Natural Heritage Gap Analysis Methodologies Used by the Ontario Ministry of Natural Resources

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William J. Crins and Philip S.G. Kor
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Ontario Ministry of Natural Resources
Ontario Parks
Planning and Research Section
Peterborough, Ontario

1.0 INTRODUCTION

The goal of the Natural Heritage Areas Program is "*to establish a system of protected natural heritage areas, representing the full spectrum of the province's natural features and ecosystems*" (OMNR 1997). For life science features, this goal is achieved through an assessment of the landform/vegetation associations in each Site District, and the selection of a set of natural heritage areas that best meets a set of five selection criteria. For earth science features, the goal is accomplished through the development of environmental themes identified by the record of Earth history in the rocks, landforms and geological processes, both past and present, of Ontario, and the selection of a set of areas that best represent these themes.

The best representatives of the life science and earth science features are denoted as provincially significant. Protective zoning designations in Provincial Parks (Wilderness, Nature Reserve, and Natural Environment zones), Conservation Reserves, and Areas of Natural and Scientific Interest (ANSIs), taken together, provide the mechanisms by which the natural heritage features of each Site District and each earth science theme can be represented and protected. The focus in site selection is on the best representation of the natural diversity of the Site District or earth science theme. In the case of life science values, both living (biotic) and non-living (abiotic) components must be assessed; hence, the setting of representation targets is based on combinations of landforms and vegetation.

2.0 LIFE SCIENCE GAP ANALYSIS

Gap analysis, in the conservation biology context, refers to an approach (or a set of methodologies) for setting and filling natural heritage targets. It facilitates the identification of features that are unrepresented or under-represented within a natural heritage areas system. Different approaches have been used in different jurisdictions, but the underlying premise is common to all approaches: natural heritage features are assessed to determine whether or not some of those features require conservation.

The purpose of this chapter of the document is to outline the current life science gap analysis methodology employed by the Ontario Ministry of Natural Resources, and to outline the application of the five site selection criteria. In this province, the primary objectives of life science gap analysis are the assessment of the conservation status of the naturally occurring landform/vegetation associations of each Site District, and the identification of the best representative areas that together contain the full array of these associations. The selection of the representative areas must be conducted using as rigorous and objective an approach as is possible with qualitative or semi-quantitative site selection criteria.

While being cognizant of the principles of conservation biology, as well as current dialogue regarding the concept of 'biological integrity', the selection of areas must be accomplished within the scope of existing policies and principles. The methodology described here serves to identify core representative areas only, in as efficient a manner as possible. In order to ensure the ecological sustainability of these core areas, as well as of the landbase as a whole, resource management activities on the intervening lands must be conducted in a manner that does not compromise the ecological attributes and functions of these core areas.

The objective of selecting the best representative sites carries with it the need to identify parts of the landscape that have been subjected to limited recent human disturbance. The objective of identifying the best remaining examples of each landform/vegetation association in a Site District means that, on occasion, relatively small remnants will be identified, although in other cases, large aggregations or assemblages of features will occur together. No assumptions about minimum size requirements have been applied *a priori*. Rather, the methodology focuses on the identification of the best examples of what presently exists. Restoration of areas and their component features, and other conservation biology objectives, potentially can be added to the system in the future, but to avoid arbitrariness in site selection, the search for sites begins with the undisturbed or least disturbed areas.

Most gap analysis projects that have been conducted in various parts of the world have focused on life science features, and in particular, species and habitat representation. Almost all jurisdictions applying gap analysis have used a broad landform template, and some have superimposed habitat or vegetation onto that landform template. Most of the variation in approach occurs in the template on which natural heritage features are assessed (landforms, soils, vegetation types, species, geographic units, etc.), in the resolution of the targets, and in the determination of adequacy of present conservation of the natural heritage values. The approach used by the OMNR to identify and select core representative life science areas for protection is outlined below.

2.1 General Approach for Life Science Gap Analysis

OMNR's gap analysis method consists of four steps:

- Identifying landform features (coarse filter);
- Identifying vegetation features on each landform unit (fine filter);
- Assessing existing representation; and
- Identifying the gaps.

Step 1: Coarse filter - landform units (enduring features)

For the ecological district being studied (in Ontario, the Site District is the unit of study), available landform maps are examined. Surficial geology, bedrock geology, and combinations of these themes, can be used to delineate the landform patterns of the district. Mapping at a scale of 1:250 000 is suitable for analysis at the Site District scale. Sources such as the biophysiographic mapping produced by Noble (e.g., 1982, 1983) have been used in central Ontario (e.g., Crins 1996). They were produced through interpretation of surficial geology, the biophysiographic units essentially consisting of aggregations and/or refinements of Ontario Land Inventory (OLI) units, taking account of mode of deposition, major and minor overburden, and ruggedness or irregularity of the terrain. These maps are somewhat similar conceptually to the physiographic mapping produced by Chapman and Putnam (1984) for southern Ontario, although produced at a somewhat finer scale.

All landform units within the Site District are tabulated in this first step of the method. The finest level of resolution in Noble's biophysiographic unit classification system is used (i.e., Ia-1 and Ia-4 are considered to be different biophysiographic (landform) units).

OLI units may also be suitable for use at this stage of the analysis, but may require some preliminary aggregation of units, to make them comparable to Noble's units. All landform units recognizable at 1:250 000 scale within the study area are tabulated and mapped in this step. Other alternative landform systems could include Chapman and Putnam's system (1984) or soil surveys for the south, a combination of the bedrock geology and surficial geology coverages produced by the Ontario Geological Survey, or the Northern Ontario Engineering Geology Terrain Study (NOEGTS) coverage in the north. However, some of these coverages are at a coarser scale than OLI or Noble's coverages, with lower resolution, and therefore, are less preferable.

Step 2: Fine filter - vegetation response to landform

Using available databases, reports, and literature, the natural vegetation types known to occur within the Site District are summarized, and are correlated with the landforms examined in Step 1. This may be accomplished most effectively in a Geographic Information System (GIS) environment, where the vegetation data sets (e.g., Forest Resource Inventory [FRI] or classified LANDSAT imagery) can be overlaid on the landform data sets, then analyzed and summarized.. In section 2.3, a step-wise analytical procedure is described for the completion of gap analysis in a GIS environment.

Overlaying the landforms and vegetation types results in tabular and cartographic outputs for each landform/vegetation unit created within the study area. When FRI is used, the working group (generally, the dominant tree species) serves as a convenient level of classification for forested vegetation types. These are further subdivided by three broad age classes (see Appendix I). Thus, for forest vegetation types, representation targets consist of young, medium-aged, and old forests of each dominant tree species in each Site District. Summary statistics for each vegetation type and age class on each landform unit can be produced.

In all cases involving the use of FRI data as the vegetation coverage, the codes representing rock outcrops and wetland types can serve as a coarse classification system (albeit far from ideal) for non-forest vegetation types.

Step 3: Assessing existing representation

Examination of landform/vegetation complexes in existing protected areas including protective zones within Provincial Parks (e.g., Wilderness, Nature Reserve, Natural Environment), National Parks, and other land designations (e.g., Conservation Reserves) is undertaken to determine which landform/vegetation features are currently protected. Only those areas regulated or zoned specifically for natural heritage protection are factored in to the assessment of existing representation.

The landform/vegetation features occurring within existing protected areas are compared with the landform/vegetation features found in the Site District as a whole (Step 2, above). The comparison of existing protected landform/vegetation types with those known to occur in the Site District yields the unfulfilled representation targets, or gaps, that still require inclusion and protection in the natural heritage areas system. Guidelines are applied to ensure that features contained within inappropriate park classes or zones (e.g., Recreation and Historical Parks; Access, Development, Historical, and Recreation/ Utilization Zones) are not considered to be represented (see Section 2.3). These guidelines do not address the question of adequacy of representation, but simply provide a means of excluding features contained within developed or otherwise disturbed parks and protected areas that might otherwise be factored into the existing representation calculations.

Step 4: Filling the gaps

Landform/vegetation features that are not yet represented in the natural heritage areas system serve as the focus for the search for new areas to fill those gaps. The focus of the method is to identify suitable sites to fill the representation gaps. Selection criteria for new sites conform to those used in existing OMNR natural heritage programs (i.e., Provincial Parks systems planning; ANSI program). These include: representation (the basis for gap analysis, including broad age-class representation of forest types), condition (the degree to which anthropogenic disturbance has occurred), diversity (the number of different landform/vegetation features within a given area), ecological considerations (e.g., local hydrological/ watershed functions), and special features (presence of populations of vulnerable, threatened, and endangered species, localized or unusual features). The application of these five selection criteria allows for the assignment of relative significance levels to each example of the unrepresented features (e.g., provincial, regional, or local significance), taking into account the surrounding landscape (other adjacent unrepresented features, nearby special features, hydrological characteristics, etc.).

FRI or LANDSAT databases and landform maps serve as the background in which the search for unrepresented features occurs. Previous disturbance of the landbase by human influences (logging, mining, road-building, hydro development, agriculture, settlement) reduces the value of certain portions of the landbase for the achievement of natural heritage representation targets. Thus, such disturbances are taken into account in the search for areas to represent required features. OMNR District/ Area Offices are canvassed for cutover maps and other information relevant to the determination of impacts on the landbase. Other sources of disturbance information may also be sought out and used, including information held by resource-based companies, planning authorities, other agencies, etc.

The entire Site District is scanned for potential representative areas. Each area that is still relatively intact, in the sense that it does not contain extensive cutovers, road networks, or other developments, is compared with respect to the landform units and forest types (working groups and age classes) that it contains. An assessment of diversity within a block (relatively undisturbed portion of a Site District) is made on the basis of the number of landform units, working groups, and broad age classes, since other site-specific measures of diversity may not be available, especially in the north. Other parameters relevant to the five selection criteria also are assessed, including juxtaposition with existing protected areas, hydrological features, size, and special features. Since very little information is available on special features in many parts of Ontario, this criterion often cannot be applied with any rigor, but when information is available, it can be used to compare otherwise similar areas.

The final result of the gap analysis is a set of provincially significant areas that, taken together, provide the best representation of the array of landform/vegetation associations known to occur in the Site District. It also results in the identification of additional sites that fulfill all or some of the selection criteria, but that are not deemed to be the best representatives. These sites are assigned lower levels of significance (regionally or locally significant).

2.2 Site Selection Criteria

Five site selection criteria are employed to assist in the determination and delineation of provincially significant sites. These are: 1) representation, 2) condition, 3) diversity, 4) ecological considerations, and 5) special features.

Landscape-scale Criteria

1) Representation

Ontario's approach to life science gap analysis can be considered to be a 'feature-representation' approach. The method attempts to identify the 'best' examples of all landform/vegetation features (given the set of selection criteria described herein), thereby representing the full array of these features. This approach recognizes the reality that some landscapes are more diverse than others, without assigning a given percentage target, and also acknowledges that the land use history differs among landscapes and/or landform units. As Harris (1984, p. 109) noted, "... *the question of how much is enough can only be fairly addressed in the context of surrounding forest conditions.*"

The most important selection criterion is representation, since the entire natural heritage areas system is based on the principle that the areas containing the best representatives of each landform/vegetation complex are to be conserved, if possible. If an area does not contain a high-quality example of at least one landform/vegetation feature, then it should not be considered further, in this context. However, determination of the best representative examples may require comparisons among several potential alternatives, and this is where the additional selection criteria become necessary.

2) Condition

In the gap analysis method described above, the landbase under consideration for contribution to representation is screened by considering existing and past land uses (but not proposed future uses), including cutovers, road networks, mining areas, other unnatural corridors (hydro-lines, railways, etc.), agricultural areas, settlements, and other types of development. In effect, condition, or the degree of anthropogenic disturbance, has already been used as a selection criterion at this point. Potential sites for consideration as natural heritage areas are screened early in the selection process for their relative condition or quality.

Local-scale (Site Comparison) Criteria

Sites that remain under consideration after the Representation and Condition criteria have been applied must be compared using the remaining three criteria. Because there is often a lack of information about special features (populations of rare, threatened, or endangered species, unusual or localized geological features or habitats, etc.), especially on the Precambrian Shield, the special features criterion is best used as a supplementary or supportive one. Thus, all else being equal with regard to representation and condition, the diversity and ecological considerations criteria can be used to determine which of several sites should be regarded as the best site for a given feature or set of features.

3) Diversity

A site is considered to be more diverse than another if it contains more high-quality, representative features. Diversity can be achieved at several scales. However, in the landscape (Site District)-scale gap analysis, assessments of diversity are made at the landform and vegetation community scales, rather than at the species scale. In most cases, species richness is unknown in these sites anyway. Thus, a site that straddles several landform units will be more diverse than a site that is entirely confined to one unit. If the sites being compared are all situated on a single landform unit, then, again all else being equal, the site with the greatest range of vegetation types is preferred. If information sources permit (e.g., FRI data), age classes within vegetation types also are considered in the assessment of relative diversity. This is done by using broad age classes, defined for each forest vegetation type (see Appendix I). At the present time, there is no method for determining the effects of past logging (particularly when removal of single or a few species was involved) or human-induced fires on age class structure of the current forests. Thus, the approach taken here is to consider the existing forest, taking account of as much information on forest disturbance as possible.

Unfortunately, most databases available for use in life science gap analysis in Ontario do not do an adequate job of classifying non-forested vegetation types. Nevertheless, an attempt also should be made to consider rock outcrops, shorelines, non-treed wetlands and other non-forested vegetation types in the assessment of diversity, even if only broad categories and presence/ absence can be determined.

4) Ecological Considerations

Ecological considerations relate to such attributes as hydrological functions and connectivity (aquatic and terrestrial). An area that provides natural, biologically meaningful connections with other nearby significant areas, or an area that contains headwater lakes, ponds, springs, or streams, will fulfill this criterion. Limiting components of habitat, such as important moose aquatic feeding areas, bat hibernacula, spawning beds, etc., could also fulfill this criterion. These features are used to refine boundaries where they occur in close proximity to the core representative features. They also may be used to distinguish among areas that otherwise are similar in their representation, condition, and diversity.

5) Special Features

Special features include populations of rare, threatened, or endangered species, and unusual or localized geological features or habitats. Some parts of Ontario are extremely rich in such information (e.g., southwestern Ontario). However, in other areas, there is a lack of information. This lack of information may be due to difficulty of access or limited survey effort, rather than an actual absence of these features. Therefore, this criterion is best used in a supplementary or supportive role. Areas should not necessarily be penalized or downgraded if they lack special features, unless areas against which they are being compared do contain known special features. The Natural Heritage Information Centre is a primary repository for data on special features in Ontario.

2.3 Step-wise Methodology for Life Science Gap Analysis

This section outlines an algorithm for data analysis which results in the identification of representative core areas that, taken together, will contain the full set of landform/vegetation features found in a given Site District.

Part 1 - assessment of unrepresented features, and options for filling gaps:

- For each Site District, overlay landform and vegetation layers;
- Summarize proportions and amounts of each landform unit within the Site District;
- Summarize proportions and amounts of each FRI Working Group by three broad age classes (see Appendix I), on each landform unit; each Working Group age class equals a vegetation type;
- Overlay existing Protected Areas layer;
- Summarize proportions and amounts of landform/vegetation types for existing protected areas;
- Subtract landform/vegetation types meeting the minimum requirements[1] that are found in

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[1] Rules for determining minimum levels of representation required in protected areas:

- At least 50 ha of any landform/vegetation feature must be contained within a protected area in order to be considered represented, at this stage in the analysis;
- At least 1% of each landform/vegetation feature must be contained within the suite of protected areas in the Site District in order to be considered represented, at this stage in the analysis.

protected areas from total set of landform/vegetation types in Site District; produce table of unprotected types.
- Overlay disturbance layers for entire Site District;
- Remove disturbed areas from Site District land base;
- Identify all areas having unprotected landform/vegetation types (polygons), subject to the minimum representation rules applied above;
- If there are landform/vegetation types within the Site District that do not occur in undisturbed areas, re-examine the disturbed landbase for those types; examination of the disturbed areas may occur in a step-wise manner until suitable polygons are found;
- Delineate clusters of contiguous unprotected landform/vegetation polygons, including single polygons;
- Tabulate and sum the number of polygon types in each cluster; produce a table summarizing the numbers, types and sizes of polygons for each cluster;
- Overlay Special Features data, where available, for the Site District;
- Produce a map of clusters, using the above layers, including labels in hard copy and digital formats, and categorize the clusters on the map according to the number of unrepresented features contained in them - the digital file will be the plot file used to create the hard copy map.

Part 2 - identification of "best" representative areas:

- Using an iterative approach, identify those clusters that, together, best represent the features not yet represented in protected areas within the Site District. This will be accomplished by searching for the clusters that contain the most unrepresented landform/vegetation features, subject to the minimum representation rules noted above.
- Select the cluster identified in Part 1 that contains the most unrepresented landform/vegetation features, subject to the minimum representation rules (see footnote 1) used above (50 ha and 1%);
- Subtract the features contained therein from the list of unrepresented features in the Site District;
- Select the next cluster identified in Part 1 that contains the most unrepresented landform/vegetation features from the revised list, subject to the minimum representation rules used above;
- Subtract the features contained therein from the revised list of unrepresented features in the Site District;
- Continue this iterative analysis until all landform/vegetation features are represented in a set of areas.

These guidelines can be customized and adjusted to meet local circumstances, or to account for new information. The above-noted guidelines were used to identify candidate sites for protection during the "Lands for Life" planning project that resulted in the Land Use Strategy (OMNR 1999).

Part 3 - option development:

- The same approach as outlined in Part 2 can be used to identify optional representative areas, if needed, for planning purposes.
- Re-do the above iterative analysis, using the clusters that contain the second largest set of unrepresented features, assuming that the sites containing the most unrepresented features cannot be protected;
- Re-do the above analysis, using the clusters that contain the third largest set of unrepresented features (development of planning scenarios).

2.4 Assumptions

The life science gap analysis approach described here requires several assumptions. The over-riding assumption implicit in this methodology is that the Site District (ecodistrict) scale is the appropriate scale at which representative features should be selected to build a natural heritage areas system. This assumption also rests on the selection of the Ecological Land Classification (ELC) system originally designed by Hills (1959), and modified by others (e.g., Burger 1993, Jalava *et al.* 1997), as the template within which these gap analyses would be conducted.

Arguments for coarser and finer scales of resolution have been made, but the Site District scale has stood the test of time in Ontario (it has been used for over 20 years for the purpose of establishing and meeting natural heritage targets), and it provides a useful scale for the determination of major ecosystem attributes and dynamics. A coarser scale (e.g., Site Region or ecoregion) forces too much generalization. The substantial variation that exists in ecosystem composition, structure, and function across an ecoregion is not well reflected when natural heritage areas are selected at this scale, assuming that the approach described in this paper is used. A finer scale of resolution would be difficult to apply in most parts of Ontario, because of the lack of ecosection definition and mapping (however, this may become available in the near future), and the limited data available on detailed distributions and specific habitat requirements of most species.

In the present approach, it is assumed that landform/vegetation associations serve as adequate surrogates for ecosystem components, especially relating to habitat. The method attempts to identify potential natural areas on the basis of aggregations of these landform/vegetation associations, so that at least some of the natural areas will contain diverse assemblages of habitats and associated species.

Another inherent assumption is that undisturbed or least disturbed examples of the landform/vegetation associations are better, from a conservation point-of-view, than more severely disturbed examples of those same associations. This assumption has as its premise that relatively undisturbed examples of ecosystems are more likely to contain and support the full range of compositional, structural, and functional attributes of those ecosystems. Thus, they provide the best available samples of those ecosystems.

The limitations of the data sets that are used in life science gap analyses in Ontario (see Section

2.5) require that assumptions be made about several types of ecosystems (particularly non-forested, wetland, and aquatic systems). Since the data sets do not contain adequate classifications for these community types, reliance must be placed on very broad categorizations (e.g., 'rock' in the FRI data set would include natural rock barrens, cliffs, alvars, etc.). By including samples of such non-forested categories from each landform type, it is assumed that the range of ecosystems in these categories can be represented in the set of sites selected in the Site District.

The gap analysis method described here uses the concept of efficiency in an attempt to identify a set of areas that represents the landform/vegetation diversity of a Site District. Thus, areas are selected based on their relative diversity, with the areas containing the most remaining unrepresented landform/vegetation features selected at each iteration. It is assumed that more diverse areas generally will support more ecological functions, and contain more habitats and species. More diverse sites also tend to be larger, although this is not always the case.

Perhaps the most important assumption, in terms of application of this methodology, is that the remainder (bulk) of the landbase is being managed on an ecologically sustainable basis. This means that, for example, appropriate silvicultural approaches are being used in the forests adjacent to these sites, that guidelines conserving non-timber values are being applied, and that natural patterns are being emulated in resource planning and management activities.

The methodology, as presently designed, focuses on core representative features, with boundaries designed to account for local hydrological, topographic, and special features. There are no provisions for additional 'buffers', because it is assumed that activities on the adjacent lands will not be detrimental to the values of the core areas. This assumption clearly does not hold true in the settled parts of Ontario, but there, natural heritage core area design is constrained largely by adjacent land uses that have removed the natural or near-natural vegetation cover. Other approaches, including restoration activities, would be required to enhance the integrity of the core areas in such landscapes. In the less densely settled or developed parts of the province, forest management can be planned and conducted in an ecologically sustainable manner, through the application of guidelines and silvicultural approaches that maintain forest types that are adapted to the local site conditions. Thus, ecological functions including nutrient and water fluxes, gene flow, and various other components of population genetics and dynamics, can be maintained across the actively managed - protected area boundary interface. The 'edges' in properly managed landscapes containing core protected areas should be soft edges, not sharp discontinuities.

2.5 Limitations

In conducting gap analyses in Ontario, it has been necessary to use data sets that may have been compiled for entirely different purposes. This is because they may be the only data sets available that can provide the necessary thematic information (vegetation, landforms, disturbances, etc.). The various data sets also have been compiled or interpreted at varying scales, so there is the potential for inaccuracies to occur when these data sets are correlated or overlaid. This problem has been addressed, in part, by the exclusion of 'slivers' (landform/vegetation features less than 1 ha in size) from consideration when assessing the diversity of potential representative areas. Nevertheless, there is still the potential for artifacts when overlaying data sets with different scales of accuracy.

Two existing data sets have potential applicability for the vegetation component of life science gap analysis. These are classified LANDSAT TM imagery, and the Forest Resource Inventory (FRI). Each has advantages and disadvantages. The current classified LANDSAT data set does not provide adequate resolution of many vegetation types. For example, it is not possible to distinguish between spruce species, nor among intolerant hardwood species, nor is it possible to distinguish between ecotypes of a particular species (e.g., upland versus lowland Black Spruce). This is possible to some degree with FRI, by examining the stand composition, and understanding the ecological preferences of the species associated with Black Spruce. Neither LANDSAT nor FRI data sets classify non-forested lands adequately. However, the FRI does contain general categories for rock outcrops and various lake and wetland types. These categories generally are inadequate for natural heritage analysis purposes. Thus, it is necessary to make assumptions about non-forested vegetation communities that may be included within the sites recommended for protection in gap analyses using these data sources. In any event, it would be preferable to have data sets that are more ecologically based. A province-wide classification of ecosections and ecosites would be ideal for gap analysis purposes, and would provide the necessary analogs to the present landform/vegetation approach.

Another limitation of the vegetation data sets is that they are interpreted, although both data sets have had some degree of ground-truthing. There has been greater emphasis placed on refining the FRI data set on Crown Land, through additional timber cruising, than there has been on private land, although even on Crown Land, the focus always has been on commercial tree species. Also, the age of the actual FRI data varies from area to area. This also is true for disturbance information, such as cutover information. Up-to-date forest history data (cutovers, roads, etc.) often exist only in paper (not in digital) form, although some of these data are available in the LANDSAT and FRI data sets. Often, it is necessary to update disturbance coverages by digitizing the newer information, and by vetting the results of gap analyses with knowledgeable staff from the district and area offices. It may be necessary to revise the boundaries of proposed protected areas in the light of these additional disturbance data.
The method focuses on existing diversity. There has been no modeling of previous landscape structure and composition. Therefore, it is possible (likely in some areas) that some landform/vegetation associations that may have occurred in the past are not included in the sets of sites identified using the current methodology. Future research in natural heritage area systems should include modeling of past ecosystem distribution. Such work could then enable the identification of ecosystems in need of restoration, and suitable locations for such efforts.

Ideally, gap analysis should be conducted with proper spatial analytical tools, in a Geographic Information System (GIS) environment. Manual analysis of data sets is possible, and has been employed in the absence of the necessary digital data sets, but it is extremely time-consuming and inefficient. However, even with GIS, the size of some of the data sets to be analyzed, especially for the larger Site Districts, can stretch the capabilities of the existing technology. Several steps in the automated methodology outlined in Section 2.3 have potential limitations that require further consideration and development in the future. The rules/guidelines with regard to minimum levels of representation in existing protected areas and new candidate sites (50 ha and 1% of the landform/vegetation feature within the Site District) were designed to ensure that features within inappropriate areas (e.g., Recreation class parks) were not considered to be representative. This does not mean that these minimal levels are adequate for representation. They should be considered for what they were intended to be, that is, minima. Adequacy of representation is an issue that has no resolution at the present time. Adequacy will depend, in part, on the dynamics of the ecosystem being considered, and also on the nature of the land uses adjacent to, but outside of, that ecosystem. Thus, again, with the methodology described here, it is critical that ecologically sustainable resource management occurs outside of the protected core representative areas.

The GIS-based algorithm relies on the contiguity/adjacency of polygons containing unrepresented landform/vegetation features when identifying clusters and assessing diversity within those clusters. Thus, breaks in the landscape, whether they are based on features that are already represented, on disturbances, or on other types of polygons that are not classified or not factored in as features for representation, will serve to limit the sizes of the clusters identified as being potential representative core areas. Most of these breaks in the landscape are consistent with the approach of identifying core areas for protection using landform/vegetation diversity and efficiency assumptions. However, water bodies also may cause breaks in the landscape. Ideally, the system of representative areas would include the full array of aquatic ecosystems, as well. The ecological considerations selection criterion assists with this. Nevertheless, water bodies (including lakes, ponds, and large rivers) are not treated as targets for representation up-front in the current methodology, and must be factored in once the clusters have been identified. This also means that water may break clusters that might otherwise have been combined. A method is being developed to minimize this effect, but it is only partially successfully at present, and therefore, it is still necessary to assess this effect manually after clusters have been generated.

Although the present GIS-based algorithm accounts for numerous combinations and permutations in the available data sets, given the current approach to representation, it seems likely that there will always be a need for informed judgement by specialists after the results of any gap analysis have been obtained.

Since gap analysis is extensive, dealing with large land bases, field inventories likely will be limited. However, the results of gap analyses will always benefit from field visits to the sites, even if these occur at some time after the analyses are completed, for the purposes of confirming the results, providing additional details on the vegetation communities of the sites (particularly with regard to understorey species and non-forested communities), and acquiring data on special features. It is possible that boundary revisions may be warranted at such time as site-specific inventories are conducted, or as information becomes available, either from staff or from members of the public who may visit these sites.

Most of the information on populations of rare, threatened, or endangered species is found in OMNR files, and in the north, much of it relates to a few “featured species”, such as Bald Eagle. Virtually nothing is known of the botany of large portions of the province. The Natural Heritage

Information Centre contains the most comprehensive data sets for rare species, and is constantly updating its data sets, but data for northern areas are still limited.

3.0 EARTH SCIENCE GAP ANALYSIS

3.1 Introduction

The goal of the Natural Heritage Areas Program is "*to establish a system of protected natural heritage areas, representing the full spectrum of the province's natural features and ecosystems*" (Ontario Ministry of Natural Resources 1997). For life science features, this goal is achieved through an assessment of the landform/vegetation associations in each Ecodistrict (formerly Site District) and the selection of a set of natural heritage areas that best meets a set of five selection criteria (Crins and Kor, in preparation). For earth science features, the goal is accomplished through the development of environmental themes identified by the record of Earth history in the rocks, landforms and geological processes, both past and present, of Ontario, and the selection of a set of areas that best represent these themes.

The best representatives of the life science and earth science features are denoted as provincially significant. Classification of, and protective zoning designations in, Provincial Parks (Wilderness, Nature Reserve, and Natural Environment), Conservation Reserves, and Areas of Natural and Scientific Interest (ANSIs), taken together, provide the mechanisms by which the natural heritage features of Ecodistricts and earth science themes can be represented and protected. The focus in site selection is on the best representation of the natural diversity of the Ecodistrict or earth science theme. In the case of life science values, both living (biotic) and non-living (abiotic) components must be assessed; hence, the setting of representation targets is based on combinations of landforms and vegetation. This has the potential of combining some life science and earth science representation into single protected areas.

3.2 Background

In 1978, a revised Parks Policy established a goal and objectives for Ontario's Provincial Parks. One major objective of the policy is: "*to protect provincially significant elements of the natural and cultural landscape of Ontario*". This objective was to be satisfied through a system of parks and zoning (now expanded to include Conservation Reserves) founded on the principles of representation, variety and permanence. The policy guideline articulating the Ministry's protection objective as applied to the geological component of the natural landscape is: "*to protect a system of earth science features representative of Ontario's earth science history and diversity*".

Earth science features are defined as the physical elements of the natural landscape, created by the earth's processes and distinguished by their composition, structure, and internal and external form. Earth science conservation is the recognition of the significant elements of the natural landscape and their protection from undue alteration by man's activities. "Gap analysis" is a term recently applied to a comparative evaluation process that seeks to achieve representation of these elements in a system of protected areas. This section explains the gap analysis process as used for earth science conservation.

The protection of geological and landform elements of the landscape has a long history in Ontario, and was formally recognized in policy as early as 1959. The gap analysis process presented in this document has been in use in Ontario since the early 1970s (Beechey and Davidson 1980; Davidson 1981, 1988), although the term "gap analysis" has only recently been applied to the process. This report represents the earth science component of a larger report dealing with earth science and life science gap analysis procedures (Crins and Kor in preparation).

3.3 Earth Science Conservation

To satisfy the Provincial Parks Policy's earth science guideline, a framework, or model, was needed to guide the selection of features. The resulting document, informally called the *Earth Science Framework* (Davidson 1981), essentially a synthesis of the geological history of Ontario, outlines the geologic themes and features which are targeted for representation in a system of protected areas.

Earth science conservation (also known as earth heritage conservation, or geological conservation) concerns the protection of selected, representative features of the province's geological history and its physical expression on the landscape in a system of protected areas. It also involves the monitoring of the remainder of the physical land base to provide alternate sites for scientific and educational opportunities. Earth science gap analysis is a selection process that determines first, the required levels of representation of the earth sciences in Ontario, and second, identifies existing levels of that representation in protected areas. The process then identifies the features which are unrepresented or under-represented in existing protected areas, and identifies sites where features of the geological history, landforms and processes in Ontario will address the completion of that representation.

The objective of the earth science gap analysis process is the identification of the representative features of the province's physical landscape that best define its past and present environments. These environments are interpreted through scientific study of the province's rock record, surface morphology, and geologic processes active in the past and in the present. In order to determine what features are most important to be set aside, it is necessary to describe the earth science diversity of the land base and to determine the most significant elements essential to the description of that diversity.

The classification of earth science diversity is based on internationally recognized (if not always agreed to) concepts of time, landform evolution (geomorphology) and geologic process. The earth sciences encompass a range of interconnected but quite distinct subdisciplines that together help to explain how Earth formed and changed through time, at depth and at the surface. Earth science representation attempts not only to identify an example of all the known geological features in the province (rock types, fossil assemblages, landforms and geological processes), but also to identify a suite of features that define the significant geological events through time. This time aspect of geological representation is found in the rock record by its lithostratigraphy, in the fossil record by its biostratigraphy, and in the landform record by its morphostratigraphy. Thus earth science representation seeks protection of the elements of the physical makeup of the province, as well as protection of complexes of the physical features of the province that define the passing of geologic time.

In the bedrock record, the protection target is to identify one best representative example of each rock type (lithology) from the full range of identifiable units that we know to occur in the exposed rock record. In addition, the protection target is to identify examples of each discrete period of time within the sequence of events in the geologic time scale as represented by individual rock units (lithostratigraphy). This inevitably results in the duplication of rock type representation, because of the inherent cyclicity in geologic processes over time.

A similar approach is required for the representation of landforms, which, in Ontario, are predominantly glacial in origin. Representation targets consist of the identification of the best examples of each landform (and its derivatives) that occurs in the province, as individual features (i.e., esker, moraine, drumlin, kame, etc.), and, the identification of landforms which best reflect the major events in the (in this case) glacial history of the province (morphostratigraphy).

The ancient geologic processes which have shaped the province are reflected in the rock record, fossil record and landform record of the current landscape. Examples include glacial and marine environments. Representation of these processes is achieved largely through the identification of sites noted for their values in representing chronology and stratigraphy. Representation targets for modern geological processes, such as lakeshore, fluvial and aeolian processes, constitute those sites that best display the current actions of a selected process and its resulting landform(s).

To accommodate the range of geologic time, stratigraphy and landform in the province, the geologic record in Ontario has been classified into **44 environmental themes** (Figure 1), each of which represents a particular, interpretable environment of formation. Each environmental theme is characterized by a set of features, or elements, of the physical landscape, be it in the rock record, the fossil record, or the landform record, that defines a set of conditions of formation, or environment. In this way, each environmental theme is distinguishable from adjacent themes. The environmental themes are tied closely to the geologic time scale, in that each theme represents a set of conditions known to occur during a particular time period of earth history. Examples of environments that helped shape the landscape and that are accompanied by physical evidence, are periods of mountain building, periods of profound erosion, the incursion of warm tropical seas, the impact of extraterrestrial objects on the earth's surface, and periods of glacial activity. The elements of each of these themes, that is, the features that serve to characterize the environment that identifies each theme, make up the representational targets of the gap analysis process. The environmental themes used in Ontario are defined and described in the *Earth Science Framework* (Davidson 1981), and are tied closely to the geological history presented in the *Geology of Ontario* (Ontario Geological Survey 1991, 1992).

The scale of representation of the elements of an environmental theme varies considerably. Individual outcrops of bedrock or unconsolidated sediment are generally small, less than 1 hectare in size (Figure 2). Individual landforms and some process themes may only need a few 10s of hectares to adequately represent enclosed features (Figure 3). Larger landforms, and associations of landforms, may require many 100s of hectares to adequately represent the identified features (Figure 4). The representation of active geological processes often encompasses large areas (Figure 5), sometimes requiring the management of areas beyond the specific identified element(s) in order to assure the continued natural functioning of the identified process(es).

Because of the wide range of scale in the types of earth science features evaluated, no

assumptions about minimum size requirements have been applied *a priori.* There are no upper or lower limits set on the amount of land to be protected for earth science features because there is no scientific basis for setting such arbitrary limits. Rather, the methodologies focus on the identification of the best examples of any features appropriate to the scale of that feature. The scale of each feature or combination of features will determine the size and shape of the site boundary required for its adequate protection.

What constitutes "best", as in the "best example" of a geological feature? By virtue of its location, history, etc., each outcrop and landform may be considered unique. Depending on the level of research and study of the geology of a specific region, each unit or feature may have several known exposures or occurrences, recognizing that not all occurrences may be known at the time of study. The best example of a geological element is chosen first from one that is known to occur, and second, one that adequately displays a range of typical characteristics by which the element is recognized. Such a best example is often chosen by the consensus of geoscientists, as reflected by its use in the literature, in field trip guidebooks and by the academic community, to characterize a certain rock type, fossil assemblage, landform or process. Additional best examples will be determined through literature review, consultation with experts in the various fields of geology, and original fieldwork by OMNR earth science staff or consultants through theme studies or regional inventories. In the identification of elements related to the landform and process themes, an important component of this field work is the review of all available remote sensing information (particularly air photos and surficial geology mapping).

The selection of the best representative examples of earth science features generally consists of those that have not been altered or impacted by man's activities. It is preferred that the morphological integrity of landform features, and the continuance of active geologic processes, be captured intact. However, for earth science gap analysis, the objective of selecting the best representative sites sometimes requires that parts of the landscape that have been subject to human disturbance be identified. The objective of identifying the best remaining examples of each feature relevant to the geologic history of the province means that, where no other examples occur or are available, then sites with acceptable degrees of impact are chosen.

While undisturbed or least disturbed sites are generally preferred in initial evaluations, a significant exception to this rule is in the selection of bedrock sites and sites consisting of unconsolidated sediments. Many of these are significant precisely because they have been artificially exposed through blasting or quarrying to reveal the internal structure of the selected geologic units or features. Road cuts, quarry faces, mine shafts, aggregate pits, etc., have existing or potential significance in defining Ontario's past environments. With every new section that is exposed, there is potential for improvement in our knowledge of an event or aspect of our geological past.

The minimum requirement of a system of protected earth science features is to represent a complete suite of elements that define each of the 44 environmental themes in Ontario. This "one-of-each" approach represents the minimum "line" required to achieve complete representation. This approach is not ideal in that it fails to provide for unforeseen events that may negatively impact this minimum. It also fails to provide the flexibility needed to address changes in ideas and concepts, and associated significant sites, with time and always expanding knowledge. Geology is a fluid science. Theories and hypotheses change as the knowledge base grows, and the list of significant sites that help to identify these new ideas may change or grow as a result.

3.4 The Gap Analysis Process for Earth Sciences

The methodology for determining the best candidate areas to represent earth science diversity within the context of an environmental theme is a comparative evaluation that has recently come to be known as "gap analysis". Gap analysis involves the description of earth science diversity in a selected theme, the identification of protection targets, the determination of which targets are already represented in a system of protected areas, and, the resultant "gaps" in representation of the diversity that still require protection. This process of comparative analysis as applied to earth science conservation has been followed in Ontario relatively unchanged since the early 1970s (Davidson 1981, Davidson 1988).

The gap analysis process is normally carried out in two phases: a broad analysis of the possible representational targets of a theme (steps 1-4 below), and a subsequent detailed inventory of specific features and sites required to complete representation (step 5 below). These steps are summarized as follows:

Step 1: Identification of significant elements of a theme (representation targets);
Step 2: Distribution mapping of the significant elements;

Step 3: Determination of existing representation within protected areas;
Step 4: Identification of features not in protected areas (the "gaps");
Step 5: Identification and comparison of selected sites capable of filling the gaps.

Step 1: Identification of significant elements of a theme (representation targets)

For the selected environmental theme, this step identifies the significant elements that make up the theme; that is, the features of the theme which characterize it. This step involves the documentation of the complexity of the theme and the variations that exist in individual features of the theme. The suite of elements so identified constitutes the representation targets of the theme.

For themes identified by the bedrock record, the targets will constitute representation of each bedrock unit within the theme and its significant variations, as well as representation of unit contacts and other important associations. A chronostratigraphy, lithostratigraphy and/or biostratigraphy are assembled from this information for each theme. For themes identified in the landscape record, representation targets will consist generally of examples of landforms and landform associations that describe the environmental conditions during the selected theme. A morphostratigraphy will be prepared for each of these themes. Representational targets for landform process themes will constitute a record of the salient elements that characterize the process, be they ancient or modern. A listing of these elements is prepared for each selected theme.

This step is primarily one of information gathering. All pertinent literature is reviewed, and discussions are sought with experts in the particular discipline or subdisciplines of geology which make up the theme (e.g., Precambrian Grenville Province bedrock; Quaternary glacial themes; Paleozoic fossil assemblages). The expertise and knowledge of the earth science surveyor/specialist conducting the gap analysis will also contribute to site identification. In this way, features that are important to the recognition of each theme are identified.

Step 2: Distribution mapping of the significant elements

The second step requires the mapping of all significant elements of the selected theme identified in Step 1. Thus, the distribution and/or general location of all features are documented and plotted. Where complete geological mapping is available, the features of a theme may be identified on the maps. The information gathering process in Step 1 will have identified the significant elements of each theme, and will likely have identified several localities for each element. All potential site locations are plotted and mapped so that they can be evaluated and compared during the field stage of gap analysis.

The scale and complexity of features that make up each theme is dependent on the state of knowledge of its component geology, and the spatial distribution of the theme elements on the landscape. Some environmental themes consist of only a few known occurrences of features, whereas others encompass a large portion of the province and constitute many features. Similarly, some aspects of the province's geology are well documented, whereas others are little known. These discrepancies in scale and knowledge will affect the number and size of representation targets for each theme.

Step 3: Determination of existing representation within protected areas

The next step in the gap analysis method is the identification of the elements of the theme that already occur in protected areas. At the time of writing, protected areas constitute Provincial Parks and Conservation Reserves. Areas of Natural and Scientific Interest (ANSIs) are also considered to contribute to the earth science protection targets, but their status on private lands (most ANSIs) means that they cannot be strictly considered as protected.

For a theme element or feature to be considered represented, it must be provincially significant, and it must be contained by appropriate protected area class or zoning, or have relative protection outside parks through municipal zoning or landowner agreements.

This step is again an information gathering exercise which involves a review of the available literature, notably earth science inventories of individual parks, and earth science theme studies, regional earth science systems plans and earth science checksheets prepared by OMNR since the early 1970s. The Earth Science Data Base housed with Ontario Parks, Peterborough, contains information on most protected areas in an electronic form.

Fieldwork of a reconnaissance nature may also be required at this stage to confirm the quality and condition of identified features, especially in protected areas for which a detailed report has not been prepared.

Step 4: Identification of features not in protected areas (the "gaps")

The previous step serves to identify the elements or features of a selected theme which are formally protected in Ontario's protected areas system. The remaining elements of the selected environmental theme that are not formally protected constitute the "gaps" in representation that require filling. Sites where these elements are found are determined from the lists prepared during Steps 1 and 2. In some cases, specific localities will have been identified. These need to be field checked for quality and condition. In many cases however, specific sites will not have been identified. The geological mapping or literature searches will have identified general localities where certain features may be found. These areas will form the basis for fieldwork to identify more specifically the location of significant features.

Step 5: Identification and comparison of selected sites capable of filling the gaps

As noted in Step 4, some unrepresented features will have been recognized through the literature and remote sensing searches of Steps 1 and 2. Where more than one site is identified as representing a feature, or if a regional or area study is needed to identify new features, a comparison of like elements from the list produced in Step 4 will be required. The comparison of sites and selection of candidate areas for protection is achieved with the application of a set of six primary selection criteria. These criteria are: representation, type sections and related features, diversity, integrity (condition), life science values and special features. These are described in more detail in the following section of the report.

Step 5 involves original fieldwork by OMNR staff or consultants to locate and evaluate the candidate sites identified in Step 4. Fieldwork is essential in order that the most up-to-date site conditions (quality, integrity, condition), and aspects of the feature(s) not evident in the literature and/or remote sensing reviews, are recorded. A gross filtering occurs at this stage to remove sites that have a history of disturbance, past or present (primarily applied to glacial, landform and process themes). Disturbance consists of any man-made activity that has altered or removed a feature from its natural state. This criterion does not generally apply to bedrock features, which are commonly best displayed in highly altered sites in which the three-dimensional character of the features are exposed, such as road cuts and quarries, or to some exposures of unconsolidated sediment, which may occur in active or abandoned aggregate pits. The resulting list of the best remaining sites constitute the set of preferred candidate protected areas for the environmental theme under study. Given that they represent the diversity of the theme in question, the sites so identified are ranked as *provincially significant* within the context of the theme.

In a large province like Ontario, there is also a need to provide for the protection of sites of regional and local significance for the benefit of scientific study and educational opportunities. Such sites also serve as back-ups for the provincially significant sites. As such, in addition to the provincially significant sites, a suite of regionally significant sites should be identified and protected. It is not the intent of the gap analysis process to bring forward regionally significant sites for formal protection. Regionally significant sites will usually be dealt with through other protection mechanisms (such as ANSIs, Areas of Concern, etc.) to ensure their future availability for research, educational and interpretative purposes.

3.5 Selection Criteria

The following site selection criteria are used in the identification and ranking of earth science features. Due to the nature of very different types of earth science features, the application of the criteria vary on a feature, and occasionally per-site, basis. Different approaches are applied to the representation and protection of bedrock sites, landforms, and landform-process themes (where these are modern processes active on the earth's surface today). The differences in approach are discussed in the following sections of the report.

1) Representation

The primary criterion for choosing earth science features is representation. A representative feature is one that best displays its components, or make-up, and its environment(s) of formation. A representative feature of the geological record can generally be thought of as one that is typical, or normal, or one that shows "classical" elements of the feature.

In the context of features exposed in bedrock outcrop, representation refers to the best available (or known) examples of each type of lithological unit (rock type) that occurs for a given theme element, as well as examples of each geological time unit as exhibited in the rock record (lithostratigraphy) for that theme element. In order to achieve this chronostratigraphic (time related) representation, the best example of some units may be less-than-ideal because the only known examples may be small, of poor quality, or have been adversely disturbed. In these cases, representation may still be sought in order to satisfy representation of the geologic time unit in the physical record. The best representative examples of the fossil record (in Ontario, Precambrian microfossils and Paleozoic macrofossils) as displayed in the rock record, and the best representative examples of past (ancient) landform-process themes as displayed in the rock record, are also sought for protection. Many of these will overlap with lithological and chronostratigraphic representation at the same site, imparting extra significance to those sites, and reducing the total number of sites identified.

In the landscape perspective, representation is also applied to both the physical form of a selected feature, and the morphostratigraphy (ordering of landform features through time) of a theme. Representation of the physical form of a feature should best display an "ideal" morphology and/or the best example(s) of deviations from the "ideal" form. Morphostratigraphy refers to representation of like features as they relate to events and time through the geologic record (e.g., an ice retreat phase of a glacial theme will produce similar landforms and related features at several stages in its history; elements of all of these may be targets for representation). Representation of the internal components of landforms and landform process themes will be sought in outcrops of unconsolidated sediment. Identification of these will follow the same process as for bedrock outcrops, discussed in the previous paragraph.

Representation also refers to the range of features that identifies a geologic event or process, both those that are active today, and those seen in the rock and landform record through time. It seeks to identify the best example of each element of the 8 landform/process themes (Figure 1) that are considered essential to their definition. A combination of all types of geological features, from bedrock outcrops to large-scale landform associations, will be required for complete representation.

2) Type Sections and related features

Type sections provide standard definitions for representative lithostratigraphic and biostratigraphic rock units. Type sections usually represent the sites where rock units were first identified, described and formally named. They are the localities against which all other occurrences of the unit are generally compared. Type sections are generally of the highest scientific value, and may also have historical value as locations where the geology of a region was first described and ranked. In Ontario, type sections are generally only applied to stratified rocks. These constitute volcanic and sedimentary rock sequences of Late Precambrian (Keweenawan) age and sedimentary sequences of Paleozoic age (concentrated in southern Ontario and the Hudson Bay/ James Bay Lowland), although some older Precambrian units have also been formalized in this way.

Related features such as reference sections and type localities represent units for which a type section has yet to be defined. This situation is common in central Ontario, where type sections have not been formalized for most of the Paleozoic stratigraphy of Manitoulin Island (most correlative units have type sections described on the Ontario mainland), or for the sedimentary units of the Precambrian Huronian Supergroup. Reference sections may also serve to supplement the type section by representing some variation or additional feature(s) of the original site. Reference sections often represent a regionally accessible site or variation of the original type section, an important factor where the unit has a widespread distribution.

The primary elements of the surficial geology of a region are defined by the distribution and association of related landforms and their stratigraphic makeup (morphostratigraphy), and by the type of individual landforms, the best example of each being referred to as a type morphology (or morphotype). In Ontario, the morphostratigraphy of glacial deposits and landforms, and the type morphologies related to these, have not been used in either a formal or consistent manner. Regional morphostratigraphies have been prepared by OMNR staff since 1972 in order to address this lack of formal structuring of the glacial geology of the province, and have been used to identify protection targets. The assignment of formal type morphologies within this morphostratigraphy has not been attempted to date.

3) Diversity

Diversity addresses the variability of form or features within a candidate site that describes a theme element. A site that incorporates more than one element or feature of the identified geologic unit (i.e., an outcrop of a bedrock formation that exhibits its range of lithologies and its contact relations with adjacent units), or, incorporates an association of features (such as a glacial landscape of drumlins, eskers and meltwater channels), usually occurs in an area more compact than several separate areas. Such associations, offering a diversity of features in a single site, are more efficient, have a higher ecological value, and may generally be ranked more favourably than a collection of individual sites in separated areas.

Very large landform features also require this approach when possible. Their size generally prohibits representation of a complete feature or association of features. This applies to features with extensive linear elements and those with broad aerial extent. Examples of linear geological features include bedrock faults and shear zones, glacial features such as meltwater channels, end moraines, eskers and raised shorelines, and geomorphological elements such as bedrock escarpments and riverine environments. Features with a broad aerial extent include bedrock domes, glacial features such as ancient lake plains, dune fields, and outwash plains, and topographic forms such as ancient meteorite impact craters.

The approach taken to representation of these large landform features focuses on the identification of the major elements which make up the feature, and seeking representation of the best examples of each of these elements. For example, the Cartier Moraine across the north shore of Lake Huron consists of a series of mounds and ridges of ice-contact sediment, anchored to bedrock knolls, which are associated with shoreline elements of glacial Lake Algonquin, such as now-abandoned (raised) beach terraces on perched deltas. Representation of this complex of features focuses on the identification of the best examples of each of these elements: an irregular mound element of ice-contact debris; a ridge element of ice-contact debris, preferably intact (i.e., identified by topography along natural boundaries); the bedrock component integral to the story of formation of the moraine; and, a perched delta with its associated beach elements. Where several elements occur together, and their form adequately display the mode of formation of the features and their link to the ice stand position marked by the moraine, an area boundary encompassing this association of elements is desirable. Such feature associations are preferred particularly because they exhibit the inter-relationships within a diverse morphology, and because they occur together, facilitating protection more easily than would a suite of separate sites.

4) Integrity (Condition)

Integrity refers to the wholeness or completeness, or condition, of a geological feature, and the lack of significant external impacts or alteration by natural or man-induced activities on this wholeness. This applies particularly to landforms, where morphological completeness is a requirement for their adequate definition. Examples of landforms for which complete morphological representation is desirable are usually relatively small and discrete (e.g., drumlins, perched deltas, aeolian dunes, landslides and their ancient scars, etc.). The best examples of these may be considered informal type morphologies.

Site integrity is not as important a factor in the representation of bedrock sites. Adequate representation of a particular lithological (bedrock) unit requires a clear face or surface which exhibits all the elements used to define the unit. These may occur in a natural setting, such as on bare bedrock surfaces (the Georgian Bay Fringe area and north shore of Lake Huron are outstanding examples of this) or in cliff face exposures (the Niagara Escarpment is the best example of this). Here, site integrity may be excellent due to the extent of exposure (horizontally and/or vertically), and constitutes an aesthetic component due to the natural setting.

In most cases, however, the best examples of representative bedrock units occur in man-made exposures such as highway or road cuts, and pits and quarries, where aesthetic qualities may be very low, but representational values are high because of the freshness and quality of exposure. Such man-made exposures are often the only available representation of the internal components of the bedrock of a region. They may provide a three-dimensional view not available anywhere else. In such cases, natural site integrity is not a consideration for representational rank. Protection of such sites will focus on ensuring that the selected outcrop is not permanently covered up or removed. Site integrity may, in some cases, be enhanced by one-time or occasional re-exposure, or "freshening", of exposures. This is particularly true of natural riverbank exposures and in man-made aggregate operations and quarries that support outstanding exposures of unconsolidated sediments.

5) Life Science Values

When comparing sites where earth science values are similar, overlapping life science values may be used to choose a site. This approach is generally only relevant to landscape sites (landforms, landform associations and/or process features) which are large enough to support significant vegetation stands or communities. Small sites (outcrop or some landform-scale features) generally do not constitute a large enough area to contribute to protection of most life science values. Smaller geological features can however, form a component of a larger life science site, and would constitute a preferable site choice given equal values elsewhere. The evaluation of overlapping life science values depends on the level of existing life science information or the availability of life science input to site selection.

The life science classification system used in the gap analysis process has a strong landform-based component in its Ecodistrict target identification (see Crins and Kor, in preparation). Protection of the diversity of landform/vegetation units (LV units) in an Ecodistrict ensures that identification of a broad range of landforms is targeted for protection. However, the landforms identified by the life science process may not (and often do not) represent the best examples of those landforms to contribute to earth science targets. Where possible, comparison with selected life science candidate protected areas is always attempted before final determination of candidate earth science areas.

6) Special Features

Where two or more sites have similar earth science values, the presence of special features may determine the selection of a preferred site. Special features may be geological, such as unusual or unique elements of a theme not represented elsewhere, or regionally important sites used for education and/or interpretation. Special features may also constitute less scientific values such as the quality of a feature's setting or the aesthetic values of a site. The geology of an area may contribute significantly to the character of that area's landscape.

Where known occurrences of a particular unit are already included in the system of protected areas, the selection of discrete bedrock and unconsolidated sediment sites (e.g., road-side outcrops, quarries, aggregate pits, etc.) popular with the geoscience community (i.e., documented in field trip guidebooks), *in addition to the sites identified in protected areas*, may be of importance because they are accessible, known to geologists, and serve to protect significant occurrences for further research and educational values. This duplication has many values, the most notable of which is that units may be observed, studied, and interpreted at some distance from the provincially significant occurrences, thereby allowing interested parties in regional settings access to good sites. Another important value of regional site duplication is in their role as backups or alternatives to the primary sites, should the primary sites be adversely disturbed or lost.

Geology, and particularly geomorphology, may create a landscape that has a profound effect on shaping the culture of the population that inhabits it. A particular landscape or landform association may be integral to that culture, be it local, regional or national. Any dramatic change in its integrity might have detrimental effects on the overall culture. Where the scientific values are equal, the choice between two or more sites may thus be determined by the cultural or aesthetic values of a particular natural setting. For example, the geology influences the setting and landscape of many areas of Ontario, and influence how these areas are perceived by the population, both residents and non-residents of those areas, beyond the required representation of individual units. Outstanding examples include, but are not restricted to, the low rocklands and lakes of Muskoka, the white quartzite hills and ridges of the LaCloche Range near Killarney, the mesa and cuesta topography of the Nor'Westers around Thunder Bay and Lake Nipigon, the quartzite canyons in the Raven Lake area near Elliott Lake, and the incised valleys of the Pinard Moraine in northeastern Ontario. Representation of such "landscapes" is integral to the earth science protection strategies of many countries worldwide. The maintenance of these landscape values in Ontario may also be considered in addition to purely scientific values during earth science gap analysis.

3.6 Comparisons with Life Science Representation

There continues to be confusion about the relationship and differentiation in the gap analysis process between earth science representation targets and life science representation targets. How does earth science representation compare to life science representation?

Earth science classification systems, based on physical features and, importantly, on time, cannot generally be correlated with the life science classification system, which is based on macroclimate, landforms, microclimate, moisture regime, and substrate (Angus Hills' division of the province into Site Regions [now Ecoregions] and Site Districts [now Ecodistricts], with classification of site conditions within each Site District [now Ecodistrict]; see Hills 1959, Burger 1993, Jalava *et al.* 1997). Although there may be some correlation between the two disciplines based on landform and substrate, the classification of earth science features is not related at all to present patterns of climate and moisture.

For example, bedrock representing the Precambrian Grenville Province occurs to a specific area of exposure, in southcentral Ontario, and nowhere else in the province. The diversity of features that reflect the history of evolution of the Grenville Province can only be found within this specific area of exposure. The geological diversity within the area of exposure of the Grenville Province, and its significance, is not affected by the vegetation patterns which occur on its surface, nor by the classification schemes devised to arrange that vegetation diversity. Therefore, the distribution of significant earth science sites required to represent the Grenville Province geological theme cannot be related to a specific Ecoregion or Ecodistrict and is therefore not affected by life science values. However, the type and aspect of the bedrock substrate may have a significant influence on the composition of the vegetation communities and species that grow on that substrate. Obvious examples are the different effects of carbonate versus granitic substrates on the vegetation communities growing on them.

Although earth science and life science classification schemes are not compatible, there is an inter-connectedness between the two disciplines at the landform/substrate level. The diversity of earth science features at the Ecodistrict level will determine the diversity of life science representation targets for vegetation communities and species. Earth science diversity in an Ecodistrict presents the biological environment with a range of temperature, exposure, aspect, moisture regime, substrate types and habitat on which vegetation types and communities develop and evolve. The land base of an area determines the diversity of the life forms that occupy and characterize that area.

As stated in the previous section, where all other factors are equal, it is a goal of the gap analysis process, where possible, to combine earth science and life science values into a set of related protected areas. Thus a suite of sites so selected will help to conserve both regional biodiversity and abiotic features.

A comparison of the gap analysis process and the site selection criteria for earth science representation and life science representation shows that these are very similar in approach. The cornerstones of both approaches are the achievement of a suite of sites that are representative, in excellent condition, and reflect the diversity of the features and history identified by the individual disciplines. See Crins and Kor (in preparation) for a more comprehensive discussion of life science classification systems, and approaches to life science gap analysis.

3.7 Assumptions

The data sets used in the earth science gap analysis process come in many forms and scales. None exists satisfactorily in any one place or as one unified entity. Primary sources include maps of bedrock and surficial geology, published in a wide variety of scale, detail and coverage, by the Ontario Geological Survey (OGS; Ontario Ministry of Northern Development and Mines) and the Geological Survey of Canada (GSC). Interpretations of the geological history of the province are extracted from a vast base of academic and professional literature sources, as well as discussions with experts in all fields of geology. Interpretations often differ due to the fluid nature of the science, as data becomes available and is disseminated to the field. Given this range of inputs, it is assumed that the present level of knowledge of the geological conditions in the province is the most up-to-date and complete, despite obvious weaknesses in that knowledge. **The Geology of Ontario** (Ontario Geological Survey 1991, 1992) summarizes the most up-to-date geological picture of the province, and provides the framework on which the interpretations used in gap analysis are based. Detailed information about the geology of much of the province is limited. Because the search for knowledge has been largely driven by past and present interest in the economic potential of an area's mineral or aggregate resources, there remain large areas of the province in which detailed data collection and interpretation has not been attempted or completed.

The geological definition and interpretations of significant sites only reflect the current state of knowledge and/or follow current understanding and theories of concepts in the particular field of geology under consideration. Theories and ideas, and their associated evidence in the field (on the ground) that may be important today, may become less important or redundant in future with the advent of new fieldwork or other studies. Advancement of new theories and concepts will involve new sites of importance in providing proof. Thus where previously important sites become less so, new sites may be introduced to define the new science. What is important in the gap analysis planning process is the opportunity to identify and protect a near-complete system of representative and significant features reflecting the present state of the science, and the flexibility to incorporate changes and advances in the science.

In the case of landforms and landform process themes, an underlying assumption is that the least disturbed a site or feature is, the better its representational value. Where undisturbed features are not available, a site with some disturbance may be preferable to no representation at all. Other jurisdictions worldwide assume some disturbance is acceptable if that disturbance has not adversely altered the conditions of the feature(s) for which identification was first proposed. This applies as well to the representation of earth science features in Ontario.

Field investigation of the attributes of the feature(s) of a site is almost always required prior to the determination of significance. For instance, bedrock sites are small enough that no matter how well documented, exact locations and present condition need to be established *in situ* in order to properly verify and protect a site. Although remote sensing techniques can determine the best likely locations for landform and process theme sites, present-day quality and condition of the identified features must be verified and established in the field prior to the determination of representation and/or significance.

3.8 Limitations

As already mentioned, geological mapping coverage and scales vary greatly across the province. Therefore, a lot is known about the geology of selected regions and/or geological environments, and hence selected environmental themes, and less is known about others. The effect this has on representation targets is that the environmental themes with a good base of knowledge may have a great number of representational targets, whereas those environmental themes about which relatively little is known will have fewer representational targets. As the knowledge base in these under-represented themes improves, with new, more detailed mapping of a region, new representational targets will present themselves, and the number of candidate sites may increase.

The data set of information related to the bedrock geology of the province is limited to sites that are known from the published literature, and those known to the geoscience and academic community. The specific attributes and values of bedrock sites are too difficult to identify through remote sensing methods (bedrock sites are generally too discrete), with the result that the geology of an area cannot easily be interpreted and compered with such regional techniques. Landforms and some process themes on the other hand can generally be identified quite easily through remote sensing techniques (through geological and topographical maps, air photos, etc.). This limits the bedrock site representation to what we know, whereas landform and some process themes can be identified through original fieldwork on a very regional level (i.e., it can therefore be done relatively quickly).

Another limitation of the gap analysis process is that much geological data, especially more detailed information, is not readily available in digital format, although coverage is improving rapidly. In addition, the scales of published data is generally too broad to be meaningful in comparing like features in an electronic environment. This limits the ready comparison of site evaluations on a regional scale through electronic means, and suggests that the process still requires a high degree of manual inputs.

4.0 ACKNOWLEGEMENTS

The life science gap analysis method has evolved from manual approaches used since before 1980, to the GIS-based iterative process described in this document. Many people have been involved in the development and application of these methods over the years, including Tom Beechey, John Riley, the Ministry's regional and district ecologists, and many others. A great deal of logistic and moral support came from Dave Watton, Harry Orr, and Adair Ireland-Smith during the development of the current refined approach. Jarmo Jalava of the Ministry’s Natural Heritage Information Centre provided important input at several stages in the writing of this document. Stimulating discussions with other practitioners of gap analysis and related approaches, in Canada and the U.S.A., such as Tom Nudds, Gary Umphrey, and Mike Jennings, have also led to a better product, notwithstanding differences in our approaches.

The earth science gap analysis process has been in use, relatively unchanged, since the early 1970s. The concepts and procedures presented in this document reflect the input and refinement of this process by many field staff during that time. Specific to this document, R.J. (Bob) Davidson, Senior Conservation Geologist, G.S. (George) Cordiner, Conservation Geologist, and Bill Crins, Senior

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Appendix I:

List of broad age classes for working groups likely to be encountered in FRI data.

White Pine	Pw	0-40 (1956-)	41-120 (1875-1955)	121+ (pre-1875)
Red Pine	Pr	as Pw		
Tamarack	L	as Pw		
Black Ash or ash	Ab or A	as Pw		
Sugar Maple	Mh	as Pw		
Yellow Birch	By	as Pw		
Red Oak	Or	as Pw		
Red/Silver Maple	Ms	as Pw		
Beech	Be	as Pw		
Basswood	Bd	as Pw		
Other hardwoods	OH or H	as Pw		
Jack Pine	Pj	0-30 (1966-)	31-70 (1925-1965)	71+ (pre-1925)
Balsam Fir	B or Bf	as Pj		
Poplar/aspen	Po	as Pj		
White Birch	Bw	as Pj		
Spruces	S, Sb, Sw	0-30 (1966-)	31-100 (1895-1965)	101+ (pre-1895)
Cedar	Ce	0-40 (1956-)	41-110 (1885-1955)	111+ (pre-1885)
Hemlock	He	0-40 (1956-)	41-140 (1855-1955)	141+ (pre-1855)