Geoindicators For Monitoring Canada's National Parks:

A Proposal

David Welch

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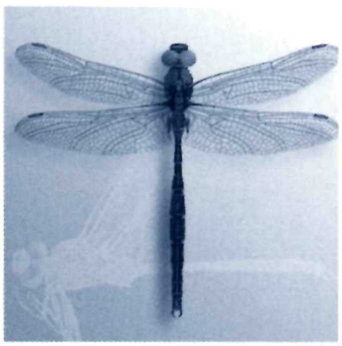

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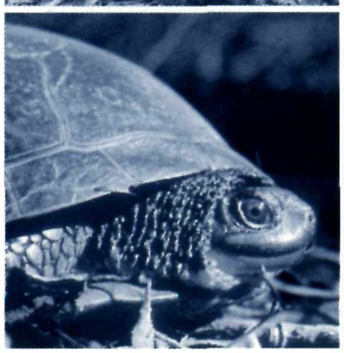

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GEOINDICATORS FOR MONITORING CANADA'S NATIONAL PARKS: A PROPOSAL

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CONTENTS

Abstract v
Résumé vi
Preamble and acknowledgements vii
Acronyms, symbols and abbreviations viii
National park condition monitoring 1
  The ecological integrity monitoring framework 1
  A geoindicators framework for ecological integrity monitoring 3
Geoindicators suites 5
  IUGS geoindicators 6
  EMAN abiotic indicators 6
  What's missing? 6
Geoindicator assessment for national park application 8
  Built environment 9
  Channel morphology 9
  Desert crusts 10
  Dunes 10
  Dust storms 11
  Extreme events 11
  Frozen ground activity 12
  Glaciers 12
  Groundwater level 13
  Groundwater quality 13
  Ice regime 14
  Karst 15
  Lake and ocean sediment 16
  Lakes 16
  Marine nearshore environments 17
  Mass movements 17
  Proxy record 18
  Sea level 18
  Seismicity 18
  Shorelines 19
  Snow avalanches 20
  Soil erosion 20
  Soil temperature 21
  Soil quality 21
  Soil water quality 22
  Streamflow 22
  Stream sediment 22
  Surface displacement 23
  Surface water quality 23

Tufa accumulation 24
Volcanism 24
Wetlands 25
Wind erosion 25
Ranking and choosing geoindicators for national parks system assessment 26
A proposal for geoindicators for national park system assessment 28
Valued features 29
Processes 29
Stresses 29
Geoindicators for specific park assessment: five examples 30
Introduction 30
Auyuittuq 30
Fundy 31
Ivvavik 32
Jasper 33
Saint Lawrence Islands 33
Discussion 34
Suitability of national parks for multi-participant geoindicator monitoring 34
Conclusions 36
Generalities 36
Implementation 37
References 38

FIGURE

1 The national parks of Canada and some geological boundaries 5

TABLES

1 Parks Canada ecological monitoring framework and indicators 2
2 Significant stresses affecting Canadian national parks 2
3 Air issues and examples of national park concerns 3
4 Possible stresses affecting geological resources of Canadian national parks 4
5 A possible geological monitoring framework and indicators for Parks Canada 4
6 IUGS geoindicators 7
7 EMAN abiotic ecological indicators 8
8 Blended list of geoindicators and national park priorities 27
9 Candidate geoindicators and measurements 28
10 Potential geoindicators for Auyuittuq National Park 31
11 Potential geoindicators for Fundy National Park 32
12 Potential geoindicators for Ivvavik National Park 32
13 Potential geoindicators for Jasper National Park 33
14 Potential geoindicators for Saint Lawrence Islands National Park 34
15 Comparisons between proposed national and potential park-level geoindicators 35

ABSTRACT

According to legislation, Parks Canada must report the state of ecological integrity (EI) of the national park system to parliament every two years. According to policy, it will also report the state of each national park's EI every five years. An ecological monitoring framework, based on biodiversity, ecological functions and stresses, has been adopted for these purposes. It calls for monitoring many biological indicators and some environmental quality indicators, such as soil nutrient status, climate and long range transport of toxics, but is silent on geoindicators. Parks Canada can fill this gap by drawing from two other frameworks, the geoindicators framework endorsed by the International Union of Geological Sciences, and abiotic indicators from the monitoring suite adopted by Canada's Ecological Monitoring and Assessment Network, 28 in all. I describe five other potential geoindicators of rapid environmental change, namely the built environment, extreme events, marine nearshore environments, snow avalanches and tufa accumulation. For the combined total of 33 geoindicators I develop a preference ranking and propose a short list of 10 for further consideration for national park system monitoring. The evaluation is based on relevance to ecosystem understanding, monitoring and management, linkage to other measures, features and processes, and practicality for long term adoption by park staff. To represent valued features I propose dunes, glaciers, lakes, shorelines and wetlands. For processes I propose frozen ground activity, groundwater level, mass movements, stream flow and soil water quality. For stresses I propose the built environment expressed as the total land and water area of modified, unrestored surfaces. An analysis of five parks, however, leads to short lists that are different from each other and from the national list. Thus a park should examine the geoindicators suite from scratch when selecting measures for its own purposes.

RÉSUMÉ

Conformément à la loi, Parcs Canada doit rendre compte au Parlement de l'état de l'intégrité écologique (IÉ) dans le réseau des parcs nationaux, tous les deux ans. En vertu de la politique, il doit aussi rendre compte de l'état de l'IÉ dans chacun des parcs nationaux, tous les cinq ans. Un cadre de surveillance écologique fondé sur la biodiversité, les fonctions et les stress écologiques a été adopté à ces fins. Il exige la surveillance d'un grand nombre d'indicateurs biologiques et de certains indicateurs de la qualité de l'environnement, comme les éléments nutritifs des sols, le climat et le transport à grande distance des substances toxiques, mais ne tient pas compte des géoindicateurs. Parcs Canada peut combler cette lacune en tirant des données de deux autres cadres, le cadre des géoindicateurs de l'Union internationale des sciences géologiques et le cadre des indicateurs abiotiques du Réseau d'évaluation et de surveillance écologiques, ce qui donne un total de 28 indicateurs. Je décris cinq autres géoindicateurs potentiels de changement environnemental soit l'environnement bâti, les événements extrêmes, les milieux marins situés à proximité du rivage des océans et des grands lacs, les avalanches et les accumulations de tuf calcaire. À partir de ce grand total de 33, j'ai établi un classement de préférence et je propose une liste abrégée de 10 géoindicateurs, aux fins d'étude plus approfondie pour la surveillance du réseau des parcs nationaux. L'évaluation est fondée sur la pertinence pour la compréhension, la surveillance et la gestion des écosystèmes, les liens avec d'autres mesures, les particularités et les processus et la valeur concrète pour le suivi à long terme par le personnel des parcs. Pour représenter les particularités valorisées, je propose les dunes, les glaciers, les lacs, les rivages et les milieux humides. Pour représenter les processus, je propose l'activité des pergélisols, le niveau de la nappe souterraine, le mouvement de masse, l'écoulement fluvial et la qualité de l'eau dans les sols. Pour ce qui est des stress, je propose l'environnement bâti, soit la superficie totale des terres et des eaux qui a été modifiée et n'est pas restaurée. Cependant, une analyse de cinq parcs a permis de dresser de courtes listes qui diffèrent les unes des autres et de la liste nationale. Par conséquent, un parc devrait reprendre la suite des géoindicateurs du début, pour choisir des mesures répondant à ses propres besoins.

PREAMBLE AND ACKNOWLEDGEMENTS

Geoindicators are measures of geological processes and phenomena occurring at or near the Earth's surface and subject to changes that are significant in understanding environmental change over periods of 100 years or less" (IUGS 1996, p.3). For convenience of style, throughout this paper I use the terms "geology," "geological" and "geo-" to refer collectively to things geological, geomorphological and pedological. Similarly, I sometimes use "park(s)" to refer to "national park(s)."

My intentions in this paper are twofold: 1) to develop a short list of geoindicators from which Parks Canada might add some to the ecological integrity monitoring framework for state of protected heritage area reporting, and 2) to evaluate geoindicators to help individual national parks choose some for their own purposes such as state of park reporting. Implementation in part or in whole will depend on the availability of funds, personnel and partners, and on their fit to other monitoring programmes. Nevertheless, their inclusion in the ecological integrity monitoring framework will provide a policy intention, as is the case for some dormant ecological indicators in the present framework. For guidance on how to select and use geoindicators at the park level, see the United States National Park Service's Geological Resource Division on-line materials (US.NPS 2000).

In September 2001 an international workshop was held at Gros Morne National Park to examine how the IUGS geoindicators may be applied to national park environmental monitoring (Berger and Liverman 2002). Before the workshop I had identified three extra indicators of geological change missing from the IUGS and EMAN slates, namely tufa accumulation, extreme events and the built environment. Workshop participants identified two others, namely snow avalanches and marine nearshore environmental changes. Participants also suggested expanding IUGS's coral growth indicator to encompass all proxy records of environmental change, which I have done here. There may yet be others. I welcome any suggestions about other potential geoindicators.

Thanks to Tony Berger, consultant, co-directors of the IUGS geoindicator initiative and friend of Gros Morne National Park, for organizing the workshop and thereby stimulating me, on behalf of Parks Canada, to consider how to enhance Parks Canada's EI monitoring framework with some abiotic indicators. Thank also to Jean Poitevin, Neil Munro and Alain Caissie, all of Parks Canada, for their detailed reviews of various early drafts, and to Doug Clark for his general observations. I also wish to credit all the participants at the workshop for several ideas that are incorporated into this version of the paper, such as the aforementioned extra geoindicators. As well, the court of open presentation stimulated me to think of better ways to organize my ideas and simpler ways to analyse them. Special thanks go to Tony Berger, again, and to Don Forbes of the Geological Survey of Canada for their detailed critique of a previous draft. As well as suggesting improvements and corrections in the details, their comments were particularly valuable in leading me to add the sections on park-specific geoindicator selection, and on the role that parks might play in supporting a multi-participant agenda for geoindicators.

Notwithstanding the valuable contributions of Parks Canada and other colleagues, this paper reflects my opinions as physical sciences advisor to the national parks programme, and does not yet represent a position formally adopted by Parks Canada.

ACRONYMS, SYMBOLS AND ABBREVIATIONS

Elements

Al	Aluminium
Ag	Silver
As	Arsenic
B	Boron
Ba	Barium
Be	Beryllium
Br	Bromine
Ca	Calcium
Cd	Cadmium
Cl	Chlorine
Cr	Chromium
Cu	Copper
F	Fluorine
Fe	Iron
H	Hydrogen
Hg	Mercury
K	Potassium
Mg	Magnesium
Mo	Molybdenum
N	Nitrogen
Na	Sodium
Ni	Nickel
O	Oxygen
P	Phosphorous
Pb	Lead
Rn	Radon
Sb	Antimony
Se	Selenium
Sr	Strontium
S	Sulphur
V	Vanadium
Zn	Zinc

Isotopes

^{2}H	Deuterium
^{3}H	Tritium
^{18}O	Oxygen 18 isotope
^{36}Cl	Isotope of chlorine
^{222}Rn	Isotope of radon

Compounds

2,4-D	Dichlorophenoxyacetic acid
2,4,5-T	2,4,5-trichlorophenol
$CaHCO_3$	Calcium bicarbonate
CO_2	Carbon dioxide
CO_3	Carbonyl (COx)
DDT	Dichloro-diphenyl-trichloroethane
HCO_3	Bicarbonate
$MgHCO_3$	Magnesium bicarbonate
$MgSO_4$	Magnesium sulphate
$NaSO_4$	Sodium sulphate
NO_3	Nitrate
SO_4	Sulphate

Acronyms

AVHRR	Advanced Very High Resolution Radiometer
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
EI	Ecological Integrity
EMAN	Ecological Monitoring and Assessment Network
GPS	Global Positioning System
IUGS	International Union for Geological Sciences
pH	Parts of Hydrogen, -Log(h^+ Moles/litre)
POPS	Persistent Organochlorine Pollutants
TDS	Total Dissolved Solids
UV-B	Ultra-Violet B Radiation

NATIONAL PARK CONDITION MONITORING

THE ECOLOGICAL INTEGRITY MONITORING FRAMEWORK

The stewardship of Canadian national parks is built on the legislated concepts of the maintenance of ecological integrity and their appreciation and enjoyment by Canadians. Delivery of these mandates depends, in part, upon obtaining and maintaining an understanding of the natural features and processes in the parks, the regions that they represent, the changes that they experience, and the natural and anthropological causes of such change. Parks Canada's policy is to conduct both a comprehensive ecological inventory and detailed studies of selected values in each national park. This information is used in management planning, interpretive programmes and resource management actions such as environmental assessment, fire restoration and species and ecosystem restorations. Species populations, ecosystems and landscapes are not static, however, so knowledge of their current state and rate of change is equally essential to good long term stewardship. Hence data base updating, monitoring and periodic assessments complement resource inventories.

The National Parks Act defines ecological integrity as "a condition that is determined to be characteristic of its natural region and likely to persist, including abiotic components and the composition and abundance of native species and biological communities, rates of change and supporting processes" (Parks Canada Agency 2000 a). The Act also requires Parks Canada to report to Parliament every two years on the state of all the national parks. The most recent of these reports was published in 1999 (Parks Canada Agency 2000 b). Furthermore, the Minister responsible for Parks Canada has committed each individual national park to assess its condition in a State of the Park report every five years (Parks Canada Agency 2001).

Parks Canada has adopted an ecological monitoring framework to guide the biennial assessment of the parks system. The framework recognizes the need to assess the state and functioning of ecosystems and the factors that change or jeopardize natural continuity. It does this in three tiers that examine 1) ecosystem structure and diversity of valued resources, 2) ecosystem functions and 3) stresses. For each of these tiers, several indicator themes and variables have been chosen. To date, the framework is well developed for biotic values but not for abiotic ones (Table 1; Parks Canada Agency 1998). About half the indicators are monitored in some way. The remainder await funding and protocol development.

Many of the resource management issues facing national park management stem from past and present human activities. Examples include the deliberate extirpation of carnivores, suppression of natural forest fires, development of towns and outlying commercial accommodations, acid rain, poaching, sport fishing and the deliberate or accidental introduction of exotic invasive species. An opinion survey of selected managers and experts at each park identified twenty-nine significant stresses broadly affecting the national system (Table 2; Parks Canada Agency 1995). In general, they relate to the land use, industry and other human activities that characterise the time since the establishment of Banff National

Table 1. Parks Canada ecological monitoring framework and indicators

Biodiversity	Ecosystem functions	Stresses
Species richness • Change in species richness • Number and extent of exotics **Population dynamics of indicator species** • Mortality/natality rates • Immigration and emigration • Population variability **Trophic structure** • Size class distribution of all taxa • Predation levels	**Succession and retrogression** • Disturbance size and frequency (fire, insects, flooding) • Vegetation age class distribution **Productivity** • Landscape or by site **Decomposition** • By site **Nutrient retention** • Ca, N by site	**Human land use patterns** • Land use, roads density, population density **Habitat fragmentation** • Patch size • Interpatch distance forest interior **Pollutants** • Sewage, petrochemicals, etc. • Long-range transportation **Climate** • Weather data • Frequency of extreme events **Other** • Park-specific issues

Table 2. Significant stresses affecting Canadian national parks

Stresses originating within the park	Stresses originating outside the park and acting directly on parks	Stresses affecting the region of which the park is a part
Infrastructure • Visitor and tourism facilities • Park infrastructure • Roads, railways and utility corridors **Activities** • Park management practices • Human disturbance of wildlife • Sport fishing • Vehicle/animal collisions • Poaching	**Exotic species** • Vegetation • Mammals • Birds • Fish • Invertebrates • Microorganisms **Pollution** • Solid waste • Petrochemical pollution • Pesticides • Sewage • Climate change • Heavy metals • Ground level ozone • Acid deposition	**Infrastructure** • Urbanization • Dams • Mining **Resource use** • Forestry • Agriculture • Hunting • Commercial fishing

Park in 1885 to the enactment in 1988 of ecological integrity as a prime consideration in park development.

These stresses are reported as general categories to allow comparisons across Canada. For example, the particular facilities, invasive species or petrochemical pollutants vary from place to place, but are grouped for national reporting purposes. Nor are the groupings mutually exclusive. For example, an upstream dam may affect the regime of a river within a park, so some would say that the stress is outside the park but acts directly upon it, whereas others might say that the stress is the change in flow regime within the park that affects park wildlife and its habitat. As well, detailed investigation will usually reveal subclasses of stress, as has since been done for air issues (Table 3; Welch 1996; Welch 2002), Parks Canada Agency 2000 b).

Table 3. Air issues and examples of national park concerns

Impact group	Issue	Sample effects	Concern
Ecosystems	Climate change	Thermokarst, drought, sea level rise, reduced sea ice	Highest
	Hazardous pollutants	Reproductive problems in wildlife	
	UV-B	Reduced plankton production, herptile deformities	
	Acid deposition	Leaching, low pH of water, fish reproduction	
	Enrichment	Nitrogen, CO_2 altering plant successions	
	Cumulative effects	Acidification, UV-B and pesticides working together	
	Ground level ozone	Leaf damage	Lowest
People	UV-B	Cataracts, skin cancer, immune deficiency	Highest
	Particulate matter	Reduced visibility (with ozone), respiratory ailments	
	Traffic, aircraft noise	Impaired wilderness experience	
	Ground level ozone	Damage to lung function, breakdown of many materials	
	Street lights	Reduced appreciation of starscapes and auroras	Lowest

A GEOINDICATORS FRAMEWORK FOR ECOLOGICAL INTEGRITY MONITORING

This paper focusses on the search for indicators of geological, geomorphological and soil features, processes and stresses for the ecological integrity monitoring framework. To begin this examination, I propose a "geo-issues" table, equivalent to Table 2, but for geology, landforms, soils, their driving processes and their stresses (Table 4). It focusses on processes and changes that can be seen over times scales matching park management programmes and human experience, i.e. years to decades, and which could have a significant impact on the geological resources of a park. For each geological issue one would then seek and propose at least one geoindicator for consideration in park condition assessments. Table 5 is one possible solution to organizing geoindicators that reflects Parks Canada's ecological monitoring framework (Table 1).

Table 4. Possible stresses affecting geological resources of Canadian national parks

Stresses originating within the park	Stresses originating outside the park and acting directly on parks	Stresses affecting the parks' greater region
Engineering works • Visitor and tourism facilities • Park infrastructure • Roads, railways and utility corridors **Activities** • Aggregate removal • Trampling • Unauthorized specimen removal	**Climate change** • Global warming • Sea-level rise • Sea-ice change **Pollution** • Acid deposition **Modification of natural processes** • Dams, flood reduction • Shoreline protection works • Beach extraction or replenishment	**Construction** • Alteration of natural views • Land development **Mining** • Water table lowering

Table 5. A possible geological monitoring framework and indicators for Parks Canada

Equivalent to biodiversity What are some geological features that would be most affected by human interference or rapid natural change?	**Equivalent to ecosystem functions** What are some processes that would be most affected by human interference or rapid natural change?	**Equivalent to stresses** What are some anthropogenic factors most likely to affect the earth's physical landscape?
Valued features Emphasis on periodic mapping and profiling of features	**Processes** Emphasis on monitoring of flows and mass transfers	**Stresses** Emphasis on quantifying anthropogenic stresses
Weathering and mineralisation • Karst development • Fossil exposure • Tufa build-up **Soil formation** • Horizon development **Landform change** • Open water in wetlands • Barrier beach complexes • Glacial bluffs and moraines • Aeolian and fluvial dunes • Marine nearshore zones • Thermokarst, frost polygons	**Soils** • Leaching **Slopes** • Solifluction • Avalanches (debris flows) **Rivers** • Discharge • Lateral erosion **Shore zones** • Longshore drift • Shoreline profile change • Ice regime **Glaciers** • Mass balance • Glacier terminus position **Dunes** • Deflation	**Global change** • Acidification • Extreme events **Direct modification** • Urbanization • Transportation corridors • Mining • Trampling **Flow management** • Dams • Shore protection works

Most of this paper describes a way to choose geoindicators for inclusion in the ecological integrity monitoring framework of Parks Canada. The need is for indicators that are relevant to at least most Canadian national parks, and would thereby contribute to the state of protected heritage areas reports of Parks Canada. However, all parks experience issues that are unique to one or just a few parks. To illustrate this, I present several case studies of how individual parks may rank geoindicators for their own state of the park reporting. Furthermore, national parks provide good opportunities for other agencies to establish long term monitoring sites of their own, not least by virtue of their wide geographic spread across Canada (Figure 1). Therefore I also provide a summary of how national parks may support national and international geoindicator monitoring programmes, even when they may not be of direct value to a given park.

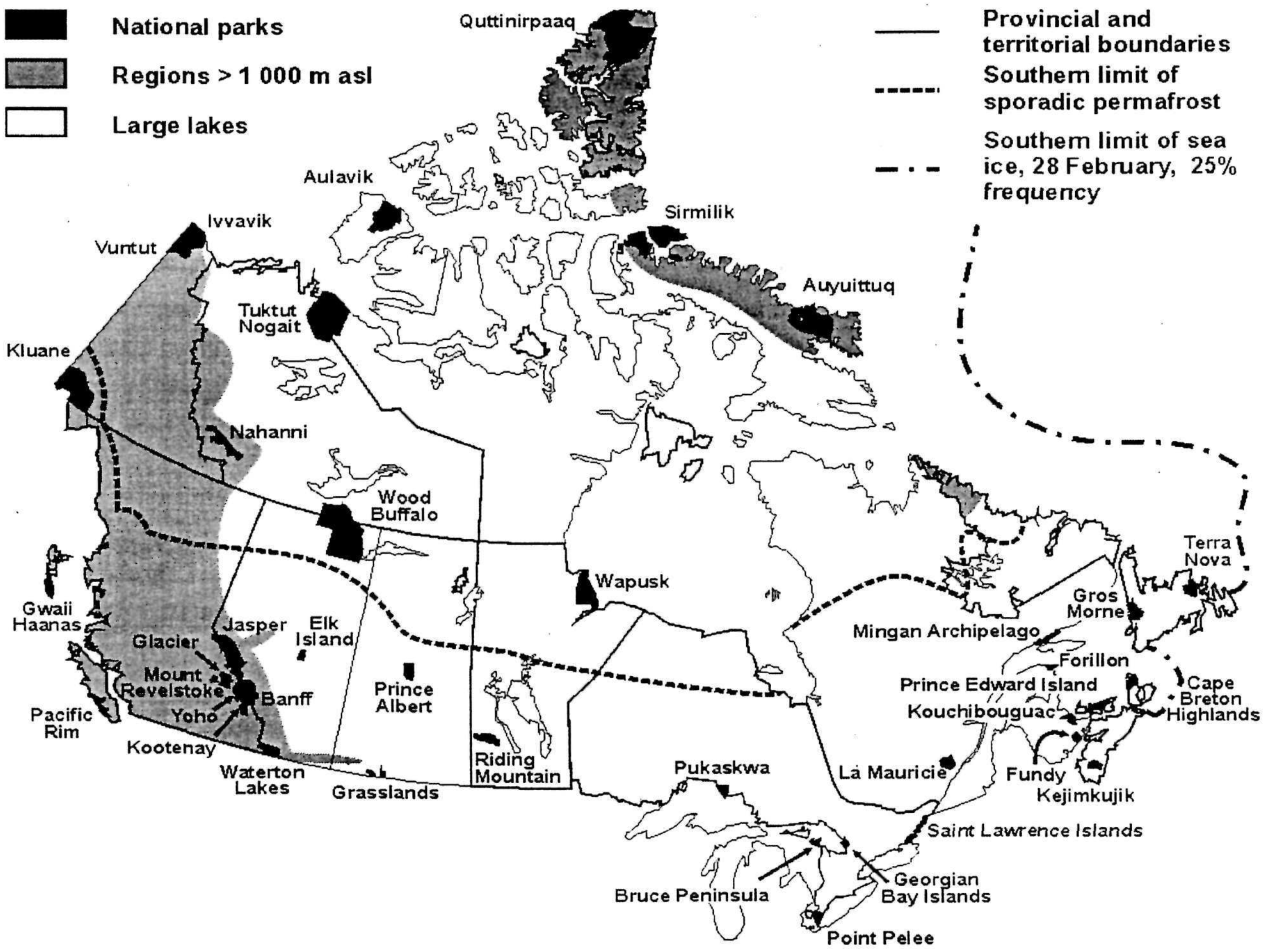

Figure 1. The national parks of Canada and some geological boundaries

GEOINDICATORS SUITES

There are two starting points for this search for preferred geoindicators, one international and one Canadian. The International Union of Geological Sciences (IUGS) has adopted a checklist of twenty-seven geoindicators of rapid environmental change, each with several possible measurement variables (Berger and Iams 1996). In this context, rapid refers to changes that are noticeable or ecologically significant within 100 years. The Canadian Environmental Monitoring and Assessment Network (EMAN) is building a set of protocols for environmental monitoring. In this section I pair up, summarize and review the IUGS and EMAN geoindicators. I then propose a subset of the most relevant and useful of these measures from a Parks Canada, nation-wide standpoint. I also examine how five specific parks may need a different geoindicator suite to a national one, and also summarize why national parks provide good venues for other agencies to consider when establishing a geoindicator monitoring programme, or any other long term environmental programme for that matter.

IUGS GEOINDICATORS

A checklist of twenty-seven geoindicators has been developed by the IUGS through its Commission on Geological Sciences for Environmental Planning (Ibid; Table 6). It was developed from standard approaches used in geology, geochemistry, geophysics, geomorphology, hydrology and other earth sciences. The indicators are designed for use in environmental and ecological monitoring, state-of-the-environment reporting, and general assessments of environmental sustainability of local, national and international scales. With their main focus on earth surface and abiotic processes, geoindicators can complement the work of ecologists and others concerned with biodiversity, ecosystem management and environmental impact assessment (Spellerberg 1991; Woodley et al. 1993).

EMAN ABIOTIC INDICATORS

The Ecological Monitoring and Assessment Network Coordinating Office is developing a suite of indicators and protocols that can be used across Canada to help provide a nationally consistent perspective on the state of Canadian ecosystems (Geomatics International Inc. 1999; North-South Environment Inc. 2001). Its abiotic indicators are presented in Table 7, of which the surface water and land indicators can be considered geoindicators. Note that there is no explicit marine component in the EMAN list.

WHAT'S MISSING?

Eight geoindicators are covered by neither the IUGS nor EMAN checklists:

- Built environment;
- Extreme events;
- Coastal sediment transport;
- Marine nearshore environments;
- Proxy record;
- Snow avalanches;

- Soil development; and
- Tufa accumulation.

Table 6. IUGS geoindicators

Phenomena	Selected measurements
Coral chemistry and growth patterns	Chemical signatures and ratios in growth layers
Desert surface crusts and fissures	Size, depth, extent of crusts and fissures
Dune formation and reactivation	Size, shape, position of dunes and sand sheets
Dust storm magnitude, duration and frequency	Frequency, length of season, volume of material
Frozen ground activity	Active layer thickness, persistence of icings, solifluction,
Glacier fluctuations	Terminus position, mass balance, equilibrium line
Groundwater quality	Salinity, acidity, pH, NO_3, DOC, SO_4, Cl, POPs
Groundwater chemistry in the unsaturated zone	Cl, NO_3, H^+, ^2H, ^3H, ^{18}O
Groundwater level	Depth to water table
Karst activity	Development, collapse, water quality, precipitate chemistry
Lake levels and salinity	Water level, area, salinity
Relative sea level	Tides, land levels
Sediment sequence and composition	Mineral content, isotopes, pollutants, pollen, pollutants
Seismicity	Earthquake size, location, depth, motions
Shoreline position	Beach profiles, water lines, bluff position, vegetation zones
Slope failure (landslides)	Cracks, subsidence, upheaval, area
Soil and sediment erosion	Creep, rill erosion, head cuts, measured and modelled soil loss
Soil quality	Physical, chemical and morphological descriptions
Streamflow	Annual and seasonal discharge, hydrograph timing
Stream channel morphology	Channel patterns, cross sections
Stream sediment storage and load	Bed load flux and storage
Subsurface temperature regime	Temperature profile
Surface displacement	Land levels, gravity, sea level
Surface water quality	Metals, nutrients, acidity, alkalinity, temperature, pollutants
Volcanic unrest	Ground displacements, seismic events, volatile outputs
Wetlands extent, structure and hydrology	Extent, indicator species, morphology, peat accumulation
Wind erosion	Vegetation cover, landform type, extent and position

Source: IUGS 1996.

Coastal sediment transport, the proxy record, marine nearshore environments, snow avalanches and soil development were suggested by participants at the 2001 Gros Morne workshop (Berger and Liverman 2002). The others were identified by me during the development of this paper. The workshop participants recommended that all these extra indicators be added to a future revision of the IUGS geoindicators list.

Three of these eight can be merged with the existing IUGS indicators. One is soil development, in the sense of horizon development, leaching and acidification, that can be considered under soil quality. The other is coastal sediment transport, both along-shore and shore-normal, that has been added to shorelines. The proxy record is really an extension of

Table 7. EMAN abiotic ecological indicators

Surface water	Climate	Land
Streams • Water flow **Lakes** • Dissolved oxygen • Temperature profile • Water clarity • Water level • Sediment trap **Ice** (lakes and rivers) • Ice phenology	**Sunlight** • Stratification • Total incoming • Seasonality • Quality **Wind** • Speed • Direction **Precipitation** • Quantity • Quality • Frequency • Type	**Soil temperature** **Permafrost depth** (i.e. active layer depth)

Source: EMAN 2001 and web site.

the IUGS's coral chemistry and growth record to include tree rings, oxygen isotopes in sediments, stalactites and stalagmite chemistry, and so forth.

GEOINDICATOR ASSESSMENT FOR NATIONAL PARK APPLICATION

In this section I blend the IUGS, EMAN and new geoindicators are blended into one list of thirty-three, simplifying many of their names compared to the IUGS nomenclature. Note that this blended list only includes the "geo" indicators from the EMAN abiotic list, as previously noted. The only EMAN geoindicator that is not covered by the IUGS list is ice phenology, or ice regime in my naming. I describe each indicator briefly, including the original IUGS and EMAN title, and the field measurements proposed. Each is assessed for three criteria, and each criterion is valued as low, medium or high.

- **Management relevance** refers to the understanding, monitoring and managing of ecological integrity in national parks throughout Canada, specifically the impact of anthropogenic stresses upon geological resources. A high ranking means that the indicator would apply to all parks, or to many parks with significant or abundant related features.

- **Linkage** refers to association with other indicators, in the sense that one may need others for proper scientific interpretation, or in the sense of collocation and integration, whereby some can be monitored together at the same place and time with little incremental cost.

- **Practicality** refers to simplicity, repeatability and economy for reliable long term monitoring by national park staff, notwithstanding changing budgets and technologies. Hence it reflects the skills, in-kind resources and opportunities likely to be available to a typical park on an indefinite basis, subject, of course, to appropriate funding and staffing.

BUILT ENVIRONMENT

IUGS title. None.
EMAN title. None.
Park examples. Parks with towns like Banff, Riding Mountain and Yoho, through highways as in Terra Nova, disjunct land parcels and enclaves as at Bruce Peninsula and Gros Morne, and parks established within the agricultural ecumene like Point Pelee and Grasslands. Many parks, such as Prince Edward Island, have a sizable number and extent of park structures like visitor centres, administration buildings, works compounds, serviced campgrounds and roads. The state of parks reports identify park infrastructure as one of the leading stresses upon ecological integrity. To date, this stress is monitored nationally through the linear measurement of roads.
Measurements. The cumulative linear or areal extent of all built structures and earthworks can be obtained from surveys and maps. A more refined measure could be the cumulative absolute volume of engineering works, e.g. berms, buildings, embankments, canals and quarries, to obtain a measure of total degree of landscape modification as a geomorphological process, and comparable to natural rates of sedimentation and deposition, or flooding and drainage. Thus, the measure of a road would include not just the driving surface but its shoulders, medians, ditches and borrow-pits. The measure of a dam would include the dam structure, approach roads and shoulders, the flooded area, and unflooded quarries from which materials were used.
Management relevance. High, since engineering works are the direct cause of loss and fragmentation of habitat, are responsible for changing environmental flows and, usually, diminish the quality of vistas. Recent surveys of stresses affecting national parks identify infrastructure as one of the leading causes of ecological integrity impairment (Parks Canada Agency 1995, 1998, 2000 b).
Linkage. Medium, since analyses based on remote sensing imagery and imported geographic data bases will tie into park geographic information systems that are actively used in data management for research and monitoring programmes.
Practicality. High, since measures can be obtained from architectural, planning and mapping records normally available to park staff, and assembled and analysed out of the field season.

CHANNEL MORPHOLOGY

IUGS title. Stream channel morphology.
EMAN title. None.
Park examples. Most parks have numerous streams or channel sections in mobile beds or easily erodible materials. Some of these are significant features in their own right, such as Ivvavik's Firth River Delta, the Athabasca and North Saskatchewan Rivers in Jasper National Park, or the tidal inlets of Prince Edward Island and Kouchibouguac.

Measurements. Ground or remote sensing surveys of channel patterns and cross-sections. Bed and bank cover types, including movable sediment, living and dead vegetation. Annual to five year intervals. Best done in relation to a streamflow gauge site.
Management relevance. Medium, since in the absence of a stream gauge, calculations based on channel dimensions can yield an estimate of peak discharge. Measures of stream channels may therefore indicate changes in catchment runoff relationships. Channel patterns are good indicators of erosion and sedimentation relationships.
Linkage. Medium. Morphological change relates to streamflow and vegetation cover, whereas the places where channel morphology changes most are poor sites for stream gauges. An ideal compromise would be for a channel morphology site to be at a mobile bed reach just upstream of a stream gauge at a stable, confined, rock-bound reach.
Practicality. Low. In-stream levelling surveys require a high investment of time and skill. Landform recognition and mapping, while relatively simple, are subjective, and only a regular photographic record would provide a reliable monitoring data set.

DESERT CRUSTS
IUGS title. Desert surface crusts and fissures.
EMAN title. None.
Parks examples. None.
Measurements. Field measurements of crust and fissure size, depth and extent, supplemented by ground surveys and remote sensing.
Management relevance. Low. Canada has no hot arid regions with playas and sabkhas.
Linkage. Low, since no other hot desert monitoring can be expected in Canadian national parks.
Practicality. Medium. The techniques are low-tech and need be conducted only every few years.

DUNES
IUGS title. Dune formation and reactivation.
EMAN title. None.
Park examples. Kejimkujik Seaside Adjunct, Kouchibouguac, Pacific Rim and Prince Edward Island.
Measurements. Changes in size, shape and position of sand dune sheets and dune fields monitored through ground surveys and remote sensing on annual to decadal time scales. Local wind records, vegetation cover and signs of trampling are essential companion data.
Management relevance. High. Canada has the world's longest coastline, and many national parks have ocean and lake coasts that comprise active and inactive sand dunes, relict dunes that are at risk of disturbance and reactivation, and some dunes presently subject to disturbance, blow-outs and other deflation activities. Canada also has several inland dune areas, as in central British Columbia and northern Saskatchewan. Although these are not currently represented by national parks, they contain natural regions that may yet be represented in the national park system. Dunes are also charismatic landforms that attract visitors. This and their association

with recreational beaches has resulted in widespread dune destabilisation and associated dune stabilisation management programmes.
Linkage. High. Measurements would be an integral part of monitoring shoreline, nearshore landform and dune vegetation.
Practicality. High. Methods are low-tech and need be applied infrequently.

DUST STORMS

Note that wind erosion is addressed as a geoindicator in its own right.
IUGS title. Dust storm magnitude, duration and frequency.
EMAN title. None.
Park examples. Mountain and Arctic parks with proglacial areas, and coastal parks with spit and dune complexes. Bare sandars, intertidal zones and Arctic deserts are common in many parks, and these are known to support significant local dust storm events from time to time. However, despite low precipitation in many such regions, they remain sufficiently moist from snow melt, low Summer temperatures and low evaporation rates to prevent widespread dust storms. Grasslands National Park may experience occasional prairie dust storms.
Measurements. Dust storm annual frequency, length of storm season and visibility observations at climate stations, and mapping the volume of transported material.
Management relevance. Low, since Canada has no extensive bare desert areas that are dry enough, long enough, for dust storms to be a major geomorphic agent.
Linkage. Medium. Textbook dust storms are rare in the national park system, but small-scale versions could parallel wind erosion, shoreline and dune field monitoring and any monitoring related to Arctic and proglacial barrens.
Practicality. Low. Storm and visibility observations would require an extensive network with hourly to daily observations, or detailed mapping of loess deposits quickly after a dust storm.

EXTREME EVENTS

IUGS title. None.
EMAN title. None.
Park examples. Mountain parks like Glacier and Kluane with active debris slides, slope failures and flash floods, coastal parks with mobile sedimentary complexes like Ivvavik, Kouchibouguac and Prince Edward Island, and any area with a major river system.
Measurements. Variables may be derived from stream gauges, lake and sea level recordings, coastal position records and climate stations, and could be based on values over certain thresholds or durations. Indirect measures could be based on human responses to environmental situations, such as frequency and duration of road closures in mountain passes, hurricane, tropical storm and tornado damages or, outside parks, weather-related insurance claims and crop drought insurance payouts. Care would have to be taken, however, to account for changes in management precautions and societal litigiousness. Distinct threshold events might provide interesting records, such as ice regime events in the indicator proposed by EMAN. In a review of progress in fluvial geomorphology, Dollar (2002) notes recent evidence that flood chronologies

indicate that during periods of rapid change there is a tendency for more frequent occurrences of large and extreme floods. As a newly proposed geoindicator, I recognize that a more thought is needed to select measurement methods and to determine relevance to ecosystem management.
Management relevance. Medium. Ecosystems are strongly governed by extreme events, not just average conditions. However, the choice of a particular type of event would vary considerably from park to park.
Linkage. High, since the measures are all analyses of other data gathering programmes.
Practicality. Medium. Extreme events can be determined after the fact from existing monitoring stations, incidence reports or insurance records. However, it will be difficult to avoid double counting the extreme values of other geoindicators such as streamflow.

FROZEN GROUND ACTIVITY

IUGS title. Frozen ground activity.
EMAN title. Permafrost depth.
Park examples. Aulavik, Auyuittuq, Ivvavik, Kluane, Nahanni, Quttinirpaaq, Sirmilik, Tuktut Nogait, Vuntut, Wapusk and Wood Buffalo.
Measurements. Features and processes include active layer thickness, frost heaving, frost crack patterns, persistence of icings (see also ice regime), thermoerosion and thermokarst features, slope stability and solifluction. Techniques include probe rods, surface position scribing recorders, precision levelling, temperature profile probes (thermistor strings), ground penetrating radar, frost tubes, breaking cables across cracks, inclinometer tubes, and ground mapping and remote sensing for larger features like icings and thermokarst. Measurements may vary from weekly in the melt season to seasonal, annual and decadal. Active layer depth should be recorded on a fixed date at the end of Summer.
Management relevance. High. By number, many parks contain permafrost. By area, the great majority of national park lands are characterized by permafrost. Even outside permafrost areas, Canada's cool temperature and boreal climates mean that virtually all of its land surface experiences several months in a frozen state. In consequence, frost heaving and cracking are ubiquitous processes, as anybody driving roads in Spring can testify.
Linkage. Medium. All permafrost monitoring sites can be expected to be paired with vegetation quadrat monitoring and a climate station.
Practicality. Medium. Measures need in situ equipment or precise survey techniques, and many sites may be needed to ensure a representative assessment of an area. However, these are simple, standard techniques of surveying or probe installation, and are already in use in Arctic parks.

GLACIERS

IUGS title. Glacier fluctuations.
EMAN title. None.
Park examples. Auyuittuq, Banff, Glacier, Jasper, Kluane, Kootenay, Mount Revelstoke, Quttinirpaaq, Sirmilik, Waterton Lakes and Yoho.

Measurements. The common ones are mass balance, total volume, equilibrium line, glacier length and/or terminus location, locations of terminal and lateral moraines and outflow discharge. Techniques include glacier surface survey and detailed levelling, remote sensing, including radar interferometry, outflow discharge and terminal lake level gauging. Closely associated climate stations are necessary to assess the relative influence of change in temperature and precipitation amounts and regimes.
Management relevance. High. Eleven parks contain either ice caps or glaciers and névés. As well, some of the longest records of glacier monitoring in Canada are in parks such as Glacier and Auyuittuq, due to the site protection and logistical support available to help support periodic field work over decades.
Linkage. Low, linking only to periodic mapping of dynamic proglacial areas.
Practicality. High, as most measures are based on standard field survey techniques or lend themselves to remote sensing.

GROUNDWATER LEVEL
IUGS title. Groundwater level.
EMAN title. None.
Park examples. The twenty-eight parks outside the zone of continuous and discontinuous permafrost.
Measurements. Dip sticks, plumb lines, automatic water-level recorders or pressure transducers from boreholes, wells or springs, usually measured monthly.
Management relevance. Medium. There are no industrial or agricultural groundwater withdrawals within parks, although water is withdrawn for campgrounds and operations use. It is conceivable that this may further reduce some river levels in the peak of summer to the detriment of in-stream resources like migrating fish. More serious is the urbanization of gateway communities and development large nearby mining operations that may result in a lowered water table, with consequences for water levels in wetlands, phreatophytic plants and base flow of rivers.
Linkage. High, as groundwater is an essential part of the hydrological cycle and water budgets up to regional scales, and since boreholes can be easily collocated with stream and vegetation monitoring sites.
Practicality. High, since boreholes or piezometers, once installed, are simple to operate, either by manual methods at monthly intervals, or automatically with data loggers.

GROUNDWATER QUALITY
IUGS title. Groundwater quality.
EMAN title. None.
Park examples. The twenty-eight parks outside the zone of continuous and discontinuous permafrost.

Measurements. Several indicator themes are proposed along with specific measures based on in situ sensors in wells, or retrieval of water samples for laboratory analysis, with data recorded seasonally or annually:

Salinity	Cl, specific electrical conductance, SO_4, Br, TDS, Mg/Ca, ^{18}O, ^2H and F.
Acidity and redox status	pH, HCO_3, redox potential, DO, Fe and As.
Radioactivity	^3H, ^{36}Cl and ^{222}Rn.
Agricultural pollution	NO_3, SO_4, DOC, K/Na ratio, P, pesticides and herbicides.
Mining pollution	SO_4, pH, Fe, As, other metals, F and Sr.
Urban pollution	Cl, HCO_3, DOC, B, hydrocarbons and organic solvents.

Management relevance. Low in terms of monitoring environmental changes related to ecological integrity in the wilderness areas typical of the majority of Canadian national parks. The quality of water in the ground and below the water table is, in itself, of no consequence to the vast majority of ecosystems. Except in karst terrain, only when the water is in soils and on the surface does its quality directly affect ecosystems, and this aspect is covered by the soil water quality and surface water quality geoindicators. However, in and near park town sites and campgrounds its relevance may be high in terms of ensuring potable drinking water and tracing pollution origin. Waste waters infiltrating from these sites may also contaminate nearby springs, wetlands and streams used by wildlife for drinking and habitat. In these two situations, intra-day to weekly measures are probably essential.

Linkage. High, as groundwater is an important part of the hydrological cycle and water budgets up to regional scales, and since boreholes can be easily collocated with stream and vegetation monitoring sites.

Practicality. High. Once a borehole is installed, seasonal or annual water samples can be easily obtained and sent to laboratory for analysis.

ICE REGIME (on surface water)

IUGS title. None.

EMAN title. Ice phenology.

Park examples. Potentially all parks, but those with no large lakes or coast line, like Grasslands or Nahanni, would probably not benefit from satellite remote sensed methods of measurement.

Measurements. The EMAN context is for lakes and streams, but clearly this indicator would also apply to coastal waters, particularly coves, bay and estuaries in terms of navigability or the appearance of open leads, or straits in terms of crossings by terrestrial animals including humans. There are many ad hoc means to determine a date of ice freeze-up and break-up on a bay, whole lake or river reach. Daily observations are needed in the appropriate seasons, for which seasonally installed camera stations would help. The ten day AVHRR composite images could provide a surrogate for bodies of water exceeding several of the sensor's one square kilometre pixels. This would probably need a record of percent ice cover tracked over several images, and then interpolated for a chosen threshold value. Radarsat is designed chiefly for ice survey and its images are routinely available for the Arctic as archived wide-scan images. However, standard and fine-scan images for the same period are hard to obtain since the satellite is set to wide-scan mode over high latitudes and this pre-empts the capture of finer resolution images of smaller targets. Ice thickness could be measured in mid-winter at selected lakes. In coastal areas, ice types, such as first-year ice, multi-year ice, pressure ridges and bergs could be recorded. A threshold value of extent or thickness of river icings might be a useful indicator in some Arctic locations.

Management relevance. Medium, in that ice regime is important only to navigation and aquatic life in most ecosystems. It has more importance in the Arctic for the role that ice plays in providing hunting territory for polar bears and island-to-island migration bridges for land mammals.

Linkage. Low, since methods are independent of most other ground-based measures.

Practicality. Medium, since some planning, effort and cost would be involved in setting up a camera station or obtaining and interpreting AVHRR or radar satellite data. The latter could be contracted, however, and AVHRR data are routinely available for Canada at very low cost. In some locations, like park town sites, volunteers and public records may provide an inexpensive way to obtain a consistent measure of ice breakup on a river.

KARST

IUGS title. Karst activity.

EMAN title. None.

Park examples. Banff, Bruce Peninsula, Jasper, Nahanni and Wood Buffalo. Nahanni is best known by virtue of its extensive cavern system and its oft-photographed and delicate tufa mounds. Jasper, Banff and Ivvavik have significant cavern systems. Bruce Peninsula has limestone pavement, and its cavities are an essential part of rattlesnake habitat. Wood Buffalo has some gypsum karst.

Measurements. Flow rates and chemistry of springs, sinking streams, drip waters and cave streams. Chemical measures include pH, temperature, Ca, Mg, Na, HCO_3 and SO_4. Pump tests on wells. Water levels in wells and of underground streams. Dye tracing to track changes in underground pathways. Mineralogy and chemistry of cave precipitates using X-ray diffraction, luminescence, isotope ratios and trace elements. Repeated levelling over suspected future sinkholes. Timing may vary from five to ten year intervals for dye tracing and cave precipitate chemistry, to hourly monitoring of stream discharge.

Management relevance. Low. Only a few parks have significant karst scenery, although these cases are well known in the park and travel literature, and preferentially visited. They also tend to be the substrate for many rare plants, animals and ecosystems. Karst caverns can also be critically important to the preservation of the palaeorecord. Otherwise, karst is not widespread enough for consideration under a national monitoring framework, unless a "special features" category is added, in which the feature may vary from park to park depending on the prominence of special features in the park's identity.

Linkage. Medium. Cave water monitoring would link to streamflow and surface water quality downstream of a karst area.

Practicality. High, in the sense that samples are easy to obtain, and can be sent to a contract laboratory for analysis.

LAKE AND OCEAN SEDIMENT

Note that the proxy record and the marine nearshore environments are addressed as a geoindicators in their own right.

IUGS title. Sediment sequence and composition.

EMAN title. Sediment trap.

Park examples. Parks with extensive coastal sedimentary environments, like Ivvavik, Kouchibouguac, Point Pelee and Prince Edward Island. Parks with lakes with major inflowing sediment-laden rivers, such as the mountain glacier parks and Wood Buffalo.

Measurements. Stratigraphy mapped using seismic and acoustic techniques from vessels. Sediment trap at the deepest point of a lake, measured annually. Sediment coring, grab sampling or dredging obtained from lakes, estuaries, ponds, bays, fjords and river bottomlands. Sediment sequences can be inferred from isotope techniques, datable tephra layers and fossil content. Sediment contents can be measured for humification, mineral content, elements, pollutants, fossil remains and many other factors.

Management relevance. Low, given that bottom sediments will reflect local and regional inputs which could be determined directly from river water quality and atmospheric inputs, for example. These are much easier to measure and there would be other, more immediate scientific benefits in terms of understanding the current and imminent state of ecosystems. Sediment studies are of high value to understanding the past, but it is hard to see the benefits to Parks Canada of monitoring their accumulation into the future.

Linkage. Medium, to lake levels and water quality.

Practicality. Low in ocean and large lake settings, as expensive vessels and equipment are needed for this. Grab sampling and gravity corers are more feasible from smaller craft on small to moderate size lakes, but it is unclear that results would have much meaning in the short to medium term compared to, say, sampling of suspended load and chemistry of inflowing waters.

LAKES

IUGS title. Lake levels and salinity.

EMAN titles. Dissolved oxygen, temperature profile, water clarity, water flow and water level.

Park examples. Most parks have lakes enclosed within them, or border on great lakes.

Measurements. Lake levels by shoreline gauges or radar altimetry, areal extent by remote sensing, temperature, and chemistry by sampling for, e.g., DOC, clarity, $CaHCO_3$, $MgHCO_3$, CO_3, $MgSO_4$ and $NaSO_4$. These indicators are sensitive to pollution and changes in water budget so monitoring would be needed at weekly to monthly frequencies. Past levels and salinity can be inferred through geomorphological and archeological studies on old shorelines, and geochemical studies of diatoms, ostracods and other bio-indicators in lake sediments.

Management relevance. High. All parks have some number of lakes and ponds. Many have many. Lakes and their riparian zones are typically of high productivity, important as habitats and as part of the food web of local to regional ecosystems, and are preferred as visiting and camping sites. They are easily accessed and measured for attributes like level and chemistry.

Linkage. Medium. Sample collection can be linked to shoreline morphology monitoring or any fishery or other aquatic habitat monitoring.

Practicality. Medium, due to simple survey techniques for surge limits and collection of water samples for laboratory analysis, but at least small boat access is necessary.

MARINE NEARSHORE ENVIRONMENTS

Note. While this indicator appears in the IUGS and EMAN lists, it may now be considered more or less the same, or overlapping with, lake and ocean sediment and the proxy record.

IUGS title. None.

EMAN title. None.

Park examples. Both national marine conservation areas (Saguenay-Saint-Lawrence and Fathom Five) and twenty-one of thirty-nine national parks have either an ocean coast or a high energy Great Lake coast (Point Pelee, Bruce Peninsula, Georgian Bay, Pukaskwa).

Measurements. Bottom profiles and sediment mapping with detailed shallow water bathymetry. Benthic organism inventories.

Management relevance. Medium. Parks Canada only has a rudimentary marine protected area system, and generally has no management authority over the water area below the high tide line.

Linkage. Medium, linking to, or even overlapping with, lake and ocean sediment, shorelines and the coral aspects of the proxy record.

Practicality. Low, since it involves diving work, water craft with real time kinetic GPS guidance, and side scan sonar systems.

MASS MOVEMENTS

IUGS title. Slope failure (landslides).

EMAN title. None.

Park examples. Most: all mountainous parks, parks of the Atlantic coast, and all parks with significant thicknesses of unconsolidated glacial or fluvial sediment. Possibly nine or ten parks do not fit these situations.

Measurements. Surveying of cracks and marker stakes, tilt meters, subsurface inclinometer and rock noise instruments, shallow seismography, volumetric surveys of talus cones, mapping by remote sensing. Frequency of measurement can vary considerably according to situation. Mapping before and after intense rain and snow melt events may be useful in hilly and mountainous terrain. Continuous rain gauging is an essential complement.

Management relevance. High. Significant ecosystem impacts of mass movements in mountainous areas tend to be catastrophic but spatially and temporally rare, and in themselves not diagnostic of landscape trends. However, moderate, repeated effects are ascribed to rock falls and debris avalanches in mountainous areas. Solifluction may be worth measuring in Arctic parks as an abiotic indicator of response to climate.

Linkage. Medium. Instrument locations are generally independent of many other measures, but general location might fit with coastal, watershed hydrology or erosion monitoring sites.

Practicality. Medium, as advanced equipment is needed for most measures. In some instances, though, such as high mountains, periodic remote sensing inventories of rock slides and avalanches may give a useful, easy measure of activity at a regional scale.

PROXY RECORD
IUGS title. Coral chemistry and growth patterns.
EMAN title. None.
Park examples. Potentially all parks.
Measurements. Paleorecord of temperatures, precipitation, growth conditions, winds, salinity, fertility, insolation, sea levels, storm incidence, river runoff and human inputs through various analysis of tree rings, speleothems, subsurface temperature profiles, fossils and trace elements in tree rings and sediment layers, isotope ratios, fluorescence, growth and mortality patterns in corals, structural damage and the age of reefs.
Management relevance. Low. Proxy records are of high value in understanding the past, and as such are of vital interest to Parks Canada to help develop knowledge of parks' natural histories. However, they are deciphered through specific projects, and are not generally regarded as a monitoring tool, hence their relevance to park monitoring is low. On the marine side, Parks Canada only has a rudimentary marine protected area system under its management.
Linkage. High. There are many linkages to other geoindicators.
Practicality. Medium, since tree ring specimens are easy to collect but others, like coral and lake sediments, involve elaborate logistics and/or equipment, and painstaking analysis.

SEA LEVEL
IUGS title. Relative sea level.
EMAN title. None.
Park examples. Seventeen parks have marine coast.
Measurements. Gauges, GPS and re-levelling surveys to track tides, storm surges and possibly wave climate.
Management relevance. Low. The rates of change of sea level *per se* are slow compared to, say, shoreline position which may also be affected by changes in storm activity and human modifications to beach sediment supply. Tide information is vital to inshore navigation by park services and visitors, but this does not make it a vital geoindicator. Sea level change due to thermal expansion, eustasy or isostasy may be significant at some parks, but its importance is more readily experienced through shoreline position monitoring.
Linkage. Medium. Sea level change links only to dune and shore morphology at coastal sites.
Practicality. Low, since a tide gauge needs to be robust and well-maintained. Surrogate measures, such as position of highest drift line, are simple but may be confounded by changes in magnitude and frequency of storm surges.

SEISMICITY
IUGS title. Seismicity.
EMAN title. None.
Parks examples. None, although earthquakes may be of local significance to hazard alerts in mountain areas, where they may trigger the collapse of moraine dammed lakes (e.g. Glacier),

talus slopes near their angles of repose (e.g. Banff), and cliffs of fractured, unstable rock (e.g. Gros Morne).
Measurements. Standard seismographs. Monitoring seismicity induced by mining or fluid extraction requires networks of instruments at less than five kilometre spacing, with data transmitted and analysed in real time.
Management relevance. Low. Seismic events are of primary concern to public safety and architectural preservation in urban areas, and as such there seems to be little value in monitoring seismicity from the standpoint of ecosystem management.
Linkage. Low. Seismic events typically originate deep beneath the surface so that the placement of seismographs is independent of other geoindicators monitoring sites and devices.
Practicality. Low. Seismology involves specialized and delicate equipment, and specialized on-site infrastructure and technical support, none of which are in the purview of Parks Canada.

SHORELINES

IUGS title. Shoreline position.
EMAN title. None.
Park examples. Both national marine conservation areas (Saguenay-Saint-Lawrence and Fathom Five) and twenty-one of thirty-nine national parks have either an ocean coast or a high energy Great Lake coast (Point Pelee, Bruce Peninsula, Georgian Bay, Pukaskwa). Of the latter, Ivvavik, Kouchibouguac and Prince Edward Island have highly dynamic coastal zones. Global warming and reduced sea ice duration could strongly affect Wapusk's shores.
Measurements. Quantitative measures may be chosen from the position of the top and bottom of bluffs, extent of foreshore and backshore vegetation, beach slopes and profiles, width of dry beach, base of the beach, cusp dimensions, mean water line, high water line, bar position and morphology, barrier crest and berm elevation, sediment size and shape, and sediment budget. Water levels, wind speed and direction, storm waves, storm surges and coastal currents are desirable complementary data. Qualitative measures include visual (direct and via remote sensing) assessment of shore morphology, erosion and deposition. Several transects and/or sediment traps can be used to derive estimates of coastal sediment transport drift. In active dune and beach sand areas, transects should be constructed and re-measured using real time kinetic GPS. Monitoring over at least a decade is necessary to discriminate the natural cycles of longshore and shore-normal drift, spit and bar features from true long-term change. Monitoring should be done seasonally and, if possible, before and after storms until natural variability is known, and once or twice a year thereafter.
Management relevance. High. Shores of all types, but especially high energy and soft sediment shores, tend to be rich in geological exposures, landforms, biodiversity, productivity and visitor attraction. In consequence they are visited and monitored frequently.
Linkage. High. Shoreline monitoring can occur alongside dune and lake or sea level monitoring. Many of the intertidal processes relate to the marine nearshore environment geoindicator.

Practicality. Medium. Above the water line, simple survey techniques can be used. Nearshore surveying is more difficult, and would be more challenging to maintain as a regular monitoring programme.

SNOW AVALANCHES
IUGS title. None.
EMAN title. None.
Park examples. Potential candidates are the fifteen mountain national parks of Alberta, British Columbia, Northwest Territories, Nunavut and the Yukon, and Cape Breton Highlands and Gros Morne in Atlantic Canada. Other hilly parks in high precipitation areas, like Forillon, may also be candidates.
Measurements. Uncertain, possibly avalanche frequency at key sites or over a controlled area, and extent and width of the run-out zone. However, measurement as a geoindicator would be problematic at accessible sites in the Alberta and British Columbia national parks by virtue of management programmes to trigger avalanches in a controlled manner.
Management relevance. High, since avalanche activity has a strong control over vegetation, in that avalanche tracks, both snow and debris avalanches, are often clear of trees and provide rich wildlife food resources from shrub foliage and berry plants. Snow avalanches are also a leading hazard for winter backcountry visitors and through traffic.
Linkage. Medium. Low for other geoindicators, but there are strong ties to the avalanche weather monitoring and control programmes of the western mountain parks.
Practicality. Low because of uncertainty over measurement methods.

SOIL EROSION
IUGS title. Soil and sediment erosion.
EMAN title. None.
Park examples. Parks with much barren land, or in areas of high seasonal climatic variability or periodic intense events, or in areas of high local relief, such as Quttinirpaaq, Grasslands or Yoho.
Measurements. Erosion pins, painted rock lines, pit traps, profile and slope measurements, repeated seasonally to once per decade.
Management relevance. High, since the state of the soil surface is a key part of ecosystem health.
Linkage. Low, since areas of active soil erosion are not likely to be the same as for permanent vegetation monitoring sites.
Practicality. Low. Erosion is very irregularly distributed in time and space, and it is difficult to determine the representivity of a site. Careful set up and protection of a field site is needed, although subsequent techniques are all based on surface measurements, as opposed to borehole profiling, heaving pins and the like.

SOIL TEMPERATURE

IUGS title. Subsurface temperature regime.
EMAN title. Soil temperature.
Park examples. All parks.
Measurements. Daily average temperature at a single depth (EMAN) or several depths within the soil profile and/or active layer (IUGS).
Management relevance. Medium for soil profile temperature, as it relates to snow conditions, vegetation type, carbon sequestration and other soil chemistry processes. Freeze-thaw cycles can play an important role in forest dieback. Deep borehole temperature profiles are of limited relevance as they are a long term, smoothed response to climate over several years to centuries. They are of great value in understanding past climates, but of low value to track present and future climate change and ecosystem responses, compared to operating a climate station.
Linkage. Low. Techniques would only parallel frozen ground activity measurements.
Practicality. Medium. Some in situ equipment is needed but much less so than for frozen ground activity.

SOIL QUALITY

IUGS title. Soil quality.
EMAN title. None.
Park examples. All parks.
Measurements. Depending on the current soil processes and within specified horizons, these can be chosen from soil texture, especially clay content, bulk density, aggregate stability, size distribution, pH, organic matter content, sodium absorption ratio, carbon exchange capacity, cation saturation and water-holding capacity. Derived measures can include pedogenesis (soil horizon development), leaching and acidification. Measurement should be expected at one to ten year intervals. Soil water and groundwater quality are closely linked.
Management relevance. Medium. Soils are critical to ecosystem productivity, and are habitat in their own right for many organisms. However, they are relatively stable and changes may not be evident for some time after other ecosystem components have experienced considerable alteration. Relevance would be higher in eastern Canada, where acid deposition has altered soils by depleting calcium and other base cations, mobilizing inorganic aluminium, and increasing the accumulation of sulfur and nitrogen in the soil.
Linkage. High, since it would tie closely to streamflow, channel morphology, soil and groundwater water quality geoindicators, and to permanent vegetation monitoring plots.
Practicality. Medium. Field collection may be labourious but not particularly complex, and specimens can be sent to a laboratory for analysis. Soil science is often in the educational background of park ecologists and ecosystem technicians. However, repeated measurements at a fixed point are impossible due to the destructive nature of soil pit digging and sample removal. A measurement of soil water quality may have to suffice (see following).

SOIL WATER QUALITY
IUGS title. Groundwater chemistry in the unsaturated zone.
EMAN title. None.
Park examples. All parks.
Measurements. Cl, NO_3, H^+, ^2H, ^3H, ^{18}O of augur or drill samples or from the sides of dug wells, measured over five to ten year intervals. Impacts and recovery from acid deposition may be tracked through Al, N, S, and Ca and other base cations.
Management relevance. Medium in terms of monitoring environmental changes related to ecological integrity across the national park system and the backcountry, wilderness areas typical of the majority of park lands and waters. The quality of soil water is, in itself, only of consequence to deep rooting plants, particularly in the case of acidification and aluminium leaching. Only when contaminated water is on the surface does its quality strongly affect nature, and this is covered under the surface water quality geoindicator.
Linkage. High, since it would tie closely to streamflow, channel morphology, soil water and groundwater quality geoindicators, and to permanent vegetation monitoring plots.
Practicality. Medium. Field collection involves some specialized equipment, but the techniques are not particularly complex, and specimens can be sent to a contract laboratory for analysis.

STREAMFLOW
IUGS title. Streamflow.
EMAN title. Water flow.
Park examples. All parks.
Measurements. Continuous to daily measures of water level at calibrated channel transects across large streams or artificial weirs on small streams.
Management relevance. High since runoff from catchments is a good indicator of water retention, or not, by a healthy, or stressed, ecosystem. Streamflow measurements can be interpreted according to total runoff in relation to precipitation, rapidity of runoff after a precipitation event, and shape and regression of hydrographs. Associated climate data are essential to interpretation.
Linkage. High. Streamflow is a cornerstone of watershed studies, and is closely linked to meteorological monitoring and to aquatic resources studies.
Practicality. Medium. Streamflow is easy to measure once a section is calibrated. The optimum stream gauge site is at a bedrock controlled, single and deep channel so that initial calibrations make it possible to monitor streamflow with just a water level recorder. Otherwise, frequent and labour intensive flow profiling using cable ways or bridges is necessary. Once running, however, there is little additional field work needed, and no samples to analyse.

STREAM SEDIMENT
IUGS title. Stream sediment storage and load.
EMAN title. None.

Park examples. All parks with extensive areas covered by unconsolidated sediments that would be subject to accelerated soil or channel erosion.
Measurements. Daily to monthly sampling of suspended sediment and bed load coring, and associated observations of stream bank conditions, cutbank exposures, overbank deposits and total sediment storage at least once every five years.
Management relevance. High, since sediment yield reflects many dynamic basin conditions, including climate, soil stability and erosion, vegetation cover and land use. Sediments are also of direct value for freshwater fish habitat, and are potential sinks and secondary sources of pollutants.
Linkage. High. Suspended and dissolved load can be measured in association with streamflow and surface water quality sites. Bed load monitoring, however, involves much greater difficulty and more equipment, and would be hard to sustain in the long term.
Practicality. Low. Frequent sampling of both suspended and bed sediment will require a sustained level of effort, and assessments of the other conditions will require specialized skills not often at hand among park staff.

SURFACE DISPLACEMENT (seismicity and mass movements are considered separately)
IUGS title. Surface displacement.
EMAN title. None.
Park examples. None.
Measurements. Precise levelling and ground surveys using the global positioning system, and laser range finders, and gravity determinations.
Management relevance. Low, since most surface displacement relates to tectonic and volcanic activity, large scale groundwater withdrawal or large reservoir filling, none of which occur to any continuous degree in national parks. Isostatic movement is covered under the relative sea level geoindicator.
Linkage. Low. Measurements of surface displacement would be independent of the measures of other geoindicators.
Practicality. Medium with respect to current surveying technologies.

SURFACE WATER QUALITY
IUGS title. Surface water quality.
EMAN title. Dissolved oxygen, temperature profile and water clarity.
Park examples. All parks have ponds, streams and rivers, and most have lakes.
Measurements. Depending on the parameter set, continuous to monthly sampling and analysis of:
Basic constituents
- Metals and trace elements - Al, Sb, As, Cd, Cr, Cu, Pb, Hg, Se, Ag, Zn;
- Nutrients - ammonium, nitrate, nitrite, total N, orthophosphate, total P;
- Major constituents and dissolved solids - Ca, Mg, Na, Cl, SO_4, HCO_3, TDS;
- Direct field measurements - acidity, alkalinity, dissolved O, pH, temperature;

Selected organic compounds of environmental significance - 2,4-D, 2,4,5-T, phenol, chlorophenols, cresols, atrazine, cyperquat, paraquat, benzidine, DDT, malathion;
Additional constituents for human health - Ba, Be, F, Mo, Ni, V, radionuclides (gross alpha, gross beta, ^{222}Rn); and
Additional constituents for agriculture - B.

Management relevance. High, especially since the ecological integrity monitoring framework includes site nutrient retention of Ca and N. Water quality can vary as a direct consequence of local to global atmospheric, aquatic and terrestrial pollution, and indirectly as a result of climate and regional land use changes. Not all constituents would be relevant for consistent monitoring across the park system, such as the organic compounds and human health items. Standard assays and direct field measurements of metals, trace elements, nutrients, dissolved solids and one or two organic compounds would be a suitable suite for park system studies.

Linkage. High, since it would tie closely to the streamflow, channel morphology, soil and groundwater water quality geoindicators, and to permanent vegetation monitoring plots.

Practicality. High, as samples can easily collected by a consistent protocol and sent to a laboratory for analysis.

TUFA ACCUMULATION

IUGS title. None.

EMAN title. None.

Park examples. Travertine terraces and Rabbit Kettle Hot Springs at Nahanni, and mineral seeps on the ultramafic Tablelands of Gros Morne.

Measurements. Annual micro-surveys of accumulation at points, along transects or aerially across terraces, using close-range photogrammetry or survey pins, similar to those for soil erosion. Samples of source water and mineral deposits can be assayed for changing mineral content and pollutants.

Management relevance. Low. Only Nahanni has tufa mounds, and changes are as likely to be the result of progressive, deep earth processes as they are of environmental change.

Linkage. Medium. Tufa accumulations tend to be on mid slopes in high relief areas, and would at most link to groundwater level, groundwater quality and karst activity monitoring.

Practicality. Low. Although measurements are simple in principle, great care must be taken when working on tufa mounds, due to their delicacy.

VOLCANISM

IUGS title. Volcanic unrest.

EMAN title. None.

Parks examples. None.

Measurements. A combination of geophysical, geodetic and geochemical methods, such as borehole strainmeter, laser distance measurement, gravimeter, tiltmeter, GPS, seismographs, ground temperatures, level of crater lakes and a wide array of geochemical parameters applied to gas emissions.

Management relevance. Low, as there are no active or semi-dormant volcanoes in national parks. Even if there were, these measures are of only immediate site significance to ecosystems, short of a major ash eruption.
Linkage. Low, since there is no volcanic activity represented in the national park system.
Practicality. Low. Even if volcanism were active in national parks, the measurement methods all involve some variety of sophisticated equipment and specialized technical support.

WETLANDS
IUGS title. Wetlands extent, structure and hydrology.
EMAN title. None.
Park examples. All parks have at least some small wetlands. Many parks have extensive wetlands, associated with boreal, montane, Arctic and alpine climates. Examples include Ivvavik, Vuntut, Wapusk and Wood Buffalo. Many smaller parks have significant proportions of their area in wetlands, such as Jasper, Elk Island, Prince Albert, Pukaskwa, Kouchibouguac and Gros Morne.
Measurements. Remote sensing, field mapping and permanent transects of the: extent and distribution of wetlands; boundary positions and relationships, especially of marine and littoral wetlands; vegetation distribution, indicator species and communities; surface morphology; hydroperiods and water budgets measured by wells, piezometers and weirs; water chemistry, particularly metals, dissolved oxygen content and humic acids in outflows; and accumulation rates at permanent plots.
Management relevance. High. Wetlands are common and important habitats, a critical part of natural watersheds and flows, and yet are sensitive to stresses like atmospheric pollution, altered precipitation and inflow regimes.
Linkage. Medium, being potentially associated with streamflow, water quality and vegetation monitoring but with quite distinct requirements for selection of instrumented sites.
Practicality. High, since wetlands ecology, plant taxonomy and related studies are already common in Parks Canada, and since most field techniques are simple.

WIND EROSION
IUGS title. Wind erosion.
EMAN title. None.
Park examples. Auyuittuq, Ivvavik, Kouchibouguac, Prince Edward Island, Waterton Lakes.
Measurements. Field observations, surveys and remote sensing of vegetation cover, dune and blowout morphology, detailed survey of micromorphology changes, and sediment traps.
Management relevance. Medium, relating mostly to coastal dunes, proglacial and late Holocene deposits.
Linkage. Medium, as it would apply wherever landforms of loose sediments might be monitored, such as dune fields, beaches, glacial outwash areas and the stony Arctic deserts.
Practicality. High, using erosion stakes, vegetation mapping and landform surveying.

RANKING AND CHOOSING GEOINDICATORS FOR NATIONAL PARKS SYSTEM ASSESSMENT

Table 8 shows the combined list of IUGS, EMAN and new geoindicators, and the assessments of their relevance to park management, their linkage to other geoindicator methods, and their practicality in light of the typical skills of national park ecosystem managers and technicians. There are many ways to assign numbers to qualitative rankings, and many ways to weight and combine those numbers to produce a combined index. As this paper is intended to stimulate discussion as much as to make a final decision, I kept the indexing method as simple as possible. I gave scores of 1, 2 or 3 for low, medium and high ratings, and integrated them by addition. The right hand column in Table 8 shows the result.

The geoindicator descriptions, analyses and ranking can guide each park in choosing what to monitor for its own unique combination of management concerns. Hypothetical examples of this appear in a later section. The opportunity to measure geoindicators for a broader mandate of change monitoring is also discussed below. At the national reporting level, Parks Canada might be reasonably expected to monitor one or two geoindicators, or groups of related geoindicators, at one or two key sites within each park. As described at the outset, Parks Canada's assessment of the park system is tied to a structure, process and stress framework. The recommendations in this and the next section reflect this. Four additional factors will help to choose geoindicators for adoption into the ecological integrity monitoring framework.

- **Dynamic edges and extent.** The IUGS geoindicators were chosen on the basis of an expectation of detecting significant environmental change within a century. However, park management and condition reporting take place over years to decades. The reporting period is five years for the proposed state-of-park reports, and, based on past experience, five to fifteen years or more for management plan renewal. Therefore the selection of geoindicators at a given park should be weighted towards common, icon or valued features and processes known to be changing at macroscopic scales within those durations.

- **Water** and air are the principal abiotic media that bring about environmental change and facilitate accumulation, transfer and decay of nutrients and biomass. Air indicators are not the subject of this paper, but geoindicators related to fluvial processes and the hydrological cycle should be given a strong preference in the context of ecological integrity monitoring.

- **Climate and vegetation.** Note that the leading measures, except for the built environment, require associated permanent climate stations and/or vegetation monitoring plots for proper analysis of driving factors like climate and biomass. All parks have these to some degree or other, so this is not a hurdle. However, there should be some consideration of placement of geoindicator monitoring sites in relation to existing climate stations or vegetation plots, and the ability to make spatial interpolations from them. In new parks, or where there are gaps in monitoring networks in existing parks, all these monitoring needs should be addressed in concert.

Table 8. Blended list of geoindicators and national park priorities

Geoindicator	IUGS	EMAN	New	Relevance[1]	Linkage[2]	Practicality[3]	Score[4]
Dunes	✓	-	-	High	High	High	9
Surface water quality	✓.	-	-	High	High	High	9
Built environment	-	-	✓	High	Medium	High	8
Wetlands	✓	-	-	High	Medium	High	8
Shorelines	✓	-	-	High	High	Medium	8
Streamflow	✓	✓	-	High	High	Medium	8
Groundwater level	-	-	-	Medium	High	High	8
Glaciers	✓	-	-	High	Low	High	7
Frozen ground activity	✓	✓	-	High	Medium	Medium	7
Lakes	✓	✓	-	High	Medium	Medium	7
Mass movements	✓	-	-	High	Medium	Medium	7
Stream sediment	✓	-	-	High	High	Low	7
Wind erosion	✓	-	-	Medium	Medium	High	7
Extreme events	✓	-	✓	Medium	High	Medium	7
Soil quality	✓	-	-	Medium	High	Medium	7
Soil water quality	✓	-	-	Medium	High	Medium	7
Groundwater quality	✓	-	-	Low	High	High	7
Snow avalanches	-	-	✓	High	Medium	Low	6
Karst	✓	-	-	Low	Medium	High	6
Proxy record	✓	-	-	Low	High	Medium	6
Soil erosion	✓	-	-	High	Low	Low	5
Ice regime on surface water	-	✓	-	Medium	Low	Medium	5
Soil temperature	✓	✓	-	Medium	Low	Medium	5
Channel morphology	✓	-	-	Medium	Medium	Low	5
Marine nearshore environment	-	-	✓	Medium	Medium	Low	5
Desert surface crusts	✓	-	-	Low	Low	Medium	4
Surface displacement	✓	-	-	Low	Low	Medium	4
Dust storms	✓	-	-	Low	Medium	Low	4
Lake and ocean sediment	✓	✓	-	Low	Medium	Low	4
Sea level	✓	-	-	Low	Medium	Low	4
Tufa accumulation	-	-	✓	Low	Medium	Low	4
Seismicity	✓	-	-	Low	Low	Low	3
Volcanism	✓	-	-	Low	Low	Low	3

1. Relevance refers only to management issues concerning national park ecological integrity.
2. Linkage refers to ties to other indicators, in the sense that one may need others for proper scientific interpretation, or that some can be monitored together at little incremental cost.
3. Practicality refers to the skills, in kind resources and opportunities likely to be available to collect these data in a typical park on an indefinite term basis.
4. Table entries are sorted by total score, relevance, practicality, linkage and alphabetical order.

- **Partnerships and extant networks.** Methods like streamflow and water level gauging, water chemistry analysis and climate data collection require a certain amount of permanent equipment, continuous maintenance, quality assurance and quality control to international standards. These are traditionally areas in which Parks Canada has relied on expertise from contractors or other federal agencies. This practice should continue, with a preference to seek government partners as the principal investigators, as opposed to academic, industry or non-profit agencies, given the long term or even indefinite nature of the desired monitoring programmes. This does not rule out the very productive and successful involvement of volunteers and students in providing people on the ground to collect data.

A PROPOSAL FOR GEOINDICATORS FOR NATIONAL PARK SYSTEM ASSESSMENT

Given the biodiversity, function and stress approach already in use in national parks' ecological integrity monitoring as outlined in Table 1, I propose that at least a couple of geoindicators be short listed for each tier of valued features, processes and stresses as proposed for geoindicator monitoring and outlined in Table 5. In Table 9 and the following passages I take the top ranked geoindicators and place them into the three tiers until at least one and no more than five indicators occupy each tier. I also summarize the properties and measurement methods. Many of the properties and methods are similar and so are pooled in the table. This short list provides a reasonable set of geoindicators for further consideration for Parks Canada's ecological integrity monitoring framework at the national reporting level.

Table 9. Candidate geoindicators and measurements

Tier and indicator	General properties	General methods
Valued features	Size, shape, and thickness of forms	Topographic surveys and transects
• Dunes	Position of landform edges	High resolution remote sensing
• Glaciers	Surface sediments and accumulation	Soil sampling and chemical
• Lakes	Soil freeze-thaw cycles and depths	analysis
• Shorelines	Water levels and flow rates	Soil probes and stakes
• Wetlands	Water chemistry	Plant identification
Processes	Indicator plants and plant associations	Water levels - wells, weirs, gauges
• Frozen ground activity	Emergency responses	Water sampling and analysis
• Groundwater level		Operational records
• Mass movements		Engineering and architectural plans
• Streamflow	**Associated mandatory properties**	
• Surface water quality	Temperature, precipitation, wind	**Associated mandatory methods**
Stresses	Biomass accumulation or loss	Climate stations
• Built environment		Permanent vegetation plots

VALUED FEATURES

- **Dunes:** widely applicable since twenty-one out of thirty-nine parks have marine or Great Lake shores; selected barrier beach complexes; detailed maps and transects; annual to decadal.

- **Glaciers:** preferably mass balance and total volume; equilibrium line, glacier length and/or terminus location; glacier surface survey and detailed levelling; remote sensing, including radar interferometry currently in development; annual to decadal.

- **Lakes:** lakes wholly within a park and preferably wholly within a monitored watershed; water level; water chemistry; weekly to annual.

- **Shorelines:** widely applicable since twenty-one out of thirty-nine parks have marine or Great Lake shores, and nearly all parks have medium to small lakes; selected barrier island complexes; related studies of old shore lines; detailed maps and transects; annual to decadal.

- **Wetlands:** ubiquitous in the park system; selected bogs and fens; detailed maps and transects; change in wetland classes and open water extent; build-up/loss of peat; multi-year to decadal measurement intervals.

PROCESSES

- **Frozen ground activity:** ubiquitous in Canadian national parks even if outside the limits of permafrost (Figure 1); soil probes and thermistors to measure freezing or thawing depth and dates; weekly to seasonal measurements; annual to multi-year mapping of selected features.

- **Groundwater level:** daily to monthly records of groundwater level in an automated borehole, preferably linked to the streamflow site since annual surface discharge and base flow are closely linked.

- **Mass movements:** Seasonal to decadal; monitoring of cracks and marker stakes, volumetric surveys of talus cones.

- **Streamflow:** continuous gauge of the largest outflowing stream whose basin is wholly contained within the park.

- **Surface water quality:** monthly sampling of water at a stream gauge, especially looking for ions, pH, total dissolved salts, suspended sediment and dissolved oxygen content.

STRESSES

- **Built environment:** change maps of built structures and substrate modifications; annual to quintennial; total area of land surface disturbed or alienated by construction works.

If a further reduction is required, then geoindicators should be drawn from the top rank of each tier until at least one and preferably two indicators are selected. While wetland monitoring is a clear choice for a geodiversity indicator, I recommend lakes rather than dunes, active shorelines and glaciers, given their greater prevalence in the national park system. If two geoindicators are desired for stress measurement, then extreme events should be reconsidered. Thus:

- Valued features - lakes and wetlands;
- Processes - streamflow and surface water quality; and
- Stresses - the built environment.

GEOINDICATORS FOR SPECIFIC PARK ASSESSMENT: FIVE EXAMPLES

INTRODUCTION

The core of this paper has addressed the selection of a limited number of geoindicators for reporting on the state of the national park system. Commonality to as many parks as possible was a primary selection criterion. However, each park has its own blend of local earth science conditions and issues, and so may find it useful to monitor additional geoindicators. To illustrate the potential contrast, I consider five parks chosen on the basis of personal knowledge derived from field research experience in each. Their locations and brief descriptions are mostly paraphrased from the Parks Canada public web site (Parks Canada Agency 2002), with additional notes from personal knowledge, particularly dealing with issues and logistics.

For each of the five parks I used educated guesses to select the geoindicators that seem best matched to the local environment and present and potential issues, coupled with the logistical considerations of linkage and practicality. Real selection should follow the United States National Park Service geoindicator scoping process (US.NPS 2000). This involves the establishment of a contact group of appropriate experts for the park and its geological environment, a scoping meeting to address local needs and geoenvironmental issues, and a panel proposal to adopt particular indicators. Throughout, the National Park Service's Geological Resources Division provides liaison, advice and technical support.

AUYUITTUQ

This is a high Arctic park located on the east coast of Baffin Island. It is centred at 67°32' N and 66°36' W. Its 19,707 sq. km are dominated by the Penny Highlands, whose granite peaks reach up to 2,100 m. Most of the highlands are covered by the Penny Ice Cap, 300 m thick and 5100 sq. km in area. The edges of the highlands have been incised by glaciers flowing from the ice cap, some of which terminate in deep fjords along Davis Strait. Terminal and lateral moraines abound. Beyond the glaciers, active talus slopes and sandar typify the lower elevations. Despite having marine coasts, shore processes within the park are limited by the long periods of ice cover and the sheltered nature of the fjord coasts.

Natural and anthropogenic changes and stresses affecting or likely to affect the geological values of the park include landscape processes and increases of commercial shipping responding to climate change, and visitor pressure on sensitive tundra terrain. Climate changes in the Arctic are expected to be much greater than in southern Canada, so parks like Auyuittuq would be good bellwethers. The remoteness and long Arctic winters of Auyuittuq keep visitor numbers low to just a couple of hundred a year, but also severely restrict access, often not possible for months at a time. In fact, most of the park is never visited by staff, local residents or tourists. On the other hand, the large scale of many features and the lack of tree cover lends the park to remote sensing methods of monitoring geomorphic change.

Table 10. Potential geoindicators for Auyuittuq National Park

Geoindicator	Examples of features, processes and stresses
Channel morphology	Channel changes, from which extreme event records may also come
Extreme events	Moraine dam ruptures, floods and sandar reworking, glacier calving, landslides
Frozen ground activity	Active layer depth, solifluction lobes
Glaciers	Terminal positions, equilibrium lines, mass balance
Ice regime	Navigability on main fjords, remote sensing of coastal waters
Mass movements	Talus production
Sea level	Combination of eustatic and isostatic changes
Soil temperature	Thermistor probes coupled with frozen ground activity monitoring
Wind erosion	Dune activity on glaciofluvial deposits

FUNDY

The park is on the north shore of the Bay of Fundy and is centred at 45°39' N and 65°06' W. Its 206 sq. km are divided into two major environmental systems, the marine coastal environment of the Bay of Fundy and the Caledonia Highlands plateau, peaking at 381 m asl. These are divided into several ecosystems: the Bay of Fundy itself, noted for the highest tides in the world which reach 12 m at the park; tidal flats; salt marshes; rocky shores and cliffs; upland bedrock hills; glacial deposits; bogs; and deeply incised river valleys.

Natural and anthropogenic changes and stresses affecting or likely to affect the geological values of the park include: increased storm activity in response to climate change; the removal of old dams changing processes in streams; human disturbance to tidal flats and salt marshes; trail compaction and trampling by the park's quarter of a million visitors each year; and acidification of lakes and soils under the continuing deposition of sulphate and nitrate acids. The small size of the park and the dominance of resistant bedrock landforms means that major geomorphological changes should not be expected. However, the park is in an accessible location and has many long term monitoring programmes, so complex methods applied to subtle changes are highly feasible.

Table 11. Potential geoindicators for Fundy National Park

Geoindicator	Examples of features, processes and stresses
Built environment	Campgrounds, roads, trails, old gravel pits, park buildings
Groundwater quality	Acidification and other long range airborne pollutants, former agricultural uses
Marine nearshore environment	Sea level and storms responding to climate change and changing the sedimentology
Proxy record	Peat and sediment deposits in and around upland bogs and lakes
Soil quality	Acidification and other long range airborne pollutants, former agricultural uses
Soil water quality	Acidification and other long range airborne pollutants, former agricultural uses
Streamflow	Regime changes due to climate change
Surface water quality	Acidification and other long range airborne pollutants, former agricultural uses

IVVAVIK

Ivvavik National Park is centred at 69°27' N and 139°19' W, and lies on the Beaufort Sea coast at the very northern end of the Yukon Territory. Most of its 9750 sq. km were never glaciated, at least in Cenozoic times. The British Mountains, up to 1655 m asl, account for two-thirds of the park's area, in which non-glacial landforms like V-shaped valleys, conical hills and tors are common. Periglacial processes, mass movement, wind and water erosion are all active processes, and the antecedent Babbage, Firth and Malcolm Rivers have carved their way through these mountains in spectacular gorges and valleys. The northern third of the park is a coastal plain of glacial and marine sediments, with active polygon formation, thermokarst and retrogressive thaw slides.

Like Auyuittuq, the park is remote and sees few visitors, most of whom raft down the Firth River. However, the area has been part of extensive and intensive environmental investigations during several periods since the 1960s in association with hydrocarbon exploration and associated environmental baseline studies and impact assessments. Present and future threats to Ivvavik include: climatic warming leading to accelerated melting of permafrost and an ice-free Arctic Ocean in summer with a huge potential for increased storms and coastal erosion; an offshore oil and gas pipeline connecting northern Alaska with the Mackenzie Delta; and pollution from Arctic shipping.

Table 12. Potential geoindicators for Ivvavik National Park

Geoindicator	Examples of features, processes and stresses
Channel morphology	Braided and incised wild rivers, mobile bed streams, deltas
Frozen ground activity	Widespread continuous permafrost, frost heaving, solifluction slopes, thermokarst
Ice regime	Ponds and streams that freeze solid; thaw leads critical for migratory waterfowl
Mass movements	Many retrogressive thaw slides; extensive colluvial hillslopes
Shorelines	Bluffs, barrier shores and estuaries already subject to intensive reworking
Soil temperature	See frozen ground activity
Wetlands	Many riparian and tundra wetlands providing critical wildlife habitat

JASPER

Jasper National Park is a 10,878.0 sq. km area centred at 52°53' N, 118°3' W and containing dramatic mountain peaks and expansive valleys. Many of the mountains rise to elevations above 3000 metres above sea level. Mount Columbia, the highest peak in Alberta, reaches 3782 m asl. The lowest point in the park is at 985 m, on the Athabasca River as it exits the park. Much of the park is above tree line and is characterized by rocky peaks, alpine tundra and talus. Numerous snow and debris avalanche tracks cut through the lower slope forests to the montane ecosystems on the valley floors. Hydrology is dominated by snowmelt and rainfall which combine to fill river channels to capacity in late June. Melting glaciers keep the water levels high through July. In midsummer, these rivers contribute significantly to the water supply required for municipal and agricultural needs further downstream.

The park is one of the most highly visited in Canada, and includes a town site, an east-west road and rail transportation corridor, the renowned Icefields Parkway, the Columbia Icefields Visitor Centre and glacier bus rides, and several outlying commercial accommodations and facilities such as the Miette Hot Springs and the Jasper Park Lodge, a luxury hotel. The park's many built facilities, roads and trails provide good access for research and monitoring sites.

Table 13. Potential geoindicators for Jasper National Park

Geoindicator	Examples of features, processes and stresses
Built environment	Jasper town site, Yellowhead and Icefields highways, large campgrounds
Channel morphology	Extensive braided reaches of the Athabasca River
Extreme events	Debris avalanches, floods, forest fires affecting slope stability
Frozen ground activity	Alpine periglacial features, frost heaving, solifluction
Glaciers	Valley and hanging glaciers retreating rapidly, Columbia Icefields
Karst	Paraglacial karst, Maligne canyon area
Mass movements	Debris avalanches, free falling debris on talus cones and sheets
Proxy record	Tree rings, pollen in lake sediment, ice cores
Snow avalanches	Widespread snow avalanche tracks
Streamflow	Glacier fed streams
Stream sediment	Mobile bed streams and high silt (rock flour) suspended load

SAINT LAWRENCE ISLANDS

This 8.7 sq. km park is centred at 72°57' N, 80°34' W, in the heart of the Thousand Islands area, an 80 km wide extension of glaciated granite hilltops joining the Canadian Shield of northern Ontario with the Adirondack Mountains in New York State. The park consists of many small islands, or parts of islands, in the Saint Lawrence channel, and a part of the mainland Ontario shore. The islands are the tops of these glacial hills and knobs flooded by the waters of the Saint Lawrence. Soil formation has been slow over the acidic granite, so that today the area retains a rugged beauty. Plant and animal migration to the area is encouraged by the moderating effects of the Great Lakes and the variety of micro-habitats which were created by the rugged topography. The Great Lakes to the west moderate the park's climate, so that many plants and animals reach the limits of their range here. The islands form a land bridge from northwest to southeast across the St. Lawrence River, aiding movement of species through the area.

The park is easily accessed from the Trans-Canada highway, the Thousand Islands Parkway and the Ivy Lea Bridge to the US. Rural homes and cottages abound on the adjacent parcels, and recreational boating is a major activity in the area. Land and water access is therefore among the easiest of all national parks, but protection from public access, essential for some long term monitoring instrumentation, is problematical.

Table 14. Potential geoindicators for Saint Lawrence Islands National Park

Geoindicator	Examples of features, processes and stresses
Built environment	Fragmented land base, major nearby highways, campgrounds, marinas, docks
Groundwater quality	Runoff from area farms, rural housing and recreational facilities, e.g golf courses
Soil quality	Acid deposition, past rural and residential land uses of the park holdings
Soil water quality	Acid deposition, past rural and residential land uses of the park holdings
Surface water quality	Pollution in the Saint Lawrence River

DISCUSSION

The long and short national short lists are shown in Table 15, along with the notional geoindicators for the five parks. Notwithstanding the provisional nature of these selections, there is a wide difference between the needs of a national framework that seeks commonality of indicators across 39 national parks of greatly varying character, and the needs of any given park in terms of its local environments, visitor uses, logistics and stresses. In this quick analysis, there is not one common indicator among the national lists and the five parks, nor even one common indicator for the five parks. However, there are commonalities among the parks characterized by Arctic or alpine tundra, as there are among those characterized by boreal and temperate forests, glaciated bedrock and proximity to rural land uses.

SUITABILITY OF NATIONAL PARKS FOR MULTI-PARTICIPANT GEOINDICATOR MONITORING

National parks serve to protect a representative portions of Canada's natural regions, and to provide compatible opportunities for its enjoyment and appreciation by Canadians now and in the future. These objectives, plus the mechanism of federal legislation needed for park creation or alteration, means that national parks are established and stable for indefinite periods of time, or, as some say, "for all time." The fostering of appreciation by Canadians, and the wise management of park values in the face of past and present stresses, requires a knowledge base founded on sound science. Thus natural and cultural resource inventory, research and monitoring are common to all national parks. As well as science for park management purposes, these same factors mean that national parks are good places for the conduct of long term monitoring by outside agencies. Parks can often provide a site that:

Table 15. Comparisons between proposed national and potential park-level geoindicators

Geoindicator	National long short list	National short short list	Auyuittuq	Fundy	Ivvavik	Jasper	Saint Lawrence Islands
Built environment	✓	✓	-	✓	-	✓	✓
Channel morphology	-	-	✓	-	✓	✓	-
Dunes	✓	-	-	-	-	-	-
Frozen ground activity	✓	-	✓	-	✓	✓	-
Glaciers	✓	-	✓	-	-	✓	-
Groundwater level	✓	-	-	-	-	-	-
Groundwater quality	-	-	-	✓	-	-	✓
Ice regime	-	-	✓	-	✓	-	-
Karst	-	-	-	-	-	✓	-
Lakes	✓	✓	-	-	-	-	-
Marine nearshore environment	-	-	-	✓	-	-	-
Mass movements	-	-	✓	-	✓	✓	-
Proxy record	-	-	-	✓	-	✓	-
Sea level	-	-	✓	-	-	-	-
Shorelines	✓	-	-	-	✓	-	-
Snow avalanches	-	-	-	-	-	✓	-
Soil quality	-	-	-	✓	-	-	✓
Soil temperature	-	-	✓	-	✓	-	-
Soil water quality	-	-	-	✓	-	-	✓
Streamflow	✓	✓	-	✓	-	✓	-
Stream sediment	-	-	-	-	-	✓	-
Surface water quality	✓	✓	-	✓	-	-	✓
Wetlands	✓	✓	-	✓	✓	-	-
Wind erosion	-	-	✓	-	-	-	-
Total	**10**	**5**	**9**	**9**	**7**	**11**	**5**

Geoindicators not on any of these lists: desert surface crusts, dust storms, extreme events, lake and ocean sediment, seismicity, soil erosion, surface displacement, tufa accumulation, volcanism.

- is protected from unnatural disturbances;
- can offer some logistical support and coordination, subject to management constraints and budgets;
- can assist with procuring, managing and archiving data;
- facilitates integration between disciplines; and
- interprets and communicates scientific results to the public.

Parks Canada has a wide breadth of monitoring at the park-by-park level. A survey of the 37 parks in 1994 revealed 595 discrete monitoring programmes, of which 191 were conducted by other agencies with permission by, or in partnership with, Parks Canada (Rissling and Welch, 1995). Another survey revealed 166 weather and climate stations within, or supported in some way by, the 39 national parks in 2001(Welch, 2002). As well as numerous single target monitoring programmes, Parks Canada hosts several long term, integrated, multi-participant monitoring programmes, particularly linked to issues of acidification, landscape change and wildlife dynamics. Notable examples can be found at Fundy, Jasper, Kejimkujik, La Mauricie and Prince Albert.

A recent minister's advisory panel on protecting ecological integrity in national parks recommended that Parks Canada take a more strategic and concerted approach to monitoring its natural assets (Parks Canada Agency, 2000 c). As a result, the Agency is developing a systematic approach to monitoring national parks and managing the resulting data, particularly for reporting the state of the national park system to parliament. The Panel also stressed the importance of working in partnership to achieve high standards in science and management.

Thus the nature of national parks and the information needs for good stewardship provide many opportunities for other agencies to seek agreements to conduct long term monitoring in these areas. Furthermore, Parks Canada is moving towards more proactive support of science programmes, at least through support-in-kind, even if the particular subject matter is not of immediate need by park managers. How might the geoindicators be selected differently if viewed from the utility of national parks for their monitoring, rather than the utility of geoindicators for park management? This would probably depend on Canada's national priorities, its position in the world, and the distinct but relatively accessible environments of national parks. Thus:

- Nordic climate - frozen ground activity, glaciers, ice regime, soil temperature, wetlands;
- World's longest coastline - marine nearshore environment, sea level, shorelines;
- Most of the world's surface freshwater - lakes; and
- Land development and pollution stresses - built environment , groundwater quality, soil quality, surface water quality.
- Mountains - mass movements, snow avalanches, streamflow.

CONCLUSIONS

GENERALITIES

The evaluations of each geoindicator show that there are many to choose from that would have at least some relevance to monitoring the state of ecosystems in national parks, and that a good proportion would have high utility. This applies to the geoindicators proposed by the IUGS as well as to the additional ones emanating from EMAN, the Gros Morne geoindicators workshop, and this paper. There are also many potential links between indicators, particularly those related to aquatic processes and features. Many potential field sites would be the same or proximate, and many of the methods involve similar techniques, or require the same ancillary measures, particularly the presence of weather and hydrometric stations. Thus whatever geoindicators are chosen for a particular situation, consideration should be given to integration with existing field monitoring programmes and with other agencies who have related interests in field subjects and data management. National parks provide good opportunities for other agencies to choose to locate their monitoring programmes. These reasons include security of sites from artificial landscape modification, possibilities for sharing field and data management logistics, the general need for protected areas to foster good science in support of ecosystem understanding, and a receptive public audience for scientific results.

Despite the commonalities between many of the geoindicators, the selection of subsets for national reporting and individual parks shows a wide variation between the need for national consistency versus local situations, and among the local situations themselves. Glaciers, for example, do not occur in most national parks, and so should not be among a final set of two or three indicators to supplement the national ecological monitoring framework of Parks Canada. In that framework's context of features, processes and stresses, truly ubiquitous measures would come down to features like: wetlands and lakes; processes like mass movements, fluvial activity and frost dynamics; and stresses indicators like the built environment.

IMPLEMENTATION

A working group should be established to finalize the selection of geoindicators to the ecological integrity monitoring framework of the national park system, to adopt or develop appropriate monitoring protocols, to adopt or develop guidelines for site selection, to estimate funding needs, to identify potential partners and available data and programmes, and to provide technical advice, training and review as needed. The group should combine, in no particular order: Parks Canada's national office, service centres and representative field units; Environment Canada's Ecological Monitoring and Assessment Coordinating Office, National Indicators and Assessment Office and Atmospheric Monitoring and Water Survey Directorate; the Geological Survey of Canada; United States counterparts such as the Geological Survey and the National Park Service Geological Resources Division; and a North American representative of the International Union of Geological Sciences.

Implementation for specific parks should follow the scoping approach of the United States National Park Service, and could be advised and supported by the proposed working group. At the time of writing (Summer 2002), Waterton Lakes National Park is about to participate in such a scoping exercise with its American partner, Glacier National Park. Results from that event may provide a model for consideration in the Parks Canada context.

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