Integrated Assessment
2003, Vol. 4, No. 3, pp. 172–184

1389-5176/03/0403-172$16.00
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Integrated Assessment and Sustainable Water and Wetland Management. A Review of Concepts and Methods

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ABSTRACT

This paper reviews and examines the potential of systematic and formalised interdisciplinary research concepts and methods for sustainable water and wetland policy and management, as advocated by the recently adopted European Water Framework Directive. Such potential lies in the integration of insights, methods and data drawn from natural and social sciences. The concept of integrated assessment is first defined in a preliminary way and is then reviewed from a range of methodological and policy analysis viewpoints. This overview addresses issues such as (1) the need for vertical and horizontal integration when linking information demand and supply; (2) procedural steps in integrated assessment; (3) useful frameworks to structure and handle complexity and uncertainty; (4) the distinction and correlation between ecological and social values of aquatic ecosystems; (5) available evaluation methods and techniques. Socially and politically sensitised forms of integrated assessment are an important step towards: (a) increasing awareness about the complex nature of the interdependency between our physical and socially constructed environment; (b) greater recognition that uncertainties and risk of irreversible change require careful consideration (precautionary principles) in decision-making, which may be facilitated by prior agreement on a sensible, preferably social learning based, evaluation process; (c) recognition that costs and benefits in complex decision-making circumstances are dynamic, as knowledge and experiences progress; (d) increasing public support for and trust in decisions because of greater transparency in the ex ante evaluation phase.

Keywords: integrated assessment, decision support, water, wetlands, sustainable management.

1. INTRODUCTION

There is widespread acceptance of the fact that water quality and the integrity of water and wetland resources are of vital importance for human well-being now and in the future.[1] Lack of awareness and incomplete information about the value of water and wetland resources in policy and decision-making processes have resulted in a failure to conserve and protect these resources, causing unrecognised social and economic costs [1]. This situation has been caused *inter alia* by (1) the public and open access nature of water and wetland resources; (2) user externalities as a result of excessive and unrestricted use of water and wetland products and services; and (3) policy intervention failures due to a lack of consistency among policies being enacted across different sectors of the economy. All three causes are related to the lack or absence of information which in turn can be linked to the complexity and 'invisibility' of the spatial relationships between groundwater, surface waters and wetlands [2].

Aquatic ecosystems are adaptive, but ecologically sensitive systems, which provide many important services to human society. This explains why in recent years much attention has been directed towards the formulation and operation of sustainable management strategies, the recent adoption of the European Water Framework Directive (2000/60/EC) being a good case in point. Both natural and social sciences can contribute to an increased understanding of relevant processes and problems associated with such strategies. The key to a better understanding of water and wetland problems and their mitigation through more sustainable management, lies in the recognition of the importance of the diversity of functions and values supplied to society at different geographical and time scales. This

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[1]Although there exists little agreement among scientists on what constitutes a wetland, partly because of their highly dynamic character, and partly because of difficulties in defining their boundaries with any precision [43], a workable definition is given by the so-called Ramsar Convention on 'Wetlands of International Importance Especially as Waterfowl Habitat' (1975): '*areas of marsh fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt including areas of marine water, the depth of which at low tide does not exceed 6 m*'.

includes a better scientific understanding of aquatic ecosystem structure and processes and the significance of the associated socio-economic and cultural values. The Water Framework Directive, which provides a much more integrated river-basin approach to water policy, is the first European Directive to explicitly recognize the importance of this interdependency between water and wetland ecosystems and their socio-economic values. Investments and water resource allocations in river basin management plans will be guided by cost recovery, cost-effectiveness criteria and the polluter pays principle. The plan formulation and assessment process must furthermore include a meaningful consultative dialogue with relevant stakeholders. Such a dialogue will inevitably raise socio-political equity issues across the range of interest groups and therefore affect the management strategies to be chosen.

This paper reviews and examines the potential for systematic and formalised interdisciplinary research concepts and methods for aquatic ecosystems. Such potential lies in the integration of insights, methods and data drawn from natural and social sciences, as highlighted in previous integrated modelling and assessment surveys [3]. The ideas and concepts presented here are to a large extent based upon the work carried out during the period 1996–1999 in an interdisciplinary research project funded by the European Commission called Ecological-Economic Analysis of Wetlands: Functions, Values and Dynamics (ECOWET).[2]

2. TUNING INFORMATION SUPPLY AND DEMAND FOR THE PURPOSE OF ENVIRONMENTAL DECISION-MAKING POLICY

In the light of an increasingly emancipated society, decision-makers are held responsible and are made accountable for their decisions, sometimes a number of years after decisions were taken. Public scrutiny, accountability and trust have become of paramount importance. Decisions have to be explained and justified, especially to those who are directly affected by them. In complex decision-making situations, various, often competing, interests may be at stake. Demand for information which reflects this plurality and diversity of interests and the way these interests are affected by decisions is increasing. Ideally, information has to encompass the various relevant dimensions of the problem a decision-maker tries to solve, i.e., information has to be comprehensive and complete, even though in practice decision-making takes place in contexts in which uncertainties and incomplete information are inevitably present to different degrees.

At the same time information has to be communicated in a meaningful and persuasive way to both decision-maker and those affected by decisions. As societal-environmental change becomes more complex and decisions, interests and value systems more inextricably connected, there is growing interest in integrated approaches to inform policy and decision-making. Integrated assessment procedures have been developed in order to avoid as many unforeseen consequences of policy decisions as possible [4].

In the context of water resources management, Mitchell [5] has argued that efforts directed towards more integrated management has three related dimensions. In the case of the management of wetlands, integration can be interpreted as follows:

(1) In systems ecology terms, i.e., to gain a better understanding of how each component of the wetland system at catchment level influences other components.
(2) In wider biogeochemical and physical systems terms, i.e., where water interacts with other biophysical elements (one of the most characteristic features of a wetland).
(3) In socio-economic and socio-cultural terms, i.e., where wetland management is linked to relevant policy networks and economic and social systems with attendant culture and history, so that the chances of a co-operative solution or mitigation strategy are maximised.

Socially and politically sensitised forms of integrated assessment are expected to be an important step towards:

(i) increasing awareness about the complex nature of the interdependency between our physical and socially constructed environment, coevolutionary processes of change;
(ii) greater recognition that uncertainties and risk of irreversible change require careful consideration (precautionary principles) in decision-making, which may be facilitated by prior agreement on a sensible, preferably social learning based, evaluation process;
(iii) recognition that costs and benefits in complex decision-making circumstances are dynamic, as knowledge and experiences progress;
(iv) increasing public support for and trust in decisions because of greater transparency in the *ex ante* evaluation phase.

Information provided to support decisions is determined to a large extent by the political characteristics of the decision-making system and the phase in the decision-making cycle (see Fig. 1). Figure 1 provides a very general characterisation of the decision-making cycle. A similar general model of decision-making processes is given, for instance, by Mintzberg et al. [6], who distinguish three phases in a decision process:

(1) Identification of opportunities, problems and crises, activating the decision process (*recognition and diagnosis*).
(2) Development of solutions (*search and design*).
(3) Selection from available solutions (*screening*, *judging*, *bargaining*) and obtaining approval for the selected solution (*authorisation).*

[2] Contract number ENV4-CT96-0273.

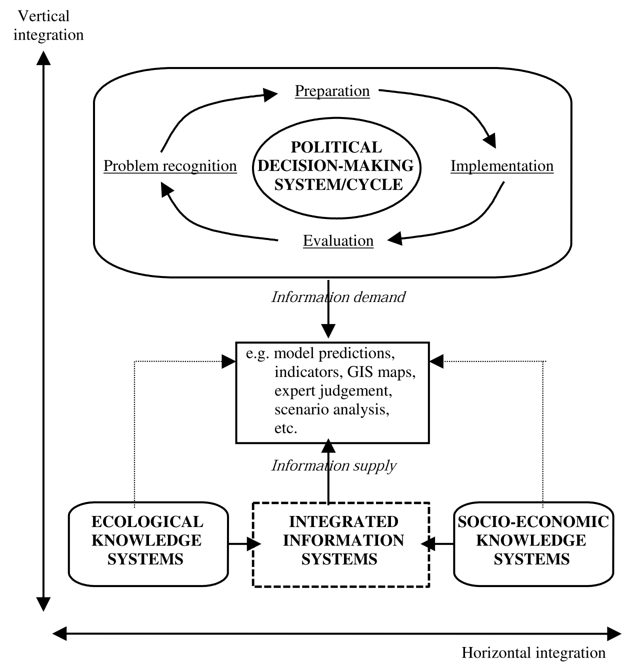


Fig. 1. General framework linking information supplied by multi-disciplinary science and decision-maker demand for information.

In Figure 1, two axes are included, depicting the demand and need for horizontal integration across scientific disciplines and the demand and need for vertical integration of information as decision-making contexts become ever more complex. An important issue linking knowledge and information across different sciences and between sciences and decision-making processes is the temporal and spatial consistency. The same problem may, for instance, play at significantly different geographical and time scales from a natural scientific perspective, a social scientific perspective and a political perspective [7]. In the literature, frameworks (such as the Driving Forces, Pressures, State, Impact and Responses (DPSIR) scoping system) and models have been developed, which try to link scientific knowledge and information systems (e.g., [8, 9]). These information systems provide an important interface between natural and human systems. Perceptions of interactions between natural and social systems are reflected in the way research is carried out and information systems are constructed (information supply).

3. INTEGRATED ASSESSMENT

Recently, there has been growing interest in integrated approaches to inform policy and decision-making, for instance in the climate change discussion [10, 11]. Various assessment forms exist, including technical, health, environmental, economic and social appraisals. In general, the need for these appraisals results from problems of choice, where decision-makers (e.g., policy makers, producers, consumers) face one or more options (e.g., policies, projects, measures, products etc.) in a given policy context [4].

The literature contains various definitions of integrated assessment. According to Weyant et al. [12], an assessment is integrated when it draws on a broader set of knowledge domains than are represented in the research product of a single discipline. Parson [13] argues that integrated assessment is a policy relevant whole, which is greater than the sum of the disciplinary parts. An appealing definition is given by Rotmans et al. [14], who define integrated assessment as '*an interdisciplinary process of combining, interpreting and communicating knowledge from diverse scientific disciplines in such a way that the whole cause-effect chain of a problem can be evaluated from a synoptic perspective with two characteristics:*

(1) *integrated assessment should have value added compared to single disciplinary oriented assessment;*
(2) *integrated assessment should provide useful information to decision makers.*'

(emphasis added)

This definition contains three important components, which are considered essential in such an approach. First of all, integrated assessment not only provides a conceptual framework, it is an interdisciplinary learning process, for experts and decision makers, and in its most inclusionary form other types of stakeholders. Setting up a collaborative framework between experts with different scientific backgrounds and experiences is often a time consuming procedure. Participants have to get used to and acquainted with each other, overcoming different uses of language, and their often fundamentally different ways of thinking, before their work can actually be put together in a meaningful and coherent way [15].

Secondly, in order for this collaborative process to be successful, communication is essential, i.e., communication between experts (scientists) and communication between experts and (lay) policy or decision-makers, especially in the case of complex decision-making contexts. One could argue that policy or decision-makers should be involved in this process right from the start for a number of reasons.

The inclusion of their policy or decision objectives determines the scope of the assessment. Although assessments may be set up in such a way as to minimise subjectivity, judgements are inevitable in any evaluation.[3] If these judgements influence outcomes in a major way, they should be made explicitly clear to the users of the evaluation. Discussing this sooner rather than later with the users of the information generated by the assessment will minimise the risk of producing overly controversial results.

[3]Scriven [44] argues, for instance, that 'the correct formulation of the role of values in evaluation research is to say that the evaluator must draw evaluative conclusions, otherwise they are doing less than their job'.

Given the inevitability of scientific uncertainties and risks, the involvement of lay decision makers in discussions about these uncertainties and risks may (a) improve the decision maker's understanding of the complexity of the problem, (b) modify accordingly expectations regarding 'the deterministic truth' behind the outcome of the integrated assessment should these uncertainties persist throughout the research, and (c) encourage the adoption of policy principles such as the Precautionary Principle or use of Safe Minimum Standards.

Involving policy or decision makers in the integrated assessment is more likely to ensure that the assessment will deliver useful information to decision makers (the third component emphasised). According to Rotmans et al. [14], integrated assessment is policy motivated research to develop an understanding of the issue, not based on disciplinary boundaries, but on boundaries defined by the problem. It offers insight to the research community for prioritization of their efforts and to the decision-making community on the design of their policies. Also Janssen [10] argues that integrated assessment is an iterative process where, on the one hand, integrated insights from the scientific community are communicated to the decision-making community and, on the other hand, experiences and learning effects from decision-makers form the input for scientific assessment. This complex and value-loaded process cannot be captured by one single approach. Depending on the problem it tries to address, it usually consists of a variety of approaches and methods, including formal, explorative, experimental and expert judgement methods.

In addition, by including also other stakeholders, an interactive, participatory and inclusionary bottom-up approach results, which may be beneficial for a number of reasons:

(1) It will help to elicit public perception of problems and possible solutions in addition to expert judgement and therefore ensure that decisions focus on the right problems (as perceived by all parties involved). In the field of risk assessment, Cvetkovich and Earle [16] argue, for instance, that effective management of environmental hazards requires knowledge of both physical environmental systems and the social-psychological processes affecting human responses to environmental conditions. Integrated assessment can also be seen as a (communication) process bringing together the knowledge and experiences of policy or decision makers, experts and lay public.
(2) Early involvement of stakeholders can be expected to increase broader social support for decisions, whatever the outcome. In sociology, positive relationships are found between the intensity of interaction and the degree of commitment (e.g., [17]).
(3) Early involvement of other stakeholders will facilitate the identification of the distribution of costs and benefits to different groups of people.
(4) It may also help decision-makers and experts to identify relevant criteria to evaluate policy outcomes, planning and implementation procedures.
(5) The exchange of information between (representatives of) various stakeholder groups and communication of different perspectives on perceived problems will inevitably result in some sort of social learning process, which may change perceptions, attitudes and behavioural patterns underlying these initially perceived problems.[4]

4. PROCEDURAL STEPS UNDERLYING DECISION SUPPORT SUCH AS INTEGRATED ASSESSMENT

In Figure 2 an attempt is made to represent the various steps underlying decision support systems in general, including integrated assessment. The logic behind the stepwise approach is closely related to ideas, which have been referred to in the literature as procedural rationality [18–20]. The stepwise procedure encompasses an iterative communication and learning process, including various feedbacks to

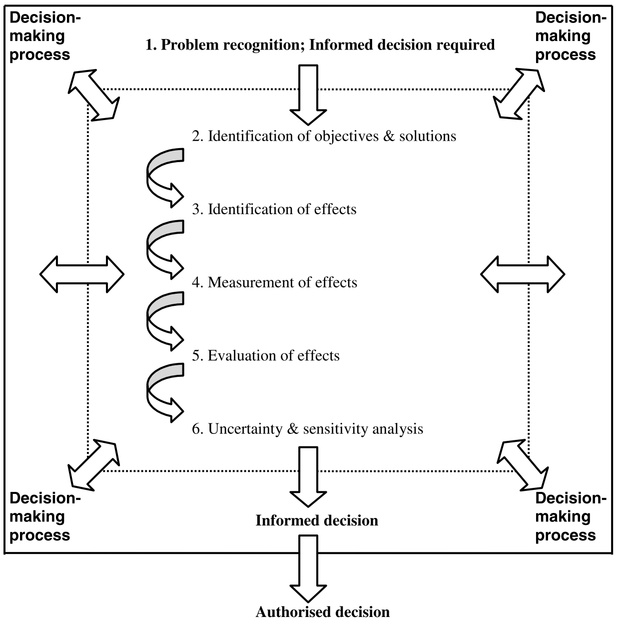


Fig. 2. Procedural steps underlying a decision support system.

[4]According to Moscovici and Doise [45], acts of decision, as well as acts of consenting, are above all acts of participation. For various reasons their value springs from the bond that they create between individuals and from the impression each one receives that he or she counts in the eyes of everybody as soon as he or she begins to participate. In this view, participation is considered a preliminary condition for following a goal, fulfilling a political, religious or even an economic mission. Hegel [46, p.105] wrote: 'if people are to take an interest in something, they must be able to actively participate in it'.

previous levels of analysis and evaluation. In Figure 2, six steps are distinguished, which will be discussed in more detail below.

4.1. Problem Recognition, Identification of Objectives and Potential Solutions

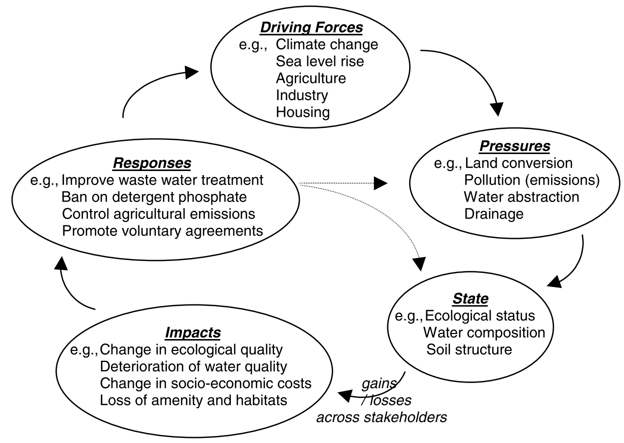
Any assessment procedure starts with an analysis which scopes the present situation, resulting in the diagnosis of (potential) problems, their nature and scale, the definition of objectives and the identification of possible solutions to perceived problems. Although not necessarily yet commonly understood, a (shared) belief in and a sense of (shared) responsibility about the problem is essential in this first stage to mandate an integrated assessment.

A number of conceptual frameworks have been developed, which help to map cause-effect relationships underlying environmental problems, including problems related to water and wetland management. These frameworks are especially helpful when facing complex problems surrounded by uncertainties. One widely applied framework will be highlighted here, since this is believed to be a very useful framework to inform decision-making, namely the Driving Forces-Pressure-State-Impact-Response (DPSIR) framework.[5]

The DPSIR framework provides a conceptual and organising backdrop for the contributions of different disciplines to the description and analysis of environmental problems. The socio-economic aspects of environmental problems are an integral part of the framework. Environmental problems can be described, analysed and evaluated vis-à-vis the economic, social and cultural context in which they arise (Fig. 3). The framework may provide an important tool for achieving a common level of *understanding* and *consensus* between researchers, natural resource managers, policy makers and other stakeholders. It provides the link between the various driving forces (endogeneous and exogeneous such as urbanisation and climate change), which pose threats to ecosystems (pressures), their impact and possible policy responses [9, 15].

Environmental pressures include for instance land conversion, agricultural development, hydrological perturbation and pollution, and their consequent impact on the various interest or stakeholder groups, who utilise the goods and services provided by aquatic ecosystems or contribute to the pressures exerted on them. The observed or perceived impacts usually stimulate some kind of social and political

[5]The SPR framework is another, internationally applied, mapping tool to scope problems. It forms the basis of Ecological Risk Assessment (ERA) methods that have been developed to help manage the impacts of contaminated sites on plants, animals, and ecosystems (e.g., [47]). An important difference between the DPSIR and the SPR framework is that the former focuses explicitly on the interaction between pressures exerted by human (including economic) activities and their effects on environmental and social systems. The SPR-framework is somewhat more restricted to the geophysical modelling of ecological risks.



Source: Adapted from Weber and Crouzet (1999).

Fig. 3. The DPSIR-framework in the context of water and wetland policy and management.

response, involving the identification of policy scenarios, options and measures which may intervene throughout the cause-effect chain and hence feedback on driving forces, pressures, state and impacts [21].

DPSIR is a framework, not a model, but it does allow for dynamic, non-linear relationships between social and ecological systems. Its main aim is to enable decision-makers to scope complex problems surrounded by uncertainties, by structuring them in a comprehensive, yet understandable way. For instance, by indicating at which point in the cause-effect chain decision-makers are actually authorised to intervene (locus of control), or where they can realistically do something about a specific problem (e.g., prevention) and not merely treat symptoms. In the latter case, the framework is still helpful, as it may show that the real problem plays at a different level or scale, outside the scope of the policy or decision-maker's remit of control.

Solutions are usually worked out in more or less detail progressively, usually stepwise, sometimes over several years. The process can evolve through water and wetland policy scenarios to concrete water and wetland management measures and instruments to implement solutions. This process occurs in a given institutional setting in which several decision-makers may play a role, at different institutional and administrative levels. Through interactions with their decision-making environment, including stakeholder groups and other groups of experts, deliberation occurs within existing formal and informal power structures, which may shift as a result of the decision-making process.

4.2. Identification of Effects

Based on individual experience, expert knowledge and judgement, a preliminary assessment is usually made of the nature of likely impacts related to different policy options, even though quantitative data and information about the exact magnitude and extent of the impacts may not (yet) be available. It is usually at this stage when potential effects are discussed, that previously implicit criteria become explicit and the grounds are laid on which policy options or management actions ultimately will be evaluated. Ideally, **evaluation criteria** should be made explicit first, based on the objectives set out in the previous stage. Subsequently the relevant effects associated with these criteria would be identified. However, in practice the identification of evaluation criteria often follows after discussion of the relevant effects. Including (other) stakeholders at this stage in the process may help to identify the distribution of positive and negative effects (costs and benefits in physical and monetary terms), across environmental assets and different institutionally categorised groups of people.

4.3. Measurement of Effects

Models and indicators are two important ways to assess the effects of alternative policy options or management actions. The procedures adopted can be quantitative and/or or qualitative. They may be based on highly advanced models in which dose-effect relationships are formalised in mathematical terms, or simply involve the use of expert judgement. The choice of any method depends upon the specific nature and scale of the problem and decision-maker demand for specific types of information. Natural and social scientists have developed their own tools, methods and procedures to measure the impacts of human intervention on aquatic ecosystems (environmental, social and economic impact assessment methods and procedures).

However, water and wetland policy and management will directly or indirectly affect both the environment and society (depending *inter alia* on the scale of implementation). Environment and society are usually inextricably linked. For example, groundwater management affects the economic activities, such as agriculture in an area, but it also affects the biological diversity present. Waste water treatment and water purification are essential for good-quality drinking water. However, their provision not only affects public health, but also the ecological quality of water and wetland ecosystems. The presence of water in a landscape often gives it its characteristic feature(s), and may play an important role in people's perception of its beauty, or be an important determinant of people's motivation to live or visit a particular location.

Understanding the interactions between aquatic ecosystems and society, including the economy, cannot be achieved by observational studies alone. Modelling of key environmental processes is a vital tool that must be used if water and wetland management is to achieve its overall sustainability goals and objectives, including a further quantification of the uncertainties in existing ecological process based models. For any group of researchers wishing to investigate and model a particular local aquatic system, or aspects of that system, to provide upscaling data for larger models, there are initially two types of information required [15]:

(1) Estimations of biogeochemical fluxes in the system as it is now and dynamic simulations of processes in aquatic ecosystems which can be used to explore the consequences of environmental change and produce forecasts of future fluxes.
(2) Measures of the forces of socio-economic changes (e.g., population growth, urbanisation etc.) on fluxes of toxics, nutrients and sediment (pressures), and assessment of the human welfare impacts of these flux changes. Such assessments of the socio-economic costs and benefits involved will provide essential management information about possible resource and value trade-offs.

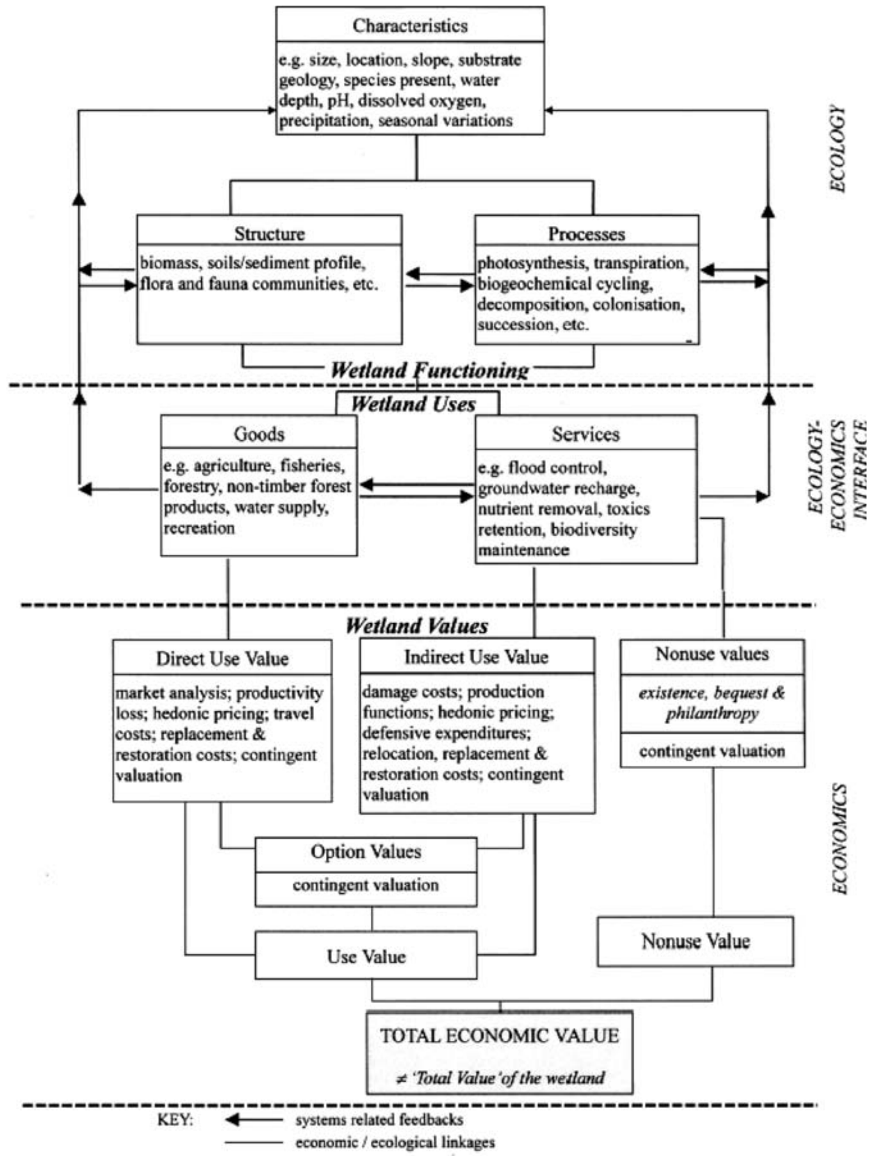
The assessment of the impact of changes in water and wetlands on human use of resources (wealth creation) and habitation (quality of life aspects) requires the application of socio-economic research methods and techniques.

Key issues related to the functioning of aquatic ecosystems and the assignment of values to ecosystem structures and functions at a catchment level which must be considered include:

- The spatial and temporal scales of ecological processes and socio-economic resource use.
- The structure, complexity and diversity which underlies ecosystem functions and their value to society.
- The dynamic (in space and time) nature of interactions between society and aquatic ecosystems.
- The uncertainties associated with these dynamics.

The essence of integrated assessment is to determine how society is affected by the functions the aquatic ecosystem performs, and changes in ecosystem functioning (possibly as a result of human use or exploitation of these functions). The key to valuing a change in an ecosystem function is establishing the link between that function and some service flow valued by people. If that link can be established, then the social value of a change in an ecosystem function can be derived from the change in the ecological value of the ecosystem service flow it supports (Fig. 4). However, the multifunctional characteristic of aquatic ecosystems at the catchment level makes comprehensive estimation of every function and linkages between them difficult. It will for example be necessary to assess features of socio-economic activities and behaviour and how these respond to changes in ecosystem functioning.

In complex decision-making situations, where a range of management options are available, each having a different impact on human and natural systems across different spatial and time scales, impacts can be measured with the help of indicators. Environmental indicators are generally understood as quantifiable variables which provide information about changes in environmental conditions. The variable itself may



Source: Turner et al. (2001).

Fig. 4. Water and wetland functions, uses and values.

describe an environmental state at a certain point in time and an analysis of these variables over time will provide information about the relevant changes and the rate of change [8].[6] However, indicators can also be descriptive (qualitative) in nature. For example, it may be difficult or even impossible to reduce a complex situation into one or more uni-dimensional variables. The variables may be highly interrelated, making the compilation of one or more presumably independent indicators meaningless. Capturing the whole range of relevant impacts on natural and social systems within different management scenarios, given the overall goal of sustainable development, will require a combination of environmental, social and economic indicators.

In practice, three main approaches can be distinguished when using indicators for integrated assessment purposes:

(1) A phenomenon in one area is indicated with the help of a phenomenon in another area. For instance, the use of biological or organic indicators for evaluating inorganic

[6]The OECD [8] defines an environmental indicator as a parameter or a value derived from parameters, which points to, provides information about, describes the state of a phenomenon/environment/area, with a significance extending beyond that directly associated with a parameter value. The UK Department of the Environment (1996) defines indicators as quantified information, which help to explain how things are changing over time.

environmental pollution, or vice versa inorganic environmental indicators to evaluate biological disruption.
(2) Sets of different types of indicators are linked in a multi-criteria type of framework. For instance, the Gross Domestic Product (GDP) measure together with unemployment rate and one or more environmental indicators are presented together to highlight overall societal well-being and welfare.
(3) Integration interpreted as aggregation, where various types of concerns are summed into one single indicator. For instance, the economic, social and environmental performance measures mentioned above (GDP, unemployment etc.) are expressed in one overall societal welfare indicator.

One of the main problems when using indicators is the scientific uncertainty over whether they actually measure features of the environment that are of interest; and whether they change in some meaningful way with respect to environmental change [22]. Ideally, one indicator can be constructed that captures the whole spectrum of relevant ecosystem attributes at different levels of organisation for sustainable management of that specific ecosystem, but this will rarely be the case. In fact, Landres et al. [23] point out the danger of, for example, wildlife habitat management policy which relies on a single indicator such as a species indicator. Given the complexity of natural systems, the probability is small that a single indicator (a-biotic, biotic, or social) can serve as an index of the structure and functioning of an entire ecosystem.

Indicators are believed to be an effective tool to simplify the communication process within which the results of measurement are provided to the user and for raising public awareness of environmental problems [8]. Communication and understanding may be assisted by decision-maker and stakeholder participation in indicator selection and development. The world-wide promotion of the concept of sustainable development has led to a growing interest in actually measuring the path towards a sustainable future – commonly referred to as sustainability indicators. Participation of stakeholders within deliberative processes is seen as a key to commitment to, and realisation of, sustainable development (e.g., [24]). The process of making different environmental, social, economic and cultural dimensions compatible across different spatial and time scales in sets of indicators is at the core of a more integrated approach to research.

The process of identification, development, selection and communication of indicators may not only involve natural and social scientific knowledge, but also normative values developed in cultural, institutional and political contexts. Decision-makers and other stakeholders can be involved in this process in different ways and at different stages (identification of effects, measurement of effects and evaluation of effects). Their involvement may also be crucial to the extent to which indicators and the ways in which they are used are accepted in different contexts.

4.4. Evaluation of Effects

Integrated assessment implies working with various values, reflecting different perspectives on water and wetland management problems. A core difficulty in integrated assessment is therefore to:

(1) relate relevant single effects, values and criteria across fields of impact in a meaningful way;
(2) make them comparable in order to be able to weight them and trade them off if necessary.

It is therefore important to identify and define all the relevant values or criteria that play a role in evaluating the effects of feasible (often already politically negotiated[7]) solutions.

Given tripartite deliberation (e.g., regulatory agency, experts and stakeholders) to evaluate policy and policy measures, the extent to which effects are positively or negatively related to a chosen reference situation needs to be examined.[8] This is usually done on the basis of a number of pre-selected or emergent evaluation criteria. For instance, the extent to which impacts of various policy options contribute to the realisation of existing policy objectives can be examined.[9] Various criteria may play a role when making a choice between different policy options and the corresponding policy measures.

Although agencies seem to prefer to promulgate and enforce regulations based on quantitative criteria, qualitative descriptions of qualitative changes in for example community structure are often the best indicators of ecological disruption [25]. In practice, qualitative descriptions of the intermediate changes or transitions between ecosystem states and ecosystem functions may sometimes prove to be the only way to assess the extent to which wetland management restores, maintains or enhances the integrity of an ecosystem.

[7]Also in the case of (implicitly or explicitly) politically negotiated solutions – for instance, increasing tap water prices is not considered a feasible alternative as access to (tap) water is considered a basic human right to which all groups of people (low and high income) should have equal access – it will increase the transparency of the decision-making process and help the identification of relevant evaluation criteria to explicitly show the values underlying the outcome of these politically negotiated solutions.

[8]The difference between this step and the previous step corresponds, for example, to the distinction made in the literature between descriptive and normative indicators (e.g. [48]). Descriptive indicators reflect an actual state or condition, whereas normative indicators relate this actual state or condition to a reference state or condition. Sustainability indicators are normative indicators since they intend to show how far off society is from a desired (sustainable) situation.

[9]These reference or target values may refer to 'static' normative valuation criteria, for example rarity, naturalness, diversity or degree of distortion are often used as important ecological valuation criteria, but may also refer to more 'dynamic' norms based on simple rules of thumb. Examples of such rules are that abstraction rates of renewable natural resources may not exceed regeneration rates over a certain period of time, or discharges into environmental media such as water cannot exceed the natural absorption capacity of this medium.

Concern for public health and safety is usually one of the most important policy objectives and will generally be one of the main factors by which the effects of policy or policy measures are evaluated. Moreover, governments often believe that these safety and health concerns should apply to everybody in society. Hence, socially just policy may be another important objective. Although governments aim for safety and good health for everybody, they usually try to realise this policy at the lowest cost possible. In other words, policy options should be as cost-effective as possible. This example clearly shows that several criteria can apply simultaneously. Based on these values and criteria, the most appropriate method can be selected (Fig. 5). In practice, an integrated assessment of effects based on prior environmental, economic and social impact assessments may prove to be very difficult, due to the fact that (1) they are usually based upon fundamentally different starting points, values and norms (Fig. 6) and (2) the associated official (institutionalised) assessment procedures often follow their own set of rules or 'procedural rationality.'

In the past, the environment has not been institutionalised as a horizontal dimension that needs to be encompassed within all relevant policies regardless of their sectoral origins. It has been observed that in Europe sectoral policies such as those driving agricultural change, transport, energy etc. have been formulated with only scant regard for the environmental implications [26]. This has led to a general advocacy of Environmental Policy Integration (EPI) [27]. While EPI is a high level objective, the implementation of which poses both institutional and administrative challenges [28, 29],

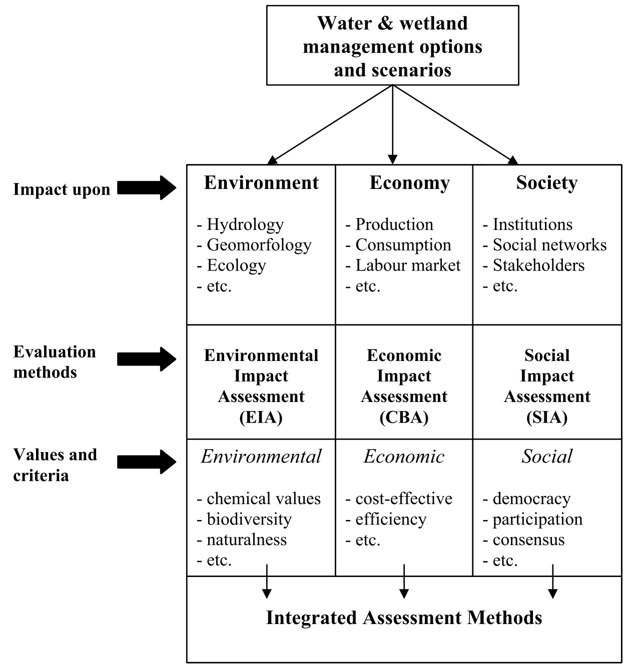


Fig. 5. Values, criteria and assessment procedures and methods.

	ECOLOGY	**ECONOMY**	**SOCIOLOGY**
Focus	▪ Ecosystem behaviour	▪ Behaviour of people	▪ Behaviour of people
Value	▪ Functional relationship between (a)biotic ecosystem components	▪ Extent to which people use scarce means (time, money etc.) to get or hold on to something	▪ Typology of why people consider something meaningful, important, good or bad
Norm	▪ Ecosystem integrity ▪ Nature targets ▪ Biodiversity ▪ etc.	▪ Efficiency ▪ Least costs ▪ etc.	▪ Democracy ▪ Public support ▪ Consensus ▪ etc.
Measure	▪ Contribution to nature targets ▪ Increase/decrease diversity ▪ etc.	▪ ▪ Revenues ▪ etc.	▪ Formal laws and regulations ▪ Unwritten codes of behaviour ▪ Organisational forms etc.
Indicators	▪ Chemical indicators ▪ Trophic levels, biomass ▪ Species ▪ etc.	▪ Market price ▪ Purchasing behaviour ▪ Willingness to pay ▪ etc.	▪ Voting behaviour, protest ▪ Habit, custom ▪ Expression of emotions, point of view, opinion etc.

Fig. 6. Overview of values and norms in different scientific disciplines.

environmental policy assessment is the process through which different options for achieving different objectives are evaluated via a set of indicators in an integrated way.

When pursuing integrated and sustainable water resources policy, this usually means that environmental, social and economic considerations play an important role in the decision-making process, and policy and enabling measures will be scrutinised for these types of concerns. For instance, in a recent communication (COM(2000)477) from the European Commission to the European Council and Parliament, water pricing is introduced as a measure to ensure sustainable and efficient use of water. Economic instruments should be an integral part of a set of measures in order '*to guarantee achievement of the social, economic and environmental objectives in a cost-effective manner.*'

Once the expected or observed impacts of policy and policy measures have been evaluated on the basis of one or more criteria, the importance of each criterion in the decision-making process has to be determined, in order to be able to make a choice between policy alternatives. The degree to which various evaluation criteria will ultimately influence the decision depends on the political context [31]. Multi-criteria analysis techniques may be an important tool to support this decision-making (for an overview, see, for example, [32]). The analytical hierarchy process [33] is another helpful tool to translate qualitative judgements by decision-makers into quantitative weights. Obviously, if all effects are expressed in monetary terms, this step is not necessary.

If one of the criteria in a multi criteria analysis (MCA) is expressed in money, for instance the financial investment costs of a river restoration project, the weights used to trade-off the various criteria scores can be interpreted theoretically as shadow prices. The outcome of the MCA is then theoretically the same as the outcome of a cost-benefit analysis (CBA) where all effects are valued through the same shadow prices. However, in practice it is usually difficult to interpret the weights in this particular way and furthermore requires a specific way of assigning weights to criteria. An important advantage of MCA techniques is that it is considered relatively easier to take into account and trade-off effects expressed in physical instead of monetary terms. Effects measured in physical terms do not have to be translated into money terms first through economic valuation techniques. In this way MCA allows more aspects or factors to play a role in the trade-off procedure than just the efficiency of river policy or management actions (the economic CBA criterion). An important disadvantage of MCA compared to CBA is that the outcome has no welfare theoretical basis or significance. In a MCA, alternative management actions are ranked relative to each other, based upon the criteria and weights included, while in the case of CBA the outcome of the evaluation of these alternative management actions can be interpreted in terms of their effect on social (economic) welfare.

4.5. Uncertainty and Sensitivity Analysis

Risk and uncertainty will be associated with both the physical outcomes associated with future environmental change and their social and economic consequences. Assessing the possible outcomes and the likelihood of perturbations to highly complex aquatic ecosystems will inevitably be fraught with difficulty. A range of possible impacts deriving from potential management actions needs to be identified, the relevant physical effects quantified, and probabilities attached to each. A particularly important aspect relating to the uncertainty of physical effects, is the existence of thresholds beyond which disproportional and possibly irreversible effects occur. These will also be important in a social and economic sense due to the disproportional extent of the impact and the inability to reverse the consequences in the future.

Analysis should not assume that all current physical, social and economic conditions will hold in the future. For instance, land use changes might be predicted for the future, perhaps due to imminent regulation or long-term trends. This might affect, for example, the quantity of nitrogen in run-off and thereby the value of a wetland as a nitrogen sink. Behaviour of individuals could also adapt to change in water system functioning, for instance with farmers changing cropping patterns as a result of increased flooding, rather than foregoing land-use or yields altogether. These changes need to be incorporated into the analysis since they can influence projected effects (costs and benefits) and hence the outcome of the integrated assessment.

Uncertainty as to the correct value for environmental, social or economic variables employed and future trends can be addressed by employing sensitivity analysis or scenario analysis. Sensitivity analysis gives more than one final answer using different figures for variables employed such as the rate of discount, the extent of a function being performed and shadow pricing ratios. This provides a range of estimates within which the true figure can be expected to fall, which is less bound by particular assumptions but might result in ambiguous recommendations. Scenario analysis envisions a number of plausible future situations with a range of parameters within the valuation model, allowing a comparison of different future outcomes and policy response options.

A useful distinction is between risk, to which meaningful probabilities of likely outcomes can be assigned, and uncertainty, where probabilities are entirely unknown. It has been suggested that the rate at which the future is discounted could be altered to incorporate a premium for risk, adjusted either upwards or downwards [34]. However, risk is better dealt with by attributing probabilities to possible outcomes, thereby estimating directly the **expected** value of future costs and benefits [35] or their 'certainty equivalents' [36], rather than in some arbitrary and often subjective addition to the discount rate which will attribute a strict (and unlikely) time profile to the treatment of risk.

As Costanza [37, p. 97] points out, '*most important environmental problems suffer from true uncertainty, not merely risk.*' Such uncertainty can be considered as 'social uncertainty' or 'natural uncertainty' [38]. Social uncertainty derives from factors such as future incomes and technology which will influence whether or not a resource is regarded as valuable in the future. Natural uncertainty is associated with our imperfect knowledge of the environment and whether there are unknown features of it that may yet prove to be of value. This might be particularly relevant to ecosystems where the multitude of functions that are being performed have historically been unappreciated. One practical means of dealing with such complete uncertainty is, for instance, to complement a cost-benefit criterion based purely upon monetary valuation, with a Safe Minimum Standards (SMS) decision rule [38–40]. It is important to recognise, however, that such rules are not panaceas for complex decisions with inevitable trade-offs; both 'costs' and 'benefits' to society still have to be evaluated.

5. CONCLUSIONS AND RECOMMENDATIONS

In order to deliver the sustainable utilisation and management of aquatic ecosystem resources, it is necessary to underpin management actions by a scientifically credible but also pragmatic environmental decision support system, which whilst having the objective of economic efficiency at its heart, nevertheless recognises other dimensions of water and wetland resources value and decision-making criteria. The decision support system incorporates a toolbox of evaluation methods and techniques, complemented by a set of environmental change indicators and an enabling analytical framework, thus allowing managers to identify operational decision steps. Individual projects or schemes can be appraised in their own right and clearly cost-ineffective options can be discarded. However, individual schemes and more extensive programmes must be further placed in a wider analytical context which encompasses spatial scales up to the level of the catchment and temporal scales in excess of the short run. Only in this way can a full appreciation of their effect on overall economic allocative efficiency and parallel sustainability objectives be gained.

The framework for decision support proposed in this paper is in line with the sustainable water resources management approach advocated by the World Bank [41], which has at its core the adoption of a comprehensive policy framework and the treatment of water as an economic good, combined with decentralized management and delivery structures, greater reliance on pricing, environmental protection and fuller participation by stakeholders. It is recognised that the adoption of such a comprehensive framework facilitates the consideration of relationships between the ecosystem and socio-economic activities in catchments. Such a management approach requires analysis to take into account social, environmental, and economic objectives; evaluate the status of water and wetland resources within each basin; assess the level and composition of projected demand; and take into consideration the views of all stakeholders. The advantages of such an approach are [42]:

- Ability to better consider both short and long term demands for water and wetland resources in an economically efficient manner.
- Ability to integrate activities and objectives that are not always feasible in separate approaches.
- Enhanced ability to manage the resources with a view to environmental issues.
- Ability to benefit from cost reductions through economies of scale.
- Ability to find efficient solutions to water and wetland quality and pollution problems.
- Facilitate action of reaching a consensus among the stakeholders, thereby reducing tensions and conflicts.
- Provides a means to assure equity and participation of beneficiaries and those impacted by development.
- Ability to adjust to changing priorities.
- Ability to prepare for emergencies such as floods.
- Provides a base for research and knowledge accumulation.

It is recognised that the complete adoption of such a procedure requires an institutional, financial and scientific capacity that may not be feasible in all countries (developed and developing). The aim should therefore be to move iteratively from a 'reduced form' procedure towards a comprehensive assessment over time. But certain elements are fundamental, i.e., the adoption, as a minimum, of the catchment scale for analysis; the recognition of the importance of the functional approach to water uses and resources; the need for problem scoping (D-P-S-I-R) which encompasses distributional impacts; and the acceptance of economic principles for water valuation albeit constrained by cultural, political and other factors.

In summary then, the 'proper' appraisal of water related projects, programmes or courses of action require a comprehensive assessment of ecosystem resources. In order to achieve this, the analyst has to undertake the following steps:

(1) At catchment scale, to determine the causes of aquatic ecosystem degradation/loss, in order to improve understanding of socio-economic impacts on ecosystem processes and attributes (e.g., with the aid of the D-P-S-I-R auditing framework).
(2) Assess the full ecological damage caused by aquatic ecosystem quality decline and/or loss.
(3) Assess the human welfare significance of such changes, via determination of the changes in the composition of

the resource and ecosystem, evaluation of ecosystem functions, provision of potential benefits of these functions in terms of goods and services, and consequent impacts on the well-being of humans who derive use or non-use benefits from such a provision.

(4) Formulate practicable indicators of environmental change and sustainable utilisation of water resources and associated ecosystems (within the D-P-S-I-R framework).

(5) Carry out evaluation analysis using monetary and non-monetary indicators (via a range of methods and techniques, including systems analysis) of alternative water and wetland usage and ecosystem change scenarios.

(6) Assess alternative water and wetland uses and ecosystem conversion/development together with conservation management policies.

(7) Present resource managers and policy makers with the relevant policy response options.

The steps presented here towards the development of a holistic integrated framework for socio-economic and environmental indicators are part of an integrated system aiming at the provision of transparent, meaningful and useful information. Ideally, this system should be able to support and link decision-making at different spatial and time scales with the objective of fostering the protection and sustainable management of natural resources.

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