Proceedings of the Ontario Workshop on Riverine Science Requirements

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A Watershed Science Centre Report
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EXECUTIVE SUMMARY

The 'Ontario Workshop on Riverine Science Requirements' brought together science workers from a variety of disciplines and agencies to determine science needs related to research and management of riverine ecosystems in Ontario. This facilitated workshop was held at the Leslie M. Frost Natural Resources Centre in Dorset, Ontario, from February 21-24, 1999. The workshop was structured to integrate participants from different disciplines into breakout groups centred around four disturbance regimes commonly affecting watersheds in Ontario: urbanization, agriculture, forestry and dams and water allocation. A series of keynote presentations introduced current stream ecosystem research and set the stage for group discussion on riverine science. A hypothesis-of-effects model was used as a conceptual framework for the development of cause-effect pathways for key issues, linking activities that change habitat with ecological indicators. Physical, chemical and biological processes and terrestrial and aquatic linkages were incorporated across spatial and temporal scales. This process helped identify knowledge gaps and research needs for better management of watersheds in Ontario.

Breakout groups recommended appropriate research methods and study designs to address scientific hypotheses related to their disturbance regimes. All groups suggested using a combination of methods: experimental management to detect changes over large scales, short-term experiments to provide insight into the processes and mechanisms involved, and democratic synthesis to provide background, direction and understanding of historical patterns. In addition, the need for literature reviews was widely recommended to summarize information available from other jurisdictions and to ensure that new studies are effective and efficient. The value of using models as a conceptual tool was also stressed, along the need to develop predictive models to forecast riverine ecosystem response to disturbances.

A number of information and research needs in the field of riverine science were identified by all groups, regardless of the land use under consideration. These critical riverine science requirements for Ontario are outlined here.

- There is a need to understand the spatial and temporal scales at which various land use activities impact upon riverine ecosystems. Consideration of scale is crucial at all stages of project design and management to ensure that measurements are appropriate for impact detection at a particular scale or across multiple scales. This highlights the need to develop methodologies to support the required measurements. It was pointed out that the spatial extent of fish populations and communities and the scale at which they function are unknown. This makes it difficult to assess hypotheses relating change in habitat to changes in population density and community composition, and to set the scale at which to apply fish habitat guidelines. A site-specific approach to stream management is currently used to maintain ecological function at a larger scale, often without confirmation of the link between scales. Management and policy goals must match the implementation approach.

- Understanding the cumulative effects of land use changes in space and time on water yield, landscape and biota was identified as a high priority science need. To assess cumulative effects and activities, useful and sensitive indicators must be determined and monitored. Establishment of data sets is required for cumulative impacts modeling.

- There is uncertainty about how to define natural variability and separate this from management effects. This is both a science and a management issue: experimentation will be necessary to determine natural variability, and predictive tools for managers are required.

- The need to critically evaluate the effectiveness of existing guidelines, best management practices (BMPs) and legislation was identified. Science results should be incorporated into guidelines for land users, and into decisions on allocation of finances for analysis, planning, implementation and monitoring of watershed plans.

- To set minimum requirements to maintain species and communities, basic ecological information is required for many species and different life cycle stages. Of particular importance is the need to know the habitat requirements for valuable, threatened and endangered species, as well as for keystone or indicator species. To determine if habitat is critical, factors that limit the population and the critical limits of these factors must first be established. Tools and indicators to predict and monitor critical habitat locations must be developed, and data to calibrate these tools for Ontario is required. Provincial scale GIS classification may provide the information needed to identify and protect critical habitat, especially in intermittent and headwater streams.

- To protect fisheries and fish community resources, fish production must be measured and monitored, and experimentally related to habitat. If production is too difficult to measure directly, useful and practical indicators of fish production should be developed.

- Many management decisions require resource inventory data. Within Ontario there is a lack of survey information on riverine fish species and community distributions. It was recommended that existing information, supplemented with new data where necessary, be used to develop and verify geographic information system tools to classify stream types within catchments and use this classification to predict fish communities, as has been done in other jurisdictions. The classification system should consider hydrologic regime, which is regionally variable and critical in predicting potential disturbance impacts.

- In addition to classification, standardized survey methodology is required for measuring fish community parameters and physical characteristics in all flowing water systems, from small drains to large rivers. The development of standard methods is critical to allow comparisons of information collected by multiple partners and across jurisdictions. Standardized methods are a strong component of successful adaptive management studies, support cumulative impact studies, and track resource changes through space and time. The transferability of tools such as habitat suitability indices requires testing, and the ecological meaningfulness of assessment and IBI scores in disturbed environments should be established. Long-term monitoring at selected sites is required to provide the data necessary to allow calibration of these tools to Ontario conditions and to address a variety of receiving water issues.

- It was recommended that predictive models should be developed to better anticipate the influences of land use on riverine ecosystems. Participants cautioned that the effectiveness of modelling tools must be validated.

- Increased emphasis should be placed on improving our understanding of the ecological processes in riparian areas. The design and utilization of riparian buffer zones during watershed development should be guided by decision support models based on maintaining ecological linkages.

- The effects of anthropogenic disturbances on metapopulation dynamics, specifically regarding population fragmentation, have not been determined. Minimal viable population size information is needed, as are models to predict the influence of disturbances on metapopulation dynamics.

- Methods to predict the possible impacts of climate change on landscapes and watersheds are required, as are mechanisms for dealing with these potentialities. Changing weather systems should be considered in experimental designs.

- The influence of disturbances in a watershed on groundwater infiltration, distribution and interaction with surface water should be studied, and the link between amounts of overland infiltration and base flow must be determined.

- Long-term ecological and resource values must be defined within a cost-benefit framework and as part of watershed plans. Evaluation criteria for assigning economic value to the biotic effects of anthropogenic disturbances should be developed; for example, dollar values for comparable pristine sites should be identified. Effective methods for recovery planning at the ecosystem scale are also required. To repair degraded ecosystems, we must define functionality and the key habitat factors that can be recreated in restoration projects.

In addition to these commonly identified riverine science requirements, groups also identified science needs specific to the disturbance regime they were considering, such as the need to assess culvert designs to ensure they are not creating barriers to fish movement or migration, and the need to determine and validate imperviousness thresholds for warm and cold water fish communities.

The identified science needs emphasize priority concerns in the field of riverine science. Attention should be given to uncertainties in these areas as scientists design and carry out research projects, and as managers and funding agencies set priorities and support inquiries into a variety of disturbance regimes.

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1.0 INTRODUCTION AND FRAMEWORK

Human activities, including agriculture, forestry, dam construction, and urban and industrial development continue to expand and impact upon landscapes and the riverine ecosystems that are integrally linked to the landscape. To protect existing riverine habitats from further degradation and to restore habitat that is already degraded we need to improve our understanding of how these land-based actions affect aquatic systems. We have much to learn about the specific mechanisms by which changes in watersheds lead to physical and biological changes in stream systems. While there has been some research on the effects of specific land use activities on adjacent stream habitat, there has been little research, particularly in Ontario, on broader scale impacts (e.g. how short term deforestation of headwater catchments influences the larger streams that these headwaters flow into) or on cumulative impacts within watersheds (e.g. the combined effects of multiple land use activities). River science is in the early stages in Ontario, as evidenced by the limited resources delegated to research and management emphasizing running water.

Given limited resources, it is important that effort is directed at key questions, that methodologies are standardized and scientifically sound and that efficiency is maximized through collaboration across jurisdictions and agencies. A facilitated workshop on riverine science requirements was identified as a means of bringing science workers together to determine critical river science issues. The Ontario Workshop on Riverine Science Requirements was held at the Leslie M. Frost Natural Resources Centre in Dorset, Ontario, from February 21-24, 1999.

The purpose of this workshop was to build a consensus on science needs related to riverine ecosystems in order to guide stream research and management in Ontario. The dynamic style of this workshop was intended to provide an atmosphere of cooperation and openness among participants, such that connections established would endure beyond the workshop and become incorporated into the regular working environment. The discussions and recommendations from the workshop are summarized in this report and will be a template for further cooperation among river science workers in Ontario. Participants' views on watershed science in Ontario were also obtained through a survey that was distributed at the workshop, and is summarized in Appendix I.

Determination of how aquatic ecosystems are affected by land use activities requires expertise in a variety of disciplines. An inclusive, multi-disciplinary and multi-agency approach was considered critical to developing an integrated picture of how these systems function. Disciplines including aquatic ecology, hydrology, geomorphology, forestry and hydrogeology were represented at the workshop, and over 70 participants were invited, consisting of scientists and managers from various levels of government, conservation authorities, private consulting firms, non-government organizations, universities, First Nations, Ontario Hydro, and jurisdictions outside of Ontario. The workshop agenda is outlined in Appendix A, and a list of steering committee members, participants and facilitators is provided in Appendix B.

Workshop participants were separated into breakout groups centred around four disturbance regimes commonly affecting watersheds in Ontario: urbanization, agriculture, forestry and dams and water allocation. The composition of breakout groups was designed to ensure that each group had participants from a variety of disciplines. To set the stage for participant discussion, a series of keynote presentations dealt with important issues in current stream ecosystem research. These presentations are contained in Appendix G. Workshop participants responded with active involvement in breakout sessions dedicated to delineating science needs.

The steering committee felt that science requirements needed to be placed in the context of river management in Ontario. Therefore, the management context for the workshop was articulated in a figure and note, demonstrating to participants where the workshop fit in the management of riverine ecosystems in Ontario, and how human activities and resulting issues were organized (see Appendix C). Similarly, participants were provided with a science brief to address the considerable body of literature describing riverine systems and the effects of human activities on these systems. The science brief synthesized a portion of the scientific literature dealing with the development and utilization of both conceptual and mechanistic models of riverine ecosystems, to help participants to articulate knowledge gaps.

The concept of spatial and temporal scale is a recurrent theme in ecological literature that was developed in the science brief. The structure of habitat in streams is related to physical processes that occur at various scales in a watershed. Broad scale episodic events, such as floods, appear to be very important in periodically 'resetting' habitat conditions along a stream. Communities that live in streams should be adapted to these natural disturbances. Holling (1992) has pointed out that the structural and functional components of ecosystems tend to be discontinuously organized across spatial and temporal scales. His theory describes nodes of organization that could be considered a community response to the underlying physical organization of the system. These considerations clearly point to the need to understand the scales at which stream ecosystems function and the importance of considering the scale of the disturbances we are trying to manage. There is also a need to understand how human disturbances fit into this dynamic system and ensure that ability of communities to reorganize is not lost.

The steering committee proposed a potential framework to be used when designing research projects to address impacts on stream habitat. The framework is essentially that described by Jones et al. (1996) with the additional consideration of spatial and temporal scale. Jones et al. (1996) describe a process involving four steps: 1) determine management objectives, 2) analyze cause-effect pathways linking habitat change to ecological effects, 3) identify indicators and 4) determine strategies to effect desirable habitat change. The key step in the process is developing cause-effect pathways by linking activities that change habitat with an ecological indicator via a series of testable sub-hypotheses. The 'hypotheses-of-effect' require a detailed analysis of the structure and function of the system being considered, an evaluation of the uncertainty involved and a clear understanding of variables to be measured (and in the case of indicator variables, a clear linkage with the variable of interest). The framework requires the explicit consideration of the spatial and temporal scales of the cause and effect as well as the scale(s) of each sub-hypothesis. Conceptually, the consideration of scales adds a third dimension to the hypothesis-of-effect diagram as illustrated in Figure 1.

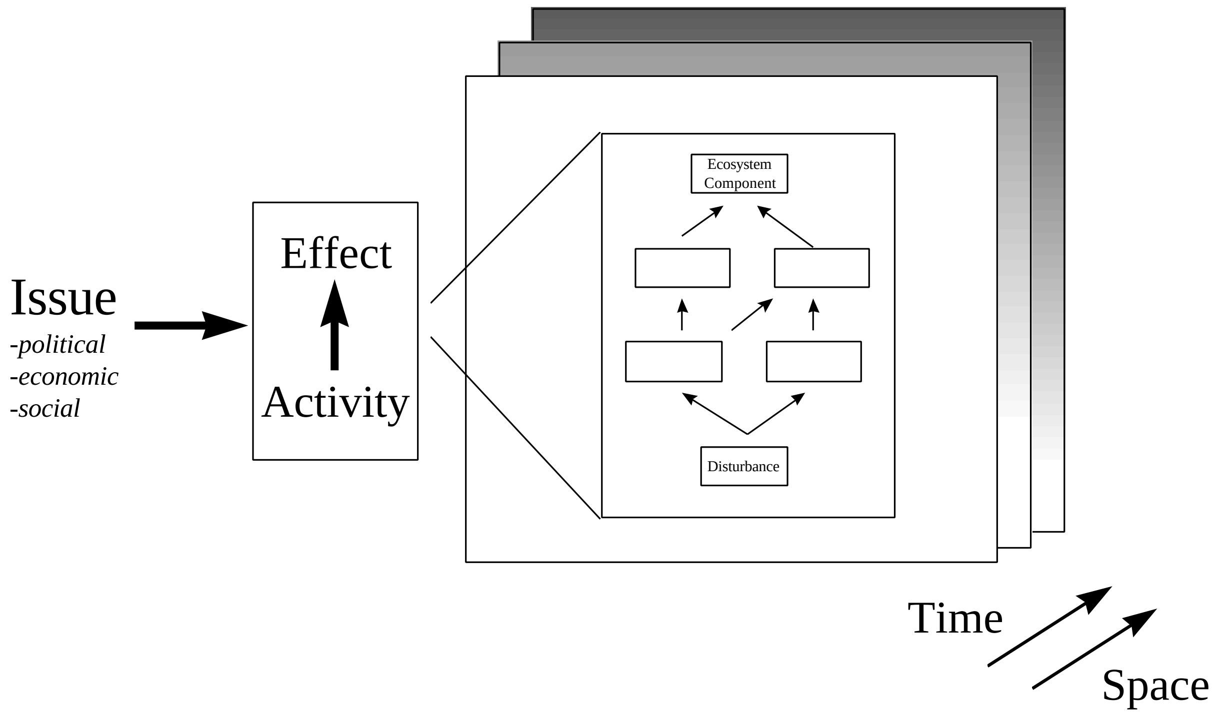

Figure 1. A simplified illustration of a multi-scale hypothesis-of-effect diagram to address the ecological effect of an activity.

This framework was tested and refined during the workshop by following through the process with the selected land use issues. Focussing on science needs in Ontario, each group identified key issues and worked through the conceptual framework incorporating physical, chemical and biological processes and terrestrial and aquatic linkages across spatial and temporal scales. This process helped identify knowledge gaps and research needs for better management of watersheds in Ontario. The remainder of this paper describes the science needs, centred on the four disturbance patterns, discussed in the context of this simple contextual model.

2.0 BREAKOUT GROUPS: DISTURBANCE REGIMES AND OBJECTIVES

Disturbance regimes are described in the Freshwater Imperative (Naiman et al. 1995) as patterns of recurring events, natural or human caused (and the interactions among them), that come from outside a freshwater ecosystem and significantly alter its structure and function. Disturbances such as floods, dewatering, drought, fires, changes in land cover or use, and biological invasions either act as reset mechanisms for ecosystems or irreversibly alter their structure and function.

For the purposes of this workshop, four anthropogenic disturbance regimes were selected for their relevance to land use issues in Ontario, and to provide focus for group discussion on riverine science. These were:

- Urbanization
- Agricultural Activities
- Forestry Activities
- Dams and Water Allocation

Workshop participants selected a disturbance regime group to participate in based on their interest, experience and field of expertise. To ensure the group sizes were balanced and a range of viewpoints and biases were contributed, group membership was multidisciplinary and multi-agency. Members included individuals representing conservation authorities, municipalities, the Ontario Ministry of Natural Resources (MNR), other provincial government agencies, federal government agencies, universities, non-governmental organizations, and consultants. In addition, each group was led by a facilitator, and at least two steering committee members were present to provide context and focus for the discussions.

Issues related to each disturbance regime were discussed in terms of their impacts on the components of a riverine ecosystem. The Hypothesis of Effects model provided a conceptual framework and guidance in the development of activity-effect linkages, and encouraged groups to focus at appropriate spatial and temporal scales while assessing the research and management needs of riverine ecosystem science. Breakout groups were given a list of objectives for each working session, and were asked to fulfill these objectives keeping in mind their selected land use activity. These objectives follow.

2.1 Breakout session 1 objectives

1. Prepare a list of key issues, effects, and activities related to the specific disturbance regime.
2. Develop a hypothesis of effects model for an important activity and effect, describing the linkages between the management action and ecosystem effect. Include a list of some specific hypotheses to be tested reflecting the identified uncertainties, and a summary of the different scales (spatial & temporal) at which each of the linkages in the diagram would operate.
3. Provide a list of key indicators to be measured.
4. Do a reality check: summarize what is known about the problem, the important gaps in theory and methodology, and the tools required to measure indicators.

2.2 Breakout session 2 objectives

1. Make recommendations on key physical and biotic parameters that could be used to evaluate land use impacts on aquatic habitat.
2. Suggest appropriate experimental designs and methodologies to address common research needs.
3. Identify major uncertainties and science need priorities for riverine management in Ontario.

3.0 WORKSHOP OUTCOMES

Products from the breakout group discussions are summarized in this section. Groups first identified issues, activities and effects specific to their disturbance regimes.

- issue: the social/political/economic problem under consideration
- activity: the specific human undertaking which is of concern
- effect: the ecological element which we are concerned about

Issues arise from a conflict between values attributed to the structure and functioning of the ecosystem and the expectation or realization that human activities may conflict with these values. Usually these conflicts are between economic and social values. Each breakout group examined one disturbance regime and the related human activities that generate ecosystem effects and resulting conflicts. The groups were asked to discuss issues arising from the impacts of the disturbance regime on riverine ecosystems.

Hypothesis of effects models linking activities and effects were developed. Illustrations of the hypothesis of effects models established for each disturbance regime are contained in Appendix F, and Appendix E lists biological and physical indicators of disturbance identified by participants. Working through these exercises encouraged awareness of riverine ecosystems outside of professional disciplines, and enabled clear and directed development of research designs and recognition of scale issues. This set the stage for a critical examination of ecosystem processes and river science requirements.

3.1 Research Approaches

Guest speakers and workshop resource material introduced participants to several complementary research approaches.

1. Traditional science:
   Controlled, non-management experiments are designed to answer focussed, testable questions. This reductionist approach is useful for detecting mechanisms and unraveling ecosystem processes. Defensible results are published in peer reviewed journals.

2. Experimental management:
   Science is done in the context of ongoing management activities, as if policies are experiments. Several alternative management actions are replicated in space and time to simulate traditional science, allowing multiple hypotheses or outcomes to be tested. A large investment in monitoring is required to assess and compare the management options, and there is a need to deal with issues of confounding effects when using experimental management. This approach requires the involvement and consensus of a variety of user groups. A feedback of knowledge between management and science provides the insight needed to refine decision-making. Many opportunities exist to take advantage of experimental management. Ongoing stakeholder participation and

cooperation will give managers the support required to ensure continued commitment to project monitoring.

3. Democratic synthesis:
A synthesis of information and experience through historical and contextual narratives is used to provide immediate answers to questions. A historical perspective can provide a description of long-term trends and occurrences, and attempt to explain patterns, without testing hypotheses. Ecological theory can be applied without supportive data, and anecdotal information can be used to verify theories. Traditional knowledge is welcomed, and experienced field workers can contribute inferential knowledge and local insights. This approach benefits from public and stakeholder involvement. Some uncertainty exists regarding how the credibility of conclusions can be evaluated, and who should be considered peers or experts for the purposes of such an evaluation.

4. Modelling:
Models provide a way to consider the "big picture", and aid in conceptualizing systems and problems. Models can be evaluated to focus on key uncertainties. Research approaches can then be identified to address these uncertainties. Users need to be aware of the limitations and assumptions of models.

Breakout groups were asked to recommend appropriate research methods and study designs to address their chosen hypothesis of effect model. All groups valued multiple approaches, and most suggested using a combination of methods: experimental management to detect changes over large scales, short-term experiments to provide insight into the processes and mechanisms involved, and democratic synthesis to provide background, direction and understanding of historical patterns. In addition, the need for literature reviews was widely recommended to establish currently available information, and to ensure that new studies are justified. The value of using models as a conceptual tool and the need to develop predictive models to forecast riverine ecosystem response to disturbances was also stressed. The specifics of each breakout group's recommended research approaches and proposed study designs are outlined below.

3.1.1 Dams and water allocation

The research objective identified by the dams and water allocation breakout group was the determination of the response of fish production (using biomass, growth, or abundance) to differing, manipulated flows. To accomplish this objective, several approaches were proposed. One impact can be studied intensively (e.g. experimental drawdown of one site compared to a second reference site). An experimental management study of a number of sites can be conducted, and passive adaptive management can be used to identify uncertainties (i.e. science needs) within the context of a specific issue (e.g. hydro generating station re-licensing) and to monitor the effects of activities. Application of existing models may also be useful to improve our understanding of a situation (e.g. PHABSIM, HEC II, habitat suitability indices).

While traditional science may be ideal for obtaining detailed information, the group felt that to get quick, useable results it is more realistic to use an experimental management approach. They suggested researchers consider using a combination of traditional experiments and experimental management. The values of adaptive management to industry must be clarified, if willing participation from industry in adaptive management through the Canadian Environmental Assessment process is to be obtained.

Study considerations:

- Select study site that has long term flow data.
- Select "quick response" indicators.
- Compare between analogous sites or reaches: use upstream sites as "controls" (longitudinal comparisons) or compare similar systems.
- Intentionally manipulate flows outside normal flow operating regime: compare existing operating flows and downstream community to community that exists after the flow change (i.e. after a new negotiated flow regime).
- Spatial scale: consider the whole watershed, focussing on the impacted area and using the rest of the watershed to get a perspective of the impact.
- Time frame: establish a baseline before the change, and measure effects after 1 season to 1 year.

3.1.2 Agriculture

The agriculture breakout group stressed the need to take advantage of existing information and data. They recommended an initial review and synthesis of current literature, and suggested researchers should also incorporate local knowledge of an area. An adaptive management approach can be used to take advantage of ongoing stream management and restoration activities. Sites previously assessed during other studies should be revisited if recent changes in land use patterns have occurred. Comparative analysis can also be effective to assess sites where different land uses occur. Existing data can be used to assess changes and monitor effects over time. As an example of an opportunity suitable to an adaptive management study, the Region of Waterloo recently committed $1.5 million to undertakings (e.g. riparian buffers, manure storage facilities, cattle fencing) which will reduce the impacts of agricultural practices on the Conestogo River.

The challenge of designing a research program to examine all types of systems needs to be addressed. To meet the needs of conservation authorities and other management agencies, a general research framework on key questions at the regional scale is required, as is a provincial "Cook Book" approach to research, with recipes for success in all geographic areas. Managers want quick access to key study results for decision-making processes. The science community should be challenged to develop experimental designs that do not create an overly lengthy process to complete, and to produce definitive results with real value for managers.

The group developed a proposal for a nested experimental plan or program with 3 major components: traditional science using experimental manipulation and monitoring of existing conditions, experimental or adaptive management, and democratic synthesis. The study design matrix is illustrated in Figure 2.

Each stratum, or set of sites, is composed of 1 type of watercourse draining 1 type of landscape. Some sites are sampled every year: these require more budget, but provide for intense data collection where everything is examined. Other sites are selected to allow random sampling across years and to cover the spatial resources of the system. These randomly sampled sites can be tied back to the fixed, intensively sampled sites. Periodically, throughout the period of sampling, the democratic synthesis process is followed.

YEARS

SITES

	0	1	2	3	4	5	6	7	8
A	X	X	X	X	X	X	X	X	X
B	X	X	X	X	X	X	X	X	X
C			X		X		X		X
D	X			X		X			
E	X	X						X	
F			X	X			X		X
G		X		X	X			X	

Stratum I

Traditional scientific analysis with democratic synthesis and evaluation

Figure 2. Experimental design schematic for the study of disturbances on riverine ecosystems.

Researchers must ensure the design has sufficient power to detect changes. Since time and funding constraints often prevent taking all the samples required, set confidence limits before taking measurements, and consider alternate statistical tests (e.g. multiple regression vs. t-test) to detect more subtle changes in populations with high predictability. Follow standard field sampling protocol for data collection. Data are gathered across sites and across years, providing temporal information about how the system works tied to spatial information about the resource.

This approach recognizes the need for a mixed design that involves traditional science, experimental management and democratic synthesis. The proposed design is mobile and flexible; depending on the question to be addressed, one approach will be emphasized more than the other (e.g. traditional vs. adaptive). This design balances tradeoffs between different goals, while providing spatial and temporal information.

Study considerations:

- The transfer of data or models across regions is difficult; we need to undertake regional studies, considering areas with similar geology, climate, etc.
- Some participants felt that the democratic synthesis approach was not viable, since it would be difficult to achieve consensus on many issues, and may not lead to defensible conclusions.
- Dynamic research is required to continually adapt methods to best answer problems and minimize variability in results.

3.1.3 Forestry

To assess the effects of forestry on streams, this group proposed using a combination of methods: controlled paired-catchment (BACI) experiments, an experimental management approach using multiple catchments, and model building. Use of controlled, paired catchment experiments is a traditional, reductionist approach that allows for an intensive examination of smaller areas (scale of 10-100km^2). An extensive design is generated, and information gathered on a large number of variables. A science driven experimental management approach allows for examination of an extensive number of sites. While fewer variables can be examined than in paired catchment studies, a greater amount of space and time can be covered. Finally, model building (hydrological or other) is recommended as a complementary method. Information gathered using the paired catchment approach can be used to parameterize models, and data collected through experimental management studies can be used to calibrate and validate models. Adaptations of the original plan are anticipated. The group recommends focussing efforts on boreal forest waters, where little research on the effects of forestry on rivers has been done.

Study considerations:

- Catchment size for paired experiments should be less than 100km^2; if catchment size is larger than 100 km^2, the effect of forestry may not be evident over the natural landscape variability (geology).
- Ensure that paired experimental sites have the same geology and climate.
- To understand cumulative impacts, pre- and post- harvest measurements for all hydrologic parameters are needed. All system inputs and outputs must be monitored over a long term, using a combination of intensive and extensive monitoring.
- Hydrologic measurement time scale will be related to catchment size (e.g. small streams: measured every hour).
- Adaptive management users must be aware of past and current forestry activity in the study area.

- Geologic variability could override land use when multiple catchments with different geology are assessed using an adaptive management approach.
- Derive model from intensively studied, controlled experimental sites; calibrate variation in uncontrolled experimental sites to this model. Note: There was some concern around the feasibility of this approach in Ontario, where there is extreme variability and subsurface flow (most calibrated studies are bedrock controlled). Some suggested solutions: (a) as a first step, see if an effect can be detected with maximum cut area; (b) use transfer coefficients, not a mass balance approach.

3.1.4 Urbanization

Several alternative approaches to research into the variety of effects of urbanization were proposed. As a first attempt to answer questions, a literature synthesis should be used to look at a range of existing case studies. The group recommended the use of controlled experiments (traditional science) and adaptive management to study the biophysical ecosystem, adapting the research approach as the study progresses. Democratic synthesis was identified as a useful approach for studying cultural impacts. Modelling was considered especially effective for addressing issues where field work has already been done, as models must be calibrated to the specific area of use. Some participants were uncomfortable using models: they questioned their effectiveness and identified the limitations and assumptions of models as troubling. Others thought models were valuable: they encourage critical thinking and are useful for conceptualizing the system and problem at the study outset.

To examine the long-term effects of urbanization, two approaches were proposed. First, a temporal study could be conducted over a minimum of 20 years. Alternatively, a cross-sectional or spatial study could be used to allow a ‘post-development’ scenario to be tested now. For example, watersheds with different degrees of imperviousness could be examined to infer the effects of urbanization. A potential confounding factor with the second approach is determining how much of the detected difference is caused by differences among watersheds.

The group identified three priority areas for analysis: high population areas, fish movement and migration corridors, and representative species.

<u>Study considerations</u>:
- Develop linkages between scientists, individuals, municipalities and other institutions/agencies.
- Explicitly state ecosystem and resource values.
- Select a sensitive watershed to test whether ecological targets are achievable.
- Select a tributary where stakeholder interest is high, as municipalities often respond to public concern (e.g. citizen input regarding Hamilton Harbour dramatically increased the restoration budget), and include the public in the evaluation process.

3.2 Science Needs

Several themes were identified across breakout groups, and are described below. These common science needs are priority concerns in the field of riverine science. Attention should be given to these areas as scientists design and carry out research projects, and as managers and funding agencies set priorities and support inquiries into a variety of disturbance regimes.

3.2.1 Scale issues in riverine science

Aquatic ecosystems are dynamic over broad spatial and temporal scales. The structure of habitat in streams is related to physical processes that occur at a variety of scales in the watershed. Large-scale episodic events, such as floods, periodically reset habitat conditions along a stream, followed by ecosystem self-organization at smaller scales. Stream communities should be adapted to these natural disturbances. In order to manage streams and protect their ability to respond to changing environmental conditions, we need to understand the scales at which stream ecosystems function and how human disturbances fit into this dynamic system.

The framework used during the workshop to address hypotheses and uncertainties about land use activities and effects on riverine ecosystems requires the explicit consideration of spatial and temporal scales. Each linkage in the cause and effect pathway may involve processes that operate at different scales. Working groups were asked to consider the scale of each sub-hypothesis, and to address issues of scale related to their disturbance regime.

It was apparent from working group discussions that there is a gap in the scientific research addressing scale issues. Consideration of scale is critical at all stages of project design and management. Breakout groups described how scale related to their disturbance regime, identified gaps and uncertainties, proposed approaches for experimental design, and addressed the needs of developers and managers. A summary of these discussions is presented here.

Scale and land use pattern

The location, distribution and extent of disturbances are known to influence the severity and types of effects on riverine ecosystems, yet the links to these effects are uncertain and unpredictable. Workshop participants referred to the following specific areas of scale and land use patterns that should be addressed. The relationships between disturbance pattern and landscape sensitivity at different spatial scales require study. The scale of disturbance (e.g. forest harvest, urban development) at which a response in hydrological conditions can be detected should be determined, as should the way in which this varies over different landscapes. The effect of the size and location of a forest cut on stream nutrient budgets, specifically nitrogen input, and the role of buffers in mediating nutrient input should be investigated. The degree to which the spatial layout of a development (e.g. pattern of urbanization, pipes) influences overland flow and the stream community should also be studied. Finally, the length of time required for the restoration of pre-disturbance (e.g. forest cut) hydrological conditions is unknown, as is the pattern of disturbance that minimizes this time. We need to understand the scale at which various impacts operate and the effects of land use patterns at a variety of scales in order to predict the consequences of our activities.

Measurable scale of impact

There may be threshold levels of disturbance below which signals cannot be separated from other variation in the measure of interest. To identify threshold levels, we need to be able to separate management effects from the range of natural variation. The 'natural variation threshold' (especially regarding catastrophic events), and the way that this varies among landscape types, should be determined. The scale of measurement for critical thresholds should also be ascertained.

The effects of disturbances (e.g. watershed urbanization) on ecological integrity depend on watershed scale. For example, urban development often completely covers smaller-scale watersheds (e.g. first order streams); water is directed through pipes, and water delivery speed increases. The degree and scale of watershed perturbation at which loss of ecosystem function occurs should be determined.

Tools appropriate to the scale of measurement are sometimes lacking. For example, small streams are difficult to identify on the 1:50 000 scale maps that are used for planning tree harvests in Ontario's Boreal Forest.

Multiple scales of impact

In many cases, disturbances can have measurable impacts at multiple scales (see Table 1). Flow variability associated with dam and water allocation activities occurs both daily (e.g. hydro dewatering and watering) and seasonally (e.g. change in spring freshet). It is difficult to separate temporal scale impacts that occur in different directions, such as the increased daily peaking of water flow associated with hydro activities and smoothing of the annual hydrograph as spring runoff is managed with dams and reservoirs. Temporal effects of disturbances can be immediate or delayed, depending on the parameter measured (e.g. water chemistry, habitat, benthic and fish communities). There is often a delay between disturbances and measurable impacts (e.g. road salt applied and signal measured in groundwater).

Multiple spatial scales may also be impacted or require consideration. For example, only the site scale is considered when deciding where to install culverts, while effects can occur at the meso-scale (e.g. disruption of important habitat downstream). Aggregate extraction is also managed at the stand or site level, but can have an influence at the landscape scale: aggregate extraction influences hydrology, and may reduce the permeability of area.

While farm boundaries are typically reach scale, livestock operations from individual farms can have impacts at other scales. Effects of farming practices can be observed and measured at the site or local level (e.g. bank trampling). Temporal effects of livestock on streams at the site level are density dependent; at greater cattle densities, effects occur more rapidly. The cumulative impacts of site scale effects can be measured at the watershed scale (e.g. sediment and nutrient impacts on downstream reaches).

In addition, biological impacts may occur at different scales than physical impacts. For example, the "zone of influence" of a dam (the area running downstream until local effects are attenuated) can be well beyond the area of observable physical impacts. Downstream areas that do not appear to be physically impacted may be affected by the removal of benthic or larval fish drift. As these examples illustrate, the scale at which impacts of disturbances are measured or managed for must suit the scale at which the impact is expressed.

Table 1. The effects of dams, the spatial scale at which these occur, and impact class. Site = smallest sampling unit; Reach = 2 full meander widths; Basin = watershed

EFFECTS	SCALE	Impact		
		Ecological	Social	Economic
Migration barrier	Basin	Yes	Yes	Yes
Temperature	Reach	Yes	No Impact	Yes
Water quality	Reach	Yes	Yes	Yes
Contaminants	Reach to Basin	Yes	Yes	Yes
Substrate Effects	Reach	Yes	No Impact	Yes
Nutrient cycling	Reach to Basin	Yes	No Impact	No Impact
Flushing Rate	Reach	Yes	No Impact	No Impact
Productivity	Basin	Yes	Yes	Yes
Habitat Availability	Reach	Yes	Yes	No Impact
Changing Flows	Reach	Yes	Yes	Yes
Sediment Transport	Reach	Yes	Yes	Yes
Fish Production	Reach	Yes	Yes	Yes
Fish Entrainment	Site	Yes	No Impact	Yes
Traditional Lifestyles	Basin	No Impact	Yes	Yes
Community	Reach to Basin	Yes	Yes	Yes
Meta-populations	Basin	Yes	Yes	Yes
Change in life history	Reach to Basin	Yes	Yes	Yes
Exploitation	Basin	Yes	Yes	Yes
Erosion/ Geomorphology	Reach	Yes	Yes	Yes
Valuable, Threatened & Endangered Species	Reach	Yes	Yes	Yes

Addressing scale with experimental design

To assess the effects of disturbances at multiple scales, scale should be explicitly considered during the design stage of an experiment. Research should be initiated at the watershed level to develop an overall picture of how the system functions, with investigations at decreasing scales to address system complexity; starting small and attempting to extrapolate this information to larger scales has not been effective. Multiple sites within a watershed should be examined, and sampling should occur at different scales so as not to miss effects occurring at any one scale. The study design needs sufficient power to detect differences, and the transferability of the results across scales should be considered.

A sampling design should be used that balances tradeoffs between spatial and temporal coverage to get temporal information about how the system works tied to spatial information about the resource. A combination of two approaches may be used: intensively study and compare two contrasting sites, and use an experimental management approach to study a suite of sites. Sample some sites intensively every year to follow a story through time, and sample other sites randomly to cover the spatial resources in strata. The design should stratify spatially by homogenous geological units (e.g. physiography, basin area, etc.), and determine inter-annual variability for fish communities and physical characteristics. Spatial studies may provide surrogates for temporal studies if sites are selected to reflect a variety of times since the occurrence of a disturbance.

Scale at which fish population functions

We don't know the scale at which fish populations function (e.g. spatial extent of population, scale of fish movement, gene flow within a species). Mitigating circumstances include the interactions that occur as populations use habitat that is fragmented and has barriers to permeability. This makes it difficult to assess hypotheses relating change in habitat (e.g. spawning habitat) to changes in population density. Further, the scale at which to apply fish habitat guidelines cannot be set without this knowledge. Currently a site-specific approach to stream management is used, with the goal of maintaining ecological function at a larger scale.

Consideration of appropriate scale through management and policy

The scale of assessment used for the management of watershed ecosystems tends to be dependent on the resources available. Instead, we need to determine and use the scale that is most effective from a management perspective. Urban development planning and assessment, for example, typically takes place on a site-by-site basis, while the cumulative effects of these site scale activities would be better dealt with using a whole watershed approach. Planning should first occur at the watershed scale to integrate site scale management activities.

Determination of the environmental impacts of small-scale development projects requires multi-scale assessments. The responsibility for the costs associated with these large-scale assessments is often uncertain, and there is no standard for splitting these costs among user groups. These questions must be addressed by watershed managers, and rapid bioassessment tools are needed to make large-scale assessments economically viable.

Implementation of fish habitat legislation is site specific, while the goal of this legislation is larger scale: no net loss of fish habitat. This conflict makes it difficult to know the scale at which to manage streams and apply fish habitat guidelines (e.g. productivity shift from upstream to downstream vs. productivity change).

The forestry group developed a matrix of management decisions and issues (e.g. decisions made by a district manager on a daily basis), listed and categorized by scale (see Table 2). This provides an overview of the issues and uncertainties around management decision points identified at a variety of scales. Fewer issues and uncertainties were identified at the meso-scale level: this was attributed to a longer history of stand management, and a better knowledge of activities and effects at this scale.

Table 2. Scale of forestry management decisions and uncertainties.

	Scale		
	Site specific (m^2)	Meso (stand; $100m^2$)	Landscape($1000m^2$)
Decision	• Culverts • Water crossings • Individual Areas of Concern (AOCs) (spawning sites, moose feeding area, etc.) • Fish habitat guidelines (F.H.G.) – local slopes	• Stand level prescription (equipment, timing, site preparation) • Location of secondary and tertiary roads • Road abandonment • Aggregate extraction for roads: gravel pit selection • landing locations/ time	• Road layout and planning • Location of cutting • Pattern of cuts – emulate natural disturbance • Fish habitat guidelines - cold vs. warm water
Problems, Uncertainties	• Are culvert barriers to migration of fish? • Poorly installed culverts • Culverts installed properly, but don't last • Location of culverts • Do ice bridges change geo-morphology? • Use of culverts other than C.S.P. • Are size of culverts appropriate for forested landscapes? • Sustainability of AOCs • Don't know location of critical habitats • Do AOCs protect ecological function? • Site specific application of AOC may not be appropriate	• What linear distance is related to change in slope (AOC)? • Exposure of shallow ground water – impounding/rutting • Soil impacts: compaction, etc. • Appropriate regeneration needed for sensitive sites • Road location – sedimentation issues; abandonment • Waterbars, ditches/side slopes • Slope stability of road • Uncertain identification of headwater areas and intermittent streams • F.H.G. may inhibit restoration activities (e.g. allocthonous inputs) • Landing/locations – interrupt hydrology • Influence of aggregate extraction on groundwater movement (may be managed at the wrong scale)	• Impact of predicted climate change on guidelines? • Cumulative effect of decisions on the landscape (e.g. multiple culverts, cuts)? • Scale at which fish populations function is unknown, so uncertain at what scale to apply F.H.G. • Road densities • Acceptance of original road corridors (e.g. during upgrades) • How does the extent of harvest impact water yield? • Emulate natural disturbance – sensible guidelines? (hydrologic perspective, loss of aquatic species) • How defensible is Table 6 in the Forest Management Plan re: boreal forests? • Are we accurately defining cold and cool water?

3.2.2 Cumulative impacts:

Cumulative impacts result from a combination of activities; no one cause-effect pathway can be identified. All groups identified areas related to their disturbance regimes where the cumulative impacts of management decisions have not been well studied. Understanding the cumulative effects of decisions in space and time on water yield, landscape and biota is identified as a high priority science need.

Many types of activities contribute to cumulative impacts on riverine systems. Multiple forest cuts, cascading hydro reservoirs, multiple culverts and expanding road networks can lead to stream habitat fragmentation and fragmentation between drainage systems. The extent of timber harvest can impact water yield and the hydrologic regime, which will in turn affect biota. Aggregate pits and quarries can alter stream thermal regimes. The cumulative effects of dams can affect species diversity, and may increase the number of species at risk. Multiple cattle access points, feedlots, and drains contribute to nutrient loading, and multiple developments incrementally reduce imperviousness and can alter groundwater budgets.

To assess cumulative effects and activities, useful and sensitive indicators must be determined and monitored. Establishment of data sets is required for cumulative impacts modelling, and such models should be developed.

The nature of cumulative impacts leads to concerns and uncertainties with how to manage such activities and impacts. Some of these management issues that need to be addressed are outlined here. Responsibility for financing and carrying out cumulative impact studies must be determined for areas where the actions of many developers or agencies have contributed to impacts. Methods must be developed to assess the incremental effects of individual developments on the larger subwatershed. Limitations or restrictions on activities that are fair to all users must be established. Finally, the success of guidelines in the amelioration of cumulative impacts should be measured. Collaboration between policy makers, managers and scientists is required to tackle these problems.

3.2.3 Natural variation

Many groups indicated that the effects of human activities, such as changes in water yield, sediment, and nutrient levels, should be kept within the range of natural variability. However, there was uncertainty about how to establish the bounds of natural variation and separate management effects from natural variability: natural systems are dynamic and a stable state does not exist in nature.

Natural variability should be defined, and threshold levels for human-induced activities established. We must determine how to deal with catastrophic events when defining natural variability. The relationship between the scale of an activity and the effect on ecosystem response also must be elucidated. For example, is there a critical threshold of forest harvesting required to detect a response in hydrological conditions at a given scale? Is there a threshold level of urbanization below which effects on habitat are not currently measurable? These questions need to be addressed so that management effects can be separated from natural variability. Sensible, specific guidelines should be developed to eliminate the uncertainty of defining natural disturbances. This is both a science and a management issue: experimentation will be necessary to determine natural variability, and predictive tools for managers are required.

According to Ontario policy, forest harvesting should emulate natural disturbances, yet the bounds of natural disturbance have not been established. Natural disturbances can be very destructive, and risks are associated with trying to emulate them. Fire, for example, may not recognize buffer strips, and can result in a huge loss of species. The sensibility of attempting to emulate natural disturbances was questioned in light of uncertainties around the comparability of timber harvest and fire impacts on hydrologic and aquatic systems.

3.2.4 Guideline effectiveness and development

The need to critically evaluate the effectiveness of existing guidelines, best management practices (BMPs) and legislation was identified. Guidelines are intended to ameliorate the impacts of development and protect against degradation, but we may not know if they have the intended results. We must determine whether best management plans actually protect a fishery. The effectiveness of guidelines in keeping watershed hydrology intact and preventing detrimental effects on the aquatic community should be assessed.

To evaluate the effectiveness of best management practices in mitigating the impacts of urbanization, management practices should be compared across watersheds where development has occurred with and without application of BMPs. Investigation is specifically required into the effects of urban BMP technologies on stormwater, discharge temperatures and impact mitigation. The efficacy of BMPs for flow regimes and storm water should be also evaluated; BMPs result in pollutants being removed, but do not prevent eutrophication. The maximum level of urban development at which desirable self-sustaining aquatic communities can be maintained should be determined, as should whether the use of BMPs increases this maximum level.

Guidelines such as ‘Timber Management Guidelines for the Protection of Fish Habitat’ (OMNR 1988) are designed to protect fish habitat during forest harvest operations. The guidelines prescribe riparian reserves (buffer strips) of various widths depending on shoreline slope and the type of fish habitat involved. The capability of these guidelines to keep watershed hydrology intact and prevent detrimental effects to the aquatic community needs to be evaluated, with specific consideration of boreal forests. Fish habitat guidelines may inhibit stream restoration activities by controlling the input of allochthonous material and woody debris into streams and lakes. Woody debris and debris dams are a major source of fish habitat that is not being managed for.

In addition to the evaluation of existing guidelines, an examination of legislative gaps is needed to identify areas where guidelines or legislation to enforce proper practices should be developed. For example, roads that access forest resources are often located at sensitive sites, and improperly placed roads can be associated with sedimentation problems. While we have the knowledge to locate roads, culverts, ditches and water bars correctly, this is often not done due to constraints on time or finances, and insufficient direction through guidelines or legislation.

Finally, guidelines cannot be applied if streams are not identified on maps. This is a concern with headwater areas and intermittent streams; we need to develop the abilities to identify these streams on maps and in the field.

Linkages between science workers, municipalities and agencies should be developed, and increased communication between scientists and decision-makers is required. Science should be incorporated into guidelines for use by developers, and incorporated into decisions on allocation of finances for analysis, planning, implementation and monitoring of watershed plans.

3.2.5 Synthesis of existing information

All groups identified a review and synthesis of existing literature as the first step to be undertaken in any study design. This is required to ensure new studies are justified, and to establish what information is already available. A literature search can be used to look for applicable known science that can be related to local Ontario situations where appropriate.

A literature search should be done to identify demonstrated, measured examples that show ecological changes caused by urbanization. If there are inconsistencies between studies, the factors responsible for differences in the results (e.g. soil type, drainage density) should be described. The stream sizes for which relationships between % infiltration and development have been developed should be identified. A review of studies correlating baseflow and thermal regime with brook trout production would also be useful. The amount of change that a stream can accommodate with no net loss in production of brook trout and other indicator species should be described. A literature review could address many of these needs and provide a foundation for new research.

A review of existing stream and fisheries data sets was also recommended. Available data sets that describe the impacts of disturbances on stream communities and demonstrate relationships between disturbances and habitat changes should be identified. This will enable us to identify gaps and areas where field studies are required. Sites with existing data can be revisited to allow comparison of old and new data.

3.2.6 Critical habitat and species requirements

There are gaps in the basic ecological information we have about many species, such as life history and habitat requirements. We need to determine critical temperatures and flow conditions for many species and different life cycle stages in order to set minimum requirements to maintain species. Of particular importance is the need to know the critical habitat requirements for valuable, threatened and endangered species, as well as for keystone or indicator species. Key features of riverine ecosystems that can be used to evaluate the health of a system and predict responses to change should be determined and described. We need to develop the science to identify keystone and indicator species for a range of stream conditions, and we need to understand the pathways and associations between physical habitat and biota. Some uncertainties in the relationships of habitat and biota specific to disturbance regimes were identified. In particular, a study is required to assess the effects of substrate changes on populations and communities upstream and downstream of dams, and in reservoirs. In addition, the relative roles of water quality and physical habitat in urban systems should be elucidated.

Critical habitat is determined by the limiting factor of the fish population. To identify critical habitat, we first need to know what factors limit the population (e.g. spawning habitat, invertebrate habitat/ food) and the critical limits of these factors (e.g. how many spawning areas are required?). We need to identify multiple, practical indicators that can be used for identifying and monitoring habitat conditions. Links between physical and biological indicators require enumeration. Predictive relationships within streams can be developed with the aid of a large stream database.

To protect critical habitats we also need to know where they are. A systematic approach is required to identify the location of critical habitat at the site level. Intermittent and headwater streams were specifically identified as being at risk with the stream mapping scale currently used for protection (1:50 000). We need to develop or refine tools to predict the location of critical habitats, and we need data to calibrate these tools for Ontario. Provincial scale GIS classification may provide us with the information we need to identify and protect critical habitat, especially in intermittent and headwater streams.

3.2.7 Measurement of fish production

In order to protect fisheries resources, we must be able to measure and monitor fish production. We currently don’t know how to experimentally relate fish production to habitat. If production is too difficult or expensive to measure directly, we need to develop useful and practical indicators of fish production.

Monitoring fish production is a management concern. A model to relate habitat loss to productivity loss is required to enable managers to deduce appropriate penalties and adequate compensation.

3.2.8 Information and methodological needs

All groups identified the need for appropriate methodologies and descriptive tools for classification and mapping that can be applied across landscapes. Methods to enable classification of aquatic ecosystems and fish habitat should be developed. Current guidelines depend on whether systems are warm, cool or cold water. However, since we don't have the extensive fish inventory necessary to establish whether we are accurately defining cold and cool water systems, a cold water classification often results by default. Geographic fish distributions should be determined, creating a template for all major watersheds that can be used for stream classification and other purposes. An organizational home is required to maintain such a database, such as the Royal Ontario Museum or another appropriate institute.

Sampling methods for measuring fish community parameters and physical characteristics should be developed for all flowing water systems, from small drains to large rivers. In order to cover the natural range and variability of fish species, sampling an area that is greater than a "reach" is recommended. Watershed and reach modules of stream assessment protocols should therefore be completed, and river "reach"-level classifications developed to allow longitudinal comparisons. The development of rapid bioassessment tools should make assessments more economically viable, especially for land developers and consultants.

Regional curves should be developed for Ontario streams to relate stream hydrology to geological characteristics. Predictive relationships should also be established for important impacts of disturbances (e.g. percent imperviousness). A method to determine homogenous geological or landscape units (i.e. physiography, surficial geography, basin area, other strata) should be defined.

The transferability of tools such as habitat suitability indices (e.g. from "natural rivers" to agricultural drains or urban streams) requires testing. Fish species in northern rivers are particularly understudied, and development of HSI information for species in this area is recommended, as habitat suitability indices are not reliable over large spatial scales. Indices of Biotic Integrity are also generally calibrated to Southern Ontario, and may not be effective in Northern Ontario, given the reduced species diversity in northern streams. The ecological meaningfulness of assessment and IBI scores in disturbed environments should be established.

To ensure accurate use of measures such as species richness and Indices of Biotic Integrity, the invertebrate and fish (especially cyprinids) identification skills of aquatic science workers need improvement. This will also enable improved assessment of the status of valuable, threatened and endangered species.

Along with these tools, we need the data to calibrate to Ontario conditions. Long-term monitoring is required to provide this data in order to address a variety of receiving water issues. Lack of information on benthic invertebrates and groundwater quantity and quality were identified as specific gaps in monitoring practices. A provincial scale G.I.S.

database of stream, groundwater, soil, and geology information should be established, along with digital elevation models and site specific identification and validation of geographic information. Data layers to predict intermittent streams and ground water upwelling areas should be included.

3.2.9 Models

Many situations were identified where models would be useful in improving our understanding of riverine ecosystems, and increasing our predictive capabilities. Models that can predict the influence of dams on metapopulation dynamics are required. Urban planners need models to enable proper design of buffer zones. A model to relate habitat loss to productivity loss is also needed; from this, appropriate compensation or penalties can be deduced.

To develop models that can predict the response of aquatic ecosystems to a variety of disturbances occurring across different spatial and temporal scales, we need to improve our overall knowledge base. We need minimal viable population information, and data sets to allow modelling of cumulative impacts must be established.

Finally, we need to evaluate the effectiveness of modelling tools in their ability to help managers maintain fish communities.

3.2.10 Buffers

Although the use of buffers is widespread as a means of protecting streams from terrestrial developments, the link between buffers and ecological processes and the importance of these processes have not been well documented. In order to make good management decisions about watershed development, we need to understand the functional role of terrestrial species in watershed ecosystems, and the linkages between terrestrial and aquatic species.

The type of cutting, site preparation and machinery used in forestry practices may impact buffer effectiveness. Foresters currently base decisions to harvest in riparian zones on soil and slope characteristics; these decisions should be based on measurable ecological process parameters. The size of buffer necessary to protect streams from the effects of urbanization is not known. Terminology (e.g. ‘minimum’ buffer requirements) should be strengthened and modified to be more specific, as developers typically comply with only the minimum standards. Model development tools are needed to aid in the creation of buffer designs that planners and biologists can agree on.

3.2.11 Fish community and metapopulation dynamics

Our understanding of metapopulations is limited. We do not know how to maintain a metapopulation, and the effects of urbanization and dams on metapopulation dynamics, specifically regarding population fragmentation, have not been determined. If activities such as dam, culvert and bridge construction and stream channelization cause isolation of fish populations, we must determine whether the remaining gene pool has enough variability for persistence of the population. Effects on population persistence may require a time scale of decades to assess. The effect of large-scale reset events on fragmented populations should also be evaluated. We need minimal viable population information, and we need to create models to predict the influence of dams and other disturbances on metapopulation dynamics.

3.2.12 Climate change

Relationships we are currently establishing, and existing guidelines, may not be valid as predicted climate changes occur. Hydrographs of urban-engineered streams, for example, are much less resilient to change than natural systems. We need methods to predict the possible impacts of climate change on landscapes and watersheds, and mechanisms for dealing with potentialities. Current mitigation measures may need to be adapted as predicted climate changes take effect. Additionally, if weather systems are changing, then these changes should be accounted for in experimental designs.

3.2.13 Geomorphology and soil erosion

The effects of bank stability and erosion on rates of change of channel forms and meander pathways are not well understood, nor are the effects of changing flow rates on channel morphology. We also need to understand the impacts of urbanization on sediment balance (e.g. times of response, source, storage, etc.). Existing uncertainties around sediment transport need to be addressed, and the accuracy of sediment transport models must be tested.

3.2.14 Determination of ecological values

Long-term ecological and resource values must be defined within a cost-benefit framework, and as part of watershed plans. Ecological and social (especially traditional) impacts should be evaluated along with the economic impacts of development (e.g. dams, urban development) so these values can be used in cost-benefit analysis early in the development process. Evaluation criteria for assigning economic value to the biotic effects of anthropogenic disturbances should be developed; for example, dollar values for comparable pristine sites should be identified. In addition, the quantifiable linkages between cultural health and a “healthy” ecosystem should be determined. Public education and support are required to ensure ecosystem values are recognized.

3.2.15 Rehabilitation potential

Effective methods for recovery planning at the ecosystem scale are required. We need to understand the rehabilitation potential of degraded streams, and the resilience of riverine ecosystems, to enable effective design of ‘natural’ agricultural drains and self-maintaining habitat. To repair degraded ecosystems, we must define functionality and the key habitat factors that can be recreated in restoration projects. Restoration and degradation processes should be compared and contrasted, recognizing the restoration trajectory in comparison to the degradation trajectory (e.g. urbanization and its impacts).

3.2.16 Groundwater infiltration and extraction

Disturbances in a watershed, such as changing flow regimes or landscape patterns, can affect groundwater infiltration, distribution and interaction with surface water in ways that we do not currently understand. Urbanization and other landscape disturbances can affect source areas for groundwater. In addition, populations place large demands on aquifers to provide water. As infiltration areas are developed, we must be able to determine the carrying capacity of local aquifers, the thresholds for water extraction, and the extent to which we can offset the effects of urbanization on infiltration. Infiltration at a site should be quantified before development occurs, and our understanding of the storage capabilities of less permeable soils requires improvement.

Aggregate extraction also influences hydrology and groundwater movement, and can reduce the permeability of an area. Extraction is managed at the stand or site scale, but should be managed at the landscape level to ensure that the critical amount of overland infiltration occurs to maintain base flow.

Methodologies are required for base flow measurement, and the base flow needed to ensure the sustainability of existing communities or ecosystems should be defined. The link between amounts of overland infiltration and base flow must be determined. To answer questions of stream flow and groundwater interactions, we need flow data resolution in time and space, and provincial GIS classification of streams.

3.3 Disturbance-specific science requirements

In addition to the identified riverine science requirements that were common to all disturbance regimes, each group also described science needs specific to research into the particular disturbance regime they considered. These questions and uncertainties that arose in individual breakout group discussions are described in this section.

3.3.1 Dams and water allocation

Water quality and nutrient cycling impacts
The effect of dam installation affect on net nutrient budgets is unknown. We need to know the magnitude and duration of nutrient pulses that may occur after flooding. Nutrient budgets should be compared before and after dam installation, and upstream and downstream of the dam, to gain a better understanding of the role of dams in effecting nutrient cycles. Finally, the links between nutrient cycling and changes in biological communities should be established.

3.3.2 Forestry

Culvert design and use
The appropriate culvert sizes for forested landscapes have not been evaluated, nor have the effects of culverts as barriers to fish migration. Culvert design may not be suitable for the protection of fish communities: often sizes are overestimated to compensate for flashiness, resulting in insufficient flow for fish to cross through the culvert at base flow. Other shapes, materials, and arrangements may be better for fish, such as installing multiple smaller pipes instead of one larger culvert. Alternative culvert designs should be evaluated.

'Environmental Guidelines for Access Roads and Water Crossings' (OMNR 1988) regulate the installation and maintenance of culverts installed during forestry operations. These guidelines are intended to ensure that culverts do not adversely impact stream ecosystem sustainability and fish productivity. However, culverts installed following these guidelines often degrade over time, likely due to installation in locations where they can't be expected to work. Careful planning and consideration of scale is required when deciding where to build roads and install culverts so important habitat downstream is not disrupted. Some of these may be science transfer issues: the knowledge exists but is not being used operationally. Proactive involvement of biologists in culvert installation can ensure field staff is properly versed on installation guidelines and local conditions are considered.

Areas of Concern (AOCs)
Shorelines adjacent to fish habitats that have been selected for timber management operations require protection, and are therefore designated as Areas of Concern. We do not know whether these AOCs actually maintain ecological function, either those that

they were intended to, and others that are not in the spatial-temporal scale of the design. The sustainability of individual AOCs (e.g. spawning sites, moose feeding areas) must be evaluated. This sustainability of AOCs is a requirement of the Environmental Bill of Rights, yet there is no monitoring metric or indicator for maintenance of sustainability.

Stand Level Prescription (Meso scale):
Improper stand level prescriptions and logistical problems in the forest industry often lead to poor quality forestry at the stand level. Stand level forestry activities can cause exposure of shallow ground water, leading to impounding and rutting. Soil impacts such as compaction can occur, and landing locations can interrupt watershed hydrology. Improper choice of road location can result in sedimentation. As well, the slope stability of abandoned roads is a concern. Sensitive or vulnerable sites are often not given the priority needed for adequate and timely regeneration.

3.3.3 Urbanization

Development targets for ecosystem protection:
Realistic targets for ecosystem functionality are unknown in urban systems. We need to determine the maximum level of urban development at which desirable self-sustaining aquatic communities can be maintained, and what functions and ecosystems can be achieved in urban areas. The level of change that can occur in landscape, groundwater flow, and thermal regimes for streams with no net loss of fish production should be established so that quantitative ecological targets for urban design can be set.

Imperviousness Threshold:
Imperviousness is commonly used as an indicator of urbanization and water routing. A threshold level of 10% watershed imperviousness has been identified, above which warm water fish communities are adversely affected (number of species, IBIs). This level needs to be validated, and the processes responsible for these impacts determined. Investigations into the effects of various degrees of imperviousness on cold water fish communities should also be established.

Additionally, the appropriateness of using imperviousness as an indicator of water routing should be evaluated. In some cases, the natural mechanisms to maintain water are more important than imperviousness.

Planning
New developments should avoid critical areas. We need a method for planning and allocation of urban growth (i.e. increased imperviousness) to areas where it would minimize impacts on landscape, and tools to assist managers in allocation of density.

4.0 CONCLUSIONS AND NEXT STEPS

We face many challenges with river science and running water management. This workshop successfully brought together the ideas of a diverse group of experts to address these challenges and identify riverine science requirements for Ontario. The 'hypothesis-of-effect' model developed for and used during the workshop provided a way to conceptualize relationships between human activities and their specific effects on riverine systems. This approach encouraged critical thinking, and was found to be effective for identifying uncertainties.

Workshop participants developed recommendations for research methods and designs. Traditional scientific analysis used in conjunction with experimental management and synthesis of existing information was widely suggested as the most effective and practical way of gathering information and results. Development and standardization of appropriate designs and methods are required to ensure effective monitoring and allow comparisons.

Each breakout group was able to articulate important issues and needs related to their respective disturbance regime. The agriculture group identified the need for the development of basic tools, useful methodologies and practical experimental designs. This group also stressed the importance of the ability to understand how aquatic communities function and how fish communities interact with habitat. The urbanization group highlighted the need to define ecosystem functions and critical areas in watersheds, and the need to understand the ecological resilience of systems in order to effectively protect and restore them. The changing flow rates associated with dams affect the hydrology and geomorphology of rivers. Understanding these dynamics and how they influence biotic productivity were priority issues recognized by the dams and water allocation breakout group. The effectiveness of existing guidelines and our ability to develop indicators of fish production and communities were the main concerns identified by the forestry group.

Science requirements that emerged across disturbance regimes should receive precedence from managers and researchers. We require an improved understanding of basic ecology, including the ability to distinguish natural variability within a system from anthropogenically-induced changes. We must ensure that work is done at the appropriate spatial and temporal scales, and we need to explore ways to effectively assess cumulative impacts of disturbances. Species inventory information and GIS data layers to predict intermittent streams and groundwater upwelling are required. Finally, the scientific knowledge that we obtain must be useful and transferable to managers and decision-makers. Effective communication of this knowledge is essential for progressive research and management of riverine systems.

A survey filled out by many participants reinforced workshop discussions, identifying the need for integrated approaches to watershed ecosystem research and indicating the importance of communicating scientific research and results to decision makers. Initial synthesis and communication of the science requirements and priorities identified at the workshop are delivered through this report. Additionally, the Watershed Science Centre provides a mechanism to address issues and set direction based on outcomes and needs identified at the workshop, and to provide a networking facility for maintaining contacts and improving communication.

Groups were not successful in identifying methodologies and current research in other jurisdictions in the field of riverine science that can be adapted or used in Ontario, despite the priority given to establishing existing knowledge before starting new research. A concentrated effort is required to provide summaries of relevant information in the variety of disciplines involved in river science research. A forum of active researchers would be useful to review and critique existing methodologies, and develop standard methods to focus on some of the key questions in riverine science research to enable scientists to tackle recognized uncertainties. Scale was identified as a critical concept that must be addressed in research design to ensure impacts are evaluated at the scale at which they are expressed rather than the scale of impact, and to enable detection of change over natural variability. As well, we require methods and acquisition of monitoring data at appropriate spatial and temporal scales to address cumulative impacts of disturbances.

To address the need for standard methods for riverine science research, the Watershed Science Centre proposes to consult interested partners to prioritize issues. Once a consensus is established, the WSC will coordinate a series of workshops to develop standard methods and designs in small group settings. Depending on the subject area addressed and method to be developed, group composition may consist of active researchers, modelers, database experts, statistical consultants and potential users.

Several other areas were identified where future workshops could build on the success and experiences of this meeting. A subsequent workshop would be useful to follow through on issue definition, determining and prioritizing critical issues that have a high feasibility of being addressed. An assembly of experts from Ontario Hydro and other agencies was specifically recommended to address and expand our understanding of dams and sediment topics. Joint project planning workshops were also suggested as a follow-up to this workshop, taking advantage of the multi-agency representation to plan collaborative projects that meet common goals and objectives. The hypothesis-of-effect diagram can assist in the development of experimental designs and research projects useful to responsible agencies in preparation for funding opportunities.

This workshop accomplished a very important first step in the examination of Ontario's riverine science needs. Organization of this information has facilitated the identification of research gaps, creating the potential for future collaborative research initiatives. Cooperation among a network of interested workers from a variety of disciplines will be necessary for better management of flowing water.

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- Centre for Northern Forest Ecosystem Research (MNR)
- Great Lakes Laboratory for Fisheries and Aquatic Sciences, Fish Habitat Management (DFO)
- Moose River Basin Environmental Information Partnership (MNR)
- Natural Heritage Section (MNR)
- Northeast Science and Technology (NEST), Aquatic Ecosystem Team (MNR)
- Research and Development Branch (MTO)
- Science and Information Resources Division (MNR)
- Watershed Science Centre

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