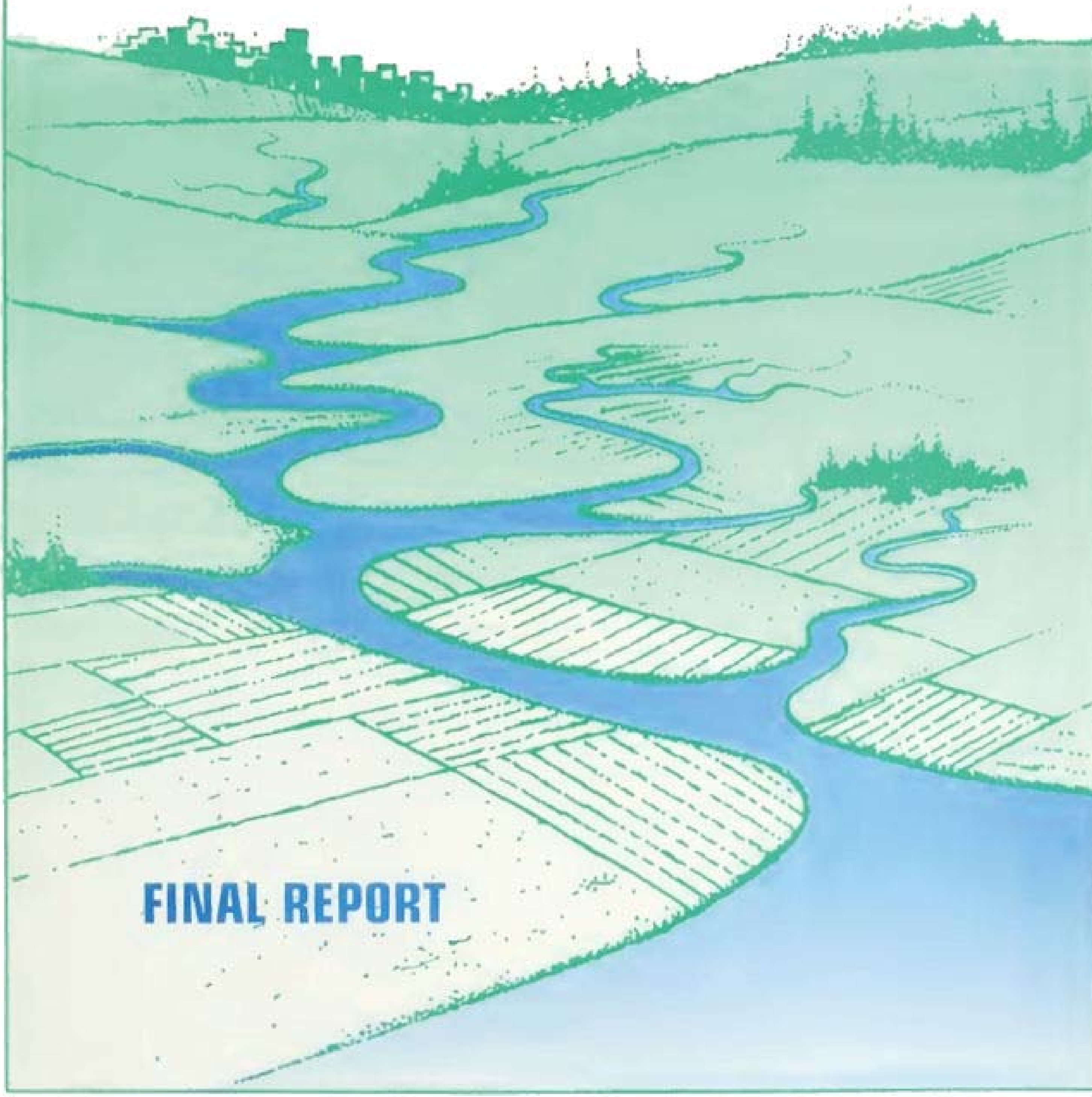
Science and
Technology
Task Group

Ontario

Watershed Planning Initiative



FINAL REPORT

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Submitted to the:

Watershed Planning Implementation
Project Management Committee (PMC)

DISCLAIMER

The Science and Technology Task Group Report is one of three Task Group reports prepared as part of the provincial Watershed Management Initiative evaluation project, formerly the Watershed Planning Initiative.

The Task Group was created by the Watershed Planning Implementation Project Management Committee to assess the relevance and responsiveness of watershed management.

This Report represents the views of the Science and Technology Task Group. It does not reflect the policy of any provincial agencies, boards or commissions. Any errors, omissions or opinions are those of the Task Group.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Province of Ontario is currently undertaking an evaluation of the Watershed Planning Initiative following a two-year period of voluntary application which began in June 1993. The evaluation is being conducted by a multi-agency Provincial Steering Committee, and three Task Groups have been formed to collect and analyze information and report on findings and recommendations. These include:

- Science and Technology Task Group: to document state-of-the-art science related to watershed planning, and examine its relevance and application in Ontario;

- Responsiveness Task Group: to explore ways of involving the public and increasing the responsiveness of watershed planning to public needs; and

- Resources and Effectiveness Task Group: to document and examine the use of financial, human and information resources in watershed planning in Ontario, and examine the effectiveness of the pilot watershed planning process.

The Science and Technology Task Group (the Task Group) attempted to address four questions:

1) Is there a need for watershed planning in Ontario?

2) What is state-of-the-art science in watershed planning?

3) Is state-of-the-art science being applied to watershed planning in Ontario?

4) What are the most critical areas of need for improving the science for watershed planning and the application of science to watershed planning in Ontario?

This report summarizes the findings of the Science and Technology Task Group with respect to state-of-the-art science as it relates to watershed planning, its relevance and application in Ontario. It is based on information from a number of sources: experience of members, review of literature, interviews and discussions with technical and scientific experts, and feedback obtained from participants at a workshop attended by representatives from the research, practitioner, and academic communities.

Vision

In conducting their work, the Task Group members developed a vision for the future which is the achievement of a sustainable environment for Ontario through planning on a watershed basis. In this vision, ecosystem function, structure and composition sustain human activities and inherently set limits to development and consumption processes. As a result, river systems have adequate base flows, groundwater is conserved, surface waters host stable self-sustaining aquatic communities, a variety of linked terrestrial systems support self-sustaining indigenous plant and animal life, clean water is available for municipal, industrial and agricultural use, and humans have access to a variety of recreational and resource use opportunities.

General Approach to Watershed Planning and Evaluation

The objective of watershed planning is to provide decision-makers with a broad understanding of ecosystem function and status, and to develop recommendations for appropriate resource management in the watershed. This will allow relevant ecosystem considerations to be integrated into land use planning and decisions and allow for better-informed resource use decisions to be made.

Watershed planning uses watersheds and subwatersheds as the biophysical basis for planning and management. It is based on using the hydrologic cycle as the pathway that integrates physical, chemical and biological processes of the basin ecosystem. Watersheds provide a fundamental unit with real boundaries of ecological significance which provide a qualitative reference frame to examine issues such as ecological stress, the cumulative effects of land use development, and other matters.

The Task Group identified a number of important considerations of ecosystem planning that are important for decision-makers involved in watershed planning. These include:

- an ecosystem approach attempts to balance environmental, social and economic needs;

- impacts on one component of a watershed can have profound effects on other components;

- each watershed is different and watershed studies need to respect this fact;

- some of the influences on watersheds will come from outside their boundaries;

- different ecosystems have boundaries of different sizes;

- scale is important in watershed planning, especially as it relates to data collection;

- ecosystems are dynamic, not static systems, in which change is normal and sometimes unpredictable; and

- ecosystems have limits to the stress they can absorb.

The ecosystem approach forces us to look, not only at air, water, land and living things, but also at the interrelationships among these components of a watershed. An integrative approach to watershed planning focuses on these interrelationships, and has a number of discrete steps:

1) Overview the system (identify what resources, habitats and human uses exist and where);

2) Define the structure, the effective linkages of the system, and key components to be studied (i.e. functions);

3) Reduce the system to its constituent components for the purpose of scientific study;

4) Study the component parts (hydrology, groundwater, aquatic systems, etc.);

5) Re-aggregate the system; and

6) Re-evaluate the overview focusing on interrelationships and the whole system.

The Task Group identified ten scientific components of watershed planning:

- Aquatics;
- Terrestrial;
- Hydrology;
- Stream Morphology;
- Water Quality;
- Groundwater;
- Economics;
- Social;
- Mapping and Data Management; and
- Integration.

Each of these components was assessed by the Task Group with respect to the state of the science and the applications of the science to watershed planning. The text in the report covers this assessment in some detail.

Observations and Conclusions

1) An ecosystem approach to planning is necessary for the achievement of a sustainable environment. Watershed planning, which uses the hydrologic cycle as the pathway that integrates physical, chemical and biological processes, is one major approach to achieving the goal of a sustainable environment.

2) Significant progress has been made in the science of watershed planning. Today's watershed plans have evolved from the Master Drainage Plans of the early 1980s that were aimed more narrowly at minimizing the impacts of development. In the last 15 years, considerable advances have been made in terms of process, scope, understanding of natural systems, and application of scientific knowledge. Practitioners have made significant strides forward in the use of GIS as a tool for understanding, communicating and predicting environmental conditions. A new science of integration is emerging.

3) The Watershed Planning Initiative has provided needed guidance and resources through the release of the documents, *Water Management on a Watershed Basis, Subwatershed Planning,* and *Integrating Water Management Objectives into Municipal Planning Documents.* The Watershed Planning Initiative has engendered an enhanced scientific focus on watershed planning and how best to do it, and its resources have allowed and encouraged scientific progress to be made in many areas of application. The evaluation, of which this report is a part, allows critical self-analysis, retrospective assessment of progress made and gaps that need to be addressed, and peer review.

4) Further clarification and guidance is needed in some areas. These include:

- clarification of what watershed and subwatershed planning is (including what its requirements are, what it can achieve, the level of effort and detail required, the major issues to be addressed, etc.);

- acknowledgement that there are many types of watershed plans driven by different needs and circumstances (e.g. plans can emphasize environmental resource management, land use change, land management change, or redevelopment and restoration);

- improved management of Phase 1 (the characterization phase) of watershed and subwatershed plans in order to streamline planning and ensure more-appropriate distribution of time, effort and funds; and

- improved issue resolution to assist those carrying out watershed and subwatershed plans in making decisions in cases where conflicts exist between provincial policies, social values, environmental needs, or existing Official Plan policies.

5) The following components of watershed planning generally reflect the state-of-the-art science:

- Aquatics
- Hydrology
- Water Quality

For each of these components, the text of the report outlines the current science, and strengths and weaknesses in its application in watershed and subwatershed planning in Ontario.

6) For the following components of watershed planning, current practice does not reflect state-of-the-art science:

- Terrestrial
- Stream Morphology
- Groundwater
- Economics
- Social
- Mapping and Data Management

For each of these components, the text of the report outlines the current science and in what way current practice (as applied in watershed and subwatershed planning) lags behind the science.

7) For one component of watershed planning — integration — the science itself is new, but emerging quickly. Integration is the study of the complete system (the watershed, its components, and their interrelationships). Both a rapidly evolving science and a process, integration in watershed planning is variable, and often rudimentary. The report notes a number of key ways in which integration can be improved, along with interim measures to help practitioners make decisions in the face of scientific uncertainties.

1.0 INTRODUCTION

1.1 Background

The Province of Ontario is currently undertaking an evaluation of the Watershed Planning Initiative (WPI). This evaluation follows a two-year period of voluntary application which began with the release in June 1993 of three documents: *Water Management on a Watershed Basis, Subwatershed Planning,* and *Integrating Water Management Objectives into Municipal Planning Documents.* These three documents describe the process and products expected from integrated watershed and subwatershed planning.

To conduct the evaluation of the Watershed Planning Initiative, a Provincial Steering Committee was set up to provide direction, ensure evaluation and make recommendations. This Steering Committee is composed of senior representatives from the Ministries of Natural Resources (MNR), Environmental and Energy (MOEE), Agriculture, Food and Rural Affairs (OMAFRA), Municipal Affairs (MMA), Transportation, Northern Mines and Development, and the Ontario Native Affairs Secretariat. The Watershed Planning Initiative evaluation is being managed by a Project Management Committee (PMC) with representation from the MNR, MOEE, OMAFRA, MMA, the Association of Conservation Authorities, and the Association of Municipalities of Ontario. The aim of the evaluation is to provide information to the Provincial Steering Committee and ultimately to Ministers and the Cabinet in order to make decisions about the future direction of watershed planning in Ontario.

The PMC identified a number of issues associated with the Watershed Planning Initiative including need and relevance, responsiveness, resources, coordination and effectiveness. Based on the issues identified, sources of information, required expertise and cost considerations, Task Groups were formed under the PMC to collect and analyze information and report on findings and recommendations. These included:

- Science and Technology: to document state-of-the-art science related to watershed planning, and examine its relevance and application in Ontario;

- Responsiveness: to explore ways of involving the public and increasing the responsiveness of watershed planning to public needs;

- Resources and Effectiveness: to document and examine the use of financial, human and information resources in watershed planning in Ontario, and examine the effectiveness of the pilot watershed planning process; and

- Coordination Team: to ensure consistency with the evaluation plan.

This Report summarizes the findings of the Science and Technology Task Group (the Task Group) with respect to state-of-the-art science as it relates to watershed planning, its relevance and application in Ontario. The Task Group collected information from a number of sources: experience of members, review of literature, and interviews and discussions with technical and scientific experts. A number of meetings were held to allow the members of the multidisciplinary Task Group to exchange information, discuss and debate the many issues associated with science and technology in watershed planning. Additional feedback on a draft version of the Task Group's report was obtained from a workshop attended by representatives from the research, practitioner, and academic communities.

Members of the Science and Technology Task Group are listed in Appendix A, and participants in the Task Group's workshop are listed in Appendix B.

1.2 WPI Goal and Vision of the Task Group

Traditionally, the management of water and related resources has largely been independent of land use planning. We now know that human activities — urbanization and non-sustainable resource use in particular — can have dramatic and cumulative effects on water resources. Channelizing rivers, removing riparian cover, consuming groundwater faster than it can be replenished, paving recharge areas, filling in wetlands and a host of other activities can have significant, sometimes irreversible effects on natural systems. These effects can include impaired water quality, degraded aquatic communities, loss of biodiversity, contamination of aquifers, erosion, and flooding. Economic impacts can include increased water treatment costs, expensive remedial actions, and loss of recreational opportunities. Taken to an extreme, the cumulative effects of such human impacts can cause ecosystems to become degraded and less able to support human systems on a continuing basis. In extreme cases, damage to ecosystems is irreversible and unable to be repaired, despite the applications of the best science and technology.

The goal of the Watershed Planning Initiative is

> "to ensure that water and related resources are managed on a sustainable basis
> to provide for the environmental, social and economic well-being of Ontario."

That goal can be translated into a vision of healthy, intact watershed ecosystems. In this vision, ecosystem function, structure and composition sustain human activities and inherently set limits to development and consumption processes. The Task Group's vision is the achievement of a sustainable environment for Ontario through planning on a watershed basis. This implies an understanding of ecosystem waste assimilation capacities, and the need to not exceed that capacity or impair its future waste absorptive capacity. It means that the harvest rates of renewable resources should be well within the regenerative capacity of the ecosystem, or as stated in the Canadian Biodiversity Strategy, we should "take no more from nature than what nature can replenish". It also implies that the depletion rates of non-renewables be equal to the rate at which renewable substitutes are sought through research and invention. Environmental sustainability means that we must live within nature's ability to sustain our activities.

In this vision, river systems have adequate base flows, groundwater is conserved, surface waters host stable self-sustaining aquatic communities, a variety of linked terrestrial systems support self-sustaining indigenous plant and animal life, clean water is available for municipal, industrial and agricultural use, and humans have access to a variety of recreational and resource use opportunities.

Watershed plans will be directed to ensure that human-induced land use and development changes do not threaten the long-term persistence of any native species within the watershed. The vision purposefully links aquatic, terrestrial and human life within the watershed as a healthy, self-sustaining ecosystem. The benefits of this are numerous and long-term (i.e. inter-generational). It means that we will plan to leave for future generations a healthy environment within which they can aspire to similar or perhaps better qualities of life. Given this vision, watershed planning becomes an integral part of the land use planning process, set within the context of environmental sustainability.

This vision will be achieved through an ecosystem approach to planning and management that balances economic, social and environmental needs, (see Figure 1). In its broadest sense, ecosystem management represents a philosophy of natural resource management that emphasizes , sustaining ecological systems and function while deriving socially-defined benefits. Ecosystems are influenced by both biological and physical changes. This means that if we are to design land use to sustain ecosystems, we must understand the effects of land use activities on both the physical and biological environment, and we must understand how these components of the environment interact with each other. In order to employ ecosystem management, we must also develop human institutions for planning and decision-making to maximise beneficial uses while minimizing adverse environmental impacts.

An ecosystem approach to planning requires that boundaries for examining the relationships between the natural environment and human activities be based on the biophysical, not the political. A hierarchy of ecosystem scales exist that are nested within each other and which overlap. For our purposes, we are using watersheds and subwatersheds as the biophysical basis for planning and management. This is based on using the hydrologic cycle as the pathway that integrates physical, chemical and biological processes of the basin ecosystem. It provides a fundamental unit with real boundaries of ecological significance which provide a quantitative reference frame to make inferences on such things as ecological stress, in-stream flow, the cumulative effects of land use development, etc. It represents the most viable approach to achieve our goal and vision.

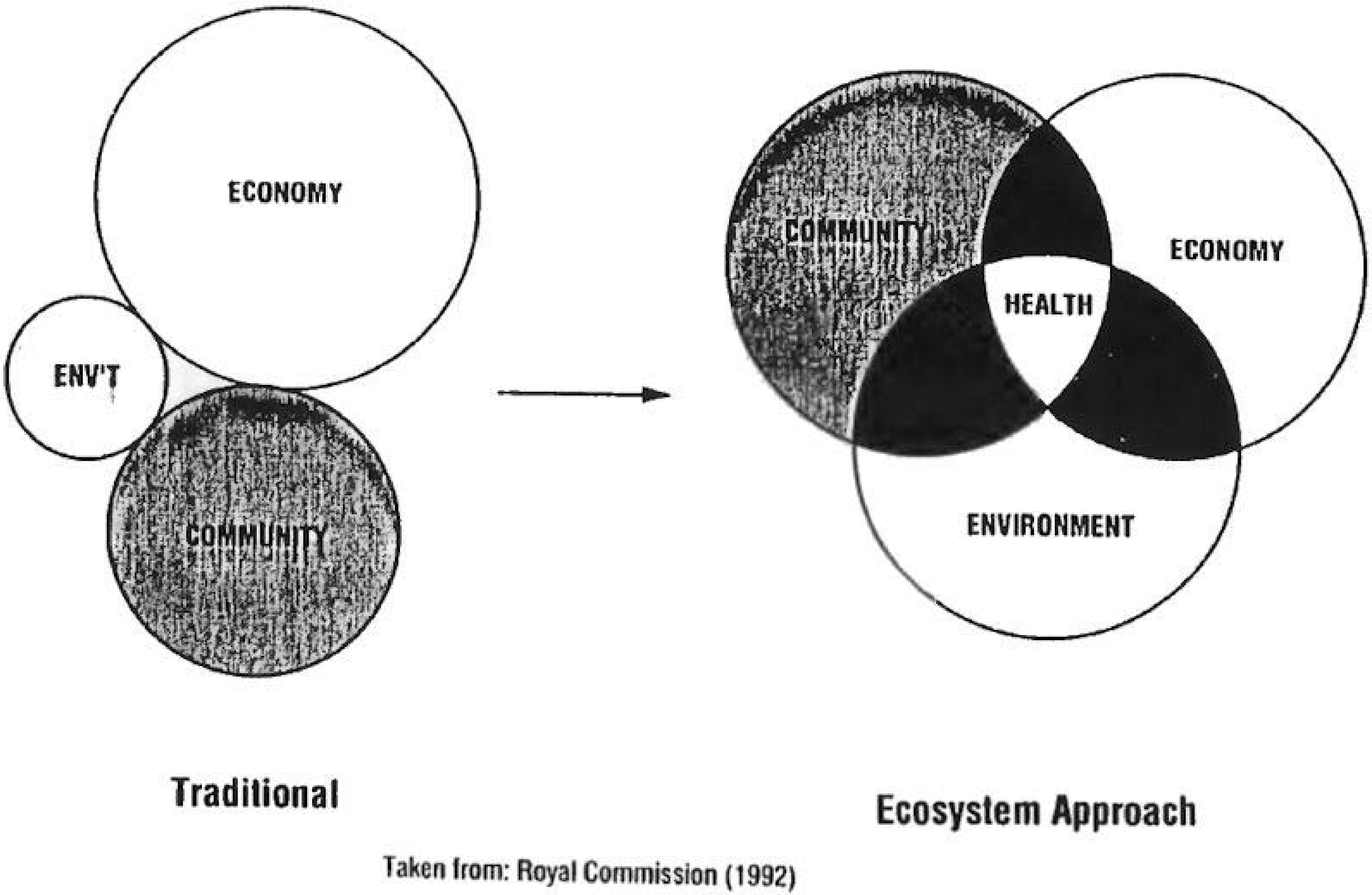


Figure 1: The Shift from Traditional to Ecosystem-Based Decision-Making.

1.3 Purpose of the Report

The Task Group examined the issue of whether watershed planning is based on sound ecosystem science. Six questions were posed to the Task Group by the PMC:

- Is there a need for watershed planning in Ontario?
- What is state-of-the-art science in watershed planning?
- Is state-of-the science applied to watershed planning in Ontario?
- What are the most critical areas of need for improving the science for watershed planning and the application of science to watershed planning in Ontario?
- Is the Watershed Planning Initiative consistent with state-of-the-art science?
- Are the Watershed Planning goals, objectives and activities logically consistent internally and with identified watershed planning needs in Ontario?

Based on the above questions, the Science and Technology Task Group generated four questions to be addressed:

1) Is there a need for watershed planning in Ontario?

2) What is state-of-the-art science in watershed planning?

3) Is state-of-the-art science being applied to watershed planning in Ontario?

4) What are the most critical areas of need for improving the science for watershed planning and the application of science to watershed planning in Ontario?

These questions guided the Task Group in conducting its overview of the state-of-the-art science as related to watershed planning. Question 1 is addressed in Sections 2.0 and 4.0 of the report and Questions 2 and 3 are addressed in Sections 3.0 to 3.10. Question 4 is addressed on an individual component basis in Sections 3.1 to 3.10, and revisited in Section 4.0.

2.0 GENERAL APPROACH

2.1 Watershed Planning: Applying the Ecosystem Approach

The objective of watershed planning is to provide decision-makers with a broad understanding of ecosystem function and status, and to develop recommendations for appropriate resource management in the watershed. This will allow relevant ecosystem considerations to be integrated into land use planning and decisions and allow for better-informed resource use decisions to be made.

A lake such as Lake Ontario consists of a basin made up of a number of rivers that drain into it — the Credit, the Humber, the Don, the Ganaraska, and others. A watershed consists of the land drained by a river and its tributaries. A subwatershed is comprised of the land drained by an individual tributary to the main watercourse. The state of a watershed is a function of the condition of the mainstream river and its component subwatersheds.

Watershed planning uses watersheds and subwatersheds as the biophysical basis for planning and management. It is based on using the hydrologic cycle as the pathway that integrates physical, chemical and biological processes of the basin ecosystem. Watersheds provided a fundamental unit with real boundaries of ecological significance which provided a quantitative reference frame to examine issues such as ecological stress, the cumulative effects of land use development, and other matters. When using watersheds as a basis for ecosystem management, there are a number of important considerations for decision-makers.

The ecosystem approach balances environmental, social and economic needs.
By its definition, the ecosystem approach attempts to integrate environmental, social and economic needs. As applied to watershed planning, this means having concern for social and economic issues in addition to environmental issues. This report looks at the scientific aspects of the social and economic dimensions of watershed planning: other aspects of social and economic issues are being considered by the Responsiveness Task Group and the Resources and Effectiveness Task Group.

Impacts on one component of a watershed can have profound effects on other components. That "everything is connected to everything else", lies at the heart of the ecosystem approach to planning and management. Some of these connections and interrelationships are obvious and well-understood; others are less predictable. Some examples:

- Overconsumption of groundwater or contamination of aquifers will have an impact on the ability of humans to use that water for municipal, industrial or agricultural use. Overconsumption of aquifers will also reduce base flows of surface waters, leading to intermittent flows in feeder streams, loss of aquatic habitat, and consequent impacts on aquatic communities.

- Contamination of surface waters can also adversely affect the ability of humans to use that water for municipal, industrial, agricultural or recreational use. Alterations in flows (due to improper stormwater management, for example) or contamination of surface waters can affect aquatic habitat and communities.

- In the terrestrial system, the removal of riparian cover can increase erosion and flooding which in turn can adversely affect aquatic habitat and communities. Deforestation of upland areas can have dramatic effects on the hydrologic cycle, reducing base flows of streams and increasing peak flows during rainfall events.

- In aquatic systems, a host of human activities can cause alterations in community, reducing biodiversity and commercial and sport angling opportunities. Loss or degradation of wetlands can adversely effect recharge of groundwater and hence effect base flow of streams.

Each watershed is different.
While watershed planning provides a framework for examining ecosystem function and status, each watershed plan must be developed with consideration of the unique physical, biological, social and economic characteristics that define the system. Geology, climate, hydrology and land use patterns are all factors that influence the state of a system. Watersheds in rural areas of southern Ontario, with their remnant natural areas, are very different than watersheds in urban areas, or watersheds in the Boreal zone of northern Ontario. Groundwater/surface water interactions are much simpler in clay soils than are those in areas of heterogeneous, complex geology. When watershed planning is carried out, the specific biophysical and socio-cultural attributes of an area need to be recognized and addressed upfront in a strategic manner. It is important too to recognize that, despite the fact that everything is connected to everything else, <u>not all information is important or relevant,</u> and information requirements will naturally vary from watershed to watershed. Variabilities in watersheds will affect the components to be considered, the level of effort required, and the costs of carrying out the plan.

Some of the influences on watersheds will come from outside their boundaries.
By definition, ecosystems are not closed systems. Seeds, spores, animals, water, chemicals and nutrients travel between ecosystems or are carried by natural processes and humans. Climatic influences on a watershed relate to airsheds which are close to provincial in scale or on nearby bodies of water. Development pressures may come from beyond the boundaries of a watershed, as may user groups for a particular resource. Watershed plans need to be developed with an understanding of external influences that may have an impact on the watershed.

Different ecosystems have boundaries of different sizes.
While the watershed is used as a framework for integrating physical, chemical and biological processes, relevant information must be gathered at appropriate scales that do not always match the boundaries of the watershed. As an example, vegetation relates strongly to landforms and geology, and information on vegetation will need to reference the Ontario Ecological Land Classification system. Information at a landscape level may be required for resources such as the Oak Ridges Moraine, the Niagara Escarpment, habitat for migratory bird species, and other important resources or systems.

Scale is important.
Scale is important with respect to the collection of information: information needs to be collected at a level of detail that is appropriate for the task at hand. There is an increasing level of detail required as one moves from a watershed plan to a subwatershed plan to a site development plan or project impact assessment, (see Figure 2). The issues of scale and data collection relate strongly to the cost of obtaining data during a watershed plan. The understanding of these issues has increased as more experience is gained in watershed and subwatershed planning.

Ecosystems change.
Ecosystems are not static: watersheds are dynamic systems in which change is normal and sometimes unpredictable. Over long periods of time, terrestrial systems undergo succession to reach climax states, wetlands dry up, and plant and animal communities adapt to global changes in temperature. Natural factors such as fire, flood and glaciation can have dramatic impacts on natural systems. In southern Ontario in particular, human impacts have significantly altered watersheds, and likely will continue to do so. Watershed planning is aimed at managing these changes in order to maintain ecological integrity over the long term.

Ecosystems have limits to the stress they can absorb.
Healthy ecosystems have integrity, or the resilience to absorb or assimilate external stresses. Ecosystems, and watersheds, have limits to what they can absorb: pushed beyond these limits, they become degraded. Degraded watersheds characteristically have little aquatic life, (usually only a few species of pollution-tolerant fish), poor water quality, high rates of erosion, and frequent flooding. Experience has shown, however, that restoration of watersheds to better states of health is possible. In many areas of the province, governments and interest groups are working together to restore streams and rivers by planting riparian cover, cleaning up streams, improving access and restoring terrestrial and aquatic habitat.

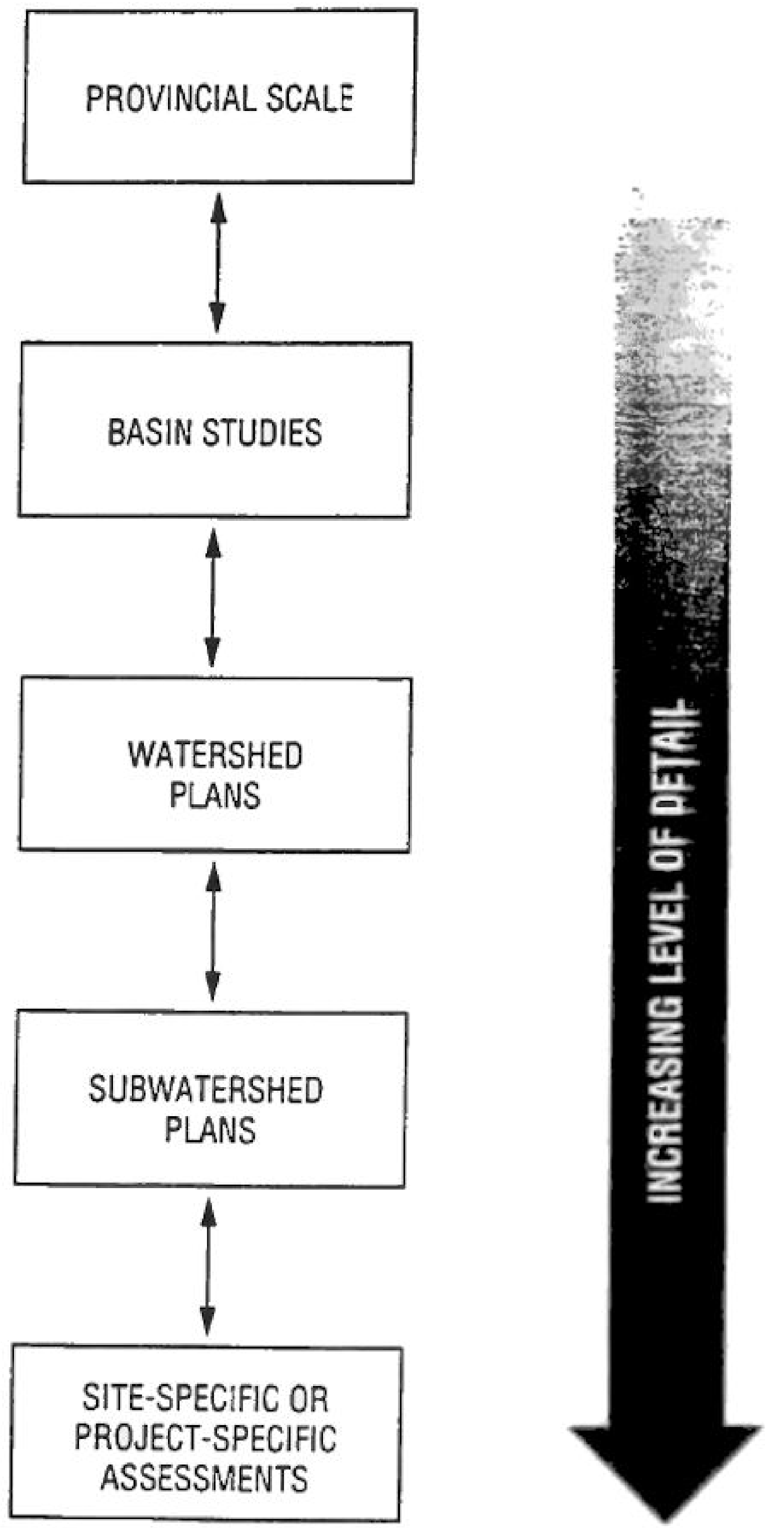


Figure 2: Scale and Data Collection in Watershed Planning.

2.2 An Integrative Approach to Watershed Planning

Assessing the Watershed Planning Initiative forces the Task Group to ask fundamental questions about how to implement an ecosystem approach to planning on a watershed basis. The ecosystem approach forces us to look, not only at air, water, land and living things, but also at the interrelationships among these components of a watershed. Traditionally, science has taken a reductionist approach, studying the individual components of a problem. In the context of a watershed, this would mean studying the streams, the groundwater, the aquatic communities, and other components of interest. Ecological planning tells us that we must do much more than just study the parts of the watershed: we need to understand how these components interact, and we need to study the whole as well. This study of interrelationships and the whole is "integration".

The need to integrate forces a change in how planning is carried out. How can we take a holistic approach to studying a watershed? An integrative (holistic) approach to watershed planning can be considered to have a number of discrete steps:

1) Overview the system (identify what resources, habitats and human uses exist and where);

2) Define the structure, the effective linkages of the system, and key components to be studied (i.e. functions);

3) Reduce the system to its constituent components for the purpose of scientific study;

4) Study the component parts (hydrology, groundwater, aquatic systems, etc.);

5) Re-aggregate the system; and

6) Re-evaluate the overview focusing on interrelationships and the whole system.

This is simply illustrated in Figure 3. The system is still disaggregated for the study of its component parts, however, this traditional approach is augmented by the process of integration which looks at interrelationships and the whole system (including the interrelationships between component parts).

Integration is used for the following:

- to provide an analysis of Valued Ecosystem Components;

- to provide an analysis of key linkages among the physical, biological and chemical components of the watershed;

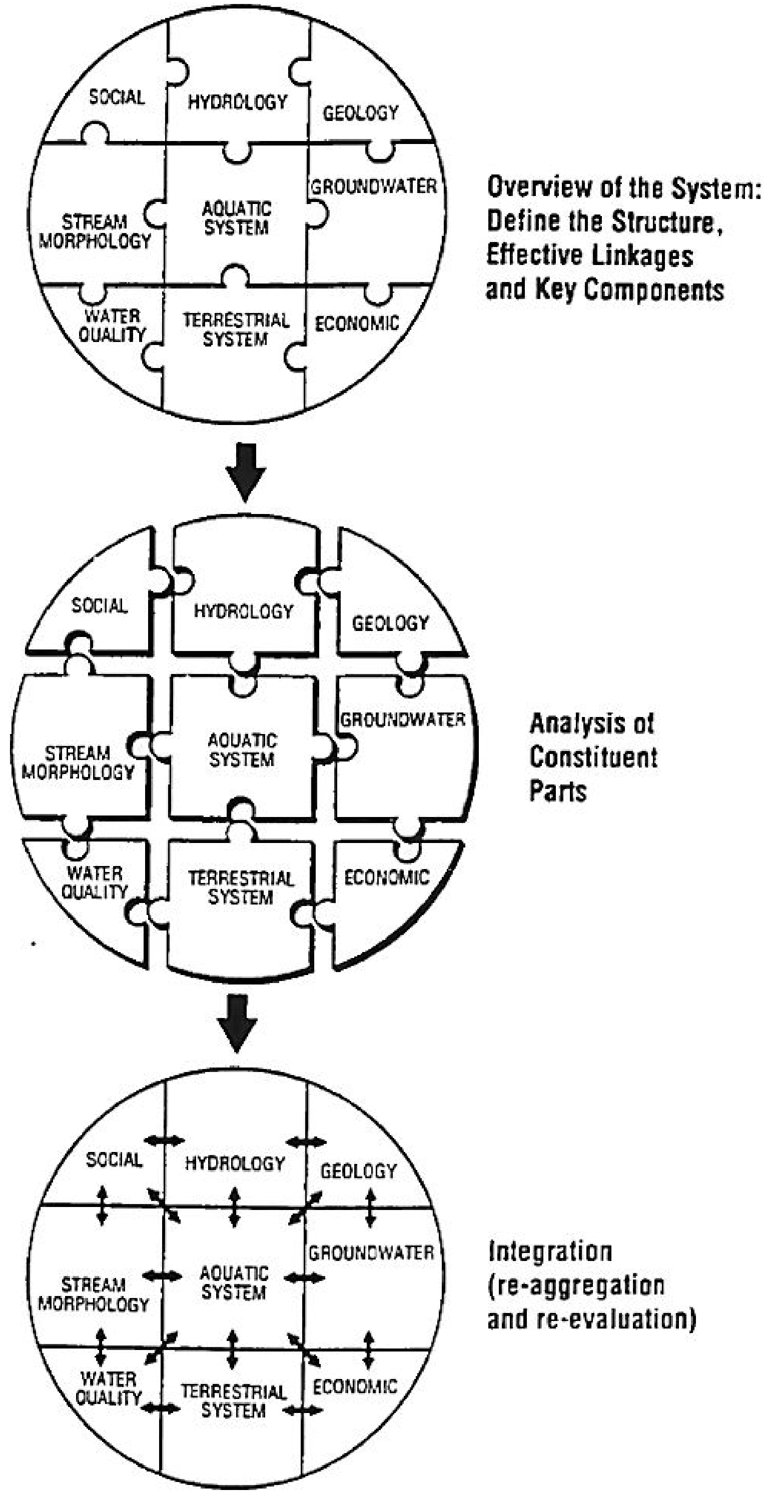


Figure 3: An Integrative Approach to Watershed Planning**.**

- to structure information that links cause and effect; and
- to analyze impacts and trade-offs between the natural and the socio-economic environments.

An assessment of the emerging science of integration is found in Section 3.10 of this report. Knowing that integration is required in watershed planning forces us to approach watershed planning in a different way, and to ask a series of challenging questions. (Additional questions are found in Appendix C).

1) How can we develop an integrated understanding of a watershed? What information do we need to know, at what scale, and at what level of detail?

2) How can we use physical and temporal scales as a conceptual underpinning for improving watershed planning, analysis and data acquisition?

3) What factors (ecological, social and economic) external to a watershed do we need to consider in planning?

4) What are the "ecological footprints" (or impacts) of traditional development? What are the "ecological footprints" of higher-density development?

5) What is sustainability? How can we measure it? How will we know when we have reached a sustainable state?

6) How can we improve our understanding of interrelationships between and among the component parts of a watershed? At what scale are scientific data available to relate cause to effect? What are the associated uncertainties?

7) How do discipline-specific knowledge bases enhance or limit watershed planning, particularly integration?

8) How do we as professionals recognize that the re-aggregation of component parts and reevaluation of the whole system are key study aspects that must be addressed in watershed planning?

9) How is watershed planning used to define and resolve conflicting provincial policies or societal needs at a watershed, subwatershed or stream length scale?

2.3 Scientific Components of Watershed Planning

Watersheds are complex ecosystems consisting of air, water, land, living things (plants, animals and humans) and the interactions among them. For the purpose of evaluating the Watershed Planning Initiative, the Task Group examined the major scientific components involved in watershed planning with respect to the state of the science, and how the science is applied in watershed planning. The scientific components of watershed planning examined are:

- Aquatics: the application of aquatic ecology and biology and the study of aquatic systems and communities within a watershed;

- Terrestrial: the application of terrestrial ecology and biology, or the study of terrestrial systems and communities within a watershed, and connections to other systems outside the watershed;

- Hydrology: the study of surface water flows in a watershed and influences on flows;

- Stream Morphology: the study of mechanisms that operate as a result of water flow within a stream channel (i.e. the erosion, transfer and deposition of sediment);

- Water Quality: the study of the physical, biological and chemical characteristics of surface waters in a watershed;

- Groundwater: the study of sub-surface water within a watershed, its occurrence, movement and chemistry and the factors that influence it including interactions with surface flow systems;

- Economics: the study of the economic aspects of a watershed, including the analysis of economic impacts of activities or plans, and the assessment of economic values;

- Social: the study of social values, social impacts, local knowledge, demographics, cultural heritage, resource use, social structures and other aspects of communities living within a watershed;

- Mapping and Data Management: the use of systems to collect, analyze, interpret and store data and to provide spatial graphical representations of data; and

- Integration: the study of the entire watershed including the interrelationships between all the scientific components of watershed planning.

2.4 Basis of Assessment

The Task Group was composed of the following: professional practitioners in the private sector who stress practical, but innovative technical approaches, academic professionals involved in watershed planning both in a research and application sense, and public sector professionals or scientists involved in the field. Drawing on experience of group members, the scientific literature, and discussions with technical and scientific experts, the Task Group made an assessment of each of the above-listed scientific components with respect to *state of the science* and *applications of the science* to watershed planning. An initial assessment was reviewed by a broad range of individuals at a workshop hosted by the Task Group and subsequently refined to reflect the input received. The results of the Task Group's assessment are found in Section 3.

State of the science was defined by the Task Group to include five parameters: science, knowledge base, current practice, information, and data. These parameters were defined accordingly:

- **"science"** was defined as scientific understanding;
- **"knowledge base"** refers to how widely scientific understanding is shared among the scientific community;
- **"current practice"** was defined as how the science is being applied by practitioners working in the field of watershed planning;
- **"information"** refers to the extent to which data can be interpreted to achieve a useable product (i.e. how useful the data are in a watershed planning process); and
- **"data"** was defined as observations (measurements, inventories, etc.).

Within the context of the tasks that are required for watershed planning, *applications of the science* was defined by the Task Group to include five parameters: characterization, prediction, issue resolution, communication and monitoring. Definitions for these parameters were:

- to **"characterize"** is to define how the system is working — that is, the elements of the system, its structure, function and interrelationships;
- **"prediction"** was defined as the ability to identify future responses to changes;
- **"issue resolution"** was defined as the ability to use information and approaches to establish values, perform assessments of relative risk and make

choices;

- **"communication"** was defined as the dissemination of knowledge to and from the study, including the existence of tools to allow communication to take place; and

- **"monitoring"** was defined as the ability to collect information to ascertain change and rates of change in the natural system, to determine whether things are improving or not, and if objectives are being met.

3.0 ASSESSMENT OF THE SCIENCE OF WATERSHED PLANNING

The following sections of the report contain the Task Group's overview assessment of the state-of-the-art and the applications of the components of watershed planning. As an aid in conducting this assessment, the Task Group developed a "snapshot" graphical illustration that is contained in Figures 4 and 5. Figure 4 illustrates the *state of the science* with respect to the parameters outlined in Section 2.4 — science, knowledge base, current practice, information and data. Figure 5 illustrates the state of *application of science* with respect to the parameters previously outlined — characterization, prediction, issue resolution, communication and monitoring.

In each case, the Task Group has assigned a rating of H (high), M (medium) or L (low). Accompanying these ratings are arrows. Vertical arrows indicate increasing progress in an area: the long vertical arrow for the "science" of stream morphology, for example, reflects the progress being made in understanding fluvial processes in heterogeneous, stratified deposits. A shorter vertical arrow would indicate a lower rate of progress. A horizontal arrow indicates a relative lack of progress with respect to understanding or practice in a particular area.

Care should be taken in interpreting Figures 4 and 5. The assessment represents the best judgements of Task Group; it is necessarily subjective and not intended to be over-analyzed. The figures are not intended to be stand-alone depictions, and should be read in conjunction with relevant parts of the text.

	science	knowledge base	current practices	information	data
aquatics	M ↑	M →	M →	H →	M →
terrestrial	M ↑	M ↑	L ↑	M ↑	M ↑
hydrology	H →	H →	M →	M →	M →
stream morphology	M ↑	L ↑	L ↑	L ↑	L ↑
water quality	M →	M →	M →	M →	M →
groundwater	M ↑	M ↑	L ↑	L ↑	L ↑
economic	M ↑	L ↑	L →	L ↑	L →
social	M ↑	L ↑	L ↑	L →	L →
mapping and data management	M ↑	M ↑	L ↑	H ↑	M ↑
integration	L ↑	L ↑	L ↑	L ↑	M ↑

Figure 4: State of the Science.

	characterize	prediction	issue resolution	communication	monitoring
aquatics	H ↑	L ↑	L ↑	H →	H →
terrestrial	M ↑	L ↑	L →	L ↑	L ↑
hydrology	H →	H ↑	M ↑	H ↑	H →
stream morphology	L ↑	L ↑	L ↑	L ↑	L ↑
water quality	M →	L →	M →	L →	M →
groundwater	M ↑	M ↑	L ↑	L ↑	M ↑
economic	L ↑	L ↑	M →	M →	L ↑
social	M ↑	L ↑	M ↑	L →	M ↑
mapping and data management	H ↑	M ↑	H ↑	H ↑	H →
integration	L ↑	L ↑	L ↑	L ↑	L →

Figure 5: Application of the Science.

3.1 Aquatics

Aquatic ecosystems are expressions of the watershed within which they reside. The way that water, nutrients, and sediments move over and through the watershed is influenced by various features including topography, geology, physiography and latitude. These movements and the processes and functions generated by these movements control, at a large scale, the overall composition, structure and function of the particular aquatic system found in that particular watershed.

The relatively large scale of watershed or subwatershed studies requires a study team to ask different questions as compared to studies of a more local nature. Important questions to be discussed in a watershed study include what type of aquatic system exists, what its major components are, and what the major biophysical and chemical functions are that provide the basis for the biotic system. Since most watershed or subwatershed studies are undertaken in order to determine ways to manage change, certain questions that are very important from a resource management perspective, such as inter-species competition, are not relevant to most watershed and subwatershed studies. What is relevant in watershed and subwatershed studies is the relationship between aquatic communities (their structure and dynamics) and the physical and chemical regimes of the watershed that support the communities (i.e. that provide food, shelter, reproductive habitat, etc.). Prior to the initiation of any study, therefore, the reasons for the study must be fully understood and the appropriate questions determined that are relevant to the issues to be addressed. Some watershed studies may be initiated primarily for fisheries or aquatic systems issues. In these circumstances, questions on community interactions and dynamics may be very appropriate.

The maintenance or restoration of fish habitat protection and aquatic biodiversity are two of the major issues that are often addressed in watershed and subwatershed studies. Fish habitat protection and restoration are required of any land use changes as part of the federal Fish Habitat Protection Policy which supports the federal Fisheries Act. Information on the potential impacts of various land use development activities on fish habitat are often major questions that are asked in watershed and subwatershed studies. Answering these questions requires an understanding of the biophysical interactions of land and water in a predictive sense.

Biodiversity and its protection and management have become major issues in Canada and Ontario. While there is presently no legislation to protect biodiversity, the Province of Ontario has developed draft policies that address the issue.

3.1.2 State of the Science

Aquatic ecology and biology is supported by a substantial foundation of *science.* Our descriptive understanding of where and how organisms use aquatic systems is extensive at a site-specific scale, and is weaker at a watershed or landscape scale. It suffers in part from a limited understanding of functional interrelationships (predictive power) between and amongst physical, chemical and biological attributes. For this reason the status of the science of aquatic ecology and biology was identified by the Task Group in Figure 4 as being "medium" and improving.

Biology — the study of organisms, their morphology, physiology, origin and distribution — is a well-established science having its modern origins dating back to Linnaeus and others in the 18th century. At small scales of analysis, aquatic biologists have been able to look at the functional relationships of organisms, their morphology and physiology relative to their chemical and physical environments. Excellent examples of the application of this information are horticulture and aquaculture.

Ecology is a broad field that examines the relationships of organisms and their living and nonliving environment. This field is relatively new, having its genesis in North America with the writings of individuals such as Pinchot, Aldo Leopold and Eugene Odum. As with the older science of biology, this discipline has been most successful at understanding of biophysical and chemical relationships in small-scale situations. A study of spatial scale in ecological research found that the majority (close to 90%) of the studies of ecology published in the primary literature considered spatial scales of less than 1 m^2. The functional relationships between communities of organisms at large spatial scales are still preliminary at this point, although the science is expanding rapidly worldwide through the relatively *new* field of Landscape Ecology.

The *knowledge base* of aquatic biology and ecology is available and shared reasonably well by researchers, scientists and professionals. With the advent of computer information networks and the Internet, this sharing of information and knowledge should improve as should its application through current practice. The danger of acquiring science without going through the process of acquiring information through personal involvement is that the understanding of how to apply the science is often not tempered by experience. From experience comes humility and caution. With this in mind, the Task Group suggests in Figure 4 that our *knowledge base* and *current practices* of traditional aquatic biology and ecology is reasonable ("medium") and presently not improving, although it could be argued that improvements in computer networking will radically improve science exchange and its application. One of the great challenges is the need to integrate aquatic ecology and biology with the other disciplines involved in watershed planning. This is perhaps the area requiring the greatest research and science (see integration discussions in Sections 3.0 and 3.10).

Currently, there is a great deal of descriptive *information* in support of the application of traditional aquatic biology and ecology to practical problems. This is indicated by a rating of "high" in Figure 4. Presently, new information is being developed but not at a rapid rate. The greatest information expansion in aquatic ecology and biology appears to be occurring with respect to non-traditional scales of analysis (e.g. landscape ecology, whole systems ecology, population ecology). This requires a more integrative approach amongst the other biological, physical and chemical sciences.

The *data* available to aid in basic analysis are quite extensive although in many instances not intensive. This is reflected in a score of "medium" rather than "high" in Figure 4. The historical data include extensive surveys by various federal and provincial agencies (e.g. MNR's Aquatic Habitat Inventory Survey system; MOEE's water survey network). Most of these data are for fish species although there is a database developed for aquatic macroinvertebrates through the MNR Stream Inventory Program. Unfortunately, funding for intensive surveys has been limited and therefore the usefulness of data to site and area-specific applications is limited. On the other hand because of its extensive nature, these types of databases are useful for regional analysis of landscape trends in water chemistry and species distribution. This situation means that additional area and site-specific information is usually required for specific watershed or subwatershed studies. What this information also indicates is that traditional approaches to measuring chemistry and biology may need to be tempered by what the information is to be used for. If the question in a watershed study is to simply understand from a descriptive sense the distribution of species of fish by various features, then the data are quite useful. If the question is why the fish occur in the described distribution, then additional information, not normally collected at sites based upon the traditional inventory methodology, may be required. What measurements should be collected to link site information to larger scale features is a need that should be addressed through the integration of the various disciplines.

3.1.3 Applications of the Science

The fields of aquatic ecology and biology have extensively examined the relationships between biotic communities and the physical and chemical characteristics of their environments. By necessity, this is a first step in developing a fundamental understanding of the structure and composition of different systems. The next step is the examination of functional relationships amongst the variables in order to understand how and why biotic systems respond to various changes in the physical and chemical attributes that define their environment. This provides descriptive power.

Most *characterization* work focuses on describing the physical, chemical and biological conditions that occur in locations where certain organisms exist. From this information comes an understanding of an organism's needs and requirements for its various life stages. The Habitat Suitability Index approach (HSI) is an excellent example of one approach to descriptive characterization. The Index of Biotic Integrity (IBI) is another approach that attempts to determine functional integrity or health of aquatic systems. This approach uses not only fish species diversity and numbers but also trophic level and incidence of disease as elements to determine relative integrity of the community at a site over time or instantaneously between many sites spatially. Other approaches are also available using fish species information. There are a variety of invertebrate indices used to characterize invertebrate information as well.

There is a wealth of knowledge on many of the common and major species found in various populated parts of the world. For this reason, the ability of aquatic ecology and biology to characterize systems has been rated by the Task Group as "high" in Figure 5. However, a descriptive understanding of other species and their physical and chemical relationships is still weak, especially for non-game species of birds, mammals and fish, reptiles and amphibians, and invertebrates. A vertical arrow depicts this ongoing development of information and characterization.

The *predictive* powers of aquatic ecology and biology — our ability to predict how an organism will respond to changes in environmental conditions — are relatively poor at this point but improving rapidly. This is reflected by the "low" rating given by the Task Group in Figure 5 and the vertical arrow. Describing an organism's environment and the physical, chemical and biological variables typical to its life requirements is relatively straightforward; understanding the functional interrelationship between and amongst these variables is not. Linearity between and amongst variables may not always occur in natural systems; instead, natural systems with their various checks and balances may more commonly be characterized as non-linear. Allen and Hoekstra (1992) and Harris (1994) emphasize the need to develop predictive power through the analysis of present descriptive information to uncover "fundamental and universal truths".

Compounding our understanding of functional interrelationships is the issue of scale, both temporal and spatial. Some organisms require extremely site-specific patches of habitat that may require relatively unique chemical, physical and biological characteristics for survival and growth (e.g. certain species of orchids). The characteristics necessary for growth and flowering may only occur in certain years in certain specific discrete locations. Without an understanding of the plant's requirements in time and space, these rare plants may disappear. On the other hand, communities of plants and animals can often be best described in terms of large spatial units controlled by geology, topography, soils and climate. The field of landscape ecology is addressing some of these issues.

Given the limitations of our predictive power in aquatic biology and ecology, and based upon the experiences of the working group, *issue resolution* for aquatics has been rated by the Task Group as "low". There is an intrinsic realization that aquatic systems are one major component of our environmental life support system. On a practical level, society extracts benefits from healthy, productive aquatic environments in a number of ways:

- healthy fish stocks provide commercial revenue;
- anglers pay for services associated with recreational fishery resources;
- healthy aquatic systems provide water supply for humans, farm animals and irrigation; and

- healthy aquatic environments provide opportunities for passive recreation.

Healthy aquatic systems basically pay for their own keep while degraded resources are, at the very least, drains on human financial resources and at the very worst, threats to health and life.

Some preliminary studies indicate that there are relationships between poor land practices, degraded aquatic environments and financial, economic, social and human health costs to society (MNR/CVCA/DOE 1994). Unfortunately the state of awareness and acceptance of the values of healthy, functional natural environments is poor in society today. There is an acknowledged need to improve the understanding of these relationships and for this reason the arrow in this box is vertical. Judging by recent initiatives such as the Crombie Commission, there appears to be a demand by society for better human living environments.

Communication of the importance of aquatic systems to humans and natural systems has been generally successful. The public understands the intrinsic benefits of aquatic systems even though it is difficult to place a "value" upon their protection. The Task Group believes that in general we have the tools to explain the importance of aquatic systems to the public. This is reflected by the "high" rating given by the Task Group to communication of aquatic issues in Figure 5. However, within the context of integration, it is difficult to communicate the understanding of the interrelationships between aquatic communities and other components of a system as these relationships are weak and poorly understood.

Monitoring of aquatic systems was rated by the Task Group as "high". Methodologies for monitoring aquatic systems in Ontario have been standardized since 1972 for inventory protocols (Aquatic Habitat Inventory Surveys, MNR) and since 1982 for stream habitat characteristics (Stream Habitat Assessment Methodology, MNR). Statistical and procedural methods for fish population assessment are also well-established. Methods for macroinvertebrate collection have also been standardized, although there has been no concurrence on analytical and statistical standard methods for characterizing macroinvertebrate communities. Although there exists in the province general methods for monitoring aquatic systems, and some of these methods are standardized, systematic data collection is seldom carried out.

3.1.4 Integration Considerations

Aquatic ecosystems and the biota within them are expressions of the physical and chemical process operating at various scales within a watershed. It follows, therefore that an understanding of the presence, distribution, relative productivity and functioning of aquatic systems cannot be complete without an understanding of the physical and chemical driving forces within the system. This entails a need for biologists and ecologists to work closely with a variety of other professionals at various times during a watershed or subwatershed study. These would include hydrologists, hydrogeologists, geomorphologists, engineers, water quality specialists and landscape geographers.

In order to generate the best possible understanding of the watershed, all disciplines should strive to optimize the value of the information provided by the other disciplines. A conceptual model of potential interactions and relationships between and amongst the various biophysical and chemical processes should be developed prior to the development of a sampling program for the study. This conceptual model can be developed after existing information and data on the system is acquired, and should be done with input from all disciplines. The benefit of such an approach is the postulation of a conceptual model which can then be tested by all the disciplines. Information collected by each professional will be focused on his/her problem within the context of the overall conceptual model and the potential interactions amongst the disciplines.

3.1.5 Key Areas for Improvement

Information on the potential impacts of various land use development activities on fish habitat are often major questions asked in watershed and subwatershed studies. Answering these questions requires an understanding of the biophysical interactions of land and water in a predictive sense, especially for fish habitat and biodiversity.

The impacts of land use change on fish habitat is an issue that is current and pressing. Given the immediate demand for answers related to the impact of land use changes on fish habitat, we need to determine the appropriate scale at which to measure characteristics that are important and formative to fish habitat and also to determine what characteristics to measure. Site level detail is too small a scale for the issues that are to be addressed through watershed and subwatershed studies except in instances of extremely limited or critical elements (e.g. barriers or specific reproductive zones). Therefore more effort must be expended to determine why the habitat features determined for the watershed or subwatershed exist where they do. We must know what processes and features create and maintain habitat characteristics spatially and temporally. This information will provide an understanding of the linkages between biophysical causes and effects. This understanding in turn provides a context for observations related to how animals use these structural features in relation to the formative agents and characteristics that create them. In this way the physical and biological disciplines develop a common currency of measurements and information that relates physical processes and forms to the way in which animals use these forms.

The issue of biodiversity and its maintenance and protection will soon need to be addressed at some level by watershed studies. Noss (1990) suggests that biodiversity does not only include the variety, type and diversity of life in any particular location but also includes the abiotic elements and processes that create the living space and habitat for the biota. Noss suggests a hierarchical scale for discussing biodiversity:

- landscape;
- community;
- species; and
- genetics.

Key descriptors include compositional elements, structural and functional elements. At present, there is great deal of descriptive (structural and compositional) information on various species but poor information on community dynamics, landscape characteristics and genetic characteristics. Functional interactions at all these scales are poorly understood. Given the scale of analysis for most watershed and subwatershed studies, it is unlikely, except for rare, threatened and endangered species, that these studies will be able to go into any detail on species-level biodiversity issues. Information similar to that needed for fish habitat analysis will be appropriate for community level analysis and the determination of biophysical requirements of communities that exist or should exist within the particular watershed. Information on expected communities can be derived from information in the literature on zoogeographic distribution of animals.

Our predictive abilities can be improved in the short run by studies that examine the response of organisms after certain types of changes have occurred. This type of information is still descriptive to a certain degree but has sufficient reliability to amount to a form of prediction. For example, there have now been many studies that have looked at the relationship between changes in perviousness of watersheds undergoing urbanization and the relationship to water quality, flow, hydraulic, fish and invertebrate characteristics. The studies do not directly address the changes in functional interrelationships that generate the effects described but do provide us with some reliability and "truths" as to the likely response of a watershed to these types of changes. However, these studies are not prescriptive which still leaves a great deal of uncertainty as to how to ameliorate negative impacts of change in the watershed, especially from a planning and design perspective.

As Allen and Hoekstra (1992) and Harris (1994) have emphasized, there is merit in querying existing databases to determine if functional interactions can be detected. Previously completed watershed and subwatershed studies may lend themselves to this process. One way of examining this information is by use of integrative frameworks that provide a new way of structuring information so that potential interactions can be examined.

3.2 Terrestrial

The ecosystem approach to analysis and management of landscapes provides a conceptual basis for dealing with issues over a range of spatial scales. It is applicable both to aquatic habitats (through watershed planning) and to terrestrial habitats (through land systems classification/ landscape ecology). Watershed planning and ecological planning both aspire to achieve ecosystem health, fit and sustainability. While the two approaches are focused on different components of the ecosystem, they complement each other and when integrated, provide a means of integrating the management of aquatic and terrestrial habitats into a single framework.

The objective of sustainable development is to achieve ecological stability, provide for ecological diversity, and maintain ecological resilience and ecological sustainability. To date, much analysis has focused on the protection of "islands" of habitat and networks of natural lands, including riparian zones and streams. The need, however, is to manage the entire landscape in a fashion that permits development to be sustainable for both human and natural ecosystems. To do this requires establishing the linkages between habitats across watersheds of the same order and between watersheds of different orders.

3.2.1 State of the Science

The Task Group has rated the *science* of terrestrial ecology as "medium". Many aspects of the science are in the developmental or confirmation stage. We are able to qualitatively describe the impacts of development on terrestrial habitat. Much current research is focused on improving the level of knowledge of inter-species interactions as they relate to habitat, and on the role of habitat in the different life stages of a species. The development of the ability to conceptually model habitats spatially has been an important step forward. The best work is currently done at the ecosite level or the subwatershed scale; there is a need to be able to integrate upwards to larger spatial scales (e.g. the ecoregion).

The *knowledge base* of terrestrial habitat systems is expanding rapidly and was rated by the Task Group as "medium". Prior to 1980, this field was primarily the domain of wildlife researchers. In the last decade, understanding of the importance of <u>systems of habitat,</u> rather than areas of habitat, has increased with the popularization of theories of island biogeography. There are now a number of journals and a growing number of scientific monographs dealing with habitat systems.

For the most part, *current practice* lags behind scientific understanding, and was rated as "low". Many practitioners, for example, lack the ability to use modern tools of analysis such as GIS. Current practice is focused primarily on relating species presence and absence to the structure of the habitat system; there is little work done on the dynamics of the system, and the importance of elements within the system. The extent of most practical exercises in management of terrestrial habitat has been the classification of land units as Areas of Natural and Scientific Interest, Environmentally Sensitive Areas, significant wetlands, or nature reserves.

Studies of the terrestrial habitat system as part of watershed planning have contributed significantly in terms of *information.* Such studies have shown that in southern Ontario, many of our habitat systems are seriously impaired and lack integrity: this is commonly due to lack of appropriate connectivity and some critical elements such as large blocks of natural areas. Many riparian corridors are fragmented, and changes in species composition have occurred as a result of introductions of invasive and exotic plants. Other issues raised include excessive "edge" type habitat relative to interior habitat, and concerns over predation by domestic and feral animals.

Terrestrial *data* was rated by the Task Group as "medium". There is an abundance of some sorts of data — bird population distribution and habitat characteristics, for example — primarily derived from the observations of nature groups and amateur ornithologists. In contrast, observations on mammals, reptiles and other animals are much more limited. A key problem is the lack of linkages between observations of a species and habitat characteristics and behaviour in the environment. These data are needed if we are to improve our ability to model and predict the impacts of landscape change.

3.2.2 Applications of the Science

The *characterization* of terrestrial systems was rated by the Task Group as "medium" in Figure 5. Current practices in subwatershed planning consist primarily of an analysis of the structure and composition of the landscape; there is relatively little analysis done on the function of different habitat elements of the landscape. The focus is generally on community types, game, and rare or endangered species as the important indicators of habitat. In general, there is little analysis of populations and population dynamics, and only general assessments of carrying capacity for different communities. While we can generally characterize what the terrestrial habitat system is (i.e. describe its component parts), we cannot characterize how it works. Accordingly, we are unable to assess the consequences of changes in habitat supply.

Current models of habitat systems lack the ability to *predict* community and population dynamics in response to alterations in habitat systems, and was rated as "low" by the Task Group. Current models are generally descriptive and in some cases can be used for prescription of mitigation. Within the field, there is much debate about our ability to predict responses in terrestrial systems. Certainly, the use of GIS in the subwatershed planning process has greatly improved our ability to understand the structural and functional relationships in terrestrial habitat systems.

For terrestrial systems, *issue resolution* was also given a "low" rating by the Task Group. The ability to resolve issues with respect to terrestrial systems is dependent on the ability to predict and describe cause and effects as they relate to habitat change. Although issues can be identified now, full resolution of issues relating to habitat preservation, management and restoration is not possible at this time. In the context of watershed planning, it is possible to identify critical habitat blocks, corridors and linkages for different communities. It is not possible to predict the optimum size of blocks for a wide range of communities, the effects of adding or deleting linkages, or the effects of breaks in continuity in corridors. The definition of widths of buffers to protect habitat from developed land is problematic, and the determination of best management practices for wildlife in urban and agricultural land is in its initial stages.

Because of the limitations of terrestrial ecology, especially with respect to the dynamics and function of the system, the Task Group rated the *communication* of the terrestrial component of watershed planning as "low".

Monitoring for terrestrial systems was rated as "low" in Figure 5. At present, monitoring of terrestrial habitat is not carried out on a systematic basis. Surveys and inventories of natural habitat are carried out on a spot basis by OMNR and various wildlife and nature organizations. This has limited the usefulness of the data for monitoring change in habitat systems. The ability to convert remotely-sensed data to digital GIS mapping systems should improve the monitoring of land cover and changes in the structure of habitat systems, but will not provide for the monitoring of habitat quality. There is a need for development of more systematic and regular monitoring of habitat quality and the effects of habitat change on plant and animal populations.

3.2.3 Integration Considerations

If we define a watershed as a set of parallel interacting systems (runoff generation, sediment, nutrient and contaminant production, aquatic and terrestrial habitat systems, and land use social systems), integration can be achieved by identifying the structural components of these systems and defining the significant interactions of these components. We can use the concepts of landscape ecology (that land system units constitute the structure of the landscape and that the flows or interactions between these units define the function of the landscape) to integrate our understanding of the watershed. In the case of the parallel interactions that follow the drainage system from land to stream (such as runoff, recharge, erosion and deposition) the structural units and interactions may be the same. In the case of terrestrial and social (land use) ecology, the structural units and interactions may be quite different. However, this approach does allow for integration of the different components of a watershed study in a manner that allows one to assess the impacts of change on the attributes of land units and the interactions of those units.

3.2.4 Key Areas for Improvement

There are at least four areas in which improvements would greatly enhance the study of terrestrial systems in watershed planning. Key needs are:

- to improve the use of GIS in analysis and prediction of the impacts of habitat change in watershed plans;

- to improve the basis for defining and the defensibility of buffers for natural areas in plan development;

- to develop an understanding of the linkages between subwatershed-scale habitat systems and those operating at regional scales;

- to develop a working understanding of the interactions between different types of land use (residential, industrial, park, open space, etc.) and different types of corridors and different sizes of habitat blocks; and

- to improve the prediction of population potential based on habitat structure and quality.

The last point above — an improvement in the prediction of population potential based on habitat structure and quality — will enhance the ability to resolve issues and communicate the significance of habitat changes to the public, and will aid in the development of habitat restoration plans.

3.3 Hydrology

3.3.1 State of the Science

The Task Group has rated *scientific understanding* of the hydrologic cycle as "high" (Figure 4), and this understanding has been refined over the last two decades. The exception to this is the limited understanding of low flows and surface/groundwater interactions. Currently several models, all based on reasonable fundamentals, are available for the prediction of flows from both rural and urban areas.

In terms of *knowledge,* a majority of professionals practising in the field of hydrology (engineers, geographers and other scientists) are well-trained through post-secondary education. Typically, their understanding is further enhanced as part of their professional training. Knowledge base for hydrology was rated by the Task Group as also being "high", (Figure 4).

With regard to *current practice,* the technical approach to hydrology is generally well-applied by a majority of the practitioners and was rated by the Task Group as "medium". The two areas of weakness include:

1) the inability of general engineering firms, through lack of training, to understand the fundamentals of hydrology (thereby producing incorrect results); and

2) the inability of the general practitioner to estimate flows based on field experience and monitoring results (as opposed to modelling approaches). This is primarily attributable to reluctance to change the historical "tried and true" approach which involves modelling to predict flows.

Generally the *information* produced from hydrological data collection is useful for estimating flow characteristics, (e.g. baseflow, annual flow, peak flow) and trends. Monitoring data, as well as modelled results, are not necessarily reliable for the estimation of surface/groundwater interaction or for ungauged small subcatchments. Hydrological information was rated as "medium" by the Task Group.

In terms of *data,* the Task Group rated hydrology as "medium" in Figure 4. A considerable database for Ontario exists through the Water Survey of Canada. Generally flow records for several decades can be obtained for most of the major watercourses in the province. A limitation in the data exists for smaller drainage areas (i.e. those less than 5 km^2). Also, correlation of flow results with groundwater records is not always available.

3.3.2 Applications of the Science

Monitoring data generally permit the *characterization* of the existing hydrologic cycle in a straightforward manner. Modelling, which in this case would characterize flows for different drainage areas or for specific design conditions, is generally accurate to within 50 percent. Characterization (again, due to the lack of understanding of surface/groundwater interactions) is less reliable for baseflow conditions. Nevertheless, hydrological characterization was rated by the Task Group as "high" in Figure 5.

The *predictive* ability of hydrology is also quite high, assuming that the data and information are available. Currently, hydrologists can predict, in a reasonable manner, flow characteristics for a variety of conditions (e.g. low, average and peak flows), for a variety of land uses (e.g. rural and urban), and for a range of physiographic conditions. Two areas where flow predictions are less reliable include baseflows and snowmelt/rainfall conditions.

In terms of ability to *resolve issues,* the representation of typical issues (e.g. the comparison of pre-development and post development flows) is relatively straightforward through graphical representation. However, this is not the case for issues related to low flows and surface/groundwater interactions. Accordingly, this was rated by the Task Group as "medium".

With regard to *communication,* hydrological issues can generally be explained easily, since absolute numbers can be used. As an example, it could be stated that peak flows have increased 100 percent over a discrete time period, or that an area which used to flood every 50 years now floods every 10 years. The Task Group assigned a "high" rating to communication of hydrological issues and concepts.

For hydrology, *monitoring* was rated by the Task Group as "high". Monitoring is well-developed with respect to scientific understanding and knowledge base. Furthermore, a majority of the disciplines involved in watershed planning are able to interpret monitoring results.

3.3.3 Integration Considerations

Throughout the course of a subwatershed study, hydrologists would integrate with virtually all disciplines. Typical integration considerations would include provision of:

- a water budget to be used by aquatic scientists;
- a time series of flows to be used by geomorphologists;
- data on precipitation, evapotranspiration and peak flow to be used by terrestrial ecologists;

- information relating to surface water/groundwater interactions to be used cooperatively with the hydrogeologist; and

- flow conditions for various conditions to define water quality conditions.

3.3.4 Key Areas for Improvement

The primary area in which improvement is needed is the integration of surface water flows with groundwater interactions. The interpretation of results, and how they may affect other components (such as aquatics or terrestrial) also needs to be refined. Lastly, the use of monitoring data to define basic principles such as a water budget should be considered further, as opposed to the use of complex modelling.

3.4 Stream Morphology

3.4.1 State of the Science

Scientific understanding was given a "medium" rating in Figure 4 by the Task Group for stream morphology, although this does not apply to all aspects of the discipline. For example, scientific understanding of channel form and function is high at a conceptual level, as is the basic understanding of the mechanics of sedimentology and erosion due to scour in one-dimensional, homogeneous and symmetrical channel systems. However, unlike the processes governing rainfall-runoff processes, which have been quantitatively described in physically-based models, no equivalent deterministic algorithms have been developed integrating processes taking place in heterogeneous, stratified deposits. The ability to reliably predict ultimate channel form in response to a change in the driving mechanisms requires the development of such models. The lack of such algorithms represents a significant limitation in the science concerning channel morphology.

The rating in *Figure* 4 for *scientific knowledge,* or how widely scientific understanding of stream morphology is shared, was "low". This is primarily because erosion control programs have traditionally been seen as the realm of the engineer and so termed "river engineering". With few exceptions, most practitioners are civil engineers with little or no academic background in fluvial geomorphology. This reflects the traditional societal view of the channel as a conduit for the efficient passage of flood waters. Consequently, the knowledge base has focused on geotechnical and hydraulic properties of channels for the determination of channel stability and flood capacity. For example, the interaction between the upland hydrologic and sediment regimes and channel form has been well described in literature pertaining to fluvial geomorphology, however, most practitioners are unaware or unable to account for off-site changes in the causative factors in the design of site-specific erosion control measures.

The state of *current practice* with respect to stream morphology was rated by the Task Group in Figure 4 as "low". This is primarily because of the traditional site-specific orientation in the planning and funding mechanisms dealing with channel instability concerns. The design of erosion control measures has also been based on traditional critical shear stress or velocity concepts. These methods have been developed based on the behaviour of a discrete particle. While this is applicable for alluvial channels formed in non-cohesive and uncompacted materials, it does not apply without modification to the majority of channel systems which are formed in stratified materials of varying degrees of cohesion and compaction. The procedure must be further modified to account for the tendency of particles to form clusters, imbricate and structurize through time.

For stream morphology, the Task Group has rated *information* (the usefulness of data) as "low". The data collected in the field and the methods so employed are largely based on the requirements of the traditional engineering-based approach to river management. Consequently, they tend to be geotechnically and hydraulically-based. While this information is certainly pertinent to understanding the behaviour of the fluvial system, of which the channel is one component, these data provide limited means by which fluvial process and form can be characterized. By obtaining measures of fluvial features and activity rates, stability and process can be better defined and the causative factors better understood. For example, failure to adequately characterize the significance and rate of upstream migration of niche points has resulted in the failure of hard lining methods due to undercutting of the downstream end of erosion control works. This was not foreseen by the designers. Unfortunately, such design failures are common. The problem stems in part from the site-specific nature of erosion control investigations and partly from the inability to recognize and interpret fluvial forms.

In terms of *data,* stream morphology was rated as "low" in Figure 4. To date, few comprehensive data collection programs have been conducted linking channel form with boundary material composition and the characterizing hydrologic and sediment regimes. Further, the incorporation of the measurement of channel morphology as a component of water resource investigations has only just recently begun and there are no uniform requirements. Even within these efforts, data collection has not been standardized and few practitioners are well trained in the collection of data to characterize fluvial systems.

3.4.2 Applications of the Science

With regard to the ability of the science of stream morphology to *characterize* systems, the Task Group gave a "low" rating in Figure 5. In order to define how a system works there must be an overall understanding of what the component parts are, their structure, and their function and interrelationships. The assumption that we have the data and information presumes that we know which questions to ask and what and how to measure the features and phenomena of importance. Without a quantified, deterministic model of the physical system, the knowledge base required to define the system is lacking.

The *predictive* ability of stream morphology was also given a "low" rating by the Task Group in Figure 5. The ability to reliably predict a change in channel morphology as a consequence of a change in the causative factors requires that we have the scientific base necessary to characterize the system. This foundation is missing and will require some investment at the basic science level. Currently, practitioners are able to indicate, in an ordinal manner and through empirical approaches, whether or not change may occur. The exact threshold at which change will occur and the magnitude of that alteration are not well understood. Environmental indices have been developed for this purpose.

Although the ability of stream morphology to *resolve issues* was rated by the Task Group as "low", the use of environmental indices describing instream erosion based on boundary material composition and the transverse distribution of excess boundary shear stress has provided a means to assess relative risk. Consequently, environmental indices are also a tool for the establishment of choices. Little work has been done to establish values based on stream morphology.

With regard *to communication,* or the ability to disseminate knowledge, stream morphology as applied received a "low" rating from the Task Group in Figure 5. Channel process-response systems are complex with numerous feedback mechanisms and inter-dependencies, which change from more-or-less dependent to more-or-less independent and back again, depending upon the conditions established by an array of other variables which are also changing through time and space. The concept of thresholds and shear stress, which appear to dominate the form of alluvial systems, are themselves difficult to explain. They are not, however, without physical analogies which are understandable to lay persons and specialist alike.

Monitoring was rated as "low" for stream morphology. Fluvial features can vary widely in both a spatial and a temporal context. In general, three spatial scales can be identified: macroforms, relating to the floodplain and the river pattern; mesoforms, which are of the scale of the channel itself; and microforms, which are associated with turbulence resulting from perturbations or secondary flow patterns within the general river flow. The temporal scale over which these forms evolve varies significantly: microforms may change within seconds to days; mesoforms evolve over days to decades; and macroforms alter over years to centuries. As a consequence, designers of monitoring programs must identify and isolate those fluvial features in which temporal and spatial scales are most compatible with the objectives of the monitoring. First, it is imperative to define well the goals and the objectives of the monitoring program. Second, the appropriate fluvial forms must be identified and a sampling protocol developed which is suitable for mapping the characteristic dimensions of these features. Third, the monitoring frequency should be sufficient to detect significant changes to these forms over time.

3.4.3 Integration Considerations

The stream morphology component of watershed planning requires integration of various disciplines. Primary interactions typically involve the stream morphologist, hydrologist, aquatic biologist and hydrogeologist. Considerations include:

- identification of discharge locations along the streams;
- discussion with the aquatic biologist to define habitat requirements including in-stream cover, riparian canopy, substrate material and channel shape; and
- selection of flow conditions to define present and future morphologic considerations.

3.4.4 Key Areas for Improvement

Many advancements have been made in the classification of fluvial systems. This has occurred despite the inherent difficulties of applying any sort of classification system to a complex, process-response systems consisting of an array of spatially and temporally overlapping forms. Classifications systems do, however, assist in the standardization of terminology while also providing a link between form and process. To date, this link has been based on an empirical approach to quantitative geomorphology. This work should be expanded, using a physically-based model, to include principles of conservation of mass and threshold-energy concepts. That is, a channel of a particular class based on form should also be correlated with the ability of the flow-sediment mixture to dislodge and transport intact boundary materials, the erodability of the material within which the channel is formed, and the competence of the channel-flow system to transport its sediment load. Relationships of this type will enable practitioners to develop a channel design manual. It is also a fundamental step towards developing a physically-based predictive model that will enable practitioners to quantitatively predict channel response to changes in driving mechanisms and the resulting ultimate channel form.

3.5 Water Quality

3.5.1 State of the Science

Of all the scientific components of watershed planning, in terms of "state of its science", water quality is one of the better understood. In Figure 4, the Task Group has rated *science* as "medium". For large river systems in southern Ontario, watershed planning teams have established a strong suite of assessment and modelling procedures. These procedures coupled with existing information bases such as the MOEE Provincial Water Quality Monitoring and federal stream flow network afford a good understanding of water quality conditions visa via water quality objectives and guidelines for the protection of aquatic life and recreational/domestic use.

For urbanized centres, pollution control planning and abatement studies in the late 1980's provide a strong scientific base for municipal point source (i.e. Combined Sewer Overflow and Sewage Treatment Plants) and stormwater assessments. Scientific procedures for investigating water quality conditions in small watersheds lacking basic water quality and stream flow information are weak. Unfortunately, there has been little progress in addressing these weaknesses. It may be that research and academic interests have shifted to the study of integrated approaches (i.e. ecosystem understanding), or to topics such as stream morphology and groundwater protection.

In Figure 4, the Task Group has rated *knowledge base* for water quality as "medium". Water quality knowledge bases are not being shared and what is known may not be reflected in the final recommendations of a watershed plan. Technical committees for watershed and subwatershed plans need to document both their successes and failures in addressing local water quality concerns. In the past, provincial agencies and Conservation Authorities had the resources to sponsor workshops which promoted successful pollution control planning and flood plain management. By providing a forum for both formal and informal criticism, significant advancements can be made in watershed planning, not only in the acquisition of knowledge, but our abilities to resolve local water quality issues.

The Task Group has rated *current practices* as "medium" (Figure 4) in terms of how well both existing water quality procedures and knowledge are being applied in the development of watershed plans. This raises the related point of what information and data are needed for decision-making and implementation of the final plan. Protocols for screening and assembling water quality data are required to better utilize limited resources. There needs to be more sharing of experiences, particularly where these have generic application.

For routine urban water quality issues such as stormwater, combined sewer overflows and discharges from sewage treatment plants, adequate *information* bases exist that allow informed management decisions to be made. By contrast, little basic water quality information exists for urbanizing watersheds or for persistent toxic substances such as pesticides and herbicides. Cost and efficiency are significant barriers to obtaining this information.

The Task Group has rated *data* as "medium" in terms of water quality analysis for larger watersheds. This rating reflects the important contribution made by MOEE's provincial water quality monitoring network and the utility of databases produced by studies such as the US Environmental Protection Agency's National Urban Runoff Program. There is a recognized deficiency in water quality data for small urban subwatersheds and rural watersheds.

Watershed planning teams need to demonstrate applications of their water quality databases beyond the watersheds in which data were collected. This is especially important in cases where data were expensive to obtain, or were shown to be essential in deriving an understanding of watershed function. Water quality data includes more than just water chemistry: increasingly it is important to use sediments and biological databases as sources of water quality information.

3.5.2 Applications of the Science

Given an adequate information and data base, watershed planning teams should be able to *characterize* water quality conditions fairly well. However, our ability to accurately *predict* future water quality or responses of water quality to watershed management proposals remains weak. In particular, concern is raised over the ability to support decision-making with regard to the extent of land use change, the evaluation of servicing proposals, or Best Management Plans to protect wetlands, transportation corridors, etc. Water quality assessments of new subdivision designs, stormwater management practices and improved construction practices are needed in order to advance our predictive capabilities.

While the need to protect and restore degraded ecosystems is widely recognized, our ability to successfully address water related quality issues is constrained by the incompatibility of current approaches to land use development and ecosystem protection. To date, we cannot establish development limits (e.g. how much development of what type should take place where). Therefore watershed plans struggle to deal with the conflict between ecological function/health and community socio-economic needs. The Task Group has accordingly rated *issue resolution* with respect to water quality as "medium" in Figure 5. Watershed plans formulated with public input are reasonably successful in *communicating* issues and required actions. However, more effort is needed to extend scientific understanding in a tangible way to watershed planning participants and stakeholders.

Water quality *monitoring* programs are intended to ascertain whether environmental responses to land use changes are consistent with the watershed or subwatershed plan's goals and objectives. Water quality monitoring programs are very easy to initiate. The science of designing and operating an effective monitoring water quality could be ranked "high", reflecting the extensive research compiled on how to design monitoring programs and interpret findings. However, in practice in watershed planning, this "state of art" of current water quality monitoring practice has not been applied, and monitoring has been rated by the Task Group as "medium". The utility of long term water quality monitoring programs such as MOEE's Provincial Water Quality Monitoring Program is well understood. However, our capability to use information obtained from shorter term monitoring programs in order to predict future conditions, support management decisions, or mitigate problems, is not as far advanced. Current experience has shown that sediment and biological studies provide a good assessment of water quality, and a good initial assessment of baseline conditions. It is becoming apparent that watershed plans will increasingly use a broader range of water quality assessment procedures.

3.5.3 Integration Considerations

Ontario's streams, lakes and rivers are excellent natural integrators of human activities and watershed features (i.e. land use, bedrock, glacial overburden, wetlands, groundwater, forest cover, etc.). In recognition of this fact, water quality studies are moving beyond the river or stream corridor to include consideration of factors that combine to influence or determine the chemistry of Ontario's surface waters. Those conducting watershed plans now spend more resources studying these factors, and less filling water bottles. The focus in watershed planning has moved from the identification of water quality problems to problem solving through integrated approaches and investigations of watershed function.

3.5.4 Key Areas for Improvement

One of the weaknesses of our current approach to water quality assessment in watershed planning is that not enough thought is given to information needs. In general, planning teams do not establish information needs for water quality and assessment upfront in watershed planning processes. A shift needs to occur whereby steering committees and the public arrive at a common understanding of critical water quality problems, when they occur, and where. This will provide direction to the study team in terms of assessing water quality, and allow the compilation of an information base that is sufficient to answer watershed-specific water quality problems.

State-of-the-art procedures for undertaking water quality assessments in watershed plans need to be assembled into a technical manual which should contain guidelines and procedures for acquiring watershed water quality data (including related biological and sediment data). Methodologies for analysis and interpretation of these data should be consolidated and made available in the manual. The province should enhance its water quality monitoring network, in order to provide a basic level of water quality information for watersheds undergoing land use changes. Proponents carrying out watershed and subwatershed plans would be greatly aided by the development of a inventory of water quality and related data bases held by provincial ministries, municipalities and conservation authorities. Once inventoried, information on location should be made available through a clearing house. Finally, more conferences and workshops would assist in fostering an improved information base for practitioners.

3.6 Groundwater

3.6.1 State of the Science

Historically, *scientific understanding* within the groundwater community has had a very solid base due to the need for groundwater exploration throughout the world. The Task Group has rated this as "medium" in Figure 4. Scientific understanding has expanded greatly over the past two decades due to an increased demand to resolve groundwater contamination issues. On-going research is being carried out in a very wide range of groundwater fronts, the majority of which relate to groundwater contamination. From a watershed planning perspective, some level of research should be focused on the further understanding of the interaction of groundwater flow systems with surface water flow systems and terrestrial systems on small and intermediate scales (i.e. metres to hundreds of metres). In addition, a further understanding of the quantification and sensitivity of groundwater recharge is needed. It is at these scales that significant linkages occur between the groundwater systems and the aquatic and terrestrial communities. The basic tools for the field investigation in this type of research are well established. The challenge is to utilize these tools to refine the understanding of the linkages and hence predict possible changes to the various ecological communities as a result of changes to ecosystem attributes.

The *knowledge base* with respect to groundwater was rated by the Task Group as "medium". Scientific knowledge is well-communicated through journals, symposiums, conferences and other academic venues. It is becoming a common practice for various agencies to conduct symposiums and workshops that are less technical and are directed at typical stakeholder audiences. These lower key technical workshops and symposiums are very effective as they tend to bridge the gap between science, land use practices and planning. The groundwater knowledge base needs to be expanded beyond its historical focus on water supply and groundwater contamination. Practitioners need to step outside traditional knowledge sources in order to understand why and how groundwater is related to the function of other ecosystem components such as coldwater fisheries, wetlands and terrestrial features. This will allow the science to be better applied.

Current practice with respect to watershed and subwatershed planning was rated by the Task Group in Figure 4 as "low". In general, the current practice does not rigorously apply the wide variety of knowledge and methodologies available to carry out detailed watershed, subwatershed and more site specific studies. A major reason for this is that significant financial resources are necessary to carry out detailed studies, particularly with respect to the length of time (i.e. 1 year or more) needed to obtain an appropriate database. A minor reason is the limited experience of the hydrogeologic community in conducting such studies, especially with respect to the groundwater function and its relationship to the various components of the ecosystem. As more watershed studies are carried out, more experience will be gained both in the methodologies which are most appropriate and the level of detail (i.e. resource commitment) required for watershed and related studies. The collection of additional groundwater data can be relatively expensive (i.e. drilling of deep wells) or inexpensive (i.e. hand-driven streambed monitoring wells). The worth of the data must be balanced with the cost of obtaining it.

The quality of groundwater *information* is inherently based on the quality of the data and the resources available to assess those data. Most of the data available is related to surficial geology, not hydrogeology. As an example, detailed information on groundwater flow exists for only a few regional settings and numerous site specific settings (i.e. around existing and proposed landfills, in subdivision development, etc.). In Figure 4, the Task Group has rated groundwater information as "low" but increasing rapidly.

The groundwater *database* for the Province of Ontario is rather limited and disjointed. The database generally consists of:

- maps and surveys dealing with surficial geology;
- water well records which contain water levels and rather limited geologic records;
- a limited set of hydrogeologic surveys; and
- site-specific hydrogeologic and geologic reports.

There is no particular agency or "clearing house" where all of this information can be readily obtained and, at present, no practical method of knowing what data currently exist. Accordingly, substantial effort may be required in assembling the database for a particular study area. The more developed areas of southern Ontario provide for a substantial level of hydrogeologic data (i.e. water well records, development reports) but areas more sparsely populated and developed will have very limited databases. Monitoring programs which would provide historical and ongoing groundwater quality and quantity data are basically non-existent. The Task Group has rated data for groundwater assessment as "low" in Figure 4. However, current practice frequently calls for long-term monitoring programs in areas of groundwater demand and reliance.

3.6.2 Applications of the Science

Although scientific understanding with respect to movement of groundwater and the transport of groundwater contaminants was considered by the Task Group to be quite high, the ability to *characterize* groundwater flow systems and their interaction with surface linkages (i.e. rivers, swamps, terrestrial features) on a practical level remains somewhat limited and was rated by the Task Group as "medium" in Figure 5. This limitation is due to the potential complexity of the subsurface and the practical limitations of defining complex systems with discrete data points, regardless of the amount of data obtained. In practice, another frequent limitation is that localized groundwater investigations are conducted without a good understanding of the entire groundwater flow system, and without an understanding of the interrelationships among the various components of the ecosystem and groundwater function.

In addition to basic, very specific or restricted research (i.e. studies on the subsurface movement of dissolved benzene), many investigations are being carried out by both researchers and consultants that are holistically employing a wider variety of hydrogeological tools to assess larger scale groundwater flow systems. In addition, a large number of studies have been carried out over longer time frames which has allowed for a more refined characterization of generic groundwater scenarios. These approaches are increasing the ability to characterize groundwater systems.

With respect to *prediction,* the ability to identify groundwater responses to human activities (such as the pumping of groundwater or changes in surface features) as well as responses to natural factors (such as drought) is based to a great extent on the characterization of the system. Increasingly, computer models are being used to simulate such responses. It is important to recognize that although computer models are an excellent tool, the accuracy of model predictions is dependent on the validity of the model to a specific setting and the quality of the data that are input into the model. The basic assessment of historical groundwater data in settings where change has occurred may lead to relatively accurate predictions in similar groundwater settings where similar factors may be imposed.

Issue resolution with respect to groundwater issues was rated by the Task Group as "low" in Figure 5. The ability to resolve issues — to establish values and make choices relating to groundwater such as the location of a landfill site, or to use a surface water pipeline versus groundwater — has been very limited. To a large extent, this has been due to a lack of technical understanding on the part of the various stakeholders in the decision-making process and a mistrust of the science. More efficient communication is a necessity. Issue resolution is improving as the science and issues relating to groundwater are moving into the public domain and the stakeholders become more groundwater literate.

The Task Group rated *communication* of groundwater issues as "low" but improving strongly. Communication of groundwater issues has historically been considered complex. As a result, this has led to a lack of understanding on the part of decision-makers and a great deal of mistrust on the part of the public. In recent years, a significant amount of effort has been expended to attempt to better communicate the science of hydrogeology and groundwater issues so that well-informed issue resolution can take place. This has included the use of open houses, public advisory committees, educational programs, and other means.

With respect to *monitoring* groundwater conditions in watersheds, there is a high level of technical ability to apply appropriate and proactive monitoring regimes. This is, of course, assuming that basic groundwater resources and flow systems have been assessed prior to the implementation of the monitoring program. It is important that the monitoring program data be assessed on a regular basis and the monitoring program refined. Such refining does not necessarily mean the collection of additional data; it could also mean a "downsizing" of the program.

3.6.3 Integration Considerations

In watershed planning, the integration of the groundwater component to other ecosystem components is focused on the linkage of groundwater flow systems to the surface. Groundwater flow systems usually exist as a result of the infiltration of precipitation into recharge areas that are highly permeable and/or topographically high. In such recharge areas, groundwater will flow downward from the water table. Once in the subsurface, water flows through one or more hydrostratigraphic units and will eventually be received as baseflow by a surface water body (such as a stream, lake or wetland) within a discharge area. In a discharge area, the net flow of groundwater is upwards to the water table. Groundwater flow systems consist of a combination of small-scale (local and/or shallow) flow systems, intermediate-scale flow systems and large scale (regional and/or deep) flow systems.

A delineation of the flow system(s) in a watershed will identify where the groundwater originates (the source), where it discharges (the receptor), and the most prominent paths it travels between these points (the aquifer pathways or more permeable hydrostratigraphic units). Having done this, one can assess the relative sensitivity of the linkage from the groundwater system to the aquatic or terrestrial systems. Knowing the level of sensitivity, one can determine the impacts of particular types and scales of lands uses (i.e. subdivisions, agriculture, gravel pits, etc.) on the groundwater flow systems and other ecosystem components.

Significant linkages include:

- groundwater baseflow to streams to maintain fish habitat (e.g. spawning areas and areas of thermal refuge);
- groundwater discharge to various wetland features; and
- maintenance of water table levels for various terrestrial features.

The quality of the groundwater, and its subsequent maintenance, can be critical to the integrity of the above-noted receptors as well as for drinking water quality.

3.6.4 Key Areas for Improvement

For groundwater investigation within the context of watershed planning, there are three key areas in which improvements could be made.

- The establishment of an efficient database and "clearing house" for groundwater data and information would be cost and resource-efficient. Currently, a substantial amount of effort is expended searching for data and information during the early stages of watershed studies, subwatershed studies and site-specific hydrogeological studies. These data are often sitting in filing cabinets and data banks in dozens of agencies and organizations.

- The application of the ecosystem approach through watershed planning requires a increased level of communication and cross-disciplinary research among the various disciplines involved (e.g. with regard to fisheries and groundwater).

- The ability to accurately characterize and predict would be improved with a more detailed understanding of 1) the characteristics and sensitivity of the interaction between groundwater and surface water, and 2) the quantification and sensitivity of groundwater recharge.

3.7 Economics

3.7.1 State of the Science

In terms of *scientific understanding,* conventional economic analysis has been well developed over the past several decades. Unfortunately, in conventional economics, biases exist against the adequate valuation of natural capital and the costs of natural resource depletion. As economists (and others) began to recognize that economic development that erodes natural capital is often not successful, concepts and techniques for the valuation of environmental impacts and ways to explicitly consider them in the conventional economic calculus were developed — environmental economics.

Although "environmental economics" helped to incorporate ecological concerns into the conventional economic framework, it tended to focus on environmental problems as sources of specific externalities that could be traced and assigned dollar values. Environmental economic research emphasized population or species-level impacts and the economic values associated with them, but did not focus on ecosystem-level impacts. In answer to this, new innovative research approaches emerged. "Ecological economics", the interface of ecology and economics, emphasizes the relationships between ecosystems and economic systems (in the broadest sense), focusing on the problems facing humanity and the life-supporting ecosystems on which we depend. As illustrated in Figure 4, the Task Group has rated the science of economics as it relates to watershed planning as "medium".

In terms of the *knowledge base* (or how widely scientific understanding is shared), information about the science of economics is available through many sources including journals, workshops, conferences, etc. Because of its scientific and technical nature, the published economics "science", however, has tended to be in a form that is too complex for use by many practitioners. The Task Group has rated.knowledge base as "low" in Figure 4 for this reason. This situation, fortunately, is changing. As the societal goal of environmental, economic, and social well-being becomes increasing entrenched in the actions of everyday activities, the transfer of the economic knowledge base is necessarily moving from within the scientific community to the policy arena. More effort is currently being directed to having a "published science" that provides a constructive dialogue for the understanding of the interface between ecology and economics.

With respect to *current practice,* the economic assessment and analysis of resource management plans is rarely carried out and has been rated by the Task Group as "low". Too often, financial analysis is performed under the guise of completing an economic analysis. The result of this is a project evaluation or benefit-cost analysis that emphasizes the directly measurable benefits and costs that are important to the decision-maker. In those instances when economic assessment and analysis are undertaken, it is usually performed for a discreet application (e.g. to assess the impacts of an action on employment or to determine an action's contribution to the economy). This is due, in part, to the analyst (user) not being able to determine how economic and ecological interactions affect the measures of benefits and costs that "people" require.

To date, the lack of readily obtainable data has limited the role of economics in the assessment and analysis of various resource management options to the simplest of cases — conventional project economic analysis. Both *information* and *data* have been rated as "low" for economics. A comprehensive database that would allow the economic assessment and analysis of proposed resource management options does not exist. Universal protocols and standards governing the collection of economic data have also yet to be compiled. In most applications (e.g. watershed planning, land use planning, etc.) the data collected tend to be biophysical in nature. Where social and economic data are available, they usually relate to a geographic area based on administrative boundaries (such as census tracts or municipal boundaries) as opposed to areas bounded by natural features, such as watersheds.

The lack of readily obtainable economic data is also attributable to overlapping institutional responsibility and authority. Currently, economic data are collected by a variety of municipal, provincial, and federal agencies, boards and commissions, each with its own need and mandate. Many agencies (both public and private) function as vertical solitudes when it comes to data sharing, and data sit, unshared, in file cabinets and databases. Finally, because of its scientific and technical nature, when economic data are communicated, this is often in a form that is not readily useable by others.

3.7.2 Applications of the Science

An ecosystem comprises two components - the natural system and the social system. Just as, hydrology, morphology, etc. are sub-systems of the natural component, economics is a subsystem of the social component. While the state of economic science allows for a high characterization of the economic process in isolation, its ability to *characterize* the interactive processes of the environment, society, and the economy is low to moderate.

One of the requirements for watershed planning is the ability to *predict* responses in a system due to changes over time. The Task Group has rated prediction for economic science as "low" in Figure 5. One of the limitations of social system research is that a complete system can seldom be constructed. There are, however, several approaches available which would allow the interrelationships between ecological and economic systems to be modelled. The predictive powers of these models are, however, constrained by the fact that many changes in the environment are not realized instantaneously or in isolation. Changes in resource use at one location can have impacts across geographical resolutions that include both short and long-term temporal dimensions.

Scientists deal with issues of facts, philosophers with issues of value, economists with both. A sign of quality economic analysis is that facts and values are separated as much as possible in empirical analysis and reporting. When there is general agreement about facts and values there is consensus, so the role of economic analysis is simple — find the most cost-effective solution. Where there is agreement about facts, but not values, the best chance for a solution is negotiation among stakeholders. Economic analysis can be developed to support such efforts at *issue resolution.* For example, if resource management plans require a change in the current economic setting then economic instruments can be used to minimize the costs of attaining these goals. Economic analysis provides the means to calibrate instruments (taxes, tradable permits, etc.) that generate incentives to maintain or improve environmental quality. Accordingly, the Task Group has rated issue resolution for economic science as "medium".

The *communication* of the results of economic assessment and analysis is, for the most part, straightforward and has been rated by the Task Group as "medium". In private enterprise countries (as opposed to socialist and Third World countries) people are accustomed to markets and therefore respond to the economic system. However, having a clear message of the results of economic assessment and analysis to communicate is conditional on having the capability to convert ecological outcomes into economic terms.

The contribution of economics to the monitoring of change in natural systems is a subject of ongoing research. Over the years, a variety of methods have been developed for assessing the full economic value of the environmental functions provided by ecosystems. New treatments have been proposed for the National Accounts that can appropriately reflect changes in the uses, roles and capacities of natural resources and the environment. Also, extensive exploration has begun on possible socio-economic indicators of sustainability (e.g. the concepts of "ecological footprints"). The limiting factor to many of these concepts is the translation of ecological data into economic terms: for this reason, the Task Group has rated *monitoring* capabilities as "low" to "medium".

3.7.3 Integration Considerations

The natural resource problems faced today are often not the resource depletion or pollution problems that were of concern twenty years ago. Today's problems tend to take the form of pervasive environmental degradation and ecological disturbances that can push the economic-environmental system to its limits and beyond. In confronting these problems, decision-makers need to recognize the ecological-economic interdependencies of the parameters that characterize and influence the system. Therefore, to understand what "environmentally sustainable" development entails and how best to operationalize it requires the convergence of economic and ecological perspectives: the understanding and sharing of knowledge about economics, aquatic and terrestrial ecology and biology, hydrology, morphology and other related disciplines.

3.7.4 Key Areas for Improvement

Although considerable gains have been made over the years to bridge the gap between traditional techniques of economic decision-making and the more environmental sensitive approach, there exist substantial voids. The first of these gaps is the need to develop valuation methods that will convert estimates of health and ecological risks and environmental damage or protection into money-based measures of costs and benefits. Secondly, uncertainties as to the validity and usefulness of non-market valuation methods to ascribe dollar values to the complex functions of resources need to be resolved. Finally, economists need to address the question of uncertainty in forecasting costs and benefits that rely on long chains of arguments that are based on complex ecological economic linkages.

There is also a need to entrench economic assessment and analysis in the development of policy and in resource management decision-making. Until recently many resource managers held the notion that biological assessment and analysis should dictate resource decision-making and policy, despite the fact that the use and stewardship of resources is ultimately driven by society. Among the reasons for this was the unavailability of economic templates, frameworks and models that could reflect the benefits and sacrifices contained in policies and programs. Today, there exists extensive literature about economic models and measures that have been applied in jurisdictions outside of Ontario. These can be applied here.

3.8 Social

The terms of reference for subwatershed planning focus primarily on the physical and biological aspects of watershed planning. However, since the development of subwatershed plans is aimed at providing input to the development of municipal plans and other land use and development management instruments, there is a clear need to develop the social dimensions of watershed planning as they relate to the societal goals and objectives of both the province and the local community.

This section deals with the process of including the societal dimensions of the community within a watershed in the development of a watershed or subwatershed plan. This includes the definition of the watershed as people relate to it as well as defining the community of interest and the structure and activities of that community as related to the watershed. This encompasses the following:

1) social values as related to the watershed:
   - water ways;
   - fish and wildlife;
   - terrestrial habitats;
   - aesthetic value; and
   - cultural attachment (meaning).

2) indigenous (local) knowledge as related to the watershed:
   - floods and droughts as related to consequences for the community;
   - water quality as perceived by the community;
   - fish and wildlife populations as perceived by the community; and
   - land use change.

3) demographic and activity and social dynamics profiles as related to the community and the watershed:
   - demographic profiles and population projections;
   - social structure profiles (organizations and interests including social networks);
   - activity patterns and resource use; and
   - aspirations and preferences.

The role which social or community-based information plays in the development of a watershed plan is to define for the plan what the issues are for the residents of the watershed as related to the watershed, to define the priorities among these issues from the point of view of the residents, and to define appropriate options for dealing with the future development (conservation/ restoration) of the watershed. The social input to the watershed planning process is also one of information: increased use of "local knowledge" to focus and enhance more technical data is becoming an accepted way of developing models of the watershed and extending information.

Finally, community-based information is used to define who does what where, and what they would like to do in the future.

At present, the social input to watershed and subwatershed plans is included in a number of ways in a number of components of the studies. Thus it is integrated with these other components and does not appear as a single sector of the watershed plan. The objective of this section is to identify the current state of social input to subwatershed planning and to assess its current use in practice in Ontario's watershed and subwatershed planning initiatives.

The social input is gathered in a number of components and phases of the watershed planning exercise. It is a key component in identifying the issues in the terms of reference for the study. In Phase 1, it appears as part of the watershed description and background. It also appears in the context of the studies on land and water use in the watershed. In Phase 2, it is important in defining the parameters of the built components hydrologic system that influence runoff and water quality. In Phase 3, social information is required to define the appropriate development scenarios for the assessment of the cumulative effects of development in the watershed and the choice of strategies for management of impacts.

3.8.1 State of the Science

In terms of social *science,* the development of techniques for improving the social dimensions of planning in the context of watershed planning has progressed slowly. The Task Group has rated this area as "medium" in Figure 4. Major steps were made in the 1960s and 70s in the context of comprehensive watershed planning. More recent innovations in the area of community and participatory planning have begun to be felt in practice. Advances that have been made in other planning sectors (community development, sustainable development, and co-management) have largely not been incorporated into watershed planning.

With regard to *knowledge base,* practitioners have learned a great deal in the initial pilot studies with regard to the need to include the social dimensions of watersheds in the plan development process. These lessons have not been systematically documented in a form that is easily usable in practice, nor has this experience been widely communicated to practitioners. Except in the case of a few specialized individuals, knowledge of the field and the skills necessary to gather the data and use it in the planning process are not widely held. Knowledge base has therefore been rated by the Task Group as "low".

In terms of *current practice,* the inclusion of the social components in subwatershed studies has been limited and not extremely well done. When social dimensions are examined, it tends to be limited to descriptions of conditions rather than analysis of social processes and values as they relate to watershed resources. The experience of planning processes which have focused more on the social issues and problems of resource management (e.g. waste management and environmental impact assessment) has not been incorporated in watershed planning practice.

Information was rated by the Task Group as "low" in Figure 4. As compared with other types of planning such as community development planning and environmental impact assessment, the use of social process and structure analysis in watershed and subwatershed planning has been quite limited. This is largely attributable to the terms of reference and the mandate for watershed and subwatershed planning which has mainly been focused on the physical and biological dimensions of the problem.

The Task Group has rated *data* as low for the social dimensions of watershed planning. With the exception of data collected by Statistics Canada and a small amount of information collected by municipalities and service groups, there is little secondary social information available. Most data is therefore collected through interviews and questionnaires. Significant opportunities exist to use the public advisory process (an increasingly-important key to the success of subwatershed planning) as a means of acquiring some of the needed social information. Issues of confidentiality and reliability of information make it difficult to gather information and communicate the results of analysis to the public.

3.8.2 Applications of the Science

The Task Group has rated the ability to *characterize* the social dimensions of watershed as "medium" (Figure 5). Current practice in characterizing social structure and dynamics of a watershed consists of development of a demographic profile based on available statistics. More elaborate profiles including income, employment, education, and other variables are generally not used. The characterization of the resource use is derived from secondary sources (e.g. water use licences, and permits) and assumptions concerning the relationship between population and resource use (per capita unit usage). Occasionally, sample surveys and interviews are conducted to develop household profiles of usage and relationships. The development of household and enterprise usage systems is carried out. The current practice in watershed planning lags behind that in more community-oriented municipal and economic development planning in terms of characterizing the social dimensions of the planning problem.

Social research in watershed planning focuses on defining the human/environment interactions and developing a participatory planning process for watershed development. In the area of human/ environment interactions, research focuses on several areas: environmental health research, resource management systems, and community-based resource management (co-management). Elements of this type of research are used in the public participation process in some subwatershed studies. The use of resource management systems in subwatershed planning is not widespread due to problems of defining the management (decision-making units) appropriately and getting appropriate data. Community management approaches have been incorporated into forestry planning, but have not been widely used for watersheds in Ontario. Community management is used in Manitoba and is the model for total catchment management in Australia.

With respect to *prediction,* the Task Group rated social assessment as low" and improving slightly. At present, the state-of-the-art in development of social impact assessment for watershed planning is very limited. We are at the stage of development of indicators of social impact and descriptive assessment of the relationship between the environment and social change.

Issue resolution for social aspects of watershed planning has been rated by the Task Group as "moderate". The ability to resolve social issues in watershed planning is not directly part of the development of a subwatershed plan: it is more directly involved in the implementation process. Resolution of social issues is however addressed through the assessment of different development scenarios and the consequence of these scenarios for the socially valued components of the watershed. Much has been drawn in this area from the experience of environmental impact assessment.

The Task Group has rated the *communication* of the social dimensions of watershed planning as "high". This has been well-developed in various sub-disciplines such as recreation, landscape aesthetics, institutional and organizational planning and resource management. While in each subdiscipline social dimensions are communicated well, major problems exist in the integration of these sub-areas in the context of a human ecosystems approach to watershed planning. In this context — the role of a watershed in community identity and in relation to quality of life issues — the information issues and consequences are not well communicated.

In general, there is little or no direct *monitoring* over time of social values, knowledge, needs or resource use within the context of watershed planning. Such things can be measured, however, through direct means (polls, user counts, etc.) and through indirect means (monitoring participation levels in community-based environmental projects or recycling programs). The incorporation of social monitoring into overall watershed monitoring will give an understanding of changes in resource and recreation needs, changes in attitudes towards the environment, and the development of a stewardship ethic.

3.8.3 Key Areas for Improvement

There is a significant need to improve current practice as it is applied to watershed planning. The social component of watershed planning is usually couched in the context of public participation in meetings and reviews, and in public education that accompanies the technical components of watershed planning. Practitioners could draw on the experience gained through other applications such as environmental assessment and community economic development. Improved application of social science to understand public values, needs, desires and knowledge will spin off into increasingly effective public participation in the planning process.

3.9 Mapping and Data Management

3.9.1 State of the Science

The *science* of mapping and the management of data as it relates to Geographic Information Systems, as well as the tools available — the hardware and software which allows data to be stored, retrieved, manipulated and mapped — has advanced considerably in the last three to five years. This was rated by the Task Group as "medium" in Figure 4. Currently, there are several digital and Geographic Information Systems (GIS) that are available for use in watershed and other planning initiatives. It should be noted, however, that the integration of data management systems with mapping systems is still not well understood.

With regard to *knowledge base,* or how widely scientific understanding is shared, only a few firms in Ontario currently possess all the skills needed to work efficiently with both data management systems and GIS systems. Limitations include: the inability to transform information from one platform such as ARCINFO to another such as SPANS; difficulties with the integration of data management systems such as QUATTRO and LOTUS with GIS systems; and the inability to use GIS models together with other technical tools *(e.g.* ARCINFO with a hydrologic model). As shown in Figure 4, the knowledge base for mapping and data management was rated by the Task Group as "medium".

The *current practice* of mapping and data management was rated by the Task Group as "low" and is limited by the following:

- lack of basic understanding with respect to the potential of GIS or GIS/data management systems;
- lack of hardware or software to appropriately employ the systems (both in the private and public sectors);
- lack of skilled technical personnel; and
- lack of a consistent standard by which GIS can be uniformly employed.

With respect to *information,* mapping and data management were rated by the Task Group as "high". GIS information, if available, may be used to answer, in a graphical manner, a considerable number of issues that frequently arise in subwatershed studies. For example, the location of significant terrestrial features, aquatic resources and their relationship to recharge/discharge areas may be clearly illustrated on one map. Data management systems may be used to summarize key findings from a study (e.g. the characterization of plant species within a given woodlot).

With respect to *data,* there is currently a lack of good, small scale (1:2,000) mapping in non-urban areas. As a result of this limitation, the relative accuracy of the mapping is frequently questioned, as is the usefulness of the results in future, more detailed assessments. There is a need, as well, to develop metadata standards, and ensure that collected data are easily obtained. Data was rated as "medium" by the Task Group.

3.9.2 Applications of the Science

As illustrated by its "high" rating in Figure 5, mapping and data management are extremely powerful tools for *characterizing* the existing state of the environment. Typically this is done through the presentation of a series of digitally based maps (e.g. terrestrial systems, recharge/discharge areas) together with a summary, in database form, of the monitoring and field information that was collected during the course of the project.

If the data and information as well as the technical skills are available, it is possible and quite useful to use mapping and data management for *predictions* of responses to future changes. This has therefore been rated by the Task Group as "medium" in Figure 5. Mapping may be used to:

- overlay different maps in order to establish interrelationships: e.g. Are wetlands located in significant recharge or discharge areas?; and

- to answer "what if'?" questions: e.g. What would the land requirements be if all class 1-6 wetlands, woodlots greater than 4 hectares, and significant recharge areas were protected?

In terms of *issue resolution,* graphical representation is especially beneficial for the purpose of relaying findings to the client and to the public at large, and has been rated by the Task Group as "high". However, care should be taken to ensure that the relative accuracy of the information is clearly understood.

Mapping may be used to succinctly and effectively *communicate* complex issues to the client and/or public. Examples include maps that illustrate areas which are developable, which may be developable subject to further study, or are considered non-developable. Another example may be mapping which ties together recreational, open space and terrestrial strategies. The Task Group has rated communication as "high" for this category.

Monitoring was rated by the Task Group as "high". A critical step in the development of monitoring systems is to define what monitoring data will be incorporated into the data management system. For example, key indicators (e.g. total copper concentrations in surface waters) that have been collected for a considerable time should be incorporated. Snapshots (onetime only data sets) which have no statistical value, may not be useful in terms of monitoring.

3.9.3 Integration Considerations

Integration considerations for this component are discussed in detail in the Integration section (3.10). The physical process of providing mapping and integrating data requires the various disciplines to provide information in digital or other forms at an appropriate detail to be used by other disciplines, (e.g. the provision of terrestrial information such that it may be used to define aquatic habitat requirements).

3.9.4 Key Areas for Improvement

Key areas of improvement include training of technical staff, upgrading hardware and software capabilities, and ensuring that all data (whether collected during the study or from an outside source) are consistent, usable by all sectors and easily available in the future (possibly through a provincial agency). Other areas for improvement include developing a consistent standard by which GIS can be used by a majority of users, and ensuring that the relative level of accuracy of GIS is understood by all parties.

3.10 Integration

Why is there a need for integration in watershed planning? In simple terms, integration is needed because the total (the watershed with its air, water, land, humans and other living things) is greater than the sum of its parts. Studying the component parts of a watershed — streams, water quality, groundwater, aquatic systems, terrestrial systems, human uses — in isolation from each other does not allow us to adequately characterize the existing system, or make predictions about the future. Integration is the study of the complete system (the watershed, its components, and their interrelationships). In terms of future planning, decision-makers need to know how groundwater consumption (for example) will affect streamflow and water quality and aquatic communities and well water and recreational use of water resources. As outlined in Section 2.1, all of these components are interconnected in complex, subtle, sometimes unknown ways. In order to achieve sustainable use of water and related resources into the future, we need to understand the interrelationships of the physical, biological and chemical components of watersheds through integration of information across disciplines. Integration is very important in the watershed planning process, and should be a planned occurrence in watershed planning studies.

Integration in watershed planning is both a process and an evolving discipline — a science that is a cross-discipline examination. As a discipline, integration is a very young science. However, as articulated in Section 2.2, an integrative approach to watershed planning can be considered to have a number of discrete steps:

1) Overview the system (identify what resources, habitats and human uses exist and where);

2) Define the structure, the effective linkages of the system, and key components to be studied (i.e. functions);

3) Reduce the system to its constituent components for the purpose of scientific study;

4) Study the component parts (hydrology, groundwater, aquatic systems, etc.);

5) Re-aggregate the system; and

6) Re-evaluate the overview focusing on interrelationships and the whole system.

Care must be taken to ensure that the system overview is properly formulated upfront (i.e. that the problem is properly defined). The major difference between the integrative approach outlined above and traditional forms of resource planning is the emphasis on linkages in Step 2 (including external influences from outside the watershed boundaries), and the re-aggregation and reevaluation of the system in Steps 5 and 6. The study of the component parts in Step 4 is carried out with a respect for linkages (e.g. by having constant communication between study team members as they carry out their tasks).

Conceptually, the science of integration is synonymous with "systems analysis". The use of a systems analysis in watershed planning has been slowed by a reliance on the traditional reductionist approach to scientific research, and by administrative and jurisdictional barriers (in particular, the fragmented distribution of responsibilities for environmental management). Systems analysis has long been applied to water management questions such as reservoir optimization to arrive at recommendations on how multiple, often competing objectives, can best be met. Critical elements in systems analysis include:

- having a clear definition of the desired management objectives;
- preparedness to make trade-offs, and acceptance that all of the identified objectives may not be possible to achieve, (this implies the establishment of priorities or weights amongst objectives); and
- accurate assessment of alternative strategies against evaluation criteria that are directly related to the established objectives.

The greatest technical challenges on integration lie in having the tools and techniques to allow re-aggregation and re-evaluation. Some of the tools available for such integration are:

- Spatial Analysis (GIS)
- Models for Pathways Analysis
  - Flood Flow
  - Water Balance
  - Water Quality Mass Balance
  - Habitat Suitability Index (HSI), Index of Biotic Integrity (IBI)
- Time Sequence of Change
- Hierarchial Frameworks (Scale Dependent)
- Trade-off Analysis (McHarg-Overlaying Matrix)

How well the science of integration is understood and applied is covered in the next sections.

3.10.1 State of the Science

The *science* of integration was rated by the Task Group as being "low" but evolving rapidly, (see Figure 4). While significant scientific understanding exists in all of the individual disciplines that are applied to watershed planning, there is still insufficient scientific understanding of how to integrate across these disciplines. This is largely a function of specific scientific disciplines that tend to become isolated from other disciplines, or to become highly-specialized and narrow as they develop.

To date, there does not exist a stand-alone scientific discipline that integrates all of the individual disciplines involved in watershed planning. However, through the use of integrated technologies such as expert-systems and GIS, we are now able to approximate the natural interactions between air, water and land in the environment and the influences that the natural boundaries have on these interactions. The process of integration requires a change in how people work and think, and it requires a non-traditional organization, made-up of an inter-disciplinary team of specially trained people.

Integrative processes are underway in Ontario through various planning initiatives (the Oak Ridges Moraine, the Waterfront Regeneration Trust, Planning Reform, etc.). However, there is not strong evidence for the same integration occurring within and among disciplines at the site level. Integrated ecosystem planning requires the use of a rational analytical approach in which systems analysis is used to predict problems, actions and their consequences (such as cumulative effects). One such system is the RAISON expert system developed by Environment Canada. The science also has to consider the question of socio-economic and ecosystem sustainability as a goal (or a vision statement), recognizing the system's complexity and the interconnections of its elements.

The Task Group rated *knowledge base* for integration as "low". Knowledge base consists of factual and inferred knowledge, and the rules and methods for describing relations and functions of phenomena (i.e. the knowledge for solving issues and problems in a system). Practitioners working in the field of integration need access to a pool of information (and data), or knowledge base, in order to be capable of inferring conclusions from the available information.

The *current practice* of watershed management has evolved over a number of decades. Watershed management is not new: as early as the late 1960s, many metropolitan areas were carrying out elaborate plans that included resource management on a watershed basis, with the goal of controlling point and non-point source pollution. However, most of these plans remained as plans — unimplemented — or emphasis was put on improving sewer systems and sewage and waste water plants. Current practice with respect to integration can only be rated by the Task Group as "low". Integration is generally done without rigour and without consideration of all disciplines. In particular, integration of the natural sciences and socio-economic sciences is poor. Despite this, the Task Group believes that integrating resource use and land use planning on a watershed basis remains a powerful approach that is capable of preserving the ecological integrity on which all life depends. Human values are an integral part of the decision to protect or rehabilitate systems, however, the goals and objectives for such actions are still implicit, rather than explicit.

Information with respect to integration was rated by the Task Group as "low". Because the science of integration is still in its infancy, (albeit evolving quickly), little information exists to demonstrate how ecosystems function and change with respect to the impacts of land use.

The Task Group rated *data* for integration as "medium". Readily obtainable data sets exist for most of the disciplines involved in watershed planning and to a lesser degree for the disciplines of social and economic science and stream morphology. Until recently, the integration of these data across the separate disciplines to support holistic environmental assessment was nearly impossible. However, data management techniques such as the increasingly widespread use of digital datasets and the storage of datasets in de facto standard formats provide the technology for accessing biophysical data. Data limitations are especially noteworthy for data pertaining to social, economics, health, industry or other related human activities.

3.10.2 Applications of the Science

As illustrated in Figure 5, the characterization, prediction, issue resolution, and communication were all rated "low" by the Task Group for integration. However, rapid improvements in the application of the science of integration could be achieved through various means including:

- by recognizing that integration is both a discipline and a process;
- by synthesis of data sets before starting a watershed study;
- by having provincial and regional scale databases developed and used as a basis for defining what is located where;
- by considering sustainability as one of the central "vision" elements;
- by developing scale-dependant questions which consider the type of information and complexity of information needed to address scale-dependant issues; and
- by conducting ecological analysis as a value system, and then incorporating it into a human value-based trade-off analysis.

Characterizing a system means not only to identify the ecological, physical, chemical and biological issues, but also the human ones (socio-economic, cultural, political and policy).

In systems analysis we are not dealing with an objective science, but with perspectiveness, or with a value system, which is central to the evaluation process. Further development in characterization would improve methods for developing an overview of ecological systems.

The integrated systems approach has to address all the above, and has to study, monitor and synthesize all the data, in order to gain an understanding of complex environmental issues. Central to this theme is the need to analyze multi-score datasets, which contain a number of different attributes from different information sources for a given location (e.g. a watershed).

While *prediction* or forecasting techniques are well-defined for specific disciplines such as hydrology, they are not for combined physical-chemical-biological questions. Ecological models must be able to define what the environment contains, how it functions and is distributed, and what relationships exist. These models are generally not used in watershed planning. The current state-of-the-art is to use hierarchical models and semi-quantitative techniques. Some macro-scale correlations are available to link cause and effect and which allow predictions to be made with some degree of certainty. An example of this is the correlation between surficial geology and brook trout habitat in some regions. Specific hydrological models are sufficiently deterministic to be used with confidence for peak flow questions, but models for ground water/surface water interactions are not as well validated for use.

It is no longer sufficient to simply predict the rise and fall of populations or changes in water quality parameters: we must be able to predict how changing populations and water quality parameters affect other parts of the ecosystem (e.g. aquatic or terrestrial communities, riparian systems, and groundwater). A cumulative effects assessment can be modelled by using spatial dynamic models that also provide the ability to work with entirely synthetic environments of any predetermined complexity. However, few data sets exist which allow such models to be tested against the "real system".

Issue resolution can be improved by defining how information and data will be used. Issue resolution not only requires a good understanding of the individual scientific disciplines, but also of integration, both as a scientific (systems analysis) discipline, and as a decision-making process to resolve a variety of issues. These include:

- applying sustainable development principles with respect to conflicts and uncertainties;

- evaluating ecological requirements, human values and biophysical limitations; and

- multiple planning initiatives such as watershed planning, land use planning, environmental assessment, infrastructure and transportation planning, etc.

Communication provides the mechanism by which the experience and knowledge gained from this process are conveyed to staff, other agencies, organizations and to the public. It is important to use all the knowledge and experience gained, in order to maximize cost savings and minimize duplications. Having a cost-effective communication systems is vital. However, the rating for communication of integration is "low". This is attributable to a number of barriers:

- lack of will by organizations to exchange data/information;
- lack of adequate decision- making organizational structures;
- lack of recognition by decision-makers to make structural changes to the organizations and operational procedures (e.g. an overemphasis on technological planning without due consideration for long-term management issues); and
- lack of systems support/staffing.

It needs to be recognized that the integration process (as offered by the available technology such as GIS) is not strictly a technical issue, but also an institutional one. As such, it requires a management of user expectations (user needs, available resources and cost/benefits). Organizational changes are often slow and difficult to achieve and can lead to failure of a project for reasons other than technical ones.

Monitoring for specific components of watershed planning studies varies widely in terms of its systematic character, the resources allocated, and the application of results. Monitoring for integration was rated by the Task Group as "low" because it has never been applied widely in watershed or subwatershed studies. However, monitoring is a well-developed science that is routinely applied for many different purposes (i.e. for monitoring compliance, failure, performance, environmental baseline data, model calibration, state of the environment, etc.). Monitoring efforts in watershed and subwatershed planning will be improved by applying a rigorous process:

1) <u>Define the goals of the monitoring program</u> (including the purpose of monitoring, the environmental issues to be addressed, and the means to determine at what level detected changes are "environmentally significant").

2) <u>Determine specific monitoring study questions</u> (e.g. the questions may describe comparisons between areas, spatial gradients, and/or changes over time).

3) <u>Design the monitoring study to address the objectives.</u> A monitoring program should identify key parameters, sampling locations, and numbers of samples required to obtain a defined level of quality assurance. Quality assurance

includes defining the number of samples needed to detect changes in a "noisy" data base, and stipulating field sampling and laboratory protocols needed to assure the quality of data. There are four elements involved in this stage:

- determine the level of effort;
- perform a systematic analysis;
- specify initial monitoring program elements; and
- evaluate the initial monitoring program and finalize.

4) Interpret the data. The data should be gathered, examined for quality, synthesized (parametrically and statistically), and then used to address the goals and objectives of the monitoring program. The interpretation phase should include the following:

- Did the monitoring program adequately address the objectives? (yes or no)
- If "yes", is there an effect? (yes or no)
- If "yes", is remedial action required?
- If "no" is answered to either question, the monitoring objectives or the monitoring program itself should be refined for the next monitoring program.

5) Define next monitoring program. A monitoring program may be needed at a much lower level of effort for a period of time, or perhaps field work should cease pending future review. These decisions should be made at this stage.

A final consideration of monitoring is that it should be remembered that some environmental resources and issues will need to be monitored at a scale larger than that of the watershed. The significance and quality of elements such as terrestrial linkages and connection points, wetlands, rare or endangered habitats and valleylands require monitoring at a landscape scale.

3.10.3 Key Areas for Improvement

State-of-the-art integration needs to be sustained in several practical ways and in the universities. The recognition of evolving interdisciplinary fields and implementation of practical measures for auditing the evolving fields will greatly assist quality control and watershed planning efforts. Some of these measures include:

- An insistence by WPI managers that problems must be addressed by teams of different disciplines in field walks and data analysis.

- Professional structures which evaluate key "new fields" and the work of novices.

- Professional self-evaluated successes and deficiencies.

The need to enhance and improve environmental conditions and values introduces the concept of using environment assessment in watershed planning. Traditionally, consideration for the environment by land use planners has been primarily, if not exclusively, concerned with settlement patterns, economic development strategies and building design: if the environment was considered at all, it was only in fragments. The consideration for environmental planning has been slow to come, but the integration of land use planning and environmental assessment, is a way to resolve environmental issues. Project level assessment cannot deal adequately with cumulative and synergistic environmental impacts which are required in integration. The overall result of current practice in the environmental assessment process, as undertaken by municipalities, has been a piecemeal approach to protecting the environment. Most ecological components (e.g. habitats) were neglected as they have no immediate use or benefit to humans in municipal settings.

The essential elements of an integrated approach to land use planning and environmental assessment include:

- the identification of the most Valued Ecological Components (VECs);

- the identification of environmental impacts of current and proposed activities, including cumulative effect assessment; and

- the identification and evaluation of the significance of these impacts.

This approach considers the impacts of land use on a watershed in its entirety, and requires environmental assessment practitioners to retrace the work of planners to confirm or refute the interpretation of the environmental factors and their decision-making trade-offs. This will require major changes in the planning approach and additional research in this area. Essentially, an integrated ecosystem-based planning approach combines the environmental assessment process directly with the planning process, thus creating one process. The requirement under the federal Environmental Assessment Act to assess cumulative effects challenges the scientific basis of environmental impact assessment to advance the theoretical understanding of and to develop methodologies to evaluate cumulative effects.

4.0 OBSERVATIONS AND CONCLUSIONS

The Science and Technology Task Group's mandate was to document state-of-the-art science related to watershed planning, and examine its relevance and application in Ontario. In carrying out its assessment, the Task Group many made observations about areas of strength and weakness, areas in which improvements are needed, and initiatives that could support watershed planning in the province. These are scattered throughout the report, especially in Sections 3.0 to 3.10 in which each scientific component of watershed planning is analyzed. This section of our report outlines some key observations. However, it is not intended to be complete by itself, and should be read in conjunction with the body of the report.

An ecosystem approach to planning is necessary for the achievement of a sustainable environment.

Characteristics of an ecosystem approach include: consideration of environmental, social and economic needs; a focus on interrelationships amongst ecosystem components; the use of ecologically-significant boundaries; and a recognition that ecosystems have limits to the stress that they can absorb. The Science and Technology Task Group has no doubt that the adoption of an ecosystem approach to planning is vital to achieving a sustainable environment. In our experience watershed planning, which uses the hydrologic cycle as the pathway that integrates physical, chemical and biological processes, is one major approach to achieving the goal of a sustainable environment. Most of the elements of watershed planning (e.g. issues associated with fisheries, groundwater, surface water, stormwater management) are already required within the context of the existing provincial planning framework, as part of the development of official plans or official plan amendments, (see Figure 6). Watershed planning (ecosystem analysis and planning on a watershed basis) provides the opportunity to address these issues in a holistic, integrated fashion and provides a context for understanding sustainable ecosystems. After watershed planning has been done, specific decisions or proposals can be examined within the context of the overall sustainability requirements of the system.

Significant progress has been made in the science of watershed planning.

The watershed plans of today are aimed at maintaining and enhancing the natural system. They have evolved from the Master Drainage Plans done in the early 1980s that were more narrowly aimed at minimizing the impacts of developments, (see Figure 7). In the last 15 years, considerable advances have been made in terms of process, scope, understanding of natural systems, and application of scientific knowledge. Practitioners have made significant strides forward in the use of GIS as a tool for understanding, communicating and predicting environmental conditions. A new science of integration is emerging, and we are beginning to have "experts" in the integration area. In general, a lot of innovative, semi-empirical applications of science are occurring in the field. These innovative approaches are not always well-understood, and are not well-communicated to others. Areas of scientific and technical progress are described throughout Sections 3.1 to 3.10. Figures 4 and 5 provide a snapshot of the state of the science and the state of its application for the identified scientific components of watershed planning using a rating system of "high", "medium" and "low".

In the last two years alone, some 60 watershed or subwatershed plans have been initiated. Some good quality watershed and subwatershed plans have been developed in the province — plans that break new ground in applying an ecosystem approach to planning. While none of these plans are likely perfect, they provide decision-makers with a much improved, systematic information base for incorporating environmental considerations in land use planning — an information base that allows them to make better-informed decisions and choices about trade-offs. In short, improvements in watershed planning have led to much improved and relevant product.

The Watershed Planning Initiative has provided needed guidance and resources.

Since June 1993, the WPI has provided much-needed guidance through the release of the documents, *Water Management on a Watershed Basis, Subwatershed Planning,* and *Integrating Water Management Objectives into Municipal Planning Documents.* The WPI has engendered an enhanced scientific focus on watershed planning and how best to do it, and its resources have allowed and encouraged scientific progress to be made in many areas of application. The WPI evaluation, of which this report is a part, is an important element that allows critical self-analysis, retrospective assessment of progress made and gaps that need to be addressed, and peer review.

Further clarification and guidance is needed in some areas.

In the opinion and experience of the Task Group, guidance from the Province is required in some areas as outlined below.

1) **Clarification of what watershed planning is:**
Across the province, expectations of watershed planning vary widely among stakeholders and decision-makers. This may be expected as we are dealing with a new, and rapidly evolving planning process. The Province, however, needs to be very clear about what watershed planning can achieve. The Province should also provide increased guidance with respect to what is entailed in watershed and subwatershed planning: the level of effort and detail required, the major issues to be addressed, the appropriate scale at which issues should be addressed, the level of resolution to be used and how the end product can be used. This needs to be communicated effectively to Conservation Authorities, municipalities and others involved in watershed planning.

2) **Acknowledgement that there are many types of watershed plans:**
The WPI guidance documents prepared by the Province focus on one type of

watershed planning — that which is driven by rapid land use changes. There are, however, other reasons for watershed planning that have given rise to approaches that vary with respect to emphasis, scope and issues addressed. Some approaches to watershed planning and their major emphasis are:

i) Environmental Resource Management
These are watershed plans that emphasize environmental protection and management. An example is the Credit River Watershed Management Plan.

ii) Land Use Changes and Environmental Management
Environmental/Land Use Strategies are carried out to determine where land use changes will occur in urbanizing watersheds. These studies focus on minimizing the impact that land use change has on the environment. Examples are the Laurel Creek and Hanlon Creek subwatershed studies.

Land Use Impact Assessment analyses are used to determine how land use changes will occur in areas that have already been designated for change but not yet developed. Examples include Brampton's Eastgate and Fletcher's Creek.

iii) Land Use Management
Watershed planning can also be carried out in areas where there is no expected major change in land use, but where land use management changes are expected. An example is the Maitland Ecosystem Health Study.

iv) Redevelopment/Restoration
Watershed planning is also beneficial areas which are already largely developed. In such areas, the emphasis will be on improving ecosystem health including habitat restoration. Examples of such studies are being carried out in the Don Watershed and in the City of Etobicoke.

Provincial documents should acknowledge different approaches to watershed planning and provide guidance to users with respect to how such approaches may differ in emphasis.

3) Improved management of Phase 1:

A common problem in watershed planning is an overemphasis on Phase 1 (the characterization phase) in terms of time, effort and dollars spent. This is usually attributable to study teams underestimating the costs of data collection. Too often, the lion's share of the project budget is spent on the characterization stage (Phase 1), leaving too little for scenario development and issue resolution. Pre-screening to identify data needs, availability and costs of collection may assist in controlling these costs. Alternately, the collection of baseline environmental data can be done separately, before the watershed plan itself is carried out. The Province can provide useful guidance in this area to those involved in watershed planning.

4) **Improved issue resolution:**
In the watershed planning process, conflicts often arise. This occurs when provincial policies conflict (e.g. agricultural preservation vs. housing policies), when social values conflict with environmental needs (e.g. the desire for development vs. the need to protect a wetland complex), or when watershed plan recommendations conflict with existing Official Plan policies (e.g. a habitat block is identified as key terrestrial element, but it is zoned for future residential use). As practised now, watershed planning doesn't address issue resolution well: there are no guidelines for aiding decision-makers, and inadequate time and money are spent on this important element of planning. In addition, making decisions about trade-offs is often left to technical and scientific consultants to do. Issue resolution is a political and public process, not a scientific process. Watershed planning guidelines should be clear on this matter. Scientists and technical staff can identify issues and predict consequences of activities, but issue resolution is the responsibility of elected officials in consultation with the public. Improved issue resolution also requires increased efforts to educate the public and decision-makers about environmental sustainability and the need to consider sustainability when making trade-offs, and the uncertainties associated with making predictions about the future.

For three components of watershed planning — aquatics, hydrology and water quality — current practice generally reflects the state-of-the-art science.

1) **Aquatics:**
The assessment of aquatic systems and communities within a watershed is supported by a substantial foundation of science in the fields of aquatic ecology and biology. Significant amounts of data exist from federal and provincial monitoring and assessment programs. The current practice in watershed and subwatershed planning with respect to aquatics was rated by the Task Group as reasonable. A major area in which the lack of scientific understanding limits current practice is with respect to the ability to make predictions about the impacts of land use changes on fish habitat. Notwithstanding this need, some descriptive predictions can be made by practitioners using information from other watersheds that have been studied as they underwent urbanization and change.

2) **Hydrology:**
The scientific understanding of hydrology and the hydrologic cycle is high, and hydrology is currently well-applied in watershed and subwatershed planning. A considerable database for Ontario exists for most of the major watercourses in the Province. The ability of hydrologists to characterize systems, predict future states and monitor changes over time is also high. A primary area in which the science could be improved is with respect to groundwater and surface water interactions.

3) **Water Quality:**

Of all the scientific components of watershed and subwatershed planning, water quality is one of the better understood. The current practice is roughly reflective of the state-of-the-art science. A substantial amount of data exists for large watersheds, but this is not so for small urban and rural watersheds. With an adequate information and data base, watershed planning teams can characterize water quality conditions fairly well. However, the ability to predict the impacts on water quality due to watershed management proposals (such as land use changes) remains fairly weak. Current practice would be improved by strategic approaches to gathering information, the development of technical manuals for water quality assessment, the development of an inventory of water quality databases, and an enhancement of the Province's water quality monitoring network.

For six components of watershed planning — terrestrial, stream morphology, groundwater, economic, social, and mapping and data management current practice does not reflect state-of-the-art science.

1) **Terrestrial:**

For the study of terrestrial systems, current practice lags significantly behind the science, particularly as it deals with linkages. This is attributable to the time lag in the shift from focusing on areas of habitat to systems of habitat. Enhanced use of GIS would assist terrestrial ecologists in making this shift, and would improve their ability to analyze and predict impacts of habitat change in watersheds.

2) **Stream Morphology:**

The current practice of fluvial geomorphology lags behind the science with respect to the understanding of interactions between upland hydrologic and sediment regimes and channel form. Stream morphology, as practised, is often focused solely on "river engineering" — the study of the geotechnical and hydraulic properties of channels as they relate to channel stability and flood capacity. Improved communication among practitioners, and clear requirements to study stream morphology broadly will help to move the application of the science forward. Improved predictive modelling is also needed, in order for practitioners to be able to quantitatively predict channel response to changes in driving mechanisms.

3) **Groundwater**

The application of science in the assessment of groundwater in watershed and subwatershed planning lags behind the science. This gap between scientific knowledge and application is in part due to the lack of funding to carry out detailed studies. It is also due to the limited experience of the groundwater community in assessing the interactions between groundwater function and other components of the ecosystem (e.g. fisheries). As more watershed studies are carried out, experience will be gained in which methodologies are most appropriate, and the level of detail needed.

4) **Economics:**

While the science of economics has made significant progress in its ability to value environmental impacts and resources, current practice in watershed and resource planning is inadequate. Economic assessment and analysis has yet to be entrenched in policy development and resource decision-making. Too often, financial analysis of the directly measurable benefits and costs that are important to the decision-maker is carried out in place of an economic analysis which would address the broad range of ecosystem-level impacts. From the science side, data collection for economics is problematic, as data are collected by a wide range of agencies and are not shared. The current ability of economists to characterize systems and make predictions about future states is limited. Major scientific gaps that need to be filled include the development of valuation methods that will convert estimates of health and ecological risks and environmental damage or protection into money-based measures of costs and benefits. Second, economists need to resolve the uncertainties around using non-market valuation methods to ascribe dollar values to resource needs. Finally, economists need to address the uncertainties resulting from forecasting costs and benefits based on complex ecological economic linkages.

5) **Social:**

The application of social science in watershed planning lags behind both the science, and its application in other planning fields such as community development, waste management and environmental impact assessment. This is in part due to the terms of reference for watershed and subwatershed planning which have been mainly focused on the physical and biological dimensions of the problem. Those carrying out watershed plans would benefit from a clear statement from the province as to the scope of social study that is expected in the process.

6) **Mapping and Data Management:**

While great strides have been made in the science of mapping, the management of data, and the development of tools such as Geographical Information Systems, current practice in watershed planning lags behind. This is due to a number of factors:

- lack of basic understanding with respect to the potential of GIS or GIS/data management systems;
- lack of hardware or software to appropriately employ the systems;
- lack of skilled technical personnel; and
- lack of a consistent standard by which GIS can be uniformly employed.

The above barriers can be overcome through improved communication amongst users, enhanced training of technical staff, upgrading of hardware and software, and steps to ensure that data collected are consistent, usable by all sectors, and available in the future.

A common theme in the Task Group's assessment of science as applied to watershed planning is the difficulty and high cost of obtaining data. Study team members can spend long hours tracking down existing data, gaining accessing to it, and converting it to a useable form. Short of setting up a centralized databank — a concept that seems unlikely in this economic climate — the best solution seems to be to set up one or more centralized clearing houses for relevant data. Such clearing houses would list what is available where, and what form the data are in, (that is, data would continue to be kept and managed by its individual owners). To function effectively, such a clearing house would need to be supported by an agreed-upon data entry and input system to ensure compatibility of data, and protocols for access and accuracy. The Task Group believes that core watershed-related data should be viewed as an essential part of the province's information infrastructure, and should be made available at minimal costs to users.

For one component of watershed planning — integration — the science itself is new, but emerging quickly.

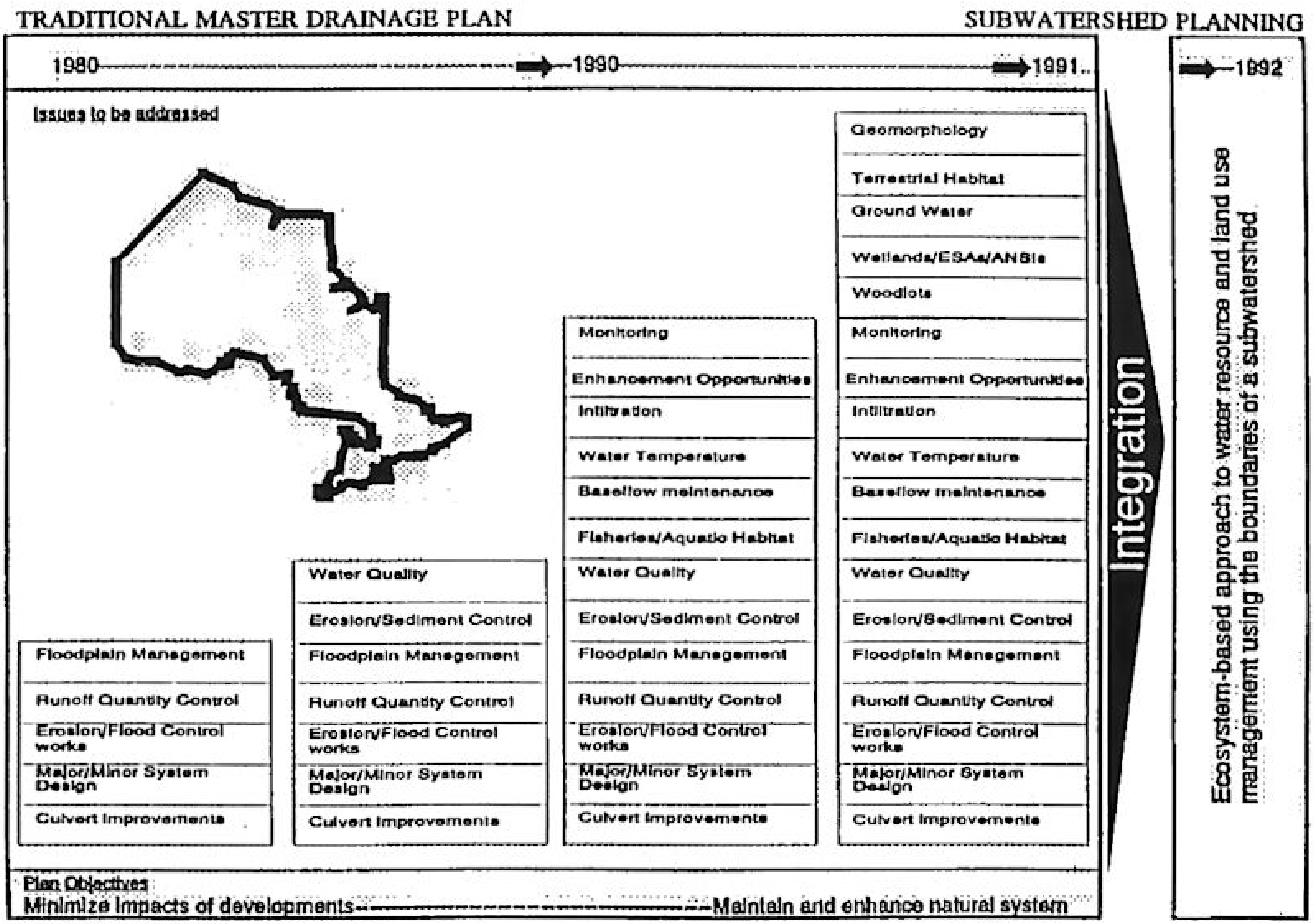
Integration is the study of the complete system (the watershed, its components, and their interrelationships). As noted in Section 3.10, integration is both a new science that is evolving rapidly and a process. Because the scientific knowledge and the knowledge base for integration is quite limited, current practice could only be rated as being "low". At present, the application of the science of integration in watershed planning is variable, and often rudimentary. Improved tools (such as GIS) are needed, as are institutional changes. The development of professional structures in the field (i.e. programs leading to degrees in integration) would improve the science. Self-evaluation of successes and failures such as an analysis of how integration has been addressed in existing watershed and subwatershed studies — would be useful to those working in the field and would help to develop more effective approaches. Enhanced communication amongst those working in the field would also help increase the knowledge base of professionals. Improvements in the science of integration will lead to improvements in its application which are required if cumulative effects are to be assessed on a watershed basis over time.

Despite the absence of an advanced science of integration, and despite our limited ability to model complex systems, there are surrogate tools available to the practitioner today. As an example, narratology (the use of historical analogies) can be used to help practitioners make predictions about future states. The use of adaptive management strategies can also assist in decision-making in a climate in which knowledge and understanding are increasing rapidly.

Figure 6: Requirements under Bill 163 for Official Plan or Official Plan Amendments that are also required for watershed planning.

Policy Number	Content for Official Plan	Content for Watershed or Subwatershed Plan
A 1.1	groundwater and surface water	surface and groundwater quality and quantity
A 1.2, A 1.4	natural heritage systems, features and areas	natural systems linkages and functions*
A 1.3	fish habitat	fisheries management*
A 2	wetlands	ecological integrity and carrying capacity
A 3.3 A 3.4	hazardous and contaminated sites	enhancement and rehabilitation of natural features
A 3.2 A 3.5	flooding and erosion	stormwater management; protection of valley systems
B 5.0 B 7.0	servicing and infrastructure	areas suitable for development; best management practices for subdivision design
B 10	development in rural areas	servicing needs; availability of sewers and water
B 12	public access to public land and water bodies	management practices for open space and greenspace corridors
B 13	significant landscapes, vistas and ridge lines	areas suitable for development; natural systems and linkages; enhancement and rehabilitation of natural features*
F 1	mineral aggregates	natural systems linkages and functions

* basis for definition of significance



Taken from: MOEE/MNR (1993)

Figure 7: Evolution of Watershed Planning.

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Appendix A

SCIENCE AND TECHNOLOGY TASK GROUP MEMBERS

NAME	AFFILIATION	AREA OF CONCENTRATION
Bill Blackport	Terraqua Investigations Ltd.	groundwater
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Hazel Breton	Credit Valley Conservation Authority	Co-Chair
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Jack Imhof	Ministry of Natural Resources	aquatics
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Douglas Legg	Ministry of Natural Resources	economics
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Doug Obright	Ministry of Municipal Affairs	data management
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Appendix B

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The following people were asked to review the draft report but did not attend the workshop:

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Dale Kellar	Commissioner of Engineering, Town of Markham
Henry Tickers	Department of the Environment, Mohawk Council of Akwesasne
Mike Price	Commissioner of Works and Environment, City of Scarborough
Bruce Reid	Rideau Valley Conservation Authority

Appendix C

QUESTIONS RELATING TO INTEGRATION

OVERVIEW LEVEL QUESTIONS

1. What data are available, how will the data be used, and how will it be synthesized to define "what's in the watershed"
   This question, for overview purposes, can be restated as "How do you develop an understanding of the watershed"?
   - How do we read a watershed?
   - How do we use the experience of the public as our "ears, eyes, nose"?
   - What data structure is available to establish how much data is needed at what scale?
     - Flying the watershed; driving the watershed
     - In-stream electro fishing, gill netting, detailed fluvial geomorphology and evaluation of habitat

2. How can we use physical scales (to relate size of perturbation to scale of habitat unit or size of aquifer) and time scale for "feeling the effect" as a conceptual underpinning for improving watershed planning, analysis and data acquisition?

3. What ecological factors from outside the watershed may become more important in the future?
   Examples
   a. Continental scale migrants and their needs for specific local habitats.
   b. Air pollution within specific airsheds.

4. How can terminology be used to assist in integration?
   Examples
   a. Chapman and Putnam definition of landscape units:
   b. Others
      - Headwater, springfed streams
      - A black forest bog on the Precambrian Shield

5. What are the ecological footprints of existing types of development (drained clay soils; aggregate areas, low density urban development, clear-cutting) as a function at particular landscape settings?

   What are the new innovative methods of development (complete implementation of 15-20 BMPs within a subwatershed; high density clustered development with green space) and their ecological footprints?

6. Is environmental sustainability the goal and vision for watershed planning? How do we redirect science to consideration of sustainability as a goal?

7. What is environmental sustainability; how do we measure sustainability?

Commentary There are multiple definitions of sustainability. The one which makes most sense, from a natural environment perspective, "is living within the environmental means to sustain humans".

Several questions and points evolve:

a. Social Limitations
b. Ecological Implications: How big is the footprint? Can it be sustained?
c. Do we understand social expectations?
d. Sustainability is better understood for certain environmental issues and larger scales, than others. How can this understanding be established for small watershed scales?
e. Printout of carrying capacity
f. A socio-economic/community/human centred, value system **is** being replaced by an ecological centred value system

8. What is the system (natural environmental system; human system) and what is the degree of symbiosis between these two components? Can these be measured, qualitatively understood or just surmised?

9. Can we use empirical data and common sense to help in forecasting? Can narratology, for example, be used to predict future states where modelling of complex systems fails us?

DATA, ANALYSIS, TOOLS

10. How are regional databases generated and synthesized, prior to starting a watershed study, such that the proper context of the environmental resources of the specific watershed being studied are known and understood? (eg for the Rouge River, the proper function of the Oak Ridges Moraine is now known. A decade ago, when Rouge River watershed study was initiated, it was not known).

11. How can technical and technological methods be improved to assist integration?
Examples
a. Overlay analysis in GIS.
b. Stress response - response frameworks of effects

12. For the key linkages between specific ecosystem components, how can an analysis of these linkages improve integration? (eg physical location of groundwater - surface water interactions)

13. What are the key technical uncertainties in the application of scientific knowledge to watershed planning?
Examples
a. What are the important terrestrial habitats and habitat requirements to protect specific biota? What better widths are required to protect raptors from urban mammals (eg dogs and cats)? Do we have proper professional direction which defines what ecological functions are realizable in an urban agricultural setting?

b. What surficial features and network of geophysical investigation is needed to define the location of aquifers, where such data has not been synthesized?

14. How are values and viewpoints addressed in the integration process?
Is this done up front, as part of the overview process, to provide direction for the study? Or is it done later in the process, once scientific data are collected? How can we translate visions generated at large scales to small scale units (for example, the site level).

15. Is it clear in the watershed planning process how the information will be used and what decisions will be made with the information?
<u>Example</u> Direction for ...
- Development application review?
- BMP review?
- Fish habitat compensation?

16. What type of relationships and at what scale are scientific data available to relate cause to effect? What are the associated uncertainties?
<u>Example</u>
a. Correlations between surficial geology and spatial patterns of Brook Trout are available in same regions.
b. How sensitive is an aquifer to changes in infiltration?
c. Are deterministic models available (e.g. a hydrological rainfall - runoff model?)

DISCIPLINE - BIASES AND COGNITIVE MODELS

17. What cognitive approach is appropriate for the problem in hand?
- induction vs deduction

18. Given that an ecosystem is an "imperfect concept", how do we *as* professionals. recognize that "re-aggregation of component parts" is one key study aspect that needs addressing in "integration"?

19. How does lack of training or experience of professional in watershed analysis and planning limit efforts of integration?

20. How are discipline-specific pieces of information processed?

21. Is an "a priori" or and "a posteriori" approach used to define "what is the question"?

TRADE-OFF METHODS FOR QUALITATIVE INFORMATION

22. How is watershed planning used to define and resolve conflicting provincial policies at a watershed, subwatershed or stream length scale? How are different weights applied, where the environmental protection objectives have different weights in terms of being or not being included in provincial policies (e.g. protection of woodlots or prime agricultural land vs fish habitat protection)?