subzone variants to TRIM base • similar process for Clearwater Forest District	• Uses an established PEM process to identify attributes within photointerpreted bioterrain polygons • subsequent field observations can upgrade important areas to full TEM standards • detailed delineation of bioterrain polygons on 1:15,000 airphotos will reduce the proportion of complex units, facilitating subsequent analysis and interpretation	• 75% of bioterrain phototyping will be digital early in fiscal '00 • IFPA will chose PEM from ELDAR or EcoGen • Proof of concept test area includes IDF, MS and ESSF BGC zones	• Keith Simpson, or Claudia Schaefer 604-541-8001 (keystone@mindlink.bc.ca)
Fort Nelson PEM	• have independent data set, random sample stratified by unsupervised classification of satellite image	• EcoGen using Forest Cover, TRIM DEM and satellite image to predict site series and BC Land Cover Class	• compare EcoGen with and without the satellite input to supervised classification of the satellite image	• Craig Delong - 250-565-6202 (Craig.Delong@gems1.gov.bc.ca) • Roger Wheate - UNBC -
Babine EFMPP TEM-PEM comparison	• framework and preliminary analysis begun	• TEM, VRIEM, ELDAR and EcoGen (VEC) will be completed on a single area	• Accuracy and Reliability assessment will be undertaken and reported.	• Richard Sims - 604-733-5220 (rasims@home.com)
Clearwater PEM/TEM hybrid	• Have detailed bioterrain photointerpretation as basis for PEM	• approach similar to Merritt • have independent TEM-4 and TEM-R for comparison	• 3-way comparison of TEM-4, TEM-R and PEM possible	• Keith Simpson, 604-541-8001 (keystone@mindlink.bc.ca)

soils–terrain–landform, topographic–drainage features). The input data to the PEM comes from existing resource inventory maps normally overlayed in a GIS.

Future PEM approaches, as illustrated in Figure 8, may have some of the features listed in the right hand column of Table 1. These approaches to the ecological stratification and interpretation of landscapes are likely to draw upon a number of primary input sources including digital terrain models, climate surfaces, surficial materials, and vegetation and other data from remotely sensed sources. When accurately georeferenced, these data can be used in varying combinations to model a number of physical and biological determinants or regimes. These spatial outputs can then be used for interpreting the occurrence of important biological and physical phenomena such as thermal energy, radiation, moisture regime and hydrologic flow, nutrients, etc. (e.g., Gallant and Hutchison 1996; Mackey 1995 and 1996; MacMillan et al. 1999; Ramlal, B. and K. Beard. 1996). While these future PEM methods offer promise for dealing with present input data quality issues, many are in earlier stages of exploration.

This future looking perspective is noted in order to indicate that the present PEM environment is evolving in terms of enabling technologies and modeling strategies for stratifying landscapes ecologically. Its existence means that the present PEM direction must, on the one hand, appropriately structure and manage the information and knowledge of the past and present (e.g., classification systems, legends, thematic maps, meta data, relationship and procedural knowledge, etc.), while on the other hand, understand how we can manage the transition through this evolution, technically and business-wise.

The PEM goal is to meet the client's business requirements effectively and efficiently by capitalizing on past and present information and knowledge and benefiting from future technologies and PEM modeling. Regarding future PEM directions, we must be mindful that many present business needs are and will continue to be tied integrally to the present day resource inventory information and knowledge set — e.g., the zone and site level units of the biogeoclimatic ecosystem classification.

3.3 Overview of the Generic PEM Process

The following provides a general description of the predictive ecosystem mapping process. It is based on experience in using two of the more developed systems. Figures 9 and 10 illustrate aspects of process.

1. **Requirements Analysis.** In consultation with the client, this initial step requires a careful determination of their interpretive needs, including level of reliability required, for the ecological mapping. At this stage the nature of the map and mapping entities should also be determined — e.g., site series level mapping or the addition of structural stage and other modifiers. Consideration of how the final PEM outputs will actually be interpreted — the interpretive "algorithm" — is also exceptionally important at this time.

   Depending on the client's inventory requirement, various alternatives may be considered, including those described below.

   - The client can manage with a straight-forward interpretation of an existing, single theme inventory (e.g., the forest cover map). In some cases, some supplementary point or mapped information may be required in areas of high priority.
   - The client's requirements are suitable for a PEM approach using existing digital coverages.
   - The client's requirements are suitable for a PEM approach but it is felt that

some other precursor mapping is required in order to attain the required level of map reliability. For example, it may be evident that some efficient terrain or bioterrain-like mapping of the area would greatly enhance the quality of the predictive map units as the relationships between existing digital data attributes and site series is weak. It may also be desirable to supplement a project with additional data like terrain mapping where terrain or soils information is absent from part of the area, of poor quality, or too small a scale.

- The existing mapped information is of too low a quality for any form of PEM. For example, the relationships between existing digital data attributes and site series is weak, additional data cannot be collected economically, or existing sources are from radically different scales (e.g., a 1:126,000 scale reconnaissance soils map and a 1:20,000 scale forest cover map). Both uncertainties in boundary placement and the thematic nature of complex polygon attributes (e.g., reconnaissance soil surveys usually have polygons that complex two or more soil series) preclude the assignment of just one attribute from a small-scale map to a derivative map produced through a GIS overlay, and can actually lead to more ambiguity in a classification. See Section 4.3 for a more detailed discussion of this issue.
- The client's requirements are at a level of detail or decision risk that detailed photo interpretation and ground sampling are the only way to acquire information of sufficient quality (i.e., conventional TEM).

2. **Data Assembly, Assessment & Preparation.** On the basis of the findings from step 1, the next stage involves assembling, assessing, reconciling and preparing all of the various map data sources (e.g., BGC, FC1, VRI, terrain units, soils, TRIM derivatives like elevation, slope, ridges). The level of effort here depends on the location of the area to be mapped and the state of the available map databases (digital or analog) and ecological relationship knowledge (field guides, map legends, reports, etc.).

   While data quality may have been assessed generally in step '1', at this stage it must be evaluated more carefully for the thematic, spatial and procedural qualities of the legacy inventory. Details on how this might be accomplished are discussed in Section 4.3. If the data sources are of acceptable quality then any analog information needs to be digitized or entered in a database. The GIS data are then processed to produce the required layers: e.g., larger-scale biogeoclimatic, various TRIM features, forest cover and selected attributes, etc. The layers are combined in various ways, from a straight GIS overlay of all layers, to a more structured, step-wise process. Either way, a resultant database is produced. This resultant database becomes the input data to be processed by the PEM knowledge base.

3. **Knowledge Base Creation.** The PEM knowledge base model processes the resultant database information from '2' and classifies or allocates each data record (i.e., the resultant overlay polygon attributes) into the most likely ecological class. The knowledge base structure and inference strategy used varies between PEM approaches, but typically involves some form of automated inferencing to apply the knowledge (see Section 4.4 for further details). The knowledge base is a coding of the relationship between each attribute selected in the data preparation stage to the site series or other ecosystem unit feature. The knowledge base structure is often a data table of site series and attributes

and values indicating the relationships. These values may be yes or no values, rankings, or probability or “belief” values. The knowledge base model or “engine” processes the relationships.

4. **Initial Classification.** An initial analysis of the input data through the knowledge base is done using starting knowledge base values for specific attributes, such as the proportion of white spruce that is “allowed” in certain ecosystem types, or the aspect and elevation ranges that are most commonly associated with specific ecological types. These starting values may be obtained from field guides or from previous PEM project models within the same biogeoclimatic unit, and/or from other available plot data. The initial output is used to evaluate the knowledge base relationships and to determine whether other attributes or new data is required.

5. **Field Data Collection.** Often as an integral part of the modeling process, field data provides both the information necessary to modify the knowledge base and to test the accuracy, consistency and sensitivity of predictions. There are three essential aspects to a field program —

   - The field work must be conducted by ecologists who are familiar with the landscapes in the project area. If the field call identifications are incorrect (i.e., if the evidence collected is of inadequate quality or is improperly interpreted), the errors propagate across the entire landscape for all map units with similar attributes.
   - Plot locations must be highly accurate. GIS overlays result in smaller polygons in the derivative layer than in any of the contributing themes. If plots are not located correctly, attributes from the wrong polygon could be improperly linked to field results, with the result that errors occur for all polygons with that attribute set.

   The initial classification (step ‘4’) can be used to guide the field work — e.g., areas where the system was unable to classify; areas where the classification is suspect and areas where complexes occur. All these situations should be targeted for more intensive surveys. The data collected at each plot must include all attributes required to confirm the ecological classification identification (e.g., site series key criteria). As well, all elements that are used as attributes in the knowledge base tables (e.g., slope, aspect, and cover type) must be recorded so that field values can be compared to the attribute values from the input data sets.

6. **Iterative Knowledge Base Analyses & Modification.** Using the field data as further input, the knowledge base is run interatively. Modifications are made to the knowledge base relationships until an acceptable level of prediction and the lowest possible level of ambiguity (complex predictions of two or more ecosystem types) is achieved. For example, slope and aspect might be more or less influential in the current project area than in a previous project area that may have provided the starting knowledge base for the PEM. Several runs are required usually to determine and correct systematic errors in predictions. The incorrect predictions that remain are almost always a consequence of landscape variations that occur at too large a scale to be captured by the available input themes or inaccuracies in the digital terrain model derivatives (e.g., overestimates or underestimates of slope or incorrect aspects). Most PEM knowledge bases provide a trace of the predictive analysis process to facilitate the identification of problem areas.

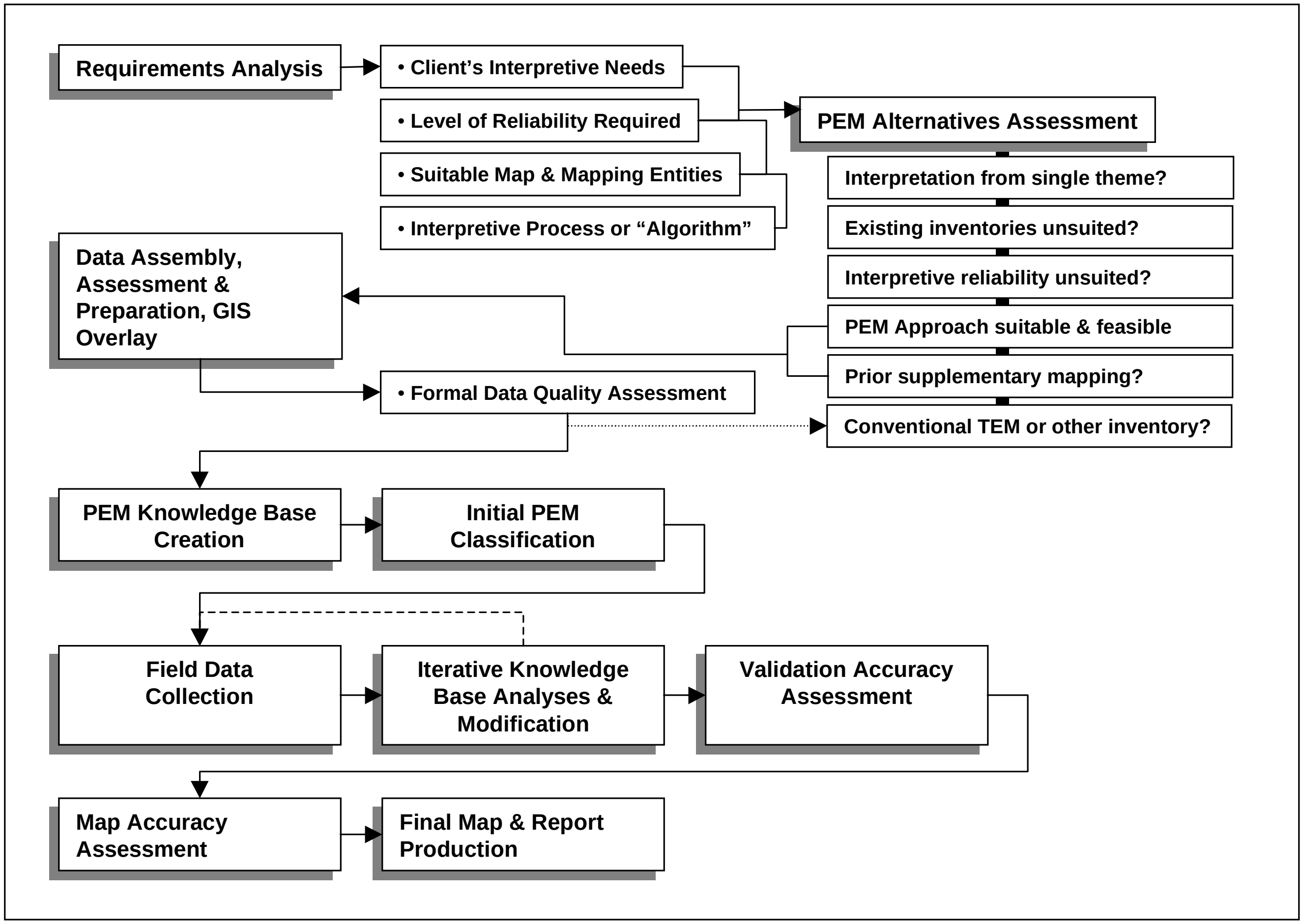

Figure 9. Generic PEM Process: general steps from requirements analysis through to final map and report production.

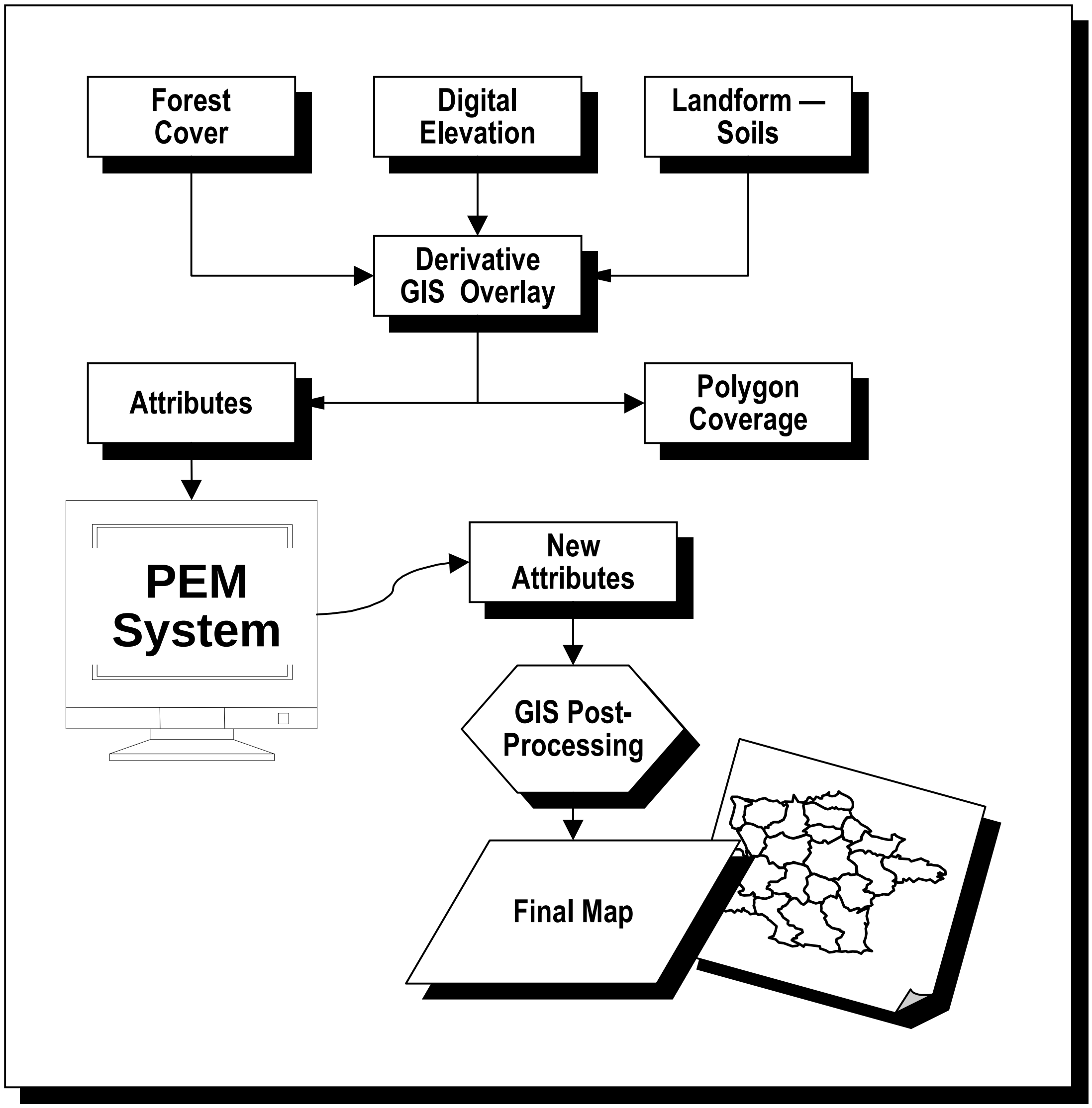

Figure 10. Example of key input themes and processes in the generation of a PEM map product (Downing et al. 1998).

7. **Validation Accuracy Assessment of Knowledge Base:** A validation accuracy[14] assessment is carried out where field plots considered to be correct are compared to the modeling system predictions. For example, a degree of error approach can be used as a measure of distance or how close the predicted class is to the actual class. The “class” in this case could be simply the ecological class (e.g., site series) or it could be a property class such as soil drainage which has particular interpretive importance (e.g., being able to differentiate very rapid to well drained units from moderately well to imperfectly drained units, from poor to very poorly drained units).

   The importance of unambiguous classifications (i.e., one prediction for a given polygon vs. two or more possible ecological types) is a preferred outcome of a PEM approach. Much depends on the natural variation in the map area, the nature and quality of the input data sets, and some initial decisions of whether all ecosystem units can be expected to be identified (may require some initial lumping of units). Experience has shown that ambiguities are generally reduced as more data layers are added to the knowledge base. For example, with only BGC, all site series in a BGC unit would be the only possible outcome. By adding-in forest cover, there are fewer ambiguities, adding-in digital terrain model derivatives there are fewer again, etc.

   With respect to the representation of complexity and ambiguities, the ability to make predictions that are neither oversimplifications of naturally compound or complex units nor overly complicated representations of simple units is important. A PEM that predicts many complex ecosystem types (two or more site series, for example) when there are in actuality few complex ecosystems is less useful to a forest manager than a system that does not. This is especially true for ecosystem types that have specific interpretive potentials or constraints. If such types are complexed with other ecosystem types that do not have the same potentials or constraints, it is difficult for the forest manager to assess the spatial extent and distribution of, for example, “high” versus “medium” sites for productivity potential.

8. **Map Accuracy & Reliability Assessment.** Ideally an independent set of check points using an unbiased sampling approach should be collected in order to assess thematic and spatial accuracy. These accuracy findings can then be used to assess the PEM reliability for the client’s intended use. These data can also be incorporated into the PEM quality control procedures and used to adjust the process to improve the output quality. However, once these data are used in this way, the results of the reliability assessment can no longer be cited until another independent sample set is collected and analyzed.

9. **Final Map & Reports Production.** The predicted ecosystem types are merged back with the original derivative GIS databases, and may be grouped in whatever way is required using GIS database functions for further interpretive analyses or for standard or custom reporting and cartographic presentation. Both standard inventory and interpretive maps and reports are prepared at this stage. Interpretations from the PEM can also be used to populate missing fields in current primary map data sources, or to flag un-reconciled information for checking.

[14] Validation accuracy is not the same as map accuracy; only subsets of the map polygons are checked.

3.4 Advantages of Predictive Ecosystem Mapping

Much of the drive behind PEM development has been to address the high cost of conventional ecosystem mapping approaches. While cost and timesavings are possible over traditional approaches, there are other advantages that should be given equal emphasis. Some of these have been experienced already while others are envisioned with their future use ('experienced' and 'envisioned' are indicated). Some of the advantages of PEM have been grouped into three categories and are summarized as follows:

- **Improvements in inventory cost, production and human resource capacity —**
  - PEM approaches provide a more systematic, consistent and repeatable stratification process when working with existing resource inventory information (experienced),
  - PEM systems have reasonable flexibility for adjusting to the particular needs of the client over standard map products and can adjust to changing information and knowledge sources (experienced),
  - PEM systems offer opportunities to increase mapping efficiency and the rate of mapping by directing field effort to complex areas and by being able to extend knowledge bases, once established, somewhat automatically to similar geographic areas (experienced),
  - increased production capacity through the transfer of knowledge sets to junior staff more efficiently, explicitly and consistently (experienced),
  - increased efficiency with map production and updating, since map-based information quality is reconciled as a part of the mapping process (envisioned);
- **Capitalize-on, add-value to and protect investments in classifications and resource inventories —**
  - capitalize-on and add-value to already available digital land information databases that are known to control or influence ecosystem conditions and their distribution pattern (experienced),
  - capitalize-on and add-value to ecological classification systems and resource inventory "expanded legends" which are already available for many jurisdictions and which provide ecosystem and landscape relationship information; as better terrain models and information bases become available and as understanding of ecological relationships improve, PEM knowledge bases and projects are able to be upgraded (experienced),
  - Conventional ecological inventory products approaches, while often rich in information content, have less flexibility than software and knowledge-based PEMs because typically each polygon is assessed individually and labeled by an interpreter; if any time changes in the mental mapping model occurs or enhanced point or spatial data becomes available, a considerable effort might need to be expended on updating the maps and database on a polygon-by-polygon basis (experienced),

- protect the large corporate investments that have been made in ecological classifications and resource inventory information by capturing this knowledge in a structured easily accessed and shared manner (envisioned);

- **Increase accessibility, knowledge improvement and acceleration —**
  - relationship knowledge captured in PEMs makes it more widely accessible and transferable across the range of public and private sector clients and stakeholder; this in turn allows for more consistent use and understanding of the information value and its limitations (envisioned),
  - more explicit and documented capture of the relationship knowledge in PEMs will enable faster improvement in our understanding of ecosystem and landscape relationships and how to best map these features in subsequent iterations (experienced / envisioned).

3.5 Disadvantages of Predictive Ecosystem Mapping

While there are an number of advantages to predictive ecosystem mapping there are also some disadvantages to consider carefully when using or considering this approach to ecologically-oriented mapping. Section 4.3 on Input Data Quality Assessment and particularly the accompanying detailed report upon which it was based, provides substantial detail on this important evaluation precursor.

- **Existing map information bases lacking in quality —**
  - existing map input sources for the PEM may be absent, non-digital and require digitizing; and
  - existing inventories are at an inappropriate scale or survey intensity level or may use map or mapping entities that are incongruous with a PEM approach.
- **Existing ecological and landscape knowledge of inadequate quality —**
  - ecological classifications or useful map legends may be absent or of limited value for the area under consideration and would not lead to relevant interpretations (note this situation can also hamper conventional TEM approaches).
- **Knowledge acquisition, extraction and/or structuring too onerous —**
  - existing classification and relationship knowledge may be difficult to assemble, inconsistent in its form or generally difficult to codify explicitly; and
  - knowledge codification results in unacceptable predictions or with predictions that are too ambiguous.
- **PEM map accuracy unacceptable for the intended use —**
  - following an independent check of map accuracy, the PEM map is determined to be of unacceptable reliability for its primary intended use (despite the input data and knowledge base interpretation being of acceptable quality).

- **Map providers may be reluctant to codify and share their knowledge —**
  - since ecological mapping knowledge becomes codified to some degree within a PEM software tool, some private firms may be reluctant to share this “intellectual property” (competitive advantage) more widely with publicly funded mapping projects; it is nonetheless important that publicly funded projects include knowledge base and output access to other stakeholders.

4. Predictive Ecosystem Mapping System Framework—1st Approximation

4.1 Framework Components and Relationships

Based on the discussions and findings of this current TEM Alternatives Task Force initiative, the following overarching 1st approximation Predictive Ecosystem Mapping Framework is proposed (see Figure 11). The PEM Framework comprises five main components, each of which contain key elements, features and other related items.

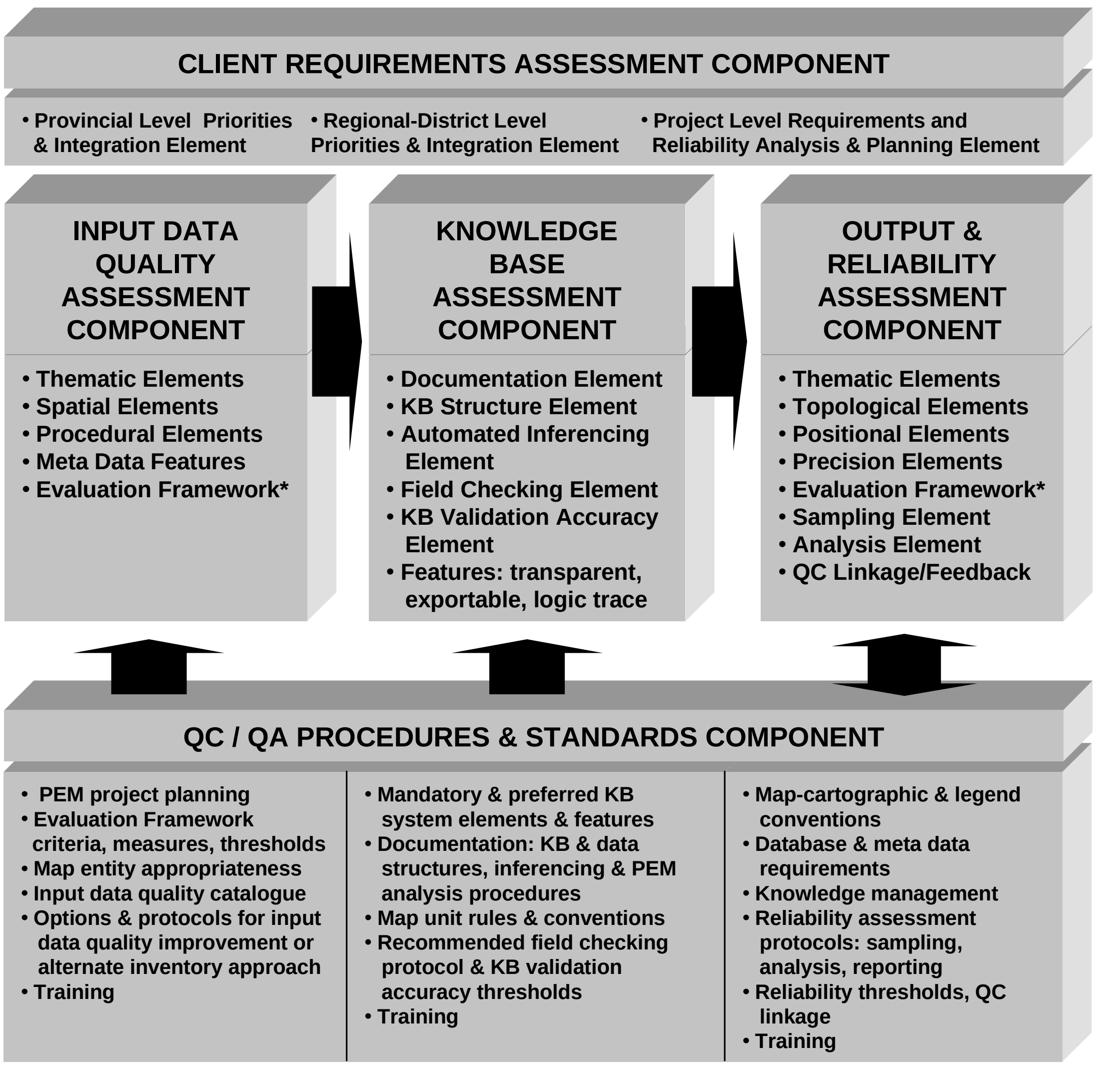

Figure 11. First approximation Predictive Ecosystem Mapping Framework.

The five main components are —

1. Client Requirement Assessment,
2. Input Data Quality Assessment,
3. Knowledge Base Assessment,
4. Output and Reliability Assessment, and
5. QC / QA Procedures and Standards.

Components 1-4 have a number of defining elements and features which together characterize their scope and function. The *QC / QA Procedures and Standards* component contains items that by and large correspond vertically, from left to right, to the core *Input Data Quality Assessment*, *Knowledge Base Assessment* and *Output and Reliability Assessment* components of the PEM framework. The PEM components closely parallel components of the current TEM RIC standards and procedures. With PEM however, the Input Data Quality and Knowledge Base Assessment components are different, but are somewhat analogous to "Mapping and Field Survey Procedures" section of the TEM RIC standard – Section 6. The Output and Reliability Assessment component of the framework can be the same for both PEM and conventional TEM. Presently this component has not been developed fully for TEM.

The analyses supporting the three central framework "pillars" — Input Data Quality Assessment, Knowledge Base Assessment and Output and Reliability Assessment — are contained in the detailed supporting study reports described earlier in Section 2.1.4. These studies identified a number of the key elements and features. Readers are encouraged to review these supporting reports in order to gain a broader appreciation of the three topics. The main recommendations are provided in Section 5.1.

4.2 Client Requirement Assessment Component

The Client Requirement Assessment Component logically drives the entire PEM inventory requirement. The priority setting for inventories occurs at different levels — provincial priorities; regional or district level needs and project level requirements analysis to determine a number of specific decision needs and interpretations that are intended to be made using the map information. Inventory needs and priorities are instigated from any one of these levels in response to an array of planning and management decision demands. Nevertheless, there is an increasing need to coordinate and integrate the PEM and TEM inventory demand better across planning levels and geographically.

As an example, the BC Vegetation Resources Inventory (VRI), has developed an implementation strategy to integrate management, provincial and national inventories. The more detailed inventory information is designed so it can relate to and be summarized at the District and Provincial level. The National Forest Inventory's requirements are in turn, compatible with the Provincial VRI. Each of these inventory levels address specific business needs. An important aspect of the VRI implementation strategy is to identify priority forest management issues across a range of stakeholders for a given area. This is followed by an assessment of the inventory solutions required and the development of an inventory plan to meet the various business needs identified. The stakeholders consulted in this process include Ministry of Forests, Branch, Region and District staff, Licensee staff who identify inventory local needs and priorities, the

Ministry of Environment, Lands and Parks, Non-Government Organizations, First nations, Contractors and the public. More specifically the Inventory Plan objectives are —

1. Define the Provincial VRI strategy for a defined unit.
2. Define the Management Unit inventory objectives.
3. Identify the National Forest Inventory Plot locations and requirements.
4. Identify the inventory activities required to satisfy the objectives for all inventories.
5. Outline the implementation steps

At the Regional and District level, the Prince Rupert Region has developed "Guidelines for Setting Operational Inventory Program Funding Priorities" (Appendix A). The intent of this document is to provide direction on inventory requirements for planning unit staff in the Forest Districts. In relation to different resource inventory requirements, the guides are focused on the interpretive need first, not the nature of the inventory product itself. The timing (inventory completion date) and cost of the inventory are two additional factors that are taken into account in the decision keys. Predictive ecosystem modeling approaches are advocated in the guide as a means to obtain cost effective inventory coverage of large areas. As an example, the decision key logic for one outcome that suggests consideration of a PEM inventory is as follows —

- Is it a continuation of last year's projects? – No;
- Is it a (recreation, terrain, timber, site productivity, growth & yield, hydrological, aboriginal, forest health, or) ecological issue? – Yes, go to page 8 key;
- Is the Forest Cover less than 5 years old? – Yes: (if No: acquire photos, full TEM/VRI Phase I);
- Do you have Terrain Stability Mapping, RIC standard level C or better? – Yes;
- Immediate need (less than 2 years or Forest Practice Code related)? – Yes: **PEM.**

At the project level, the purpose of an ecological land resource inventory in solving land use planning and management needs is to predict the physical and biological results of various management practices. An ecological land resource inventory cannot possibly provide the information necessary to define all aspects of the planning requirement. The primary requirement of the inventory and the responsibility of the mapper is to provide reliable information. Often the mapper is responsible for providing the interpretive products based on the ecological inventory.

Meeting the requirements of the resource inventory requires a clear statement of the inventory objectives, a problem analysis to ensure that it is possible to meet the objectives and a clearly defined set of procedures to meet those objectives that can be met (Moon and Selby 1989). It is important to keep in mind that standard inventory products, while operational and procedurally practical, cannot practically provide all answers to all questions. By and large these inventories provide information of a general nature on the capability of an area to support specific resource uses. For any project therefore, it is important to ascertain the questions that are being asked of the inventory first, then develop a mapping and sampling approach in a manner that will answer the questions with an acceptable level of reliability.

4.3 Data Input Quality Assessment Component

This section has been addressed by the detailed supporting study findings of *the Problem Analysis on Data Quality Assessment Issues* undertaken by CDT–Core Design Technologies Inc (Moon 1999a). The following summary information is taken directly from this report. The full report is available upon request.

Summary

This report emphasizes the elements of data quality, the inventory procedures that influence data quality, and a formal framework for evaluating the quality of data inputs to predictive ecosystem mapping (PEM). There are two reasons for this. The first is that following the definition of the elements of data quality for input to PEM, a quick review of potential input map products indicated that the quality of this data for PEM purposes is suspect. The second is that some users of potential input data do not understand the nature of the data nor its limitations for PEM. Given the potentially serious impact of these conditions, it was necessary to develop and explain the rationale for a rigorous, supportable framework for a formal evaluation of PEM input sources. This included —

1. Development a detailed rationale for the elements of data quality,
2. Identification of the inventory procedures that influence data quality and explain their impact,
3. Identification of the meta-data (documentation) needed to evaluate data quality,
4. Proposal of a framework and criteria for the evaluation of input data quality.

The framework is useful for evaluating both data inputs to predictive ecosystem mapping and for evaluating outputs from predictive ecosystem mapping. The framework was developed from the perspective of someone wishing to understand the fitness or utility of map information. It is developed with the knowledge that much of the meta-data about map products that could be used in evaluating data quality will be missing for most maps and that surrogates will have to be used. In all cases, the evaluation is dependent on the actual use to which the final product will be applied.

The framework is applicable to any thematic input or output map. It is applicable to a class of maps, an individual map, or portions of individual maps. The rating concentrates on the confidence with which the data can be used, and it incorporates both thematic and spatial criteria. The framework is developed in six stages.

Development of the Framework

Stage 1: The background, context, and scope of the report are defined.

Stage 2: The review of predictive ecosystem mapping, as applied in BC, and the identification of the character and nature of the data elements or attributes used in the predictive ecosystem mapping process.

Stage 3: The identification and discussion of the elements of data quality relevant to predictive ecosystem mapping input and output products. These elements were identified as thematic and spatial in nature.
Thematic elements refer to the information conveyed by the map and it's associated reports and data. Thematic data may include forest cover, soils, terrain, et cetera. The thematic elements relate to thematic precision (exactness or resolution),

thematic accuracy (correctness within the defined precision), and the nature of thematic contents (what thematic information the map portrays).

Spatial elements are positional and topological in nature. Positional refers to the actual location of a point, line, or polygon on the map and in the real world. Topological refers to the relationship of points, lines and polygons to each other. They may be positionally incorrect but if they are in correct relation to each other (e.g., inside, outside, left, right, et cetera) they are topologically correct. Positional accuracy insures topological accuracy but topological accuracy does not insure positional accuracy. Positional accuracy for maps used in an overlay process is critical because inaccurate input maps produce incorrect combinations of properties in the overlay product. Incorrect inputs to predictive mapping produce incorrect interpretations even if the interpretation procedure is correct.

Stage 4: The identification and discussion of procedures, which will affect the quality of input and output data. The procedures and their possible impact on data quality are discussed.

Stage 5: The identification, documentation, and discussion of meta-data (data about the data) needed to adequately evaluate the data presented both for its quality and applicability to predictive ecosystem mapping.

Stage 6: The development, presentation, explanation, and limited application of a framework for evaluating input and output data quality.

Conclusions

Data quality issues, unrelated to the original purposes of potential PEM input maps, suggest serious problems with the application existing inventory data for PEM. The evaluation of data input sources requires a tightly reasoned, widely accepted framework to ensure acceptance of potentially negative conclusions. The framework for data quality evaluation presented in this report proposes such a framework. It is, however, only a framework with suggested criteria. It is not proposed as a final procedure with definitive criteria nor has it been extensively tested. It does appear to have the following merits.

1. It provides a list of issues that should be addressed when determining the quality of data inputs or outputs related to predictive ecosystem mapping.
2. It provides a systematic process and suggests criteria for evaluating the quality of data inputs to or outputs from PEM.
3. It provides a framework for the creation, documentation, and implementation of data quality standards for predictive ecosystem mapping input and output products.

The main recommendations from this report are provided in Section 5.1.2.

4.4 Knowledge Base Assessment Component

This section has been addressed by the detailed supporting study findings of the *Situation Analysis for Knowledge-Based Systems* undertaken by CDT–Core Design Technologies Inc. (Moon 1999b). The following summary information is taken directly from this report. The full report is available upon request.

Summary

Knowledge-based Systems and Knowledge Management

The term knowledge-based systems, generally refers to expert system approaches to prediction or decision support. In reality, knowledge-based systems include all predictive and decision support models. The growing recognition of the need to integrate, manage, and share knowledge has led to the emergence of the new "magic bullet" called knowledge management. The "new" knowledge management paradigm proposes to capture informal knowledge based on personal experience and learning, and to integrate it with more discipline or domain specific formal knowledge in a knowledge base.

The Current Situation

The term knowledge management has become popular and we are seeing frequent press references to knowledge management and its importance to the survival of companies in the next millennium. In reality, it is not new. It is, rather, newly popular or perhaps newly understood outside of academic circles. It builds on the successes and failures of data and information management activities and applications. Knowledge management is part of the continuum of data → information → knowledge → wisdom.

Knowledge management research is expanding the tools available for knowledge capture beyond traditional empirical, process, and expert systems approaches. Knowledge management, like data and information management, consists of the following: creating, updating, retrieving, deleting, and archiving15. Knowledge management should allow simple, yet powerful access to knowledge for update and use (via reasoning). It should take into account differences among users and among requirements for different problem-solving tasks. The key to effective knowledge management is the representational model used to store and access knowledge resident in the knowledge base.

The field of knowledge management is highly volatile and its similarity to data management activities during the 1970's and 80's is both striking and understandable. Similar to the way many organizations were storing data in the 1970's, many organizations are already practicing elements of what is now known as knowledge management but they are doing so in an uncoordinated and frequently ad hoc manner. There is a growing recognition of the need for and value of knowledge sharing and reuse between and within systems and organizations. However, just as the major impediments to data integration were inconsistent or incompatible concepts, definitions, terminology, structures, and formats, the major impediments to knowledge integration will be inconsistent or incompatible concepts, definitions, terminology, structures, and formats. Unfortunately, the standards and protocols to enable such sharing and reuse are only just emerging.

Conclusions

The issue of knowledge management will become increasingly important. It is important to find a balance between planning for and facilitating knowledge integration and unduly constraining research and application testing of valuable knowledge-based applications. It is feasible to develop a knowledge structure that could be used to document and allow the exchange of all the knowledge structures reviewed in this report. To function as a knowledge repository, this

[15] Archiving a knowledge base should not be confused with backing up a knowledge base. Archiving implies a software independent format with complete schemas and dictionaries to allow recovery of the knowledge independent of the original software used to create and manage the knowledge base.

structure would require a set of utilities to import and export the various knowledge structures extant and evolving. Such a system, while having the advantage of storing the contents of multiple knowledge bases would not constitute the vision of integrated knowledge bases implicit in current writings. To meet this vision, we also require the following knowledge-specific components —

- consistent and widely accepted knowledge models (ontologies)
- consistent and widely accepted knowledge structures (schemas)
- consistent and widely accepted knowledge manipulation languages, which will in turn require:
- a consistent and widely accepted knowledge dictionary
- a consistent and widely accepted knowledge syntax
- consistent and widely accepted inference mechanisms

The predictive ecosystem mapping (PEM) knowledge structures used in British Columbia represent a small component of possible approaches to PEM. The establishment of knowledge-structure and knowledge-exchange standards at this time would prove counter productive and restrictive. The standards would also be obsolete before completion. However, we can minimize the pain associated with integrating knowledge bases when the need arises. To do so, we need to plan for eventual knowledge exchange, work to coordinate our efforts, and most importantly document our current and evolving knowledge bases.

In particular, we can document, against a generic knowledge structure, the concepts, processes and mechanisms presumed to produce the ecosystems represented in Terrestrial Ecosystem Mapping (TEM) and predicted in PEM. This ontology of Terrestrial Ecosystem Mapping could be developed in the knowledge repository described above. The ontology should encompass the inputs to predictive ecosystem mapping (e.g., forest cover, vegetation, bioterrain, and soil).

The main recommendations are provided in Section 5.1.2.

4.5 Output & Reliability Assessment Component

This section has been addressed by the detailed supporting study findings *of Problem Analysis on Reliability, Quality Control and Validation of Predictive Ecosystem Mapping* undertaken by R.A. Sims & Associates (Sims and Matheson 1999). The following summary information is taken directly from this report. The full report is available upon request.

Summary

In establishing the working principles for PEM, it is recognized that reliability assessment is a significant issue. Mapping of ecological relationships can be a complex and multidimensional task, and PEM needs an effective set of tools and approaches for reliability assessment, so that accurate and useful PEM products can be developed.

PEMs involve the production of spatial models and GIS-based algorithms. PEM outputs are typically not derived from a process of manual air photo-interpretation of linework and attributes, and don't result in a set of document photos with annotations that can then be used as a basis for reliability checking. As a result, PEMs must instead be assessed in relation to independently-collected reference datasets.

The full report reviews issues related to the development of a set of reliability assessment methodologies for PEM. Spatial (topological) accuracy versus thematic accuracy is generally considered, as well as the need to focus reliability assessment on the intended end-uses for individual PEM projects. Consideration of thematic elements is the most important aspect for reliability assessment, and this involves the characterization of PEM project outputs in relation to their thematic accuracy, precision and reliability. Following the review of background concepts and aspects influencing reliability assessment, a formalized framework for reliability assessment is presented in the full reports.

Implementation of PEM as an operational tool presents a number of challenges. The development of an effective approach to reliability assessment is fundamental in the implementation process.

Conclusions

Reliability assessment is a significant issue for all resource inventories. It is particularly evident as an issue in ecosystem mapping because the mapping of ecological relationships can be a complex and multidimensional issue. Directed independent checking is required in order to confirm characteristics that are not readily observed on the ground using simple observational principles.

Typically, explicit tests of accuracy and reliability are not conducted for resource inventory maps. Errors in a map are often believed to "cancel each other out" or, in some other manner, to disappear or be negligible in their overall effect upon an individual map or study area. Because overall accuracy and reliability will additional effort to determine objectively, they are often assumed to have a low effect on a map's informational content. A variety of studies have shown, however, that many thematic maps used in natural resource management have very low levels of reliability. Given the challenges that exist for the assessment of existing traditional map products, there are some major obstacles that must be resolved before operational assessments of PEM can be made.

The main recommendations are provided in Section 5.1.2.

4.6 QC / QA Procedures & Standards Component

Referring back to Figure 11, the bottom Component of the PEM Framework is the *Quality Control, Quality Assurance and Standards* component of the PEM system. For each of the middle pillar components, examples of some of the key QC / QA Procedures and Standards are listed. For the Input Data Quality phase, a draft Evaluation Framework has been developed for assessing input data quality (Moon 1999a) which will have approved criteria, measures and thresholds (see recommendation set 2 in Section 5.1). When applied against a number of typical inventory product + era combinations (types), there is the potential to develop an input data quality catalogue that will list some reference quality values. Since PEMs use existing overlayed map information, there may be a need to consider what will be the most appropriate form for the predicted mapping units. In other cases, it may be determined on the basis of the input quality assessment, that other options and protocols will need to be invoked to enhancing the input data quality (e.g., undertaking bioterrain mapping in some areas; see also Figure 9).

Regarding the Knowledge Base (KB) component, it is likely that a number of mandatory and preferred elements and features will be identified for a KB system. As well, full documentation of the KB and data structures, KB inferencing strategy and PEM analysis procedures are likely to be required. Further, a minimum field checking protocol and KB validation accuracy procedure, with threshold, will probably be required as a part of the project plan and as a means to check on the capability and consistency of the knowledge base to correctly interpret the ecological relationships that have been entered into the system. Most elements of the KBs will need to be transparent (i.e., not “black boxes”) such that all aspects of the KB are clear and well documented. Knowledge relationships and the inference logic captured in the KB will need to be exportable in non-proprietary form so it can be understood, transferred and shared.

The Output Reliability Assessment component will have some standards and procedures that are very similar to conventional TEM such as map-cartographic and legend conventions and database reports. An increasingly important element will be ensuring that the meta data are complete for all aspects of the PEM process and product (see also Section 6, Moon 1999a).

The accuracy and reliability assessment procedures will increasingly be an important component of the PEM procedures and standards. In the future, it is anticipated that it will have clear and practical protocols dealing with things like sampling design, map stratification, degree of errors, analyses, thresholds, reporting requirements and feedback mechanisms for continuous PEM improvement.

The need for appropriate training for all aspects of the PEM system is recognized as an important aspect for assuring consistent quality.

5. Recommendations for Establishing a Standard

5.1 Assumptions & Recommendations

5.1.1 Assumptions

In this concluding section, we put forward a set of recommendations and next steps necessary for the development of PEM standards and procedures. We base these recommendations and anticipated tasks against the following assumptions.

Assumption 1: **A final custodian for the PEM inventory approach to TEM will be assigned along with the attendant resources to support the added infrastructure requirements.** While every effort will be made to make PEM procedures and standards follow a similar or analogous structure to the one used for TEM, there will be extra infrastructure needs where the process differs. Some of these additions may however, also beneficial to conventional TEM.

Assumption 2: **The relative demand and interest in using PEM approaches to TEM will continue, irrespective of changes in the inventory business environment. Given the present fiscal circumstances, in fact, the demand for PEM approaches is likely to grow.**

Assumption 3: **Meeting the proposed December 1999 deadline for PEM standards and the schedule of precursor activities will be dependent on access to sufficient financial and expert resources.** The present undertaking has attempted to address the topic as fully as possible so that the final standards will be well-founded and long standing. The same comprehensive treatment of the topic and level of quality is preferred right through to the formation of the PEM standards. We anticipate some of the existing and future work in this area will have wider spin-off benefits to the broader resource inventory community and initiatives such as FRIC.

Assumption 4: **The proposed Forest Resources Inventory Council activities in the future will not have an impact on the recommendations and proposed tasks outlined below.** However, many aspects of the FRIC mandate should have direct bearing on the TEM and PEM activities and directions in the future. In fact, future work of the Task Force may be helpful to the FRIC initiative and every effort will be made to communicate our progress, and cooperate and contribute where and when appropriate.

5.1.2 Recommendations

On the basis of the findings of this current TEM Alternatives Task Force initiative in conjunction with other resources inventory activities, we put forward the following recommendations. If accepted and acted upon, we believe these recommendations will allow for the completion and approval by the RIC of a set of standards and procedures for PEM by December 1999.

Recommendation Set 1 — Organization: **The TEM Alternatives Task Force remain in place under the present mandate until December 1999 at which time the PEM standards will be completed and passed on to the custodial agency.** The present mandate is to coordinate the development, piloting, and documentation of TEM Alternatives, predictive ecosystem mapping approaches being the prevailing form, for the purpose of developing RIC standards and procedures.

1a) Current Task Force members, particularly those outside government, should be asked if they are willing and interested in continuing to contribute until December 1999.

1b) The RIC should consider if the present Task Force composition is appropriate in light of the findings of this initiative and other developments, and whether or not the Task Force should be expanded to include, for example, representation from Forest Renewal BC, Forest Resources Inventory Council (FRIC), NGOs, consultants that provide TEM-PEM mapping services, and other specialists. In consideration of resource limitations and efficiencies, it is felt that the Task Force should not exceed ten people.

1c) Reporting directly to RIC, the Task Force would serve mainly a steering, review and "oversight" function. Many of the Task Force activities would be coordinated and undertaken by a Secretariat Team, perhaps similar to what was done for the present initiative. Specialized technical tasks would be undertaken by smaller groups, as required, from within and outside the Task Force, sometimes involving specialists from within government or the private sector. Specific activities will be of a technical, information system, or infrastructure-custodial nature and will follow a fiscal 1999-2000 work-project plan.

Recommendation Set 2 — Technical: **Data Input Quality Assessment** (from Problem Analysis on Data Quality Assessment Issues report by CDT–Core Decision Technologies Inc.)

Preamble—

Data quality issues, unrelated to the original purposes of potential PEM input maps, suggest serious problems with the application of existing inventory data for PEM. The evaluation of data input sources requires a tightly reasoned, widely accepted framework to ensure acceptance of potentially negative conclusions. The framework for data quality evaluation presented in this report proposes such a framework. It is, however, only a framework with suggested criteria. It is not proposed as a final procedure with definitive criteria nor has it been extensively tested. It does appear to have the following merits.

- It provides a list of issues that should be addressed when determining the quality of data inputs or outputs related to predictive ecosystem mapping.
- It provides a systematic process and suggests criteria for evaluating the quality of data inputs to or outputs from PEM.
- It provides a framework for the creation, documentation, and implementation of data quality standards for predictive ecosystem mapping input and output products.

Recommendations —

2a) **The framework should be tested and evaluated against a variety of possible PEM input sources and output products** to:

- identify and incorporate issues which may have been missed
- test the appropriateness of the concepts and criteria used
- refine the framework and criteria prior to presentation to a workshop involving practitioners of input mapping products, terrestrial ecosystem mapping products, and predictive ecosystem mapping products

2b) **A selection of potential data inputs should be evaluated for thematic and spatial accuracy in the field, the nature and magnitude of errors documented, and the implications of these errors on the quality of PEM output determined. The test areas should be stratified on results of the evaluation framework applied to existing data sources**.

2c) **A workshop consisting of practitioners of input mapping products, terrestrial ecosystem mapping, and predictive ecosystem mapping should be sponsored prior to final development of PEM standards** to:

- review and contribute to the framework
- make recommendations on the adoption and use of the framework or a modified framework to establish and implement data quality standards for input and output products

2d) **An expert committee should be struck, if supported by the workshop to establish the criteria and ratings to be used as RIC standards for the evaluation of input and output data quality related to terrestrial and predictive ecosystem mapping.** The relationship to the data custodian responsibility also needs to be considered in relation to this (see Assumption 1, Section 5.1.1)

Recommendation Set 3 — Technical: **Knowledge-Based Systems** (from Situation Analysis for Knowledge-Based Systems report by CDT–Core Decision Technologies Inc.)

Preamble—

The following recommendations come from understanding of the history and problems associated with database management. It would be fair to say that the problem of integrating knowledge bases will be an order of magnitude greater than that of integrating databases. It is instructive to note that most organizations have yet to successfully integrate their disparate databases.

3a) **Define Limited Scope for Future Work.** The issue of corporate knowledge management, while comparable to corporate data and information management, is significantly more complex and larger in scope. The RIC should carefully consider the scope of knowledge management and determine what if any elements fit within their mandate for standards. The management of inventory-related knowledge-based systems and their supporting databases may be appropriate. Specifically this should include taxonomic models, empirical models, process models, expert systems, and ontological classifications. (Note: Ontologies are the formal specification of the entities, concepts, and for a domain — e.g., the definitions of classes, relations, functions, and other objects is called an ontology. They form the basis for knowledge sharing between multiple knowledge bases in the same sense that data dictionaries form the basis for sharing between multiple databases.)

3b) **Conduct Inventory of Knowledge-Based Systems.** If standards pertaining to knowledge-based systems and knowledge management are within the mandate for standards, they can be justified on the need for knowledge base and knowledge-based systems integration. A pre-requisite for the development of standards to support integration is an inventory of the knowledge-based systems currently used for inventory-related tasks. The inventory should include:

- the business area and processes supported by each system,
- the knowledge products produced and their application,
- the type of system, knowledge structures, and inferencing procedures used,
- the input requirements and formats, and
- the level and completeness of supporting data and documentation.

3c) **Create the BC Ecosystem Ontology.** It is important that the concepts, processes, and criteria underlying the ecosystem classification be formally and unambiguously documented in computer retrievable format as a formal ontology. The ontology would identify the dominant processes acting at each level of the classification and the relative contribution of these processes and the mechanisms by which they are presumed to produce the classes identified at each level. The ontology would be structured around the TEM classification system with the processes, balances, and mechanisms documented as relationships between classes at the same level, between levels, and between classes at different levels. The integration of the ontology with a database of class attributes would provide an effective standard for communication, correlation, and quality assurance and quality control of both TEM and PEM mapping.

While the information necessary to construct the ontology exists, it is in the form of internal documents, conference presentations, manuals, and scientific papers. This material should be compiled as a formal ontology in a generic knowledge structure that can be accessed by workers in the field of predictive ecosystem mapping. The ontology could be used to ensure that workers are using the correct ontology, that they are applying it appropriately, and that class attributes are consistent with the ontology. The ontology, not the generic knowledge structure, should be established as TEM and PEM standards.

3d) **Establish Documentation Standards.** Establish a set of documentation and meta-data standards for current and proposed knowledge-based applications. The nature of the documentation will vary depending on the type of knowledge-based system being documented but should include:

- A description of the knowledge structures used. The documentation will vary depending on the knowledge structures used but should include a description of: *frames* (including slots, slot values, etc.) for frame-based systems; *classes* (including methods, data structures, etc.) and *objects* for object-based systems; *entities* and *relations* (including membership rules, domains, etc) for relational data-based systems; *column* and *row* definitions together with the method and domain definitions of cells for belief matrix-based systems

For large knowledge bases, this could be onerous, and an alternative would be examples and automated procedures to produce the descriptions.

- A description of the inferencing processes used including rule bases, decision trees, simulation models, knowledge retrieval algorithms, or processing functions.

3e) **Provide Coordination.** The RIC may wish to consider a coordination role in knowledge management and knowledge-based systems for inventory. This could include organizing annual meetings of practitioners to monitor and encourage knowledge base integration. When the magnitude of knowledge-based systems work warrants, the committee may choose to create a public and private sector working-group on knowledge standards and knowledge exchange.

Recommendation Set 4 — Technical: **Reliability Assessment & Quality Control** (from Problem Analysis on Reliability, Quality Control and Validation of Predictive Ecosystem Mapping report by R.A. Sims & Associates)

Preamble—

The following steps still need to be individually addressed in more detail, prior to implementing any standard procedure for PEM reliability assessment. These items can be developed through either a strategic planning and testing effort, or via some directed pilot projects.

- The needs of resource managers/planners must be firmly established, so that PEM outputs, in particular interpretive products, are properly developed.
- The need for reliability assessment increases as PEMs become more removed from primary data sources. This necessitates that some boundaries be established - at some point - as to what is acceptable and not as a PEM tool or technology.

4a) **The expectations for spatial accuracy of PEM need to be more firmly established, as there are some interpretations that may not be able to achieve the accuracy (and precision) that is needed for detailed decision-making.**

4b) **The PEM reliability assessment system that evolves from this exercise should attempt to partition the errors in mapping, so that systematic problems can be identified, and so mitigation efforts can be focused. This may be a difficult thing to put into practice, but a set of tools that effectively partition errors would provide the best solution.**

- PEM reliability assessment metadata must be incorporated into project metadata standards. A mechanism for this needs to be defined and described, ideally, at the outset.
- A mechanism is needed for PEM change management, given the potential for rapid technological change with PEM-related tools. Only when the products and interpretations from PEM and the needs of resource planners are clearly understood, can alternatives to robust tests of reliability be considered.

4c) **Future considerations about PEM map reliability should also be considered, as part of a larger initiative involving ecosystem map reliability as a whole in BC, so that the right ecosystem mapping systems are applied under the appropriate circumstances. One component of this is monitoring the evolving needs for new types of interpretive products or intended applications for PEMs**.

Recommendation Set 5 — Future: **TEM Alternatives and PEM inventory and interpretive methods require the support and resources for further development of the techniques. This R&D effort should be led by the Ministry of Forests Research Branch, but with strong collaboration with the Ministry of Environment, Lands & Parks, Regional and District government staff and other R&D agencies such as Canadian Forest Service.** It is recognized that the time frame and support for PEM research is outside the scope of the 1999-2000 fiscal year initiative.

5a) In light of limited resources, continued R&D should strike a balance between building upon existing developments and looking ahead to changing enabling technologies (hardware and software) and modeling methods that characterize the technical paradigm shift we are amidst (see Section 3.1 and 3.2).

5b) It is important to recognize that PEM prototypes were not necessarily intended to function as robust, well designed information–knowledge based systems. As these techniques mature and are in demand operationally, the prototype tools will likely require sound re-design, system engineering and full documentation if they are to be, supportable and maintainable. As was the case with GIS technology, collaboration with the private sector software companies may be more appropriate in the longer term.

5c) The R&D effort is encouraged to go beyond BC's borders in seeking collaboration, particularly with respect to future PEM developments. BC's interests and needs are very similar to those being expressed in other provincial jurisdictions today. Considerable efficiencies and expertise might be gained by taking a wider sweep of the "intellectual landscape" geographically and in terms of domain expertise.

Recommendation Set 6 — Communication: **TEM Alternatives and PEM approaches and developments should continue to be communicated effectively to the resources inventory community — RIC, primary and secondary users, map producers, resource ministries staff and funding agencies.** There is considerable confusion across the resources inventory community over these approaches in terms of what they are, how they are used and their advantages and limitations. Although this White Paper provides considerable clarity on the topic, there will still be a need for further extension and communication in order to ensure a fuller understanding of where PEM approaches are appropriate and where they are not.

6a) Within the current Internet web structure for RIC, the TEM Alternatives Task Force activities and outputs such as this White Paper should be published and maintained as later approximations are developed and as new information on the topic becomes available. Resources to support this will need to be designated.

6b) Once reviewed, the White Paper should also be made available from a print-on-demand service as required.

6c) PEM Case Studies, as envisioned under this initiative, need to be developed in order to demonstrate working examples of PEM applications. The PEM Framework described in Section 4.1 will now provide a template for structuring and reporting on these experiences in a consistent and comparable manner.

6d) While understanding and awareness of PEM approaches are important, **the Task Force and PEM advocates must to mindful of not overselling PEM and create a level of expectation that is unwarranted or untested.** This situation could lead to the clients being dissatisfied and the providers losing credibility. Diligent application of the present PEM Framework and future standards will help to ensure that this does not occur.

Recommendation 7 — Extension: **Linked to Recommendation 2, the current TEM and PEM initiative needs to undertake supplementary extension work that is focused on fundamental and underpinning classification, mapping, inventory and interpretive concepts and practicalities.** The TEM, TEM Alternatives and PEM activity thrust over the past few years has revealed a short fall in understanding of these generic, underpinning principles of land resource classification, mapping and interpretation. This knowledge, once more prevalent in the province and available for teaching and mentoring, is readily being lost through attrition, downsizing, retirements, changing priorities, etc. A more thorough understanding of these principles among technical agency staff, map producers and the clients will go along way towards ensuring that PEM approaches are used appropriately.

Recommendation Set 8 — Transition Management: **Up until the completion and implementation of a PEM standard, the TEM Alternatives Task Force, mainly through the present Secretariat Team, should continue to coordinate and structure TEM proposals that advocate a PEM approach guided by the components, elements and features of PEM Framework in this White Paper.** While it is premature to impose strict standards and procedures presently, this White Paper along with the supporting detailed reports, provides considerable information that will help in managing the transition period.

8a) In the immediate future, proponents advocating a PEM approach will be encouraged to read this White Paper and to structure their inventory proposal such that it addresses the PEM Framework components, elements, features, protocol and implied processes.

8b) Paralleling '3a', the proponents will also asked to document all aspects of their project fully including — the client requirements analysis; input data including data quality assessment; knowledge base structures, transparency and processes; field checking and validation accuracy; map output conventions, meta data and processes; and reliability assessment procedures and findings. It is likely that this information will be made available to other proponents in the form of case studies.

5.2 *"A Business Approach to TEM and TEM Alternatives" Report Checkpoint*

Given that the TEM Alternatives Task Force was precipitated by some of the PEM-related findings of the Biggs et al. report — "A Business Approach to Terrestrial Ecosystem Mapping (TEM) and TEM Alternatives" (November 1997), the following provides a checkpoint on the status of the issues and recommendations raised, some of which are more related to the existing TEM program, not PEM per se. This section is included in this document so that continuity and congruence with this previous study is maintained and reported on to RIC and the broader TEM-PEM community.

The issues and recommendations in bold-italics are verbatim from the original report. Issues 3 and 4 are grouped because they are similar and have the same response.

5.2.1 Issues Raised

Issue 1: Currently, there is insufficient infrastructure for TEM.

> **"**TEM is suffering from insufficient levels of support and infrastructure critical to its success."

Although there has been some progress on many of the items identified as part of the required infrastructure, there is no long-term plan or support, and continuity suffers. A short-term solution using the BC Conservation Foundation bridges the gap between project-funded quality control and the need for a central QC process.

Funding for conversion of completed TEM projects into the corporate database is not assured.

The following quotes from Biggs et al. (1997) remain pertinent —

> "PEM alternatives to TEM will also require substantial infrastructure. At present, the infrastructure is inadequate to deliver TEM and if additional PEM products are authorized, infrastructure must also be expanded to support them."
>
> "High priority areas need to be defined in tangible terms using LRMP issues tables or some other standardized planning process and then designated for future TEM mapping."

Section 4.2 of this White Paper identifies the Inventory Requirement Assessment Component of a 1st approximation PEM framework. This recognizes and outlines the need for the reconciliation and integration of priorities at Provincial, Regional, District and Project levels. This requirement needs to deal with within and between inventory programs at the RIC level and may also become an item within the mandate of the Forest Resources Inventory Council.

***Issue 2: Standards are needed for TEM and any TEM alternatives that are to be applied operationally*.**

Revised TEM standards were accepted formally by RIC in May, 1998, and are now in-place, publicized and have been explained to the TEM community. The development of well-defined, yet sufficiently flexible RIC-accepted standards for TEM alternatives, mainly in the form of PEM, are the focus of the present initiative and this White Paper.

Issue 3: Before undertaking TEM or a TEM alternative, project objectives should be clearly identified.

Issue 4: Wildlife habitat objectives for TEM and TEM alternatives need additional consideration.

> "A clearer process is needed for 1) developing both provincial and regional strategies for TEM implementation, and 2) establishing more rigorous review criteria for those individual TEM projects that are proposed by forest companies or agencies."

Again, Section 4.2 of this White Paper report identifies the Inventory Requirement Assessment Component of the 1st approximation PEM Framework. This recognizes and outlines the need for the reconciliation and integration of priorities at Provincial, Regional, District and Project levels. This requirement needs to deal with within and between inventory programs at the RIC level and may also become an item within the mandate of the Forest Resources Inventory Council.

In the interim, the TEM Alternatives Task Force has produced a "decision matrix" (Appendix B) to assist clients to select an ecosystem mapping process that considers information requirements, available resources and local constraints.

Issue 5: Standardized BGC linework at 1:20 000, or an approach to consistently derive this product, does not exist.

A rule-based approach to localization of BGC subzone/variant linework to the 1:20 000 TRIM base has been completed for the Arrow and Columbia Forest Districts. Similar work is underway in the Prince George Region and the Merritt Forest District.

Tools have been developed for 94F and 93N in the Prince George Region to localize linework to 1:250 000 from the existing 1:500 000.

Marvin Eng, Research Branch, Ministry of Forests, is collaborating with Regional Ecologists to create the set of instructions, independent of GIS (can run in ARC/INFO or PAMAP), but these projects require a clean digital elevation model.

Issue 6: The definition of TEM alternatives is different if you are a client than if you are a scientist.

> "There are two camps when TEM alternatives are being discussed. From the industrial client's perspective, TEM alternatives should be quick, cheap, reliable, and based on the business to be used to assist their immediate planning needs at a broader scale ... TEM providers and the scientific community, on the other hand, are focused upon finding TEM alternatives that closely approach TEM standards."

We are following the principle that the choice of TEM or TEM Alternatives should be determined on the basis of the intended application and level of reliability required of the inventory information first, followed by considerations of budget and time frame. Inexpensive, poor reliability maps serve little purpose despite their cost attractiveness. Conversely, expensive, full-featured TEM inventories may be overkill for some broader, capability applications that can tolerate low levels of reliability. While their is a desire to keep inventory costs affordable, industry clients are also cognizant of the need for reliable data.

Issue 7: Concern exists regarding the role of bioterrain mapping as an intermediate step for TEM.

> "There is an ongoing debate within the TEM community regarding the role for bioterrain; it is not a requirement in TEM, but is recommended as a useful initial stratification for TEM projects."

The revised standards approved by RIC in May 1998 RIC de-emphasized bioterrain. In areas where terrain has high predictive value for ecosystem distribution, bioterrain typing is being used to form the landform and material basis for PEM.

Related "terrain mapping" issues were raised regularly in interviews with resource inventory specialists during the cursory Situation Analysis undertaken in this present initiative. It was evident from these discussions that further rationalization of the role and relationship of terrain mapping to other resource inventory programs is required.

Issue 8: There is information available to clients, or in the production of TEM, that is currently not being used.

A strategy for using silviculture prescription information for TEM and TEM Alternatives is still required.

Broad Ecosystem Inventory (BEI) mapping at a scale of 1:250 000 is currently being updated to reflect RIC standards and 1995 BGC linework. Seamless, province-wide coverage is anticipated by March, 2000.

Issue 9: The thoroughness of TEM usually exceeds clients' current business needs for ecological information to support Land Use Planning.

> "All clients have basic needs for information to facilitate better decision-making, but not all need or desire TEM products. TEM provides more information than some clients can use or handle and duplicates information that is available from other sources..."

In general, the various existing procedures outlined in Section 4.2 of this report and interim tools like the "decision matrix" in Appendix B support the need for rational and integrated methods for assessing the interpretive needs of clients and hence, what inventory approaches and products are most suitable. Further work in this area nonetheless is required.

5.2.2 Recommendations Advanced

Recommendation 1: A single agency must assume TEM custodianship.

> "Such an agency would assume responsibility for the diverse elements of TEM, including: provision/allocation of adequate resources and staff for infrastructure management; correlation and quality assurance; training and educating; data warehousing; data distribution; and developing classification."

The Ministry of Environment Lands & Parks (MOELP) has been designated as the custodian for TEM. Custodianship for PEM has not been decided at this time, but there are parallel concerns regarding the attendant responsibilities and for adequate resourcing. While PEM uses different approaches, there are a number of similar or at least analogous processes to TEM. For these reasons, it is logical to have PEM custodianship reside with the same agency that handles TEM — i.e., MOELP.

Recommendation 2: Approved RIC Standards are required for TEM and TEM alternatives.

Revised TEM standards were formally accepted by RIC in May, 1998, and are in place, publicized and clearly explained to the TEM community. Formal, well-defined and RIC-accepted standards for TEM alternatives are the subject of the present initiative.

Recommendation 3: Before enabling TEM or TEM alternatives, an adequate infrastructure must be provided by the custodian.

> "The custodian must provide support for:
>
> - development of a business strategy for TEM and TEM Alternatives;
> - Regional Ecologist support and commitment;
> - biogeoclimatic ecosystem classification (BEC) efforts for site series and biogeoclimatic (BGC) mapping at 1:20 000 and 1:50 000;
> - GIS and field database management;
> - quality assurance functions;
> - maintenance of provincial directions and regular review/adjustment as required;
> - developing and piloting TEM Alternatives;
> - review and formal update of standards;
> - training, mentoring and certification;
> - reliability checking conducted on an as-required basis;
> - overseeing and undertaking data conversion/standardization; and
> - warehousing, quality assurance, maintenance and distribution of incoming TEM and associated databases (in part, so that there can be some province-wide capabilities for roll-up and analyses)."

Progress has been achieved on many of these items, but long-term planning and commitment are required to protect investments in TEM and TEM alternatives.

Recommendation 4: Products, both spatial and non-spatial, need to be developed to meet client-specific requirements for ecological information.

> "TEM alternatives must be piloted under controlled conditions on areas where TEM projects have been or are being conducted."

In the absence of an approved method for reliability assessment, and full-cost accounting of TEM and TEM Alternatives, there are several initiatives presently underway, generally funded as part of FRBC pilots, that are attempting to compare TEM Alternatives to existing TEM. These evaluations are critical to the implementation of TEM Alternatives and the present initiatives may be inadequate to answer the question.

Timely implementation of an approved reliability assessment framework would increase the value of these initiatives.

Recommendation 5: A number of modifications need to be made to TEM.

The following actions occurred in response to this recommendation —

- TEM standard modifications were approved by RIC in May of 1998 with the intent that minimal update or revision would be required for 2-3 years. A change management process, modeled after that in place for VRI, is being developed to accommodate suggested refinements.
- A viable infrastructure with an adequate level of support is an ongoing requirement and challenge.

- Quality assurance continues to represent a "bottle-neck" for TEM.
- Processes to identify and incorporate efficiencies have been implemented.
- Strategies to communicate clear methodologies to clients and others have been implemented such as the Internet ECOMAPPING listserver and web-based distribution of standards and procedures; and
- Prioritization of all new projects on a regional and provincial basis to the limits of available funding and infrastructure capability is accomplished through evolving processes administered by FRBC.

Recommendation 6: Prior to approving TEM or TEM alternative projects, clients must clearly articulate project objectives and the use to which project data will be put.

Again, Section 4.2 of this White Paper report identifies the Inventory Requirement Assessment Component of the 1st approximation PEM Framework. This recognizes and outlines the need for the reconciliation and integration priorities at Provincial, Regional, District and Project levels.

In the interim, the TEM Alternatives Task Force has produced a "decision matrix" (Appendix B) to assist clients to select an ecosystem mapping process that considers information requirements, available resources and local constraints.

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7. Glossary of Predictive Ecosystem Mapping Terms

The following glossary provides a definition of some of the key terms used in this White Paper and the supporting detailed studies by Moon (1999a,b) and Sims and Matheson (1999).

Please note that the order of the terms is not alphabetical but rather follows a more sequential flow of how the information items tend to relate to one another.

TEM Alternatives: Alternative procedures to the RIC Terrestrial Ecosystem Mapping standard, that produce inventory or information products with similarities to TEM products or that provide similar interpretive value. *Predictive ecosystem mapping* approaches represent the prevailing form of TEM alternatives being used in BC.

Predictive Ecosystem Mapping: A computer, GIS and knowledge based method to stratifying landscapes into ecologically-oriented map units based on the overlaying of existing mapped themes and the processing of the resultant attributes by normally automated inferencing software with a formalized knowledge base comprising ecological–landscape relationships.

Mapping Terms

Entity: a class or type of thing involved in the mapping process. An entity may be a site, site series, a soil, a polygon, a plant community, etc.

Instance: a specific occurrence or example of an *entity* (e.g., the Princeton soil association, site series SwAt – Step moss, polygon 192)

Map-feature: a point, line or polygon representing a site, linear feature, or area on a map.

Mapping-entities: any *entities* used in the mapping process but not necessarily labeled on the map. For example, a series forms part of the definition of a soil association that is being mapped or a stratum forms part of a geological formation that is being mapped. The series or strata are not labeled directly on a map, rather the association or formation that they comprise is labeled. While the series and strata are mapping-entities (entities used in the mapping process), they are not *map-entities* (represented as labels on the map).

Map-entities: *mapping-entities* used to label map features (digital or analogue). In the discussion above, both soil series and soil associations are *mapping-entities* but if the map features are labeled with soil associations, the association is the map-entity. If the map features are labeled with series then the series is the map-entity. Map features may be labeled with multiple map-entities. If map-entities consist of single mapping-entities, they are said to form *simple* map-units. If the map-entities consist of multiple mapping-entities, they are said to be *compound* or *complex* (see below). Both mapping-entities and map-entities can be simple, complex, or compound.

Simple entities: are *entities* which, for the purposes of the inventory, are not defined as being composed of other entities. For example, a soil series is an abstraction of multiple soil polypedons but, if reference to the individual polypedons is not part of the inventory definition, the series is a simple entity. A tree species has many occurrences or instances, but if reference to individual trees is not part of the inventory definition, the species is a simple entity.

Compound entities: are defined as consisting of two or more *entities*. The compound entity inherits the properties of its members or components. In compound *map-entities*, the definition includes a predictable or derivable pattern of the member entities comprising the compound entity. It is important to note that knowledge of the pattern and distribution of component units within compound unit cannot be recovered unless recorded as part of a formal map-entity definition, annotated as part of the map-entity symbol, or recoverable as a description from the report. Soil catena, soil associations, and forest cover types are examples of compound entities.

Compound entities may show first order through n-order compounding. A first order compound entity is composed of simple entities. A second order compound entity is composed of first order compound entities and so on. The essential distinction is that the pattern or distribution of all component entities of whatever order can be predicted or derived.

Complex entities: are defined as consisting of two or more *entities*. The complex entity inherits the properties of its members. Unlike *compound* entities, the definition of a complex entity does not include a predictable or derivable pattern of the member entities that would allow their specific location at a larger scale. For example, the merging of adjacent *map-entities* into a single polygon because they could not be mapped at the inventory scale. There is no way of predicting, based on landscape information, where in the polygon each map-entity occurs.

Multiplex entities: are *entities* consisting of two or more *compound* or *complex entities* for which the pattern of all member components cannot be predicted. An entity consisting of two or more compound entities is multiplex if the distribution of the member compound entities cannot be predicted or derived.

Map Legends — Open & Closed Legends: During the 1980's, there was much debate in the soils community over open versus closed legends. Terrain maps (open) and many soil maps (closed) of the 1980s represent the opposing camps. In an *open legend*, the *map-entities* and their modifiers that are found in a map polygon are listed in the polygon label with some indication of proportion or dominance (e.g., rCv/gMbv//Rs). In other words, the polygon label describes the polygon and the legend provides definitions for the components of the symbol. In a *closed legend*, the polygon label represents an abstraction of a number of similar polygons and the legend presents a description of this abstraction. These descriptions, of necessity, provide less precise estimates of proportional content than can be assigned to a polygon using an open legend and the information detail lost in the generalization process cannot be recovered.

Map Accuracy, Precision, Reliability and Overlay Terms

Map Reliability: The term map reliability is widely used but its use is informal. In this White Paper, the use of the term map reliability will refer to *thematic accuracy*, *spatial accuracy* and *precision* <u>as they effect the specific application</u> of the map information.

Thematic Precision: Refers to the exactness with which *mapping-entities* are defined. For example, a soil entity may be defined as having imperfect drainage. This would be a more precise definition than if it were defined as having drainage ranging from moderately well to poor. Precision may refer to:

1. the exactness with which attributes defining mapping-entities are defined generally
2. the exactness of the attributes associated with a mapping-entity within a specific polygon as opposed to its general definition ('1')

3. the exactness with which the composition and distribution of mapping individuals in a compound map-entity are defined generally
4. the exactness of the composition and distribution of mapping individuals in a specific polygon labeled as a compound map-entity as opposed to its general definition (‘3’).

Thematic Accuracy: The correctness of polygon labeling. It is related to *thematic precision* but not distinguished by it. In simple terms, a polygon is correctly labeled if the attributes of the polygon fall within the defined attribute ranges of the map unit and its components. There is generally an inverse relationship between thematic precision and *thematic accuracy* in mapping projects.

Thematic Content (& Utility): At the highest level, this refers to the resource being inventoried — forest cover, soil, terrain, etc.). Content also includes the landscape and resource concepts embodied in the map such as the nature of the *map* and *mapping entities* (see definitions above) used in the inventory together with any additional map symbol components which modify or further characterize these entities. The distribution, pattern and relationships of mapping entities within a compound map unit can have a significant impact on interpretations and also are a part of the thematic content of a map.

Positional Precision: The exactness with which a location can be determined. With GIS technology use there is a tendency to confuse the positional precision possible within a GIS and the positional precision at which the original data was compiled.

Positional Accuracy: The degree to which map coordinates correspond to real world coordinates of features shown on the map. As with thematic accuracy and precision, increasing the precision claimed reduces the magnitude of location error that will result in a defined error. Positional accuracy is often stated as the probability of a map feature being represented within a specified distance. Note that cartographic enhancement techniques used to portray thematic information that is either too detailed or too complex for presentation at the chosen presentation scale, while *topologically* correct is spatially incorrect and if mis-used can introduce significant positional, distance and area errors. A number of biological and land use inventories have been compiled against base maps that had employed such cartographic enhancements.

Topological Accuracy: The properties of points, lines or polygons that are not normally affected by change in size, shape or absolute position. Topological attributes are always within reference to two or more features and use terms such as inside, outside, left of, right of, contiguous with, congruent with, connected to, etc. Topological accuracy is normally much greater than *positional accuracy*. Maps are frequently used as a means of locating oneself in the field by reference to topological relationships, while positional inaccuracies often go unnoticed.

Spatial Utility: Spatial utility is determined by how well the *positional accuracy* and *precision* and *topological accuracy* meet the needs of the inventory. Positional accuracy and precision will have a significant impact on the registration of multiple map themes. If positional accuracy and precision are inadequate, the overlay process will produce a significant number and area of artifact polygons that have no real world expression.

Spatial Overlay: The superposition of two or more thematic maps to produce a resultant map in which boundaries from each contributing map are used to form polygons in the resultant map. Each polygon in the resultant map carries the identifier of each contributing thematic polygon. If *positional errors* exist in either or both of the maps used in the overlay, the resulting polygons and their attributes will be artifacts of the overlay process and will not represent reality. The process is mechanical and is uninfluenced by the *thematic content* of the contributing maps.

Positional Errors: If one or more of the maps contributing to the resultant map has positional errors then all resultants of map or maps will inherit those positional errors. Positional errors may arise from at least four sources —

- Errors in the base map used for mono-restitution. Mono-restitution is commonly used to refer to moving delineated features from aerial photography to a base map. More correctly, it refers to the process of converting spatial information to a common coordinate system. Errors may result from two possible sources:
    - the master base map compilation process
    - the reproduction process (e.g., printing distortions)
    - shrink / swell during mono-restitution
- Errors in the mono-restitution process
- Errors in determining the location during the inventory process
- Errors resulting from the sliver removal process used to reconcile apparent small polygon artifacts resulting from the *spatial overlay* process.

Topological Errors: Occur as a result of *positional errors* in one or more of the maps contributing to the overlay, the mono-restitution process may generate topological inconsistencies between the contributing maps.

Thematic Overlay: Occur with the combination of thematic information associated with each input polygon contributing to the resultant polygon in a spatial overlay. If contributing polygons have errors in the characterization of the feature being transferred (i.e., *characterization errors*), the error will be propagated to all of the resultants to which it contributes. The overlay of compound map-units on compound map-units presents the problem of reconciling which of the possible thematic combinations actually occur in the resultant (i.e., *reconciliation errors*). For example, the simple overlay of a compound polygon A^7B^3 with compound polygon X^5Y^5 produces the following possible proportions for each thematic resultant: AX from 21% to 50%; AY from 21% to 50%; BX from 0% to 30%, BY from 0% to 30%. There is no *a priori* method of determining the actual proportional representation unless some combinations can be shown to impossible.

Combined Spatial & Thematic Errors: The combination of spatial and thematic overlay errors with *compound map-units* can result in compounding or reducing the errors associated each of the spatial or thematic errors. Depending on the nature of the compound map-unit and the distribution of components in the compound unit, the resultant polygons may have none, one, or more of the components of the contributing polygon represented in the resultant. *Positional errors* create artifact polygons that imply thematic combinations that do not exist. In some cases, this situation makes an estimation of *map reliability* impossible.

Knowledge-based Systems and Knowledge Management Terms

Knowledge: Knowledge is information with meaning. In the context of decision support, is a part of progression from data to information, to knowledge or prediction (the use of information in the context of interactions, relations, or problems).

Knowledge-Based Systems: Generally refers to *expert system* approaches to prediction or decision support. Broadly speaking, knowledge-based systems incorporate data and information with rules, relationships, probabilities and logic to: predict outcomes, support decisions, classify unknowns, identify new relationships and patterns. A knowledge-based system requires at least two components: a knowledge base and an inference or knowledge engine that is used to apply the knowledge to the problem or question. Other components such as a user interface and reporting and tracing functions are also necessary and often are critical to the success or failure of the system. More technically and specifically, knowledge-base "old" and new systems such as taxonomic models, empirical statistical models, process models, simulation-system models, expert systems, artificial neural networks, belief matrices, and decision trees.

Knowledge Management: New management practices fundamental to capitalizing on the knowledge-based economy. The term has become popular with frequent references to its importance to the survival of organizations in the next millennium. In reality, the fundamentals are not overly new but, it is new to many outside of academic circles. It builds on the successes and failures of data and information management activities and applications. Knowledge management is part of the continuum of data → information → knowledge → wisdom. Knowledge management, like data and information management consists of the following operations —

- Create – the entry of additional knowledge into the knowledge base. Creation in this sense does not refer to the development or acquisition of new knowledge. It refers rather to its entry into a knowledge base.
- Update – the modification of knowledge resident in the knowledge base.
- Retrieve – the retrieval of relevant knowledge from the knowledge base for application.
- Delete – the deletion or elimination of knowledge from the knowledge base.
- Archive[16] – the long-term storage of knowledge in a separate location from the active knowledge base. Archiving is done for security, for increased performance of the active knowledge base through the removal of no-longer-needed knowledge, or both.

The key to effective knowledge management is the representational model used to store and access knowledge in the knowledge base. The emergence of knowledge management as an integrated and coherent set of tools and concepts is going to require the development of at least the following knowledge specific components:

- consistent and widely accepted knowledge models (ontologies)
- consistent and widely accepted knowledge structures (schemas)
- consistent and widely accepted knowledge manipulation language, which will in turn require:
    - a consistent and widely accepted knowledge dictionary
    - a consistent and widely accepted knowledge syntax
    - consistent and widely accepted inference mechanisms

Knowledge Functions: Refers to activities or functions that can be applied to knowledge including — knowledge acquisition, *knowledge representation*, *knowledge management* and knowledge usage. Knowledge acquisition includes: developing new knowledge (research), adding value to information to create knowledge, and converting implicit (or tacit) knowledge to explicit knowledge.

Knowledge Representation: Refers to the storage of knowledge in structures that enable the fast and accurate access of knowledge as well as the easy understanding of the content and its structure — i.e., *knowledge management*. Knowledge sources may be in the form of documents,

[16] Archiving a knowledge base should not be confused with backing up a knowledge base. Archiving implies a software independent format with complete schemas and dictionaries to allow recovery of the knowledge independent of the original software used to create and manage the knowledge base.

diagrams, flow charts, databases, etc. Electronic knowledge structures for these knowledge forms requires the creation of *ontologies*, data models and schemas and *semantic networks*, etc.

Ontologies: A representational vocabulary for a shared domain of discourse in terms of definition of classes, relations, functions, processes and other objects. Ontologies are the basis for knowledge integration and are analogous to data dictionaries and data models for data management and integration.

Expert Systems: Expert systems attempt to formalize heuristic (informal or rule of thumb) knowledge in a form that can be used by an inference engine to apply the knowledge to problems. Most expert systems are *rule based* and use a series of if-then-else statements to process input data to a logical outcome. Another approach uses a *belief matrix* as the knowledge base which records the belief in or the probability of an event or occurrence against a condition. In the case of identification, the belief class will occur under each of a specified set of conditions whereby the inference engine produces a weighted sum of beliefs for each condition, for each class and assigns the class with the highest weighted belief to the set of conditions. These approaches deal with a level of uncertainty, and a number of solutions with their attached belief values are possible. *Decision trees* are similar to forward chaining, rule-based systems but uncertainty levels can be attached to each stage of the process and each possible solution is evaluated, and a final probability or certainty value is attached each solution. *Object-oriented, fuzzy logic networks* use dependency networks which offer several significant advantages over the more traditional rule-based approaches by being more readily modularized and faster to build, test and maintain incrementally.

Knowledge Syntax: Defines grammatical rules for languages of inference and retrieval.

Semantic Networks: Define relationships of meaning between words and concepts.

Appendices

Appendix A: Guidelines for Setting Operational Inventory Funding Priorities

BACKGROUND

The following flow charts were prepared in an attempt to provide some direction for Forest Districts (Planning Units) in preparing their 1998/99 Operational Inventory Plan (OIP). .

Inventory Issue

The first chart is a list of issues or concerns that you may want to address with inventory projects. You should examine the whole list. Look carefully at what the information will be used for, *not* the inventory type itself. Each issue has one or more flow charts assigned to it. The flow charts are designed to assist in your decision making. The outcomes, or products of your decisions may be a survey or inventory.

Inventory Need

The type of product to answer your issue may also depend on the immediacy of your need.

- *Immediate* needs are required in less than 2 years, or are required to meet Forest Practices Code requirements.
- *Medium* needs are those that are required in the next 2-5 years or are required for a higher level plan or TSR.
- *Low* needs are not required for 5 years or more.

Many inventory products take 2 or more years to complete and therefore the size and scope of a project may make it an immediate need — e.g., an inventory that takes 3 years to complete, but is required for TSR II in 3 years.

Cost

Many of the inventory products have a cost estimate assigned to them. Many inventory products are still in the design phase and therefore costs are extremely high. Other inventory costs depend on the scope or size of the project. In general the larger the area covered the less the unit cost is. Some costs are a best "guestimate".

GENERAL APPROACH

The best approach to inventory planning is:

- Decide on the type of inventory is that required to meet the issue or concern;
- Determine how quickly the inventory is needed;
- Choose the inventory methodology that covers the most area for the least cost.

For example, the ideal approach to an ecological inventory is to do some form of ecosystem mapping using a predictive model, then follow up with detailed mapping projects only as necessary. Models cost far less and cover a greater area in a shorter time. PEM (Predictive Ecosystem Model) is a local model being evaluated by MOF(Allen Banner and Del Meidinger) and MOELP. It shows great promise and will be free. The model should be available within the next 2 years.

Inventories Funded by FRBC

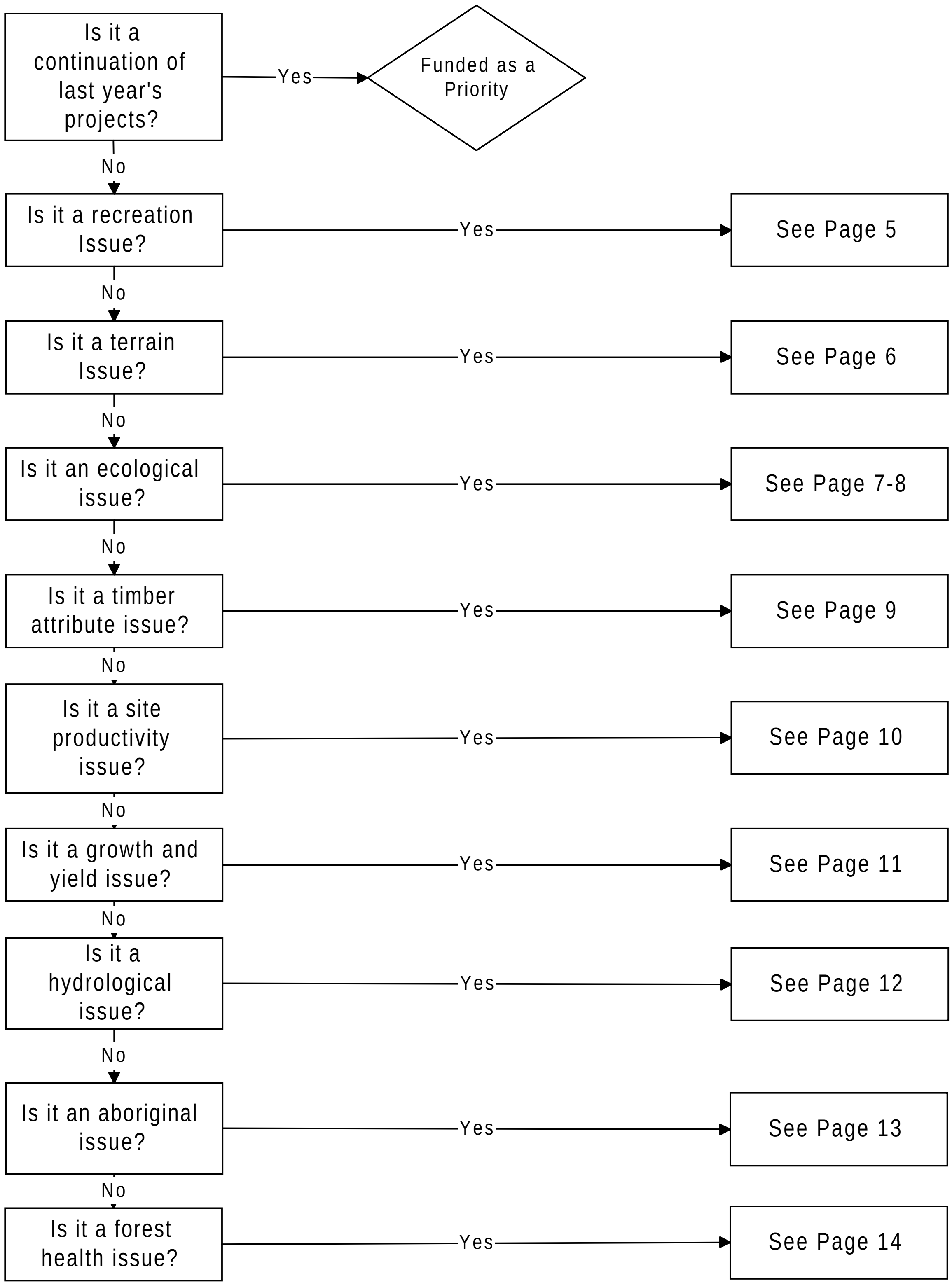
Inventories funded by FRBC that you should consider when setting priorities are the nine types of inventory listed in the Forest Renewal BC's Land Based Programs Handbook 1997/98 (Section 4.4), plus the following that were previously funded by FRBC Framework in the Region:

- Growth and Yield
- Site Productivity
- Vegetation Resources Inventory (VRI) - the new standard for replacing forest cover
- Traditional Use Studies
- Archaeological Overview Assessments

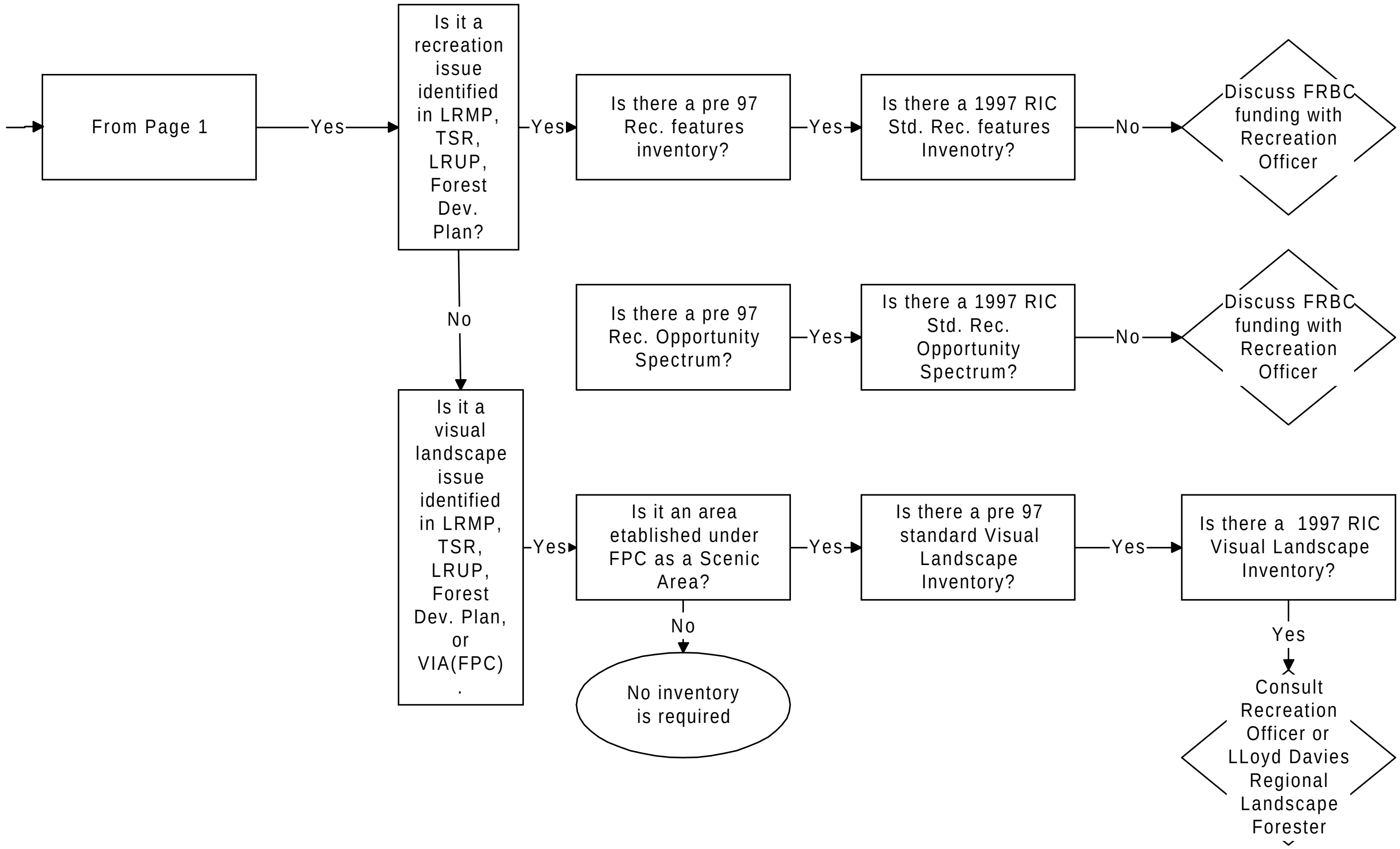
Documents you should review prior to decision making are:

1) BC Ministry of Environment Lands and Parks/ Ministry of Forests, North West Regional Inventory Committee. *Resource Inventory Projects Priority Setting Structure, Process and Criteria for Prince Rupert/ Skeena Regions,* Smithers, June 1997.
2) BC Ministry of Environment Lands and Parks/ Ministry of Forests, North West Regional Inventory Committee Resources Inventory Strategy for North-western British Columbia, Smithers, June 1997.
3) BC Ministry of Forests, Prince Rupert Forest Region Aboriginal Affairs Program. Traditional Use Study Five year Management Strategy and Implementation Plan , September, 1996.
4) BC Ministry of Forests, Timber Supply Branch. Forest Management Issues Identified Through the AAC Determination Process, Prince Rupert Forest Region, Victoria, 1996.
5) Forest Renewal BC. New Delivery System Guide Book , Draft 2, July 14, 1997.
6) Forest Renewal BC. land -Based Programs handbook 1997/98, Victoria,1997.
7) Memo from Ann Morrison. TEM/VRI Integration Pilot Project , August 25, 1997.
8) OIKOS Ecological Services Ltd. Morrison IRM Unit ,Terrestrial Ecosystem Mapping - Progress Report, Smithers, August 11,1997.
9) Resources Inventory Committee WEB Site . http://www.for.gov.bc.ca/ric

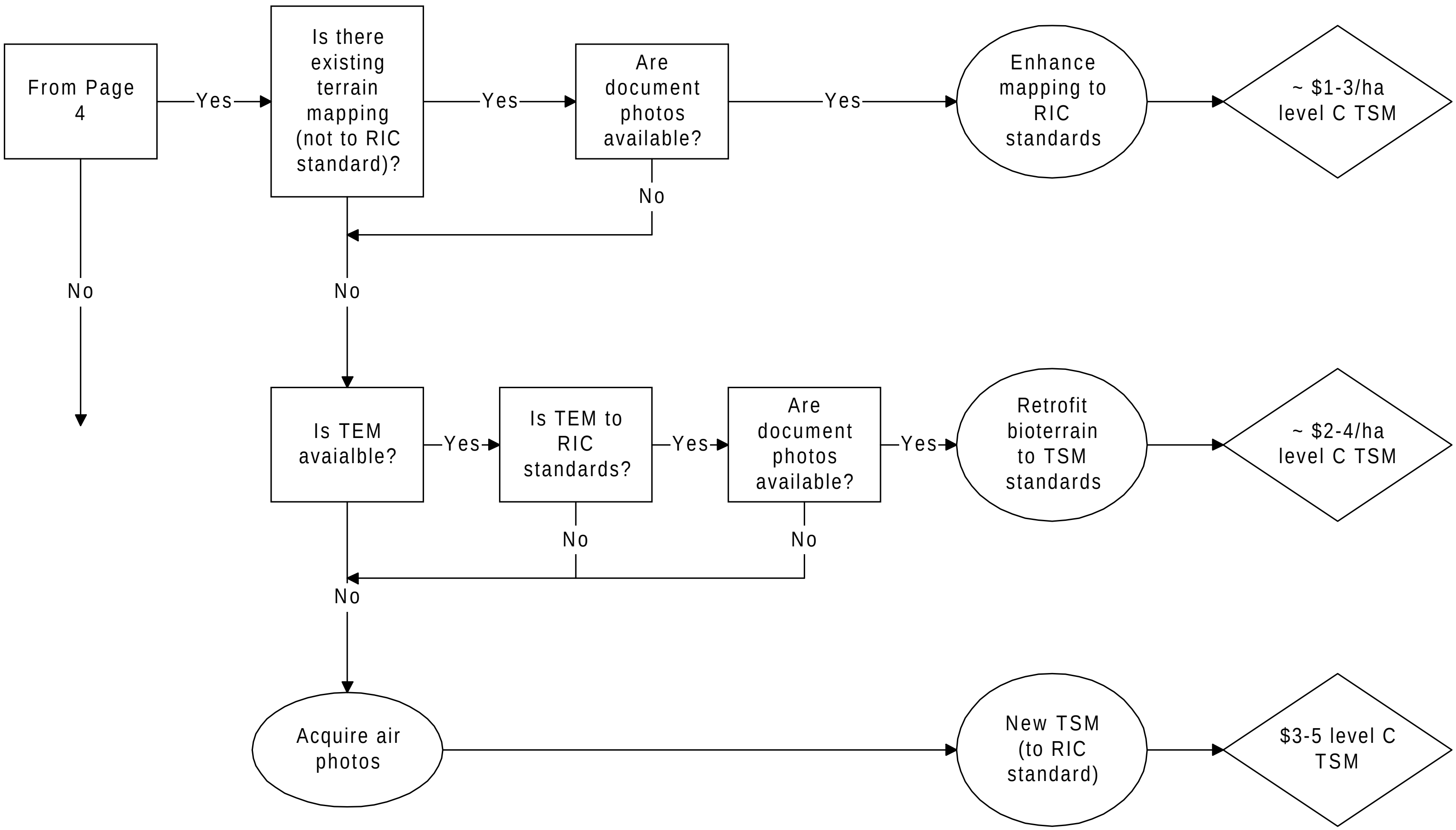
Issues or Concerns You Want to Address



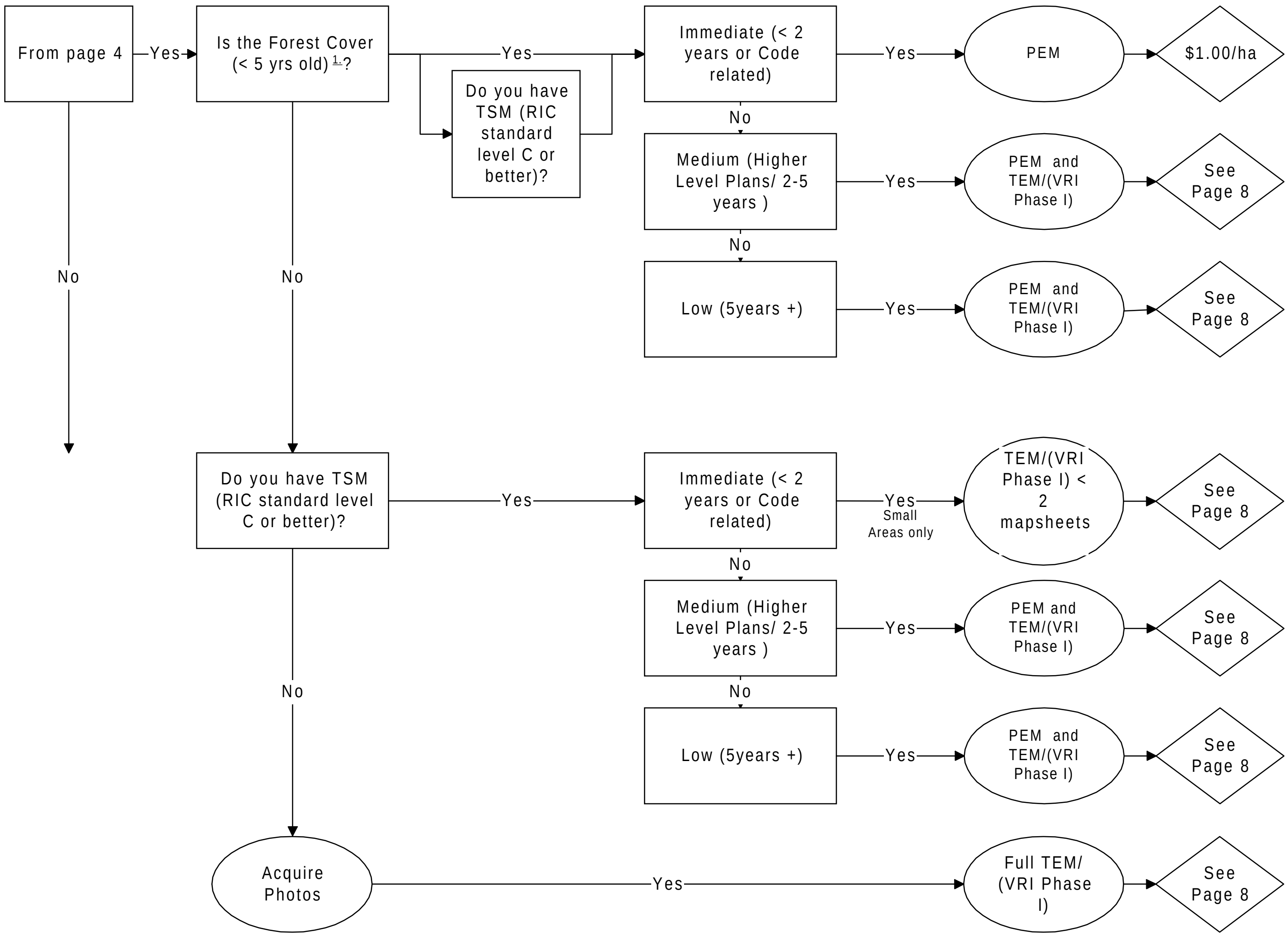
Recreation Issues or Concerns



Terrain Issues or Concerns\\

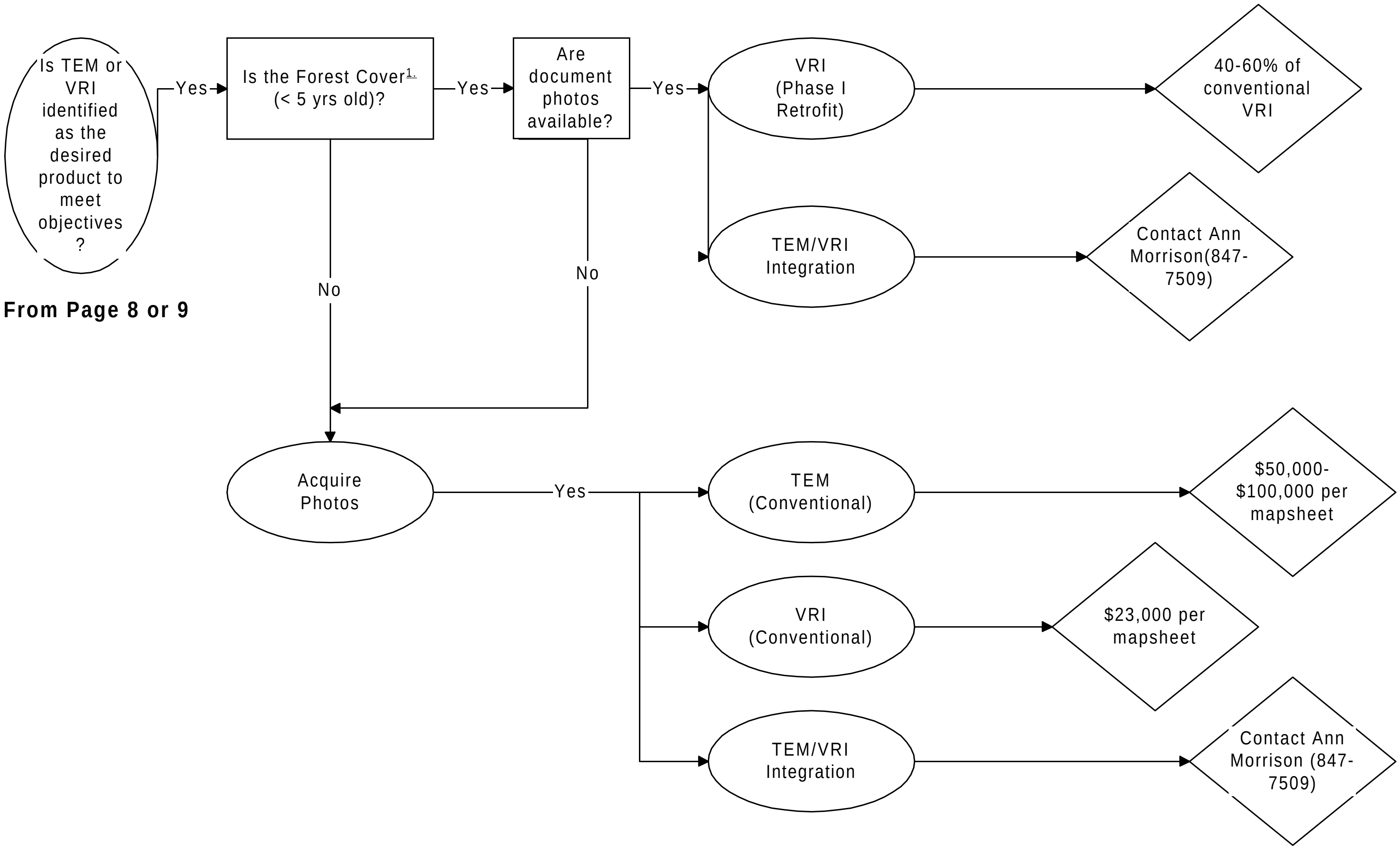


Ecological Issues or Concerns



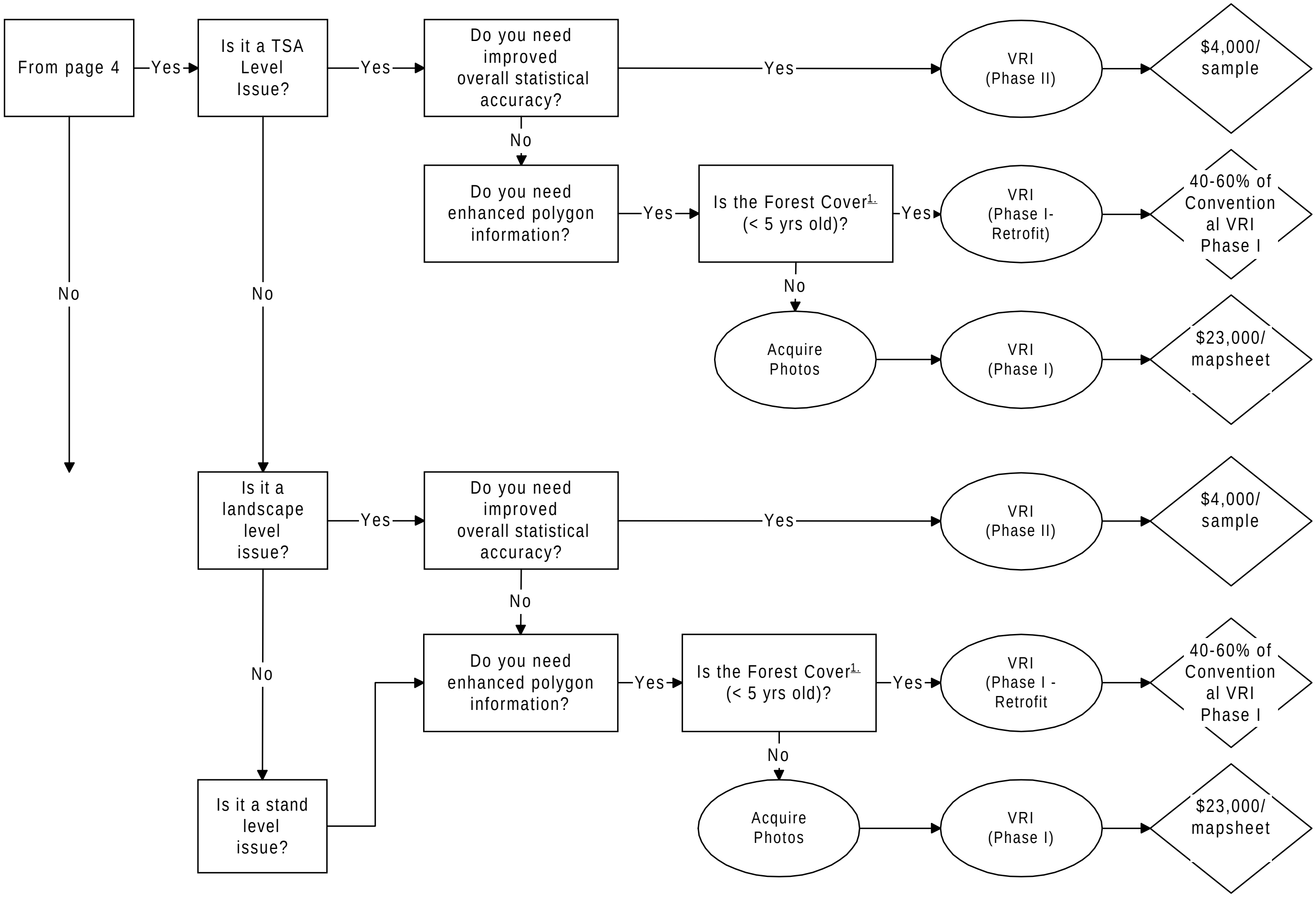
Ecological Issues or Concerns (continued)

Terrestrial Ecosystem Mapping/Vegetation Resources Inventory Integration



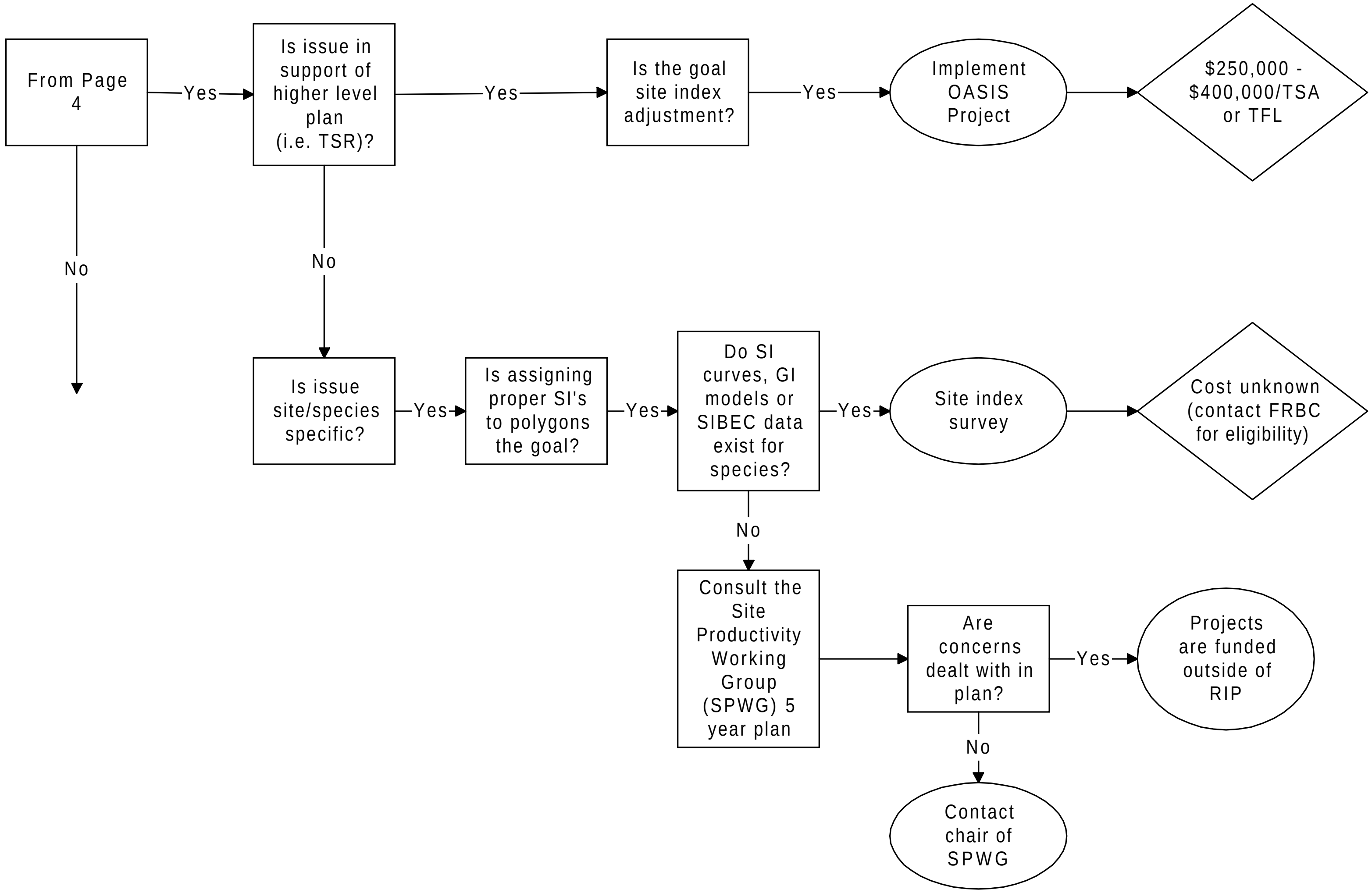
1.Forest Cover, (<5years old) - assumes that the typed document photos at 1:15,000 scale exist.

Timber Attribute Issues or Concerns

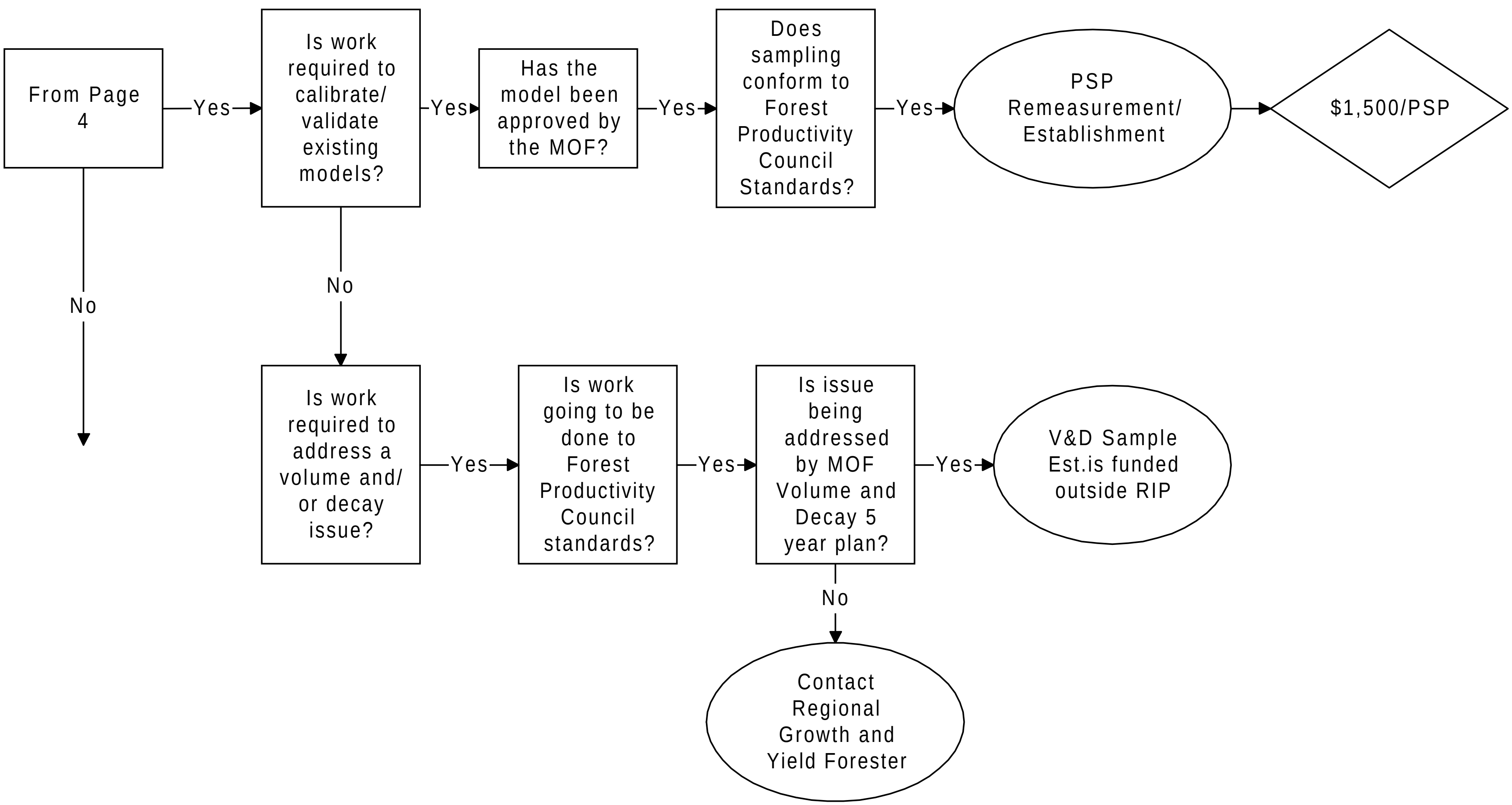


1. Forest Cover, (<5years old) - assumes that the typed document photos at 1:15,000 scale exist.

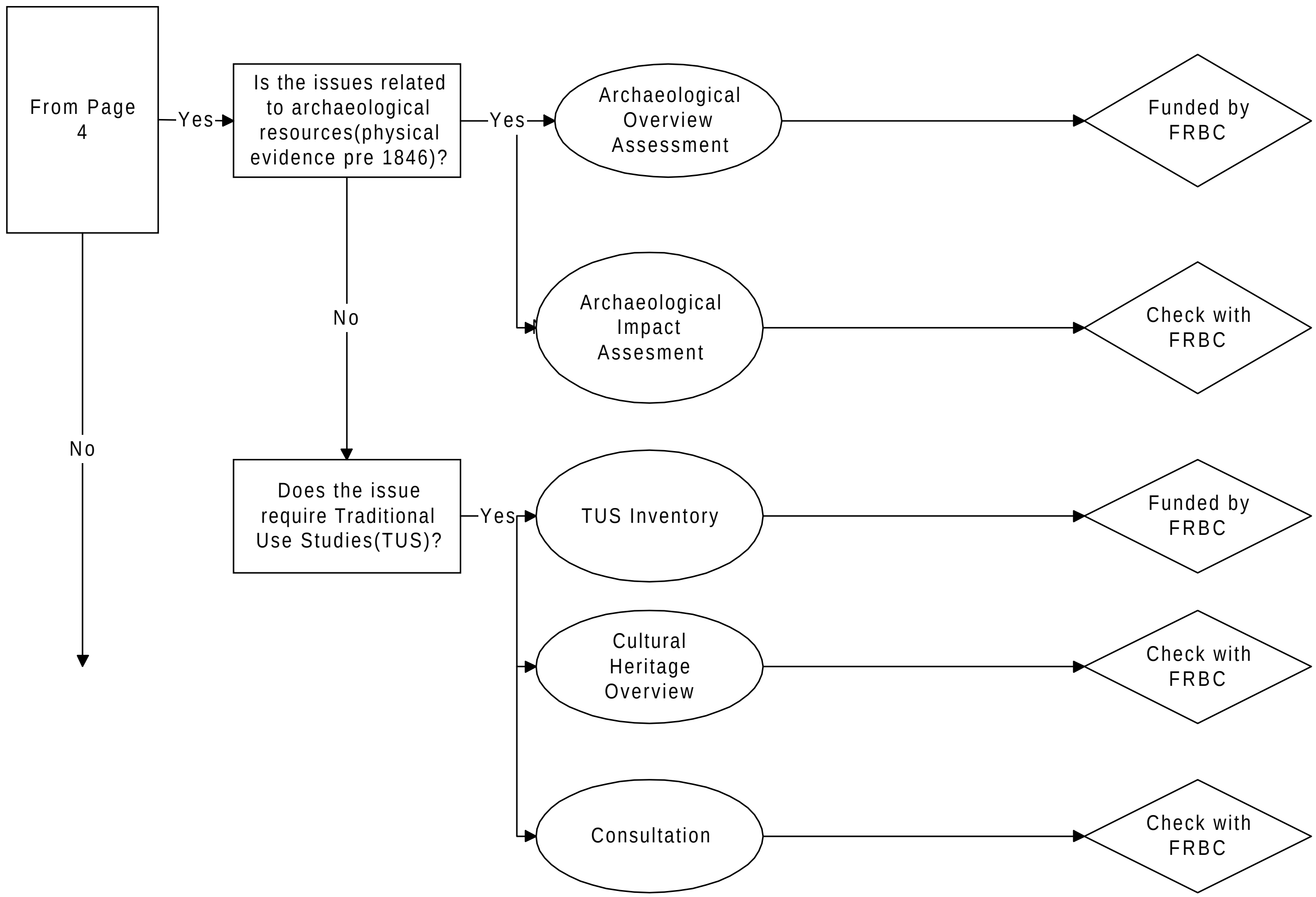
Site Productivity Issues or Concerns



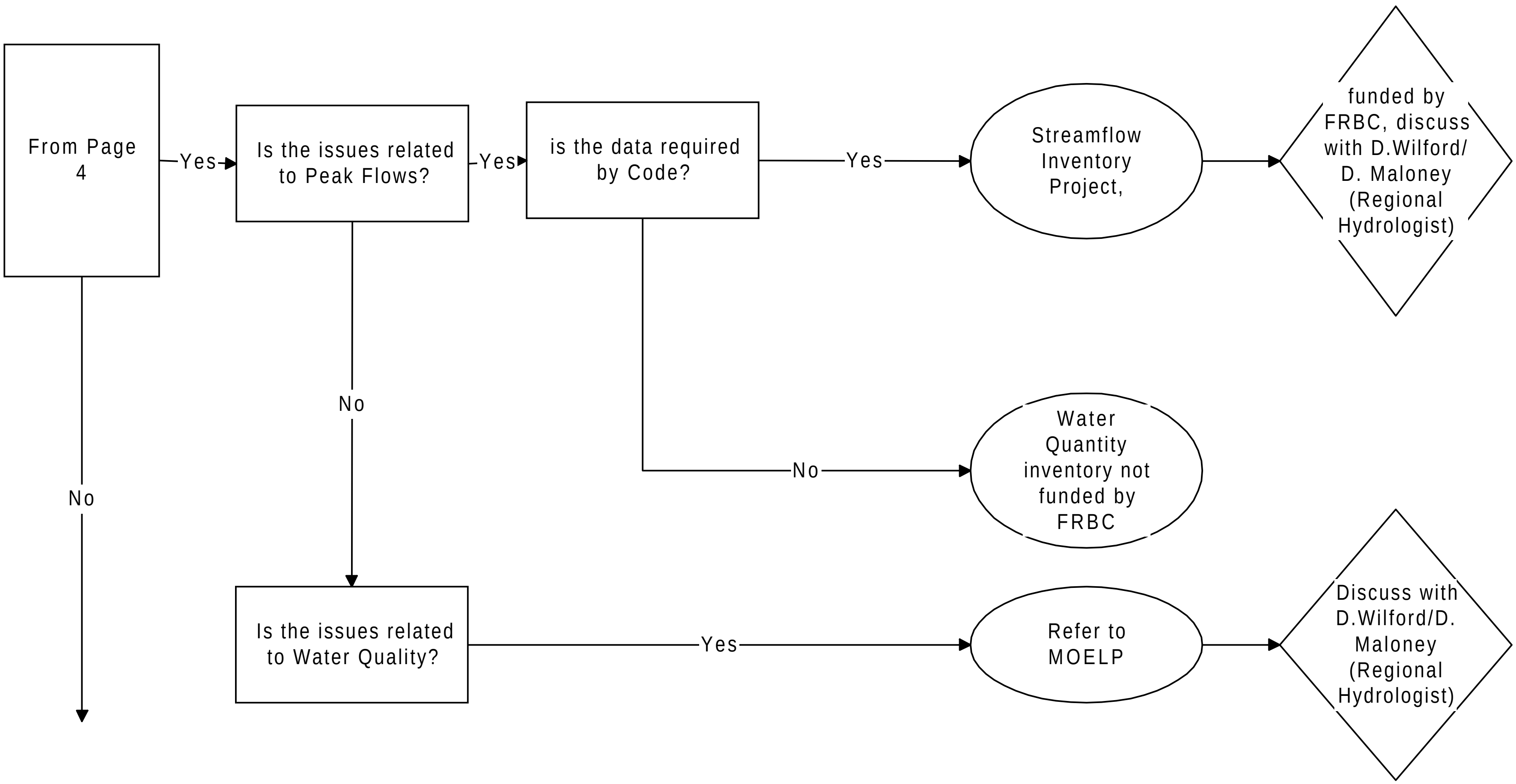
Growth and Yield Issues or Concerns



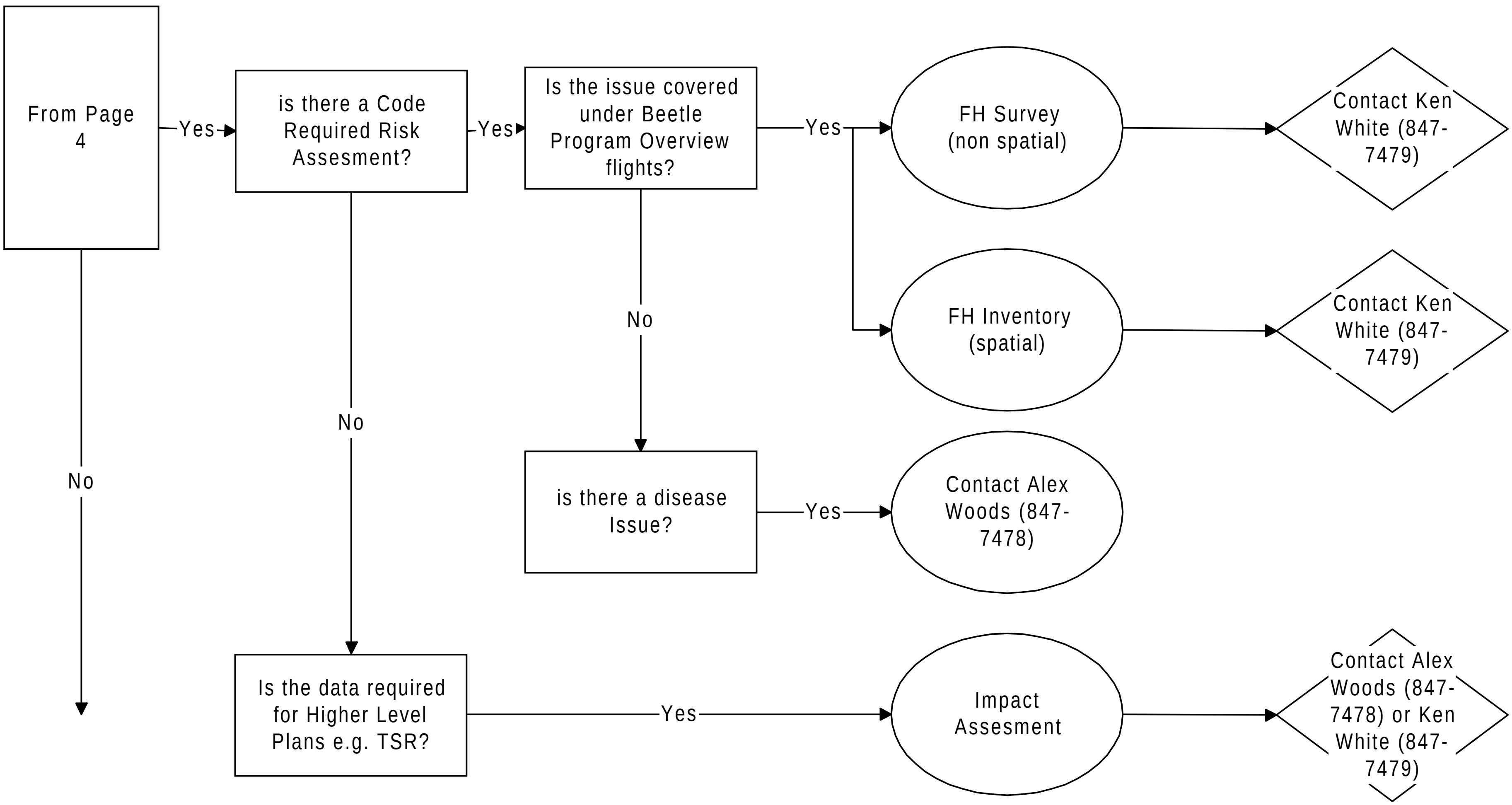
Aboriginal Issues or Concerns



Hydrological Issues or Concerns



Forest health Issues or Concerns



Appendix B: Decision Matrix for TEM and Tem Alternatives

Decision Matrix for TEM and Tem Alternatives

Ecosystem inventories help with resource management planning and land use conflicts by allowing managers to forecast physical and biological effects of various management practices over space and time. A clear understanding of the interpretive needs, priorities and methods of the resource manager at the outset of an inventory will have a major influence on data requirements, scale, survey intensity, and map reliability. The level of reliability should be guided by the consequences or risk of an incorrect interpretation or decision being made. If certain planning decisions are unlikely to have serious consequences, then the need for reliability may be relatively low - e.g., broad, regional level evaluation of forest productivity. On the other hand, if the choice of management options can have serious consequences, then map reliability should be high - e.g., protection of rare wildlife habitat.

The Standard for Terrestrial Ecosystem Mapping (TEM) was recently updated and approved by RIC. This standard includes three survey intensity options for mapping at 1:20k to 1:50k. The previous standard, of about 20% polygon inspections, is maintained as Level 4. Two levels of lower survey intensity are presented as Level 5 (about 10% polygon inspections) and Level R (reconnaissance sampling only).

Computer-based TEM-alternatives (called PEM, or predictive ecosystem mapping), help to formalize our understanding of ecological and land-feature relationships. These approaches are by and large consistent with and complementary to traditional TEM procedures. PEM systems help to force greater consistency with TEM protocols and offer the potential for increasing production rates, decreasing costs, and building capacity. They also have the potential to become a more integral component of evolving corporate information and knowledge bases. PEM and conventional TEM methods will be, at a minimum, complementary, or possibly converge.

Sampling effort, which has a strong impact on the rate and cost of an inventory, should be concentrated in areas where the potential consequences of interpretive error are the greatest. Interpretive requirements, in relation to risk, are key determinants of an inventory specification which in turn influence the reliability, cost, and rate of the inventory.

The following tables have been produced by the TEM-Alternatives Task Force to aid resource managers in deciding whether to use TEM or one of several TEM-alternatives for a given application. This is a first approximation generated with the best available information. Improvements to information may result in a set of updated tables.

The TEM-Alternatives Task Force would like feedback on the format and content of these matrices. The Task Force membership includes:

Del Meidinger, MoF, Research Branch, Victoria
Dave Clark, MELP, Resources Inventory Branch, Victoria
Bobby Love, MoF, Prince Rupert Region
Rob Stewart, MELP, Kispiox Forest District
Bill Beese, MacMillan-Bloedel, Nanaimo
Fritz Nijold, Weldwood, Quesnel
Fern Schultz, facilitator (MoF, Resources Inventory Branch, Victoria)

and was assisted by Keith Jones (R. Keith Jones and Associates).

Send your comments to: Dave Clark <dclark@fwhdept.env.gov.bc.ca> or to

Del Meidinger <Del.Meidinger@gems2.gov.bc.ca>

The following ‘codes’ are used in the tables:

BGC 1:250	Biogeoclimatic units @ 1:250,000
BEI	Broad Ecosystem Inventory. Broad Ecosystem Units are groupings of site series, mapped within BGC subzone variants at 1:250,000
LOC. BGC	Biogeoclimatic units localized to a larger scale, e.g., 1:50,000
PEM-1	Predictive ecosystem mapping, level 1 (basic data sources, e.g., TRIM, BGC, FC1/VRI)
PEM-2	PEM, level 2 (basic plus additional data sources, e.g., localized BGC, terrain, soils, or image analysis)
TEM-R 1:50	Terrestrial ecosystem mapping, survey intensity level ‘R’, 1:50,000 (reconnaissance level, <5% of polygons field checked)
TEM-5 1:50	Terrestrial ecosystem mapping, survey intensity level ‘5’, 1:50,000 (5 -14% of polygons field checked)
TEM-4 1:50	Terrestrial ecosystem mapping, survey intensity level ‘4’, 1:50,000 (15 -25% of polygons field checked)
TEM-R 1:20	Terrestrial ecosystem mapping, survey intensity level ‘R’, 1:20,000 (reconnaissance level, <5% of polygons field checked)
TEM-5 1:20	Terrestrial ecosystem mapping, survey intensity level ‘5’, 1:20,000 (5 -14% of polygons field checked)
TEM-4 1:20	Terrestrial ecosystem mapping, survey intensity level ‘4’, 1:20,000 (15 -25% of polygons field checked)
VRI-ESS	Vegetation resources inventory – Estimated Site Series (site series predicted directly from VRI phase 1 photo estimation)
C & I	Criteria and Indicators of forest sustainability
State of …	State of the Environment, State of the Forest, etc. Reporting
TS Analysis	Timber Supply Analysis from ecosystem-based site index
LRMP	Local Resource Management Plan
PAS	Protected Area Strategy (considering local ecosystems)
BDG-Repr.	Biodiversity Guidebook (FPC), determining representation at the variant level, or at the ecosystem unit (site series) level
IWS (1° strat.)	Identified Wildlife Strategy, primary stratification for population inventory and for determining Wildlife Habitat Areas
Env. Assess.	Environmental Assessment for impact and mitigation. May require detailed effort for 1° area of development and generalized inventory over a larger area for 2° impacts and context.

TABLE 1. TEM and TEM Alternatives Methods Meeting Present Business Needs

	BGC 1:250	BEI	LOC BGC	PEM-1	PEM-2	TEM-R 1:50	TEM-5 1:50	TEM-4 1:50	TEM-R 1:20	TEM-5 1:20	TEM-4 1:20	VRI-ESS
Provincial Criteria & Indicators	✓	☑	✓	☒								
State of …	☑	✓	✓	✓								
Regional												
LRMP	✓	☑	✓	☒	✓	✓	✓					✓
Timber Supply Analysis (ecological basis)				✓	☒	✓	✓	✓	✓	✓	☒	✓
Protected Areas Strategy (localized)	☑	✓	✓	☒								
Sub-Regional/ Operational												
BDG -Representation Variant	☑		☒									
BDG -Representation Eco unit / Site series				✓	☒	✓	✓	✓	☒	✓	✓	✓
IWS (1° stratification.)		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
Ungulate Winter Range				✓	✓	✓	✓	✓	✓	✓	✓	✓
Env. Assess.		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓

✓ = Method <u>can</u> be used.
☒ = Preferred method (timely, cost effective).
☑ = Presently used method.

TABLE 2. Comparison of TEM and TEM Alternatives using Selected Attributes

	LOC. BGC	PEM-1	PEM-2	TEM-R 1:50	TEM-5 1:50	TEM-4 1:50	TEM-R 1:20	TEM-5 1:20	TEM-4 1:20	VRI-ESS[4]
Reliability (Site Series)		L	L-M	L-M	M	M-H	M	M-H	H	L-M
Cost	$	$	$	$	$$	$$	$$	$$$	$$$	$
Time to completion	1/2	1/2	1/2	1	2	2	1	2	2	1/2
Expertise required	E,G	E,G	E,G	E,T,G	E,T,G	E,T,G	E,T,G	E,T,G	E,T,G	E,G
Field work required	L	L	L	L	M	H	L	M	H	L
Existing Data Source Quality										
FC/VRI species	H[3]	M	M							H
DEM	H	H	H	H	H	H	M	M	M	M
TERRAIN			M	M[2]	H[2]	H[2]	M2	H[2]	H[2]	
FC/VRI age /stocking		M	M	M	H	H	M	H	H	H

Footnotes:

1. Digital Elevation Model required <u>if</u> modeling modifiers, e.g., aspect.
2. Existing terrain will lower cost for TEM.
3. Useful where FC reflects ecological boundaries.
4. Assumes that input data (VRI phase 1) is complete and clean

Key:

Reliability (Site Series): H – high, M – moderate, L – low
Cost: $ – low, $$ – moderate, $$$ – high
Time (to completion): ½ year, 1 year, 2 years
Team (expertise required): E – ecologist, T – terrain (geomorphologist), G – GIS, F - forester
Field (sampling required): L – low, M – moderate, H – high
Existing data source quality
(relative to the needs of the output product): L – low, M – moderate, H – high

TABLE 3. Comparison of Selected Attributes by Inventory

	VRI	PEM	TEM	TSM
Forest Cover	Y	-	-	-
Site Series	(Y)	Y	Y	-
Terrain (Surf. Material)	-	-	Y	Y
Structural Stage	(Y)	(Y)	Y	-
Site Modifiers	(Y)	(Y)	Y	(Y)
Terrain Texture	-	-	(Y)	Y
Plant Species	(Y)	(Y)	(Y)	-

Y = Spatial data collected in inventory
(Y) = Attribute can be derived from data collected in inventory

VRI = Vegetation Resources Inventory
PEM = Predictive Ecosystem Mapping
TEM = Terrestrial Ecosystem Mapping
TSM = Terrain Stability Mapping