Chapter 2

Developing an Ecosystem Context for the Management of Water and Water Systems

J. G. Imhof

Fisheries Policy Branch, Ontario Ministry of Natural Resources, P.O. Box 5000, Maple, Ontario L6A 1S9

W.K. Annable

Department of Earth Sciences, University of Waterloo, Waterloo, Ontario N2L 3G1

2.1 Introduction

The complexity of issues dealing with the surface waters within an urban area often overwhelm the planners, engineers, biologists and ultimately the decision-makers. Faced with a depressing array of seemingly contradictory or multi-directional objectives such as flood protection, drainage, water quality, health, odour, safety, recreation, domestic water demands, and natural environmental concerns, agencies regulate and each discipline responds to these issues by attempting to simplify the issues within their own field of experience.

By simplification within each discipline the overall problems become partitioned into a set of sub-issues which allow a feeling

Imhof, J.G. and W.K. Annable. 1993. "Developing an Ecosystem Context for the Management of Water and Water Systems." *Journal of Water Management Modeling* R175-02. doi: 10.14796/JWMM.R175-02.

© CHI 1993 www.chijournal.org ISSN: 2292-6062 (Formerly in New Techniques for Modelling the Management of Stormwater Quality Impacts. ISBN: 0-87371-898-4)

of satisfaction within each discipline. The results are that engineers consider water as a waste product and manage it accordingly, hydrogeologists recommend prevention of water infiltration in urban areas and then also express concern for dwindling water supplies, planners design communities and cannot understand why environmental concerns cannot be addressed after the fact and biologists manage in-channel habitat along small portions of stream oblivious to alterations in watershed pathways and processes that will negate their efforts.

Agencies in turn set regulatory standards for variables in the environment, based upon the minimum standard necessary to meet their bureaucratic, technical or environmental objectives. This process of regulation in turn leads to development designs that use the minimum standards as targets. This regulatory approach by minimum standard has fostered the creation of minimum environment.

A change in the philosophy and approach to modelling water and water systems is necessary. This paper discusses the need to move from managing the component parts of a system to model development, application and integration into a systems framework based upon a logical, interactive ecosystem unit which, in the case of water, is likely to be the watershed. This paper discusses the need to move from a regulatory basis for system management to a process based management system.

2.2 Overview and Perspective

2.2.1 Past Approach

Man has modified water-based environments throughout the world. Most major catchments in North America and Europe have been altered significantly (Minshall 1988; Bacalbasa-Dobrovici 1989; Backiel and Penczak 1989; Brousseau and Goodchild 1989; Hesse et al. 1989; Lelek 1989; Mann 1989; Sedell et al. 1989; Ward and Stanford 1989). Modifications of temperate North American rivers, their catchments and water

budgets has occurred over a relatively short period (i.e. 200 years) compared to European rivers (i.e. >1000 years)(Bacalbasa-Dobrovici 1989; Lelek 1989; Mann 1989).

Degrading processes vary from catchment to catchment and from continent to continent but include changes in water quality through discharge of surface run-off and groundwaters from agricultural and urban landscapes, direct human and animal wastes, industrial wastes and sediment loading through poor landuse practices. Alterations in the morphometry of river channels and their floodplains occur through the increases in surficial run-off, flow volumes, increased flow energies and sediments from the catchment as well as damming, draining, channelizing, dredging, dyking, and filling. Water abstraction for municipal and industrial purposes reduce water supply from groundwater sources while landuse practices that increase the imperviousness of the catchment reduce groundwater replenishment. Acting as a whole, these alterations have created problems for the management of not only natural environments and ecosystems but also for the management of human dominated environments. Conventional urbanization with its two primary components of residential and industrial development appears to be the endpoint in the structural degradation of rivers and their basins (Steedman 1988; Regier et al. 1989; Imhof et al. 1991).

Alterations of the water budget of a catchment and the modifications to physical, chemical and biological pathways and processes can be classified as a syndrome of conventional urbanization. The results of conventional urbanization syndrome is characterized by reductions in tributary density, alteration or barriers to migration of fish and other animals, increases in frequency and magnitude of storm events and peak discharges. These modifications result in a concurrent reduction in baseflows, increased sediment loads, reduction in channel and floodplain complexity, and impaired water quality (Klein 1979; Steedman 1987, 1988; Imhof et al. 1991).

The structural degradation of rivers and their catchments alters water inputs into the ground and acts to simplify, modify or eliminate physical habitat features required by aquatic ecosystems

(lakes, streams and wetlands) and their plant and animal communities (Regier et al. 1989). Klein (1979) demonstrates that water quantity (discharge), water quality and fish species diversity are directly linked to the percent imperviousness of a catchment. Changes in percent imperviousness of a catchment are linked to urbanization; downward infiltration of water is impeded and lateral surface run-off is expedited; tributary density is reduced. The water budget is altered. Run-off which in a forested watershed is an artifact becomes the dominant component of an urban/urbanizing watershed. Steedman (1988) demonstrated that urbanization affected the hydrology, hydraulics, water quality and fish community of streams flowing through urban and urbanizing areas.

Water quality degradation also occurs through the discharge of human and animal wastes resulting in either a toxic reaction (e.g. toxic levels of ammonia) or a chronic change (e.g. depleted oxygen due to high BOD). These effects increase costs of treatment for water supply managers and in natural environments often create chemical barriers which isolate fish and other animals from various portions of the river system that may be necessary for their life cycle. Industrial processes also discharge hazardous material into rivers and into saturated and unsaturated groundwater zones (e.g. halogenated chemicals; heavy metals; cyanide; arsenic; etc) increasing the costs associated with environmental management.

Water is viewed as a resource and as a waste product. This is the contradictory dichotomy under which managers presently operate. Within any watershed, the state of the streams and rivers are an expression of the results of this dichotomy and the management processes that have been put in place to use and dispose of water (Hynes 1975).

As an example, watershed management has operated within the engineering context that natural resources of a watershed such as its rivers must serve an absolute, direct human need in order to be of use. Therefore many rivers are viewed as sources of cheap energy, water supply, hydraulic waste, floodwater disposal and at its worst, convenient conduits of human waste. Hydrologic

modelling of the watershed in its existing state is often conducted to determine the engineering specifications for drainage, the ability of the channel to handle the *waste water* and the implications on erosion and flooding. Once all these physical factors are satisfied, attempts are then made to accommodate the ecological needs of the river. In this manner, planning and management allows for a simplistic drainage template to be overlaid upon the river and its watershed and then attempt to *fit* sound environmental management within this context. This approach is environmentally and economically unsustainable.

In many jurisdictions, including Ontario, Canada, most hydrologic engineering in urban watersheds embraces the paradigm that water is a waste product or a hazard and must be moved off the land as fast as *humanly possible*. Modelling is usually done on the design storm basis using 1:2 year, 1:5 year, 1:25 year or 1:100 year recurring events for hydrologic and hydraulic modelling and design. Since rivers modify their channels during the annual storm which has an annual return rate of 1:1 to 1.5:1 (Leopold et al. 1964; Leopold 1968), this time scale discrepancy in the two approaches causes fundamental changes to the river: its' morphology; recharge capability and ultimately the water quality; productivity and biodiversity. The assumption that the existing stream morphology and flow regime is the correct system is a tacit approval of the historical record of human pioneering, settlement and development which has resulted in these existing degraded conditions. For example, the lack of fluvial geomorphological input in river channel management, despite the well-established science of the discipline is testimony to the compartmentalized engineering view of rivers as simply conduits of waste water. This traditional hydrologic engineering approach has been challenged in Germany over the last several years and has resulted in a multi-million dollar program to *de-engineer* and re-naturalize their rivers (Arnold et al. 1989).

2.2.2 Present Practices

In Ontario, there have been major changes in the last 10 years in the process and management of urban water quality and quantity. Some of these changes in the last several years are the result of importing technology refined in the State of Maryland.

In the late 1970's the Province of Ontario began to request a comprehensive approach to stormwater management. This was a result of concerns identified by various government agencies over changes in flood, erosion and water quality resulting from urban drainage designs and management. The focus for stormwater quantity and quality control shifted from the specific small development to a larger scale of analysis which encompassed portions of drainage systems in the sub-basins of larger river systems. This was an attempt to predict and manage for cumulative impacts of stormwater discharge on the river channel downstream of the newly developed lands within the watershed and to ensure proper capacity of channels, erosion control, flooding, etc. These plans were called *Master Drainage Plans* (MDP).

Despite this attempt to manage water and water supply in a more integrative fashion, the emphasis was flooding, focusing on surficial concerns for water on the surface of the land and its fate upon entering a natural channel (often ignoring headwater/recharge regions). The objective was to convey water off the land and where necessary detain it so that discharge characteristics in the modified landscape would emulate *pre-development* flow conditions based upon certain design rainfall events (e.g. 1:2 yr; 1:5 yr; 1:25 yr). Often the context for *pre-development* was simply the degraded agricultural state. Once the major requirements for drainage were met, consideration was then given to attempting to *fit in* environmental concerns such as water quality and fisheries. In some of the models and analyses, consideration was given to shallow groundwater flow, but only as input to the hydrologic and hydraulic modelling components.

Although the MDP approach was a major step forward in the management of surface water quantity and later quality, it was

still a two-dimensional approach, occurring as a supporting process to the landuse planning process. The landuse planning process determines the preferred use of the land based upon economic and sociological considerations. The MDP process is then used to ensure that the designs to be placed upon the landscape will function to remove water from the area and not overly affect river conditions and water quality downstream. Only recently in Ontario have MDP's examined the related issues of water supply quantity and quality. In order to do this, other water budget parameters such as infiltration, throughflow, and evapotranspiration would have to be considered and the unit of investigation expanded to encompass an integrative, physical/ecological unit of land.

The result of this planning and modelling approach is that many of the environmental alterations resulting from changes in the water budget including physical, chemical and biological processes within the study basin are not predictable. These changes include modifications to channel form, dimensions, stability, ability to efficiently transport water and bedload at all major design stages; modification to water quality in the receiving channel; interference, reduction or contamination of well water supplies; destruction of fish habitat; alteration of nutrient cycling in streams; etc.

There is no opportunity in the present MDP process to set quantifiable objectives, targets or standards that are designed to: avoid environmental damage; achieve reasonable development within an area that does not compromise the integrity of local ecosystems; and improve the condition of the local environment as development proceeds.

The present process of model development and planning for stormwater management and water quality is not being applied within an ecosystem context. Without this integrative focus there is no way to examine within a common physical/chemical/biological context the landbase and potential alterations to environmental features and processes that society requires, desires, or wishes to avoid (eg. fish, wildlife, water supply and quality, avoid damaging floods, contamination of wells, erosion,

etc.). As well the ecosystem context is important in order to create the *one window* approach to the examination of water and water resource management in a way that allows all issues and opportunities to be examined at the same time. This information would also be extremely useful as objective input into the cause:effect relationships of potential landuse planning decisions in municipalities residing in the ecosystem unit.

2.2.3 Present Processes

The present landuse planning process has not succeeded in resolving the interactive and oft-times seemingly conflicting issues revolving around landuse, water supply and management. Presently, landuse decisions are made prior to more technical analyses of the condition and functioning of the physical environment. It is only once development is proposed for a portion of land that the full rigour of the environmental analyses and reviews occur. The approach apparently taken by most States and Provinces has been that environmental concerns are addressed once the land is actually slated for development.

Most jurisdictions in North America have some form of environmental legislation and planning in place to minimize destruction or degradation of the environment. Ontario has one of the most complex and seemingly sophisticated systems of any jurisdiction.

Government initiated landuse proposals are subject to the Ontario Environmental Assessment Act which requires environmental assessment for any public undertaking. Depending upon the size, complexity or potential impact of an undertaking, each proposal is subject to some level of environmental scrutiny ranging from a full environmental assessment for high impact proposals (e.g. hydroelectric projects) down to relatively simple straightforward conditions of development (e.g. dock construction). The requirements of the Act can be applied to private sector undertakings, although this rarely occurs.

Privately initiated proposals are generally regulated under the

provisions of the Ontario Planning Act. The Act regulates landuse planning in the Province and provides for the subdivision of land and development controls through a specific process of landuse designation, enforcement, modification and approval. The Act is implemented at the regional and municipal level. To ensure a sound consistent approach to land management at the municipal level, the Planning Act requires the development of Municipal Official Plans (OP). The OP is a strategic plan that establishes long-term landuse management goals and objectives for the municipality. It designates a present and proposed landuse designation on all lands in the municipality and ensures a consistent mechanism for amendments to the plan, development proposals, drainage and servicing studies and plans for subdivision, etc. Although Provincial approval agencies (e.g. environmental agencies) may recommend modifications to the OP, the designation of land is driven by economic, development and political interests.

On a day-to-day basis within a municipality, repercussions to the natural environment and the sustainability of water and water based resources are usually addressed by environmental agencies at the plan for subdivision level when detailed plans are submitted. At this point, the developer has already received approval to develop his land from various Provincial, Regional and local government agencies and has invested substantial monies in the design and engineering of his undertaking. Comments by environmental managers and biologists on the need to modify design at this point are usually viewed with some hostility leading to confrontation. Environmental reviewers also have difficulty in determining the cumulative impacts of a series of small developments on the physical, chemical and biological interactions within the watershed. This planning process leads to further degradation of the watershed environment and its physical and biological resources. This situation has lead to the realization that ecosystems cannot be managed on a plan-for-subdivision level.

Presently, regulations are used to ensure that the negative effects of landuse development are mitigated or minimized. This

is usually done through a regulatory process implemented at the site planning level. This is somewhat akin to enforcing restrictions of a certain nature on a site when the first question that should have been asked is whether this type of development or landuse is appropriate at all. This approach has continued to result in incremental deterioration of water quantity and quality despite the best efforts of technologists, in part because it appears that management by minimum standards becomes a target for design which in turn ensures a minimum environment. Perhaps it is time to view technology as a tool and develop an integrative systemic or ecosystemic management and planning process that directs the best use of the land for the entire ecosystem (people, plants, fish and animals). The process would also improve resolution of the most appropriate tool or tools (eg. soft or hard BMPs) to use for the land to be altered. The process ultimately enables managers to *design out* potential problems before they occur.

2.2.4 Developing an Ecosystem Approach and Context

There have been discussions on using an Ecosystem Approach for managing resources and landuse (I.J.C. 1978; Likens 1984). An Ecosystem Approach attempts to examine and identify the inter-relationships among biophysical, chemical and human elements of the ecological system. It recognizes the dynamic nature of the ecosystem, incorporates concepts of carrying capacity, resilience and sustainability. The approach strives to develop management targets based upon the potential of the ecosystem in accordance with a balance between the needs of the natural system and human requirements. Although this concept has been proposed in the past, the difficulty has always been in determining how to apply the approach, how to integrate the disciplines and the modelling efforts that would examine the various components of the ecosystem and finally how to implement the approach through established approval systems.

An Ecosystem Approach requires a number of key elements:

a logical geographic/ecological unit; an analytical process that allows for a view of the interactions between human and natural components of the ecosystem; and use of a physical pathway that interacts and integrates physical, chemical and biological processes (Imhof et al. 1991). The approach must have the ability to develop targets, standards and guidelines for landuse management, development, protection and rehabilitation, and there must be a planning process used that merges the ecological targets and preferred ecological management scenarios into the municipal, regional and state/provincial planning processes.

For water and water resource systems, we suggest that investigators and managers use the hydrologic cycle encompassed within certain physical ecosystem boundaries (Figure 2.1). For most urbanizing riverine based areas in North America, we suggest a process entitled *Watershed Management Planning* (WMP) be considered as one application of the Ecosystem Approach to management. In this process, a watershed is delineated as the geographical unit that encompasses the 4-dimensional characteristics of an ecosystem composed of aquatic environments and up-slope terrestrial environments linked by a common element, water (Figure 2.2). This then allows us to study the land:water interactions in a clearly defined geographic setting. The use of the hydrologic cycle provides a clearly measurable pathway in which the characteristics of the land can be modelled and the implications of water movement over and through the watershed can be analyzed for its implications on the biotic and human dominated environments. The hydrologic cycle also allows for the development of targets for environmental and landuse management that are quantifiable.

2.3 Framework for Model Development and Application

Two processes are required in order to employ an ecosystem approach effectively. One is a scientific/technical framework and

Figure 2.1: Geographically based hydrologic units.

Figure 2.2: Hydrologic and ecologic pathways within a watershed.

process for model development, calibration and validation based upon a logical, ecosystem unit. The other component is a planning framework and process that incorporates the information from the ecosystem model into the various resource, environmental and landuse planning streams. For the purpose of this discussion we will examine these components using the watershed/subwatershed as the ecosystem unit.

2.3.1 Creation of a Scientific/Technical Modelling Process

Modelling is used extensively in the field of water and water resource management. In generic terms, any reproduction of a system is a model. Models that make use of algorithms in an attempt to reproduce a system are termed mathematical models.

What is common to all mathematical models is the balance of some observable quantities or variables which conceptualize the object to be simulated. The equations defining balances usually imply the formulation of constitutive laws. For example, in the case of various water discharge models these would include the hydrologic transport, generation and decay processes. Presently models are used to fit an endpoint objective such as a desire to move a certain amount of water down a channel without considering the implications to the ideal functioning of the channel. The final results often have limited consistency because the models of conveyance transport ignore the local micro-scale equations (eg. fluvial geomorphology) which actually define full system function. Because of the scale of the system to be modelled, simplifying assumptions must be used, this approach often produces results in which computed values do not compare well with measured values. In these instances the modeller will adapt the natural system into the confines of the generic model being employed at the time. This approach leads to inconsistencies between the analytical and empirical data with the result that the modeller will attempt to fit the natural system parameters into the parameters of the analytical model.

The forecasting capabilities of mathematical models are tied

to statistics because of the nature of the systems that models try to reproduce. In this spirit statistical mechanics and its two dimensional thermodynamic applications have inspired various ecological models. In spite of some other well-established similarities between traditional statistical and thermodynamic models and ecological models, the linkages between the two fields are not so clearly understood.

Previously, in the field of ecological modelling the deterministic character of the basic equations have made them very attractive for forecasting. This characteristic has been generally useful in decision-making. Presently, these expert systems develop a life of their own because of the experimental method by which they are derived: i) screen the quality of information contained in the measured values, ii) yield results affected by uncertainty, and iii) offer options to the decision-maker. As a result, the form and function predicted by this modelling approach often bares no resemblance to the natural functioning system and as a result the options provided the decision-makers are invalid.

Presently, in ecological studies, process conceptualization for model development is carried out in an intuitive manner. Assumed in this process is that the link between the original system and the conceptual model can be defined through a functional transformation of macroscopic variables. However, environmental experimentation is strongly affected by the scale of observation for both sampling protocols and the significance of the data. Present ecological models are also affected by the choice of time and spatial scales. These scales define the parameters and determine the suitable algorithms for the model. As a result of this approach the modeller is placing very narrow contrived mathematical boundaries from generic models into heterogeneous domains. As well the time scales may not be interactive between the spatial, temporal, physical, biological, chemical, and geological processes and scales. Therefore the effects of cross-linking submodels from two or more disciplines might obscure or alter the expected events because time averages will differ from ensemble averages. The present method to

resolve these anomalies is to incorporate fuzzy partitioning algorithms at the cross-over position to quantify the cross-disciplinary linkages. Consequently, the utilization of fuzzy parameters in present inter-disciplinary modelling methods is a convenient means of qualifying the model, leading to a highly acceptable yet low precision representation of the ecosystem (Figure 2.3, left hand side).

Networked ascending integration is an alternative method which foregoes the problematic factoring of fuzzy parameters into the modelling infrastructure. This approach generates a self-derived system which defines the models representative of the unique watershed system. This approach provides greater reproducibility and precision in definition of the watershed. In essence the *real life* physical parameters dictate the appropriate models rather than using standardized, convenient, generic models.

A vertical integration procedure is used for selection of models (Figure 2.4) which have to ultimately supply information to several inter-disciplinary levels of the networked model. This selection criteria process reduces the dependency on fuzzy parameters, thereby improving integrated modelling precision and accuracy. The iterative steps are model building blocks, (eg. geology, climate, hydrology, hydrogeology, and biology) taken in a methodical non-biased sequence to formulate the definition of the conceptual watershed model. Each discipline is responsible for its submodel selection procedure. Each submodel should be mathematically suited to the physical conditions while providing input/output pathways to the consolidated network infrastructure.

Therefore, the first step in a watershed study is the determination of the initial disciplines for the study. Once there is a level of confidence in the disciplines selected, the first iteration of the watershed model is the selection of submodel components. The submodels are networked to validate the watershed model against empirical information. If the watershed model is not valid, the suite of submodels are reviewed based upon the incongruities found within the watershed model. Based upon this review, redefinition of the disciplines and the submodels

Figure 2.3: A conceptual framework showing the results of the traditional and ecosystem approach to watershed modelling.

Figure 2.4: A vertical integration procedure for the selection of watershed sub-models.

would be reevaluated. The above process is repeated until such time as the watershed model as a whole is validated. For the abiotic portions of the model, the fundamental means by which validation is quantified and qualified is by means of a watershed mass balance (Figure 2.3, right hand side). For example, the submodel for groundwater must reflect accurately the functions of the regional and multi-surficial groundwater systems, the locations of discharge and recharge so that they may be integrated in the hydrologic and biological system analyses while maintaining hydrologic and chemical mass balances within own modelling domain and the domains of the other submodels. Biotic components in turn would be validated by their correlations with the abiotic components.

By our definition, Watershed Management Planning is a holistic, integrative approach to the management of land:water on a watershed basis. It strives to identify the functional attributes of each area of the watershed and recognize the interdependencies of components within the watershed. Based upon this understanding, the process then determines optimal, feasible ecosystem targets within which the human social fabric can be interwoven.

The use of the watershed as an ecosystem unit is contingent upon setting the appropriate scale and resolution for planning (e.g. full basin; sub-basin; single tributary system). The selection of the appropriate scale and its corresponding resolution will be based, at least in the short-term, upon local and regional planning issues. Although sub-basin watershed plans may be adequate to address ecological and human considerations in the sub-basin, by foregoing the full basin study prior to the sub-basin study, there will be a loss in efficiency and flexibility of managing the entire system and its supporting sub-basins as an integrated unit.

Since WMPs will require an interdisciplinary team made up of a variety of disciplines (including and not limited to hydrogeology, hydrology, hydraulics, geomorphology, aquatic and terrestrial ecology, engineering, environmental and municipal planning, water quality and toxicology and data management), there is an explicit need to ensure that the study process

incorporates an interdisciplinary and data integration mechanism so that pathway and process modelling of the watershed or sub-basin can be developed, tested and used to develop and assess various target scenarios for the watershed.

2.3.2 Creation of a Ecosystem Planning Process

The model development process and its ecosystemic application are deterministic. The ecosystem being studied (eg. a watershed) has formed and evolved based upon the geology and climate of the region, modified by biotic processes and additional abiotic processes. In turn the ecosystem itself, if examined carefully, defines its functions and form and these in turn provide the information for determining how best to manage the system to ensure both a thriving, functional natural environment and human dominated environment (see Figure 2.3).

Once the study has developed a view of the form and function of the watershed system, environmental/ecological targets can be determined that will ensure that the physical pathways and processes remain intact and functional. Once these targets have been set, various landuse/resource management options can be examined in order to determine opportunities for development or resource management. Analyses of cause:effect relationships within the watershed can then be determined for the various desired uses and ecological/economic implications of any proposed management decision can be identified.

To ensure the proposed WMP management scenarios are implemented, the WMP process must be integrated into the state or provincial planning process. In Ontario, planning legislation such as Planning Act and the Official Planning (OP) process are two of the keys to implementing the ecological targets and management scenarios developed by the WMP process. The WMP process would complement the OP process by providing a scientific and objective process for the determining opportunities and constraints for the use of land in the watershed. In order for WMP to be used as an effective, objective tool, WMP's must

occur prior to or early into the resource, environmental or landuse planning process. If WMP's precede planning decisions, then quantifiable, achievable, environmental objectives can be identified and used to make informed planning decisions. Potential cumulative impacts on natural environments can be avoided, designed out of a project or at worst, mitigated by using WMP to set ecological goals, targets and landuse recommendations as the input into municipal planning. People can have their homes, their livelihood, and healthy, clean rivers and healthy fish communities.

2.4 Conclusions

The management of water and water-based resources is in fundamental transition. Never before has there been a greater demand across North America for better water conservation, water quality, healthier aquatic systems, and benign development. People now want to maintain and rehabilitate their streams, rivers and lakes so that these systems are once more *drinkable, swimmable, fishable and enjoyable*.

The old tools, standards, regulations and models do not appear to be achieving the results that many desire. Concerns range from the loss of streams, lakes and wetlands to depletion of well fields, water quality degradation, etc. There are several possible reasons for this: the tools, models and processes are compartmentized and non-integrative; they are being applied at the wrong scale; models are being applied outside their domain; there is no common context in which to examine, analyze and model the water system within an ecological unit. Although an ecosystem, such as a watershed, may be of interest for a variety of reasons, the various planning processes (resource; environmental; municipal) all plan in isolation of each other. This is especially true when portions of the watershed are slated for modification for any reason. This has resulted in an inability to develop environmental objectives, targets and standards to guide and design developments in order to maintain the natural

water-based biophysical systems that society wishes to protect and rehabilitate.

What is needed is a new process that manages the land:water base within an ecological unit in which the needs of natural components of the ecosystem are met or exceeded while at the same time accommodating reasonable human development and growth.

Application of an ecosystem approach and context requires a fundamental change in philosophy. The shift is from a regulatory based process for environmental management addressed through a site-specific, compartmentized, application of environmental standards to a process based planning and analytical/modelling system integrated within a definable ecosystem unit (eg. watershed or sub-basin). The process creates the integrative context for the determination of ecosystem form and function, application and networking of appropriate models. This can lead to the determination of ecological targets as the standards for use of the land and its water resources.

For the management of water and water systems, use of a physical pathway such as the hydrologic cycle, bound within a logical, geographic ecosystem unit, such as a watershed and using an appropriate functioning time scale, appears to offer great efficiencies. Efficiencies not only in costs and benefits but also as valuable, objective information for the development of human uses of the water and water resources that will not compromise the sustainability of the ecosystem and its physical resources.

Ecosystems are complex systems, driven in part by physical and chemical pathways and processes, but also modified by biotic communities and processes. Ecosystems are extremely resilient because of the built-in feed-back loops, as well as their adaptability and flexibility to change. The individual who approaches ecological modelling as a science might assume that, as computing capabilities progress, system dynamics can be determined with a prefixed level of accuracy. This deterministic view of natural systems derives from classical mechanics which asserts that if one knew all the physical laws and the initial state of the universe, one could predict the future. Unfortunately (or,

fortunately) it is impossible to analytically solve all the equations needed even for a small subsystem. In the present compartmentized approach to modelling, this has lead to the overuse of fuzzy parameters that act as qualitative and quantitative connectors between the models used by each discipline. The use of fuzzy parameters is in part a result of cross-discipline uncertainties.

As an alternative, for consideration, is the process illustrated in Figure 2.3 (right side). Whereby the natural system itself is used by the team to determine the structure of the study, the data collection requirements, submodels used and the linkages between them. This will not avoid the use of some fuzzy parameters but will eliminate the cross-disciplinary uncertainties and minimize intra-disciplinary data deficiencies. This ecological model development process will produce a deterministic watershed model of higher precision which has the fundamental scientific requirement of being reproducible and representative of the study domain: in this case the natural watershed system.

If this process is integrated with a landuse planning process, implications of proposed landuse alterations upon natural environments, water conservation (surficial and groundwater) and human needs could be determined. Management scenarios could be proposed that would recommend landuse designations, development targets and standards designed to protect and improve natural environments and improve the efficiency of water management (e.g. flood and erosion control, aquifer management, servicing, stormwater management, fish habitat protection, etc.) as development proceeded within the watershed.

2.5 References

- Arnold, V, J. Hottges, G. Rourie, M. Einsele, S. Englich, V. Ernst, H. Herberg, and F.K. Holtmeier. 1989. Removing strait-jackets from rivers and streams. *German Research, Reports of the DFG* 1989 (1): 22-24.

Bacalbasa-Dobrovici, N. 1989. The Danube River and its fisheries. Proceedings of the International Large Rivers Symposium. *Canadian Special Publication of Fisheries and Aquatic Sciences* 106: 455-468.

Backiel, T., and T. Penczak. 1989. The fish and fisheries in the Vistula River and its tributary, the Pilica River. Proceedings of the International Large Rivers Symposium. *Canadian Special Publication of Fisheries and Aquatic Sciences* 106: 488-503.

Brousseau C.S., and G.A. Goodchild. 1989. Fisheries and yields in the Moose River basin, Ontario. Proceedings of the International Large Rivers Symposium. *Canadian Special Publication of Fisheries and Aquatic Sciences* 106: 145-158.

Hesse, L.W., J.C. Schmulbach, J.M. Carr, K.D. Keenlyne, D.G. Unkenholz, J.W. Robinson, and G.E. Mestl. 1989. Missouri River fishery resources in relation to past, present, and future stresses. Proceedings of the International Large Rivers Symposium. *Canadian Special Publication of Fisheries and Aquatic Sciences* 106: 352-371.

Hynes, H.B.N. 1975. The stream and its valley. Edgardo Baldi Memorial Lecture. *Verhin International Verein. Limnology* 19: 1-15.

Imhof, J.G., R.J. Planck, F.M. Johnson, and L.C. Halyk. 1991. Watershed urbanization and managing stream habitat for fish. *Transactions of the 56th North American Wildlife & Natural Resources Conference* 56: 269-283.

International Joint Commission. 1978. The ecosystem approach. Great Lakes Research Advisory Board. 47 p.

Klein, R.D. 1979. Urbanization and stream quality impairment. *Water Resources Bulletin* 15: 948-963.

Lelek, A. 1989. The Rhine River and some of its tributaries under human impact in the last two centuries. Proceedings of the International Large Rivers Symposium. *Canadian Special Publication of Fisheries and Aquatic Sciences* 106: 469-487.

Leopold, L.B. 1968. Hydrology for urban land planning - a guidebook on the hydrologic effects of urban land use. *United States Geological Surveys, Circular* 554. 18 p.

Leopold, L.B., W.G. Wolman, and J.P. Miller. 1964. *Fluvial Processes in Geomorphology*. Freeman and Sons, San Francisco, CA. 522 p.

Likens, G.E. 1984. Edgardo Baldi Memorial Lecture. Beyond the shoreline: A watershed-ecosystem approach. *Verhin International Verein. Limnology* 22: 1-22.

Mann, R.H.K. 1989. The management problems and fisheries of three major British rivers: the Thames, Trent and Wye. Proceedings of the International Large Rivers Symposium. *Canadian Special Publication of Fisheries and Aquatic Sciences* 106: 444-454.

Minshall, G.W. 1988. Stream ecosystem theory: a global perspective. *Journal of the North American Benthological Society* 7: 263-288.

Regier, H.A., R.L. Welcomme, R.J. Steedman, and H.F. Henderson. 1989. Rehabilitation of degraded river ecosystems. Proceedings of the International Large Rivers Symposium. *Canadian Special Publication of Fisheries and Aquatic Sciences* 106: 86-97.

Sedell, J.R., J.E. Richey, and F.J. Swanson. 1989. The river continuum concept: A basis for the expected ecosystem behaviour of very large rivers? Proceedings of the International Large Rivers Symposium. *Canadian Special Publication of Fisheries and Aquatic Sciences* 106: 49-55.

Steedman, R.J. 1987. *Comparative Analysis of Stream Degradation and Rehabilitation in the Toronto Area*. Doctoral dissertation, University of Toronto, Toronto, Canada.

Steedman, R.J. 1988. Modification and assessment of an index of biotic integrity to quantify stream quality in southern Ontario. *Canadian Journal of Fisheries and Aquatic Sciences* 45: 492-501.

Ward J.V., and J.A. Stanford. 1989. Riverine ecosystems: The influence of man catchment dynamics and fish ecology. Proceedings of the International Large Rivers Symposium. *Canadian Special Publication of Fisheries and Aquatic Sciences* 106: 56-64.