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published in
Environmental Management
2002

DOI (link to publisher)
10.1007/s002670010211

ENVIRONMENTAL AUDITING

DOI: 10.1007/s002670010211

Indicators for Transboundary River Management

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ABSTRACT / The aim of this paper is to analyze the potential of indicators for integrated river basin management and to develop a set of indicators for the management of transboundary river basins. An indicator, comprising a variable or some aggregation of variables, describes a system or process such that it has significance beyond the face value of its components. Integrated river basin management takes into account policies and measures for the multifunctional use of rivers on a catchment scale and associated institutional changes. Indicators are useful instruments for this process for two reasons. Firstly, they meet the information need of policy- and decision-makers. Secondly, indicators can be used to structure the definition and description of information needs and collection of information between the different international, institutional, and sectoral management levels. The development of indicators involves a number of steps: definition of aim, construction of conceptual model, selection of variables, comparison with selection criteria, database assessment, and indicator selection. In this paper these steps are discussed and specified for integrated river basin management. This results in a set of indicators describing the pressure to the river, the state of the river ecosystem, the impact to goods and services provided by the river, and the societal response. The proposed set of indicators measured at a river basin scale provides integrated information on the use and supply of goods and services, underlying cause–effect relationships and possible trade-offs and their spatial distribution (e.g., upstream versus downstream). Furthermore, we propose a division of tasks and responsibilities for river basin management with regard to the development of indicators, data collection, and their application in decision-making.

Throughout history, human use of goods and service provided by rivers has changed them dramatically. These changes have impacted the river ecosystem, which is expressed by a reduction of species diversity and abundance (Wolff 1978, Admiraal and others 1993, Tittizer and Krebs 1996) and the supply of goods and services, such as drinking water production (RIWA 1997, Ietswaart and Van Dijk 1996), fisheries (Lelek 1989, IKSR 1993), and recreation. The cause–effect relationships underlying these changes are spatially and temporally displaced due to the unidirectional flow from the catchment to the river mouth (Burns 1991, Petts 1994). Policy-makers and water management bodies face the challenge of managing the complex spatial and temporal cause–effect relationships in watersheds and coping with conflicting interests in order to attain a more equitable and sustainable situation than is presently the case. This needs for an all-encompassing approach, and hence concepts such as integrated or comprehensive river basin management have been developed (Downs and Gregory 1991, De Jong and others 1994). River basin management needs practical instruments to implement such concepts in practice and to develop, implement, and evaluate their policies. Indicators are potential tools. The aim of this paper is to (1) analyze the potential of indicators as policy instrument for integrated management of transboundary river basins and (2) develop a set of indicators for the management of transboundary rivers.

A transboundary river is defined in this paper as a river that crosses the borders of two or more states. We focus in this paper on Western Europe, as their transboundary river management is relatively complex. Various European rivers flow through countries having different cultural backgrounds and different political systems. Furthermore, Europe has a number of supranational institutions, such as the European Union, as well as international river basin committees (Rhine, Meuse, Scheldt), which can play a role in the development and use of policy instruments.

KEY WORDS: Indicator; Transboundary River management; Pressure–state–impact–response.

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In the following section the need for a more integrated approach in river basin management is described. The definition and use of the policy instrument 'indicator' is discussed, then a set of pressure-state-impact-response indicators is proposed and the application of these indicators in transboundary river basin management is discussed. Finally, some conclusions are drawn.

Role of Indicators in River Basin Management: From Fragmentation to Integration

This section analyses the potential role that indicators can play in transboundary river basin management. We argue that this role is twofold. First, indicators can structure the large variety of information needs and flows within management. Second, indicators can condense data into the information needed for management. Both aspects are needed to achieve a comprehensive management, as will be argued in following sections. The evolution of river basin management in Western Europe is taken as a departure point.

River management is presently organized in a fragmented way. The policies of various sectors (e.g., agriculture, fishery, drinking water, industry, and transport) are hardly coordinated, even though they influence the same water system (De Jong and others 1994). Responsibilities for water management tend to be shared by a number of statutory authorities. River basin management was hierarchical involving local, regional, national, and occasionally international levels. Tasks and responsibilities differ at each spatial level. The implementation of policy is top-down oriented, and the information flow is bottom-up. Many rivers display such a management structure.

Transboundary river basins cross national boundaries and so add a further spatial complexity to management. Interests differ among riparian states. Downstream states bear the impacts of upstream use. Upstream states are less exposed to the negative effects of their use and may be less motivated to change their actions, for example, to abate pollution. Furthermore, cultural differences in decision- and policy-making and in management approaches may complicate the introduction of effective management regimes (for example, compare the federal political system in Germany with the centralized system in the Netherlands and France) (Eberg 1997). This extra complexity of river basins crossing national boundaries occurs in a large number of river basins in Europe, for example, the Rhine, Meuse, Scheldt, Donau, and Elbe. In the United States and Australia almost all river basins lie inside the national boundaries and cross only the regional boundaries of states.

This fragmentation of management into sectors; local, regional, and national institutions; and riparian states is a product of history and is in conflict with the natural functioning of a river system. The dynamic equilibrium of a river channel implies that a change in hydrological and geomorphologic characteristics upstream (e.g., due to changes in land use or river regulation) will change the abiotic environment downstream (Leopold and Langbein 1962). The river ecosystem is characterized by a longitudinal continuum of dynamic processes determining spatial species distributions (Vannote and others 1980). Furthermore, the wide spatial and temporal scale of cause–effect relationships will result in a hierarchy of causes in a watershed culminating into downstream ecological effects (Burns 1991). The combination of fragmented management, multiple human pressures, and multiple environmental impacts, spatial and temporal dynamics, and the large scale of transboundary rivers hamper the linking of individual causes to any one effect.

It has become increasingly evident during the last decade that an integrated view on river basins is needed to tackle environmental problems in rivers. A range of interpretations has been given to integrated river basin management, which can be classified into three groups (Downs and Gregory 1991):

- Emphasis on the *multiobjective* nature, for example integrated, comprehensive, total, unified.
- Accent to the spatial scale, which stresses that the *drainage basin* is the basic functional unit area (e.g., river basin, catchment, ecosystem, watershed, and floodplain).
- Focus on *institutional change* needed in order to evolve from a fragmented to an integrated management (e.g., management, planning, and development). An example is a study on the effectiveness of European models of river basin management for integrated management (Mostert 1998).

Savenije and van der Zaag (1998) defined integrated water resources management as management that considers all physical aspects and societal interests simultaneously, while taking a long-term perspective. They distinguished three important preconditions for integrated river management: (1) a good political atmosphere among riparian states; (2) an effective legal–institutional organization of international agreements and plans and institutional models to execute them; and (3) operational support and technical cooperation on information collection and knowledge exchange, such as monitoring, joint research, and plans.

The importance of an integrated, basinwide approach to management is recognized in the latest "Council directive establishing a framework for community action in the field of water policy" published on 26 February 1997 by the European Commission (Commission of the European Communities 1997). According to this directive the member states have to establish "river basin districts." In each of these districts an administrative structure has to be set up and authorities designated to coordinate the implementation of the directive. This includes the preparation of a river basin plan every six years on: (1) the measures to be taken to reach a "good water status," (2) monitoring results, and (3) an assessment of environmental impacts and an economic analysis of water use.

Van Rooy and De Jong (1995) take the integrated approach one step further and describe comprehensive river basin management as part of global development. This means that the societal trade-offs made between ecological, economic, and social objectives at a national, international, or global scale are the basis for management decisions at a river basin scale. River basin management needs tools and instruments to describe economic, societal, and environmental interests in order to make appropriate trade-offs.

At present, a significant gap still exists between the theory on integrated and comprehensive water management and its implementation. Three types of bottlenecks are identified by De Jong and others (1994): (1) institutional fragmentation of water management; (2) communication problems within and between organizations, disciplines, and countries due to the use of different languages, specialist language, or disputes over competence; and (3) sociopolitical bottlenecks relating to views on water that are more oriented to single instead of multiple use.

Indicators may assist to overcome the gap between theory and practice for two reasons. In the first place, they can provide information on economic activity and the condition of the river ecosystem and its supply of goods and services. This information will help to clarify the complex cause–effect relationships in rivers. In the second place, indicators can streamline the information flows between the different international, institutional, and sectoral management levels. The variety of tasks, responsibilities, and interests will cause differences in information needs among each layer of the hierarchical administrative structure and between up- and downstream states. Parameter definition and methodological approaches can vary between institutions and riparian countries, partly due to different scientific and policy cultures. Responsibilities with regards to data collection are fragmented. A streamlined and uniform flow of information will diminish both fragmentation and communication problems. Indicators could structure the definition and description of information needs and the collection of information by international, institutional, and sectoral management levels. They provide a common source of information and communication means for different stakeholders in management and policy-making.

Definition of Indicators and Their Use in Environmental Management

Lorenz (1999) reviewed a number of definitions on indicators and indices. On that basis we propose the following definitions to allow for a clear distinction between an indicator and an index:

- An indicator, comprising a variable or some aggregation of variables, describes a system or process such that it has significance beyond the face value of its components. It aims to communicate information on the system or process. The dominant criterion lying behind an indicator's specification is scientific knowledge and judgement.
- An index is a mathematical aggregation of variables or indicators, often across very different measurement units so that the result is dimensionless. An index aims to provide compact and targeted information for management and policy development. The problem of combining the individual components is overcome by scaling and weighting, processes which will reflect societal preferences

The aim of an indicator as a policy instrument is to provide information to policy- and decision-makers and so assist them in management of a particular system. The development and use of indicators is driven by the information need of policy. Criteria for the selection of indicators from a set of variables have been proposed (Van Harten and others 1995, De Zwart 1995, Hendriks 1995, Swart and Bakkes 1995, OECD 1994, Kuik and Verbruggen 1991, Liverman and others 1988) and are scientific, policy, and measurement oriented. The aggregation of variables into an indicator may be likened combining apples and oranges into fruit. An index combines apples and exercise to indicate health. The emphasis in an index is not on scientific justification, but to respond to societal needs. It will inevitably contain subjective and debatable elements. The underlying indicators also have a communicative function and will increase the transparency of the resulting index. Figure

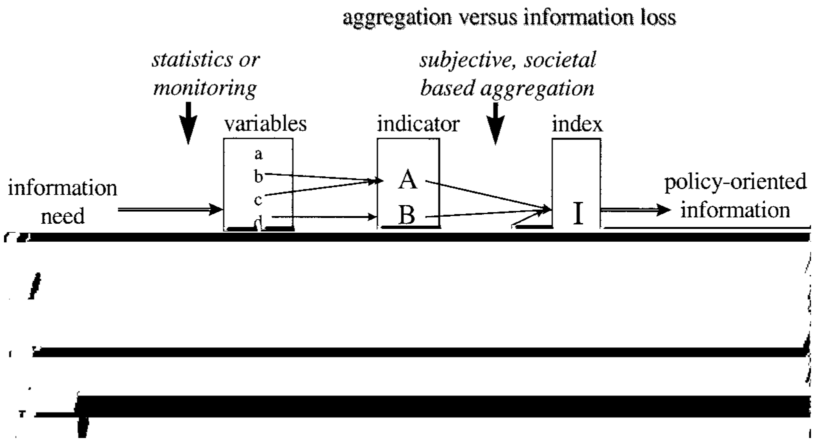

Figure 1. Translation of an information need into policy-oriented information via variables, indicators, and indices.

1 represents the difference between variables, indicators, and indices in a diagram. Aggregation of a number of indicators to one index involves the various steps of selection, scaling (transforming indicators into dimensionless measures), weighting (valuation), and mathematical manipulation. These steps will require some combination of expert judgement, Delphi techniques, multicriteria analysis, public opinion polls, value-based decisions, and modeling experiments. Rotmans (1997) emphasizes that caution should be taken with such steps, because they are highly value-based, and therefore greatly dependent on the subjective perceptions involved and are subject to change. Aggregation of information will lead automatically to information loss. The risk exists that all interesting nuances and local differences in data are translated in indicator values giving mediocre results over a large scale. On the other hand, no aggregation of data at all will also lead to information loss, as it is difficult to derive information from a large amount of detailed data. The aim of an indicator or index will guide the extent to which information loss can be justified. The information loss can be minimized by using an aggregation procedure that allows a ready return to the original data. The indices and indicators provide a structure to the databases with the underlying variables. The development of indicators and indices implies making trade-offs between the level of aggregation and acceptable information loss and the scientific and policy requirements.

The trade-offs depend on the aim, the user, the system under consideration and knowledge about it, data availability, and available financial resources. This initial selection of indicators and the associated set of variables are scientifically based, but as the need is policy-driven, a trade-off between scientific robustness and simplification for management is inevitable. From the policy point of view a limited set of indicators will be more preferable, which can be in conflict with a scientifically sound systems description. This search for the right balance between the policy aim of indicators and their scientific foundation requires an on-going dialogue between scientists and policy-makers to improve the indicator set continuously.

There is a certain risk of misuse of indicators. In that case the indicator is used to describe a different or broader objective or subject than it really does. A well-known example is gross national product (GNP), an indicator for economic growth. GNP is, however, often equated with welfare, which is a much broader economic concept than economic growth (Ahmad and others 1989). The advantage of indicators is that they are transparent and relatively simple to understand due to their communication function. They should always be accompanied with clear statements as to their limitations. This reduces, but does not remove, the risk of abuse.

Indicators can be used in a variety of ways. Most commonly their function is descriptive. However, more information can be gleaned by time series, comparison with reference levels, and linking indicators to models. Most indicators are measured regularly, and the resulting time series shows trends. These trends may provide information on the system's functioning or its response to management. This assumes consistency in data collection and indicator construction.

The indicator can be compared with a reference level, which represents some desired state. This is the numerical and nominal target of the indicator. Policy targets can be used to assess the effectiveness of management (see indicators developed by Adriaanse 1993). Other reference levels include sustainability criteria (e.g., Gilbert and Feenstra, 1994, Azar and others 1996) and historical states (e.g., the AMOEBE) (Ten Brink and others 1991). A time series permits assessment as to

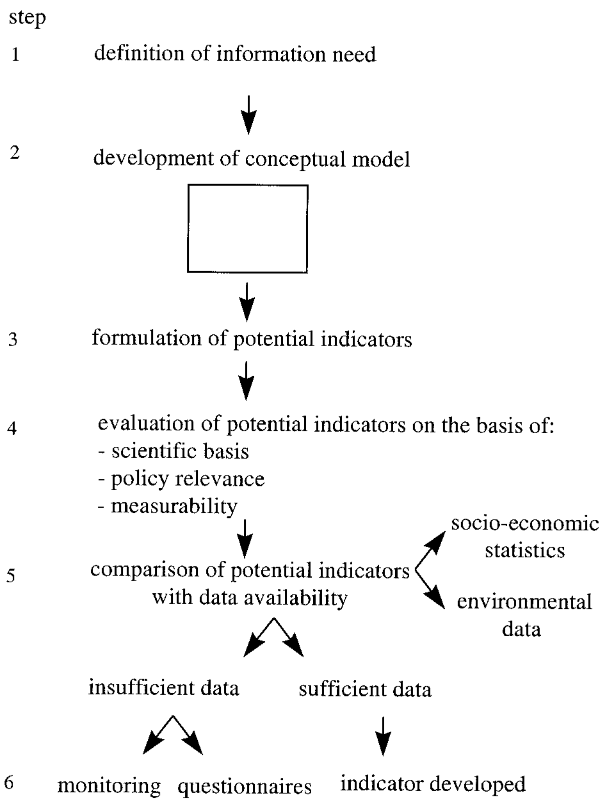

Figure 2. Schematic representation of the process of indicator selection.

whether the system is moving towards or away from the reference level. Such an assessment could assist in the better targeting of measures. Specification of reference levels depends strongly on the purpose of the indicator, its users, and the issue being reflected.

The use of indicators as discussed so far is retrospective in nature. Decision and policy makers also need information on possible future developments. Linkage of models and indicators extends a time series into an (estimated) future. Alternative futures can be assessed in terms of how well each scenario moves the system towards a desired state. Gilbert and Feenstra (1994) developed a sustainability indicator for cadmium accumulation in soil and demonstrated the power of such a combination of indicator, simulation modeling, scenario analysis, and reference levels.

Development of Indicators for River Basin Management

A guideline for indicator selection has been developed to make the indicator selection process more transparent. The different steps of the guideline are presented in Figure 2 (adapted from Verhallen 1995) and will be discussed in more detail in this section.

Potential Pressure–State–Impact–Response Indicators

The aim of the indicators is to provide information for the development, implementation, and evaluation of policies for integrated river management. The elaboration of a conceptual model will be the basis for a set of indicators. A conceptual model is a verbal or visual abstraction of a part of a world from a certain point of view. Information on the system, its spatial and temporal scale, and the cause–effect chain can be put into the conceptual model, representing the environmental problem to be solved (Bakkes and others 1994).

We propose the pressure–state–impact–response framework (Turner and others 2000, Swart and Bakkes 1995, Van Harten and others 1995, Hoekstra 1995, Hammond and others 1995, Rotmans and others 1994, Adriaanse 1993, OECD 1994, Bakkes and others 1994) to describe cause–effect relationships between human use and the river. Next to being an useful tool to describe cause–effect relationships the PSIR framework is also used by international organizations, such as the OECD (OECD 1994), UNEP (Bakkes and others 1994), and EPA (Schulze and Colby 1997). The use of the same framework should improve the linkage of indicator sets developed at different levels. Pressure refers to human activities and its influence on the environment. State refers to ecosystem functioning. Impact describes the effect of a change of state to the supply of environmental goods and services. Finally, response describes societal response to environmental changes. It should be noted that an economic activity, e.g., recreation, can be a source of pressure on the river and be impacted by a change in the river's state caused by other uses.

The variables that describe dominant processes and characteristics in the conceptual model are identified as potential indicators. The elaboration in the conceptual model will address the following: (1) relevance for river management, (2) system description, and (3) reference levels. A set of pressure, state, impact, and response indicators and their underlying variables is proposed on the basis of the elaboration in Tables 1–4, respectively.

Pressure. Pressure indicators describe the socioeconomic use of the river and the changes made to river system by this socioeconomic use. The relevance for river basin management is the provision of information on the contribution of the river's natural capital to economic activity in region and the resulting pressure on the river ecosystem and its environmental goods and services. This information will help decision-makers in the river basin to make more considered trade-offs

Table 1. Potential pressure indicators for river basin management[a]

System part	Indicators	Variables
Socioeconomic benefits		
	Total value added	Value added of economic activities using river's goods and services
	Total turnover	Turnover of economic activities using river's goods and services
	Total production	Production of economic activities using river's goods and services
	Total employment	Employment of economic activities using river's goods and services
Environmental pressure		
Emissions	Emission of substance *x* (in kg) or load of *x* (kg/m^3)	Point sources: effluent monitoring, permits; diffuse sources: land use and population number in combination with emission coefficients
Resource extraction	Volume of extracted resource (kg or m^3)	Extraction data per economic sector (e.g. drinking water, energy, fisheries)
System modification	% regulated river length	Ratio of regulated length and total length
	Number of dams and weirs	Number and location of number of dams and weirs
	% natural floodplain	Ratio of natural and total floodplain area
Pressure/activity		
	Waste intensity	Ratio of waste production to economic production of sector
	Energy intensity	Ratio of energy use to economic production of sector
	Space intensity	Ratio of river area (river & floodplain) used to economic production of sector
	Resource intensity	Ratio of river resource use to economic production data

[a]Three types of pressure indicators are distinguished: (1) on the socioeconomic use of the river and benefits derived; (2) on environmental pressure caused by the socioeconomic activity, and(3) on the relationship between economic value and environmental pressure.

The economic activity indicators can be expressed per economic sector (e.g., navigation). The spatial scale can be regional or subbasin, national, international, or basinwide. The indicators can be expressed per year or in change per year (e.g., decrease in nutrient load per year, increase in percent natural floodplain per year), if time series are available.

between the benefits derived from river use and the resulting pressure on the river ecosystem. Table 1 proposes the set of pressure indicators.

Different types of pressure indicators are distinguished: (1) indicators describing the socioeconomic use of the river and benefits derived, (2) indicators describing the changes made to the river in environmental terms, and (3) indicators describing the relationship between economic value and environmental pressure.

The first type of indicator aims to describe the socioeconomic value of river use for the region by some standard economic terms, such as the value added, turnover, production, and the number of employees engaged in economic activities. The second type of pressure indicators describes the environmental pressure caused by the economic activity (e.g., emissions, natural resource extraction, system modification).

The third type of indicators describes the pressure intensity of an economic activity by calculating the ratio between a certain environmental pressure (e.g., waste production, energy consumption, use of space and resources) and the total economic production. This type of indicator gives information on the relative pressure of an economic activity, in addition the absolute numbers produced by the first two type of indicators.

References for the pressure indicators can be sustainability criteria, policy goals, or environmental standards. An economic sustainability criterion is that welfare over time has to be constant or increase. An example of a sustainability criterion of environmental pressure is that resource extraction has to equal the natural regeneration rate. Policy goals of economic activity can be a economic growth percentage or an unemployment rate. A policy goal of environmental pressure is the target of 50% emission reduction of priority pollutants, as stated in the Rhine Action Plan. Examples of standards are effluent discharge standards and safety standards for navigation and flooding.

State. State indicators describe the functioning of the river (eco)system. The relevance for river basin management lies in the intrinsic value of the river ecosystem, its life support function and its capacity to supply goods and services. The functioning of a natural river ecosystem has been analyzed by a review of theoretical concepts in river ecology (Lorenz and others 1997) and is summarized below. Table 2 gives an overview of potential state indicators, which have been derived on the basis of the review.

The steering factor for river ecosystem functioning is the abiotic environment, which is described by hydrological, geomorphological, and water quality characteristics. From up- to downstream the abiotic characteristics form a gradient of increasing discharge, increasing channel size, and decreasing substrate size.

The biotic ecosystem functioning reflects the abiotic

Table 2. Potential state indicators for river basin management[a]

System Part	Indicators	Variables
Abiotic		
Longitudinal gradient of		
Hydrology		
	stream order	
	flow velocity	
	flood pulse	flood amplitude, -duration, -timing, -frequency, rate of change
Geomorphology	channel size	width, depth
	channel form	straight, meandering, braided, regulated
	channel substrate	size classification: cobbles, sand clay
lateral gradient		
from channel to	size	length of natural riparian zone, area of natural floodplain
terrestrial surroundings	spatial distribution	distribution of terrestrial surroundings along river
	habitat diversity	gradient in moisture, nutrient level, mineral richness, substrate
	vegetation pattern	gradient in biomass and diversity
	exchange of matter	volume and frequency of import and export of nutrients and organic matter
longitudinal connectivity	barriers in channel	number and location of dams and weirs
lateral connectivity	river floodplain interaction	area of frequently flooded floodplain
water quality	water quality	concentration of physical-chemical variables
Biotic		
Functional		
	flux of matter	input, processing and output of nutrients, minerals and organic matter
	P/R ratio	primary production, respiration
	trophic level	chlorophyll concentration
Structural		
	spatial distribution	gradients of algae, macro-invertebrates, fish zonation
	abundance of indicator species	top predators (birds, mammals, fish), species with complex life cycles (insects, amphibians), migrating fish, floodplain species, sensitive species

[a]The state indicators describe abiotic and biotic processes and elements.

The indicators can be expressed per km, per river reach (e.g., Hochrhein) or at a national or basin-wide level and can be expressed per month, season, year, or in change per year, if time series are available.

gradient and is described by functional and structural characteristics. Functional characteristics of a river ecosystem focus on resource cycling through a river system, e.g., the flux of matter from source to mouth. Matter occurs in the form of inorganic nutrients and minerals, particulate matter or organisms. Processes influencing resource cycling are input, processing, and retention of matter. The intensity of these processes and the source and size of organic matter changes from up- to downstream. The river is fed by input of allochtonous organic matter from the vegetation in the riparian zone (upstream), instream primary production (midstream), and exchange of nutrients, minerals, organic matter and organisms between river and floodplain (downstream). The P/R ratio describes the main source of organic matter of a part of the river; allochtonous organic matter ($P/R < 1$, part is heterotrophic) or primairy production ($P/R > 1$; part is autotrophic). The indicator trophic level defines the extent of primairy production. Two types of retention mechanisms are distinguished: (1) physical retention structures and processes, such as dams or vegetation in riparian zones and floodplains; and (2), biological retention by uptake of nutrients and organic matter in the foodweb. Interaction of all these factors determines the output of matter at a river or river section. The indicator retention is defined as the difference between input and output of matter in a river or river reach and can be calculated by subtracting the load of nutrients (total C, N and P) between sites along the length axis.

Structural characteristics include species distribution, diversity, and abundance of a river ecosystem. The proposed indicator describes the spatial shifts in species composition reflected by gradients in macroinvertebrate functional feeding groups or the zonation of fishes or benthic organisms. These shifts are caused by a spatial and temporal variation in dominant sources of inputs, hydrological and geomorphological characteristics relating to increasing stream order, and physical and biological retention mechanisms in the river catchment.

Table 3. Potential impact indicators for river basin management[a]

System part	Indicators	Variables
Regulation		
Assimilation capacity	load of waste assimilated	difference in loads over time
Biodiversity	species diversity	total number of species
Water and sediment discharge	discharge of water and sediment	water discharge, sediment load
	flood frequency and risk	predicted and occurred flood frequency
Production		
Water	volume of extractable water for industrial and household purposes	water quantity and quality, standards
Fish	biomass of consumable fish	abundance and health of consumption fish, health standards
Energy	volume of extractable energy	water discharge
Minerals	volume of extractable minerals	sedimentation rate and sediment quality
Carrier		
Habitation	area of nonflooded floodplain	% embanked and % natural floodplain
Agriculture	area of fertile floodplain	sedimentation rate and quality on floodplain
Navigation	maximum number of ships transportable load	minimal and maximal discharge, channel geomorphology
Recreation	potential recreation area	% natural floodplain, water quality, biodiversity, fish abundance

[a]Three types of impact indicators are distinguished: Regulation describes services provided by the regulation processes of ecosystems. Production describes the supply of goods. Carrier describes the service provided by the use of space in ecosystems.

The supply can be expressed per river reach or at a regional, subbasin, national or international, basin-wide level. The indicators can be expressed per year or in change per year, if time series are available.

Table 4. Potential response indicators for river basin management

System part	Indicator	Variable
need for response	R	PSI indicators and references
response change with time	dR/dt	PSI indicators over time and references
spatial distribution of response	$f(R_{\mathrm{upstream}}, R_{\mathrm{midstream}}, R_{\mathrm{downstream}})$	PSI indicators and references of up-, mid-, and downstream
extent of response	planned and achieved emission reduction	agreements, plans, budget, trends in water quality
	planned and achieved river restoration	agreements, plans, budget, hectares of nature development, number of fish passages

[a]Response indicators describe the need for response and the extent of response.

A number of references for ecosystem assessment are presently used. The first type of references are based on an undisturbed river having authentic hydrological, geomorphological, and ecological characteristics comparable to the river that is to be assessed (Wassen 1990, Hooijer 1996). Finding a similar, but undisturbed large transboundary river as reference is difficult, as all large rivers in Europe and North America have been impacted. Only for smaller rivers can an undisturbed reference river be found (Boon 1992, Wassen 1990).

The second type of references relate to a historical analysis of river characteristics in a predisturbance phase (natural background water quality, species occurrence, hydrogeomorphological characteristics) (Ten Brink 1991). A historical reference has the disadvantage that it may turn out to be an unreachable goal, because many human effects are irreversible. The reference value in the AMOEBE predates major changes and so can be equated to a relatively undisturbed state (Ten Brink 1991, Ten Brink and others 1991). However, the exotic species that have invaded the Rhine are not included in the AMOEBE, although they dominate the macroinvertebrate population (Van den Brink and others 1991, Bij de Vaate 1993, Bij de Vaate and Greijdanus-Klaas 1995, Rajagopal and others 1998). Therefore, the outcome of AMOEBE can be questioned. Another example is the natural background water quality, showing the full extent of human impact. However, a certain level of human emissions will be inevitable, and it might be more relevant to know the possible effects of increased concentrations.

The third type are effect reference levels based on the risk of ecological impact. Examples are ecotoxicological parameters (50% effect concentration, 50% lethal concentration, and no observed effect concentration) as reference for ecological effects of toxic substances (Van der Meent and others 1990) or the threshold nutrient level in shallow lakes that mark the transition between the clear and turbid state (Hosper 1997, Scheffer 1998). In the Netherlands, environmental standards for pollutants are based on a protection of 95% of the species in aquatic or terrestrial ecosystems (maximum acceptable risk level). This value is divided by an application factor to arrive at negligible risk level (MinVROM 1994a, Van Straalen and Denneman 1989).

The recognition of the irreversibility of human impact increasingly attracts attention to the return of ecosystem processes as the starting point for ecological assessment, such as flood frequency, sedimentation patterns, succession (Nienhuis and Leuven 1998, Pedroli and others 1996, World Wildlife Fund 1996). Therefore, theoretical knowledge on ecosystem functioning is needed (Lorenz and others 1997).

Policy goals for ecological functioning are, for example, the IRC objective for the return of the salmon in the Rhine by the year 2000.

Impact. Impact indicators provide information on the supply of environmental goods and services. This is relevant for river basin management as a decline in the capacity to supply goods and services may have future, unspecified economic implications. Table 3 presents a number of impact indicators. The impact indicators are classified according to the type of good or service they describe. Regulation describes services provided by the regulation processes of ecosystems. Production describes the supply of goods and carrier describes the service provided by the use of space in ecosystems.

The quantity, quality, and location of the good or service supplied depends on the ecological processes and socioeconomic requirements with regard to that good or service. The supply of goods depends on the quantity and quality of natural resources. For the supply of services, the ecological processes or available space are important. Use of a service may lead to a physical flow into the river (e.g., emissions), while use of a good usually means the extraction out of the river (e.g., water, fish).

The sustainability criterion as a reference level would argue for a fair sharing of costs and benefits between up- and downstream use of goods and services. The spatial distribution of the use and supply of goods and services should be in balance. A policy-based reference can be based on the demand for goods and services. For example, Dutch policy has stated that the ratio of surface water to groundwater extraction for drinking water should change from 0.5 to 2 to reduce the desiccation of nature due to decreasing groundwater tables (MinVROM 1994b). Environmental quality objectives can be a reference for the supply (e.g., drinking water standards, irrigation standards, swimming standards), as they are quality requirements for goods or services derived from the river.

Response. A response indicator describes:

1. The gap between what society desires and what society has, indicating the need for societal response, if desires exceed means. In this study this means the discrepancy between reference and actual situation for pressure, state, and impact.

2. How fast society is moving towards or away from it. This is indicated by the change of the need for societal response over time. It will depend on the policy measures taken, their severity and the time plan.

This information is relevant for river basin management, as it indicates the need to take measures and the extent to which measures have already been taken. Table 4 presents some response indicators. Two different types of response indicators are needed; one indicating the need for societal response and its change over time, and one describing the societal response itself. The need for societal response can be described as a function of the difference between reference and condition of pressure, state, and impact. Different weights can be applied to each type of indicator.

$$R = f[w_1(r_p - c_p),\ w_2(r_s - c_s),\ w_3(r_i - c_i)] \quad (1)$$

where R is the need for response; $w_{1,2,3}$ are weighting factors; $r_{\mathrm{p,s,i}}$ are reference levels of pressure, state, or impact; and $c_{\mathrm{p,s,i}}$ are conditions of pressure, state, or impact.

As there exists a delay between the implementation of policy measures and the measurement of actual effect in the river environment, the development over time is also important. The change of the need for societal response with time is described by:

$$\frac{dR}{dt} = f[(w_1(r_p - c_p),\ w_2(r_s - c_s),\ w_3(r_i - c_i)),\ t] \quad (2)$$

The actual societal response can be measured by describing the plans, policies, and measures on ecological rehabilitation. The pressure, state, and impact indicators in both equations should have a cause–effect relationship. For example, the environmental pressure indicator describes the total emissions of nutrients. The economic pressure indicator describes the socioeconomic benefits of nutrient emitters (e.g., agriculture, industry). The state indicator describes the nutrient levels and trophic state, and the impact indicator describes the supply of drinking water, the potential recreation area, and the biodiversity. The reference levels can be policy aims of emission reduction, water quality, and functional standards. For the causal processes that are not well known, the data collection and monitoring of indicators can provide information to relate cause and effect in the future.

For international river management the spatial distribution of the need for societal response is relevant information, as it indicates the spatial distribution of use, ecological functioning and downstream supply of goods and services.

Comparison of Indicators with Selection Criteria

Criteria for the selection of indicators from a set of variables have been proposed and are scientific, policy, and measurement oriented (Van Harten 1995, De Zwart 1995, Hendriks 1995, Swart and Bakkes 1995, OECD 1994, Kuik and Verbruggen 1991, Liverman and others 1988). The purpose of the indicator will determine the importance of each criterion. This paper focuses primarily on scientific and policy requirements. We argue that the potential indicators fulfill the following selection criteria. With regard to the scientific criteria, the indicators have a "basis in scientific knowledge" and are "representative of the problem"; most of them can be "described quantitatively." With regard to the policy criteria, the PSIR framework "describes cause–effect relationships." For each indicator type "different reference levels" (e.g., sustainability criteria, policy goals) have been proposed. The policy requirement "tailored to the needs of primary users" is, however, not completely fulfilled. The indicators were developed on the basis of a scientific analysis of environmental problems and causes in rivers. They were not derived through interviews with policy-makers and river managers on their specific information needs nor were they based on an analysis of the policy phase of environmental problems (Winsemius 1986). Furthermore, the potential indicators have not been compared yet with measurability criteria. The proposed indicators should be considered as illustration of an integrated indicator set. The actual indicators used by river basin management will change over time and depend on existing information needs and policy phases.

Data Availability

Existing databases should be assessed for their support for indicator construction. Data on socioeconomic activities can be found in socioeconomic databases and statistics. Data on the quantity and quality of resources may be obtained from literature, monitoring programs, surveys, and special projects. Conversion of data to the appropriate spatial scale can pose problems. Statistics tend to be collected for administrative regions and then aggregated to larger spatial levels, whereas these data are needed at a basin or subbasin level.

The dependence of indicator development on data can lead to the situation that data availability drives the selection of indicators, which, in turn, reinforces the collection of the same data. Water quality monitoring systems have suffered from the "data rich, but information poor syndrome," in which plenty of data are produced but are not tailored to information needs (Ward and others 1986). The linking of monitoring systems to a set of indicators, selected according to this procedure, would ensure that they are designed in response to information needs as well as scientific interest and measurability. Guidelines for the design and implementation of monitoring systems (Adriaanse and others 1994, Cofino 1993) bear a strong resemblance to the guideline for indicator development.

This step is important in indicator selection, yet it must not dominate the process. Information need must drive indicator selection. Comparison with data availability may lead to modification of the indicator set, but should also feedback to more precise specification of data needs with more efficient design of monitoring programs. An important element of the latter is coordination of socioeconomic and environmental data collection and harmonization of associated spatial and temporal scales. Changing indicators means disruption of time series. While upgrading is necessary, it is a balance between better information to be gained at that moment or information gained on trends from long time series of data (less than perfect).

The development of indicators and their measurement by monitoring programs is to be viewed as a continuous, dynamic process, as information needs and measurement techniques can change over time. This dynamic process can be represented by a quality spiral, in which its ongoing nature and the feedback to assure meeting information needs are incorporated (Cofino 1993).

Application of PSIR Indicators in River Basin Management

The aim of this section is to show how the use of indicators can improve coordination of information needs and flows within river management. A division of tasks and responsibilities is proposed for each level of management with regard to indicator development, data collection, indicator construction, and assessment of the provided information. An overview is presented in Figure 3.

We distinguish four levels of management. At the

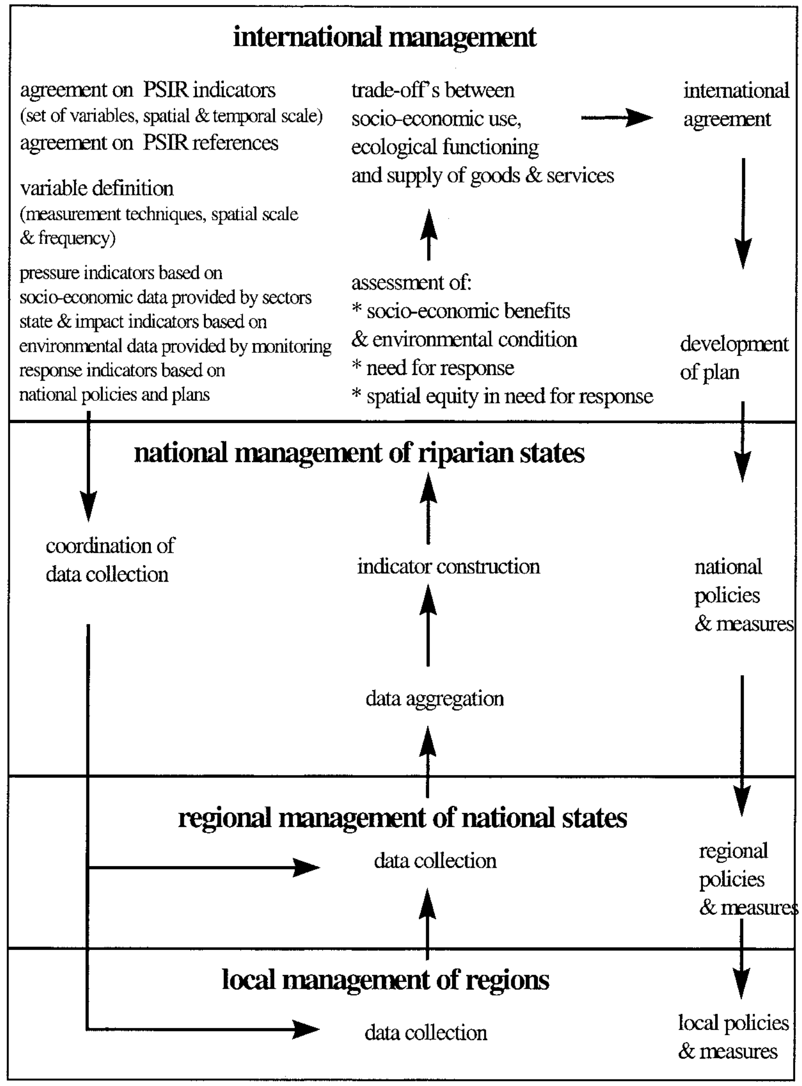

Figure 3. Proposed tasks and responsibilities of river basin management with regard to indicator development, data collection, and indicator application in decision-making.

highest spatial level comes international management, which consists of some sort of basin commission, composed of all basin states, like the International Rhine Commission. One spatial level lower is the national management of each basin state (e.g., Germany, The Netherlands, France). The third level is the regional management of national states, such as provinces, departments, or federal states. The lowest level consist of local management by municipalities or water boards. International river management should reach agreement on the set of PSIR indicators, their underlying variables, the measurement techniques, and spatial scales and temporal frequency of data collection. The indicators proposed in Table 1–4 are an illustration. The actual indicators used by river basin management will change over time and depend on existing information needs and policy phases.

A good way to reach agreement on the indicators is to form an international group of scientists and policymakers from the different basin states and let them develop a set of indicators, perhaps in a workshop environment or via a Delphi procedure. Dieperink (1997) concluded from his analysis on the process of decision-making within the International Rhine Commission that the intensive cooperation between scientists of the basin states gave a positive impulse to the achievement of international agreements by decision-makers.

Furthermore, agreement should be reached on the reference values for the PSIR indicators. The references will reflect the aims with regard to economy, society, and environment of the riparian states. Transboundary river basin management has to deal with national governments having different political preferences and economic, environmental, and social aims. More clarity and transparency on these aims is a necessary step in developing integrated policies.

National river management should provide the national values of the PSIR indicators for international management. They coordinate data collection by regional and local management. Pressure indicators will be based on socioeconomic data provided by economic sectors and collected in socioeconomic databases and statistics. State and impact indicators will be based on environmental data derived from monitoring by the national or regional monitoring department of water management. Response indicators describe the difference between present condition and reference and measures already taken.

At the regional and local level data are collected for the national level. The regional level can collect data for subbasin (e.g., diffuse emissions), river reach (e.g., monitoring of water quality and hydrology), or administrative region (e.g., socioeconomic statistics, measures, and policies). Data collection for transboundary river basin management can overlap with data requirements for local, regional, and national management. Complete overlap of data requirements for all management levels would be ideal, as no additional data have to be collected. Partial overlap will probably be current practice in water management. An assessment of present data requirements per management level can help to search for a set of river basin indicators having the largest overlap.

National management has to aggregate these data from the regional level to a national scale and to determine the value of the indicator. Aggregation could occur in a mathematical way (e.g., summing up all emissions per substance per nation) or by visualization (e.g. water quality of the river by different colors).

International river basin management can use the information provided by the national PSIR indicators for:

- Assessment of socioeconomic benefits derived from the river and assessment of the environmental and ecological condition of the river on the basis of indicator values and references.
- Assessment of need for response on the basis of the difference between actual and reference levels.
- Assessment of the spatial distribution of the use and supply of goods and services and spatial distribution of socioeconomic benefits and ecological and economic impacts of river use.

If there is a need for response, international river management has to make trade-offs between economic use of goods and services and the ecological effects and socioeconomic impact and between up-and downstream. Most often these trade-offs will be political compromises, which are established during negotiations between the different national riparian states. The compromises will be formulated in international agreements and plans. These plans are the basis for implementation of activities through national policies and measures. By linking the indicators to models, relationships and dynamics can be simulated and future conditions predicted. Possible trade-offs and policy measures can be analyzed. For example, by linking models on emission, water quality, and biological response, the pressure, state, and impact chain of pollution is described. The aim of the SQR project (Sustainability and Environmental Quality in Transboundary Riverbasins) (Delft University of Technology and Institute for Environmental Studies 1996) is to develop a decision framework by linking different models. Other examples on how combined economic–ecological models can help to solve transboundary river problems, in particular on the sharing of water resources, are described in Giannis and Lekakis (1996, 1997) and Lekakis (1998). For the evaluation of policy measures, performance indicators can be used to reflect the level of achievement of each management objective. In comparing the predicted effects of alternative measures, insights can be gained into the possible trade-offs, and their acceptability. Weights have to be given to each of these objectives in order to rank alternative management actions. These weights will reflect the aims and sociopolitical preferences of river basin managers.

Conclusion

The aim of this paper is to analyze the potential of indicators for integrated management of transboundary river basins and to develop indicators for a more sustainable management of transboundary rivers. The management of transboundary rivers is complicated by large spatial, institutional, and sectoral fragmentation. This is a major constraint to the development of integrated, basin-oriented policies. Indicators can drive coordination of information needs and data collection by the different institutional, international, and sectoral levels.

Indicators can meet the information needs of policy- and decision-makers. A set of pressure, state, impact and response (PSIR) indicators measured at a river basin scale provides integrated information on the use and supply of goods and services, underlying cause–

effect relationships, and possible trade-offs and their spatial distribution (particularly upstream versus downstream). In this paper a set of potential indicators has been presented.

A division of tasks among river basin management authorities has been proposed with regard to indicator development, data collection, and aggregation. Beside information on the current situation, policy-makers need information on possible future developments. By linking the PSIR indicators to models, cause–effect relationships can be simulated, trade-offs analyzed and the effectiveness of policy measures checked.

This paper builds in some scientific rigor into indicator development for policy-making and shows how science can advise management and policy and fits within the discipline of management science as well as environmental policy. Although the study has a Western European focus, the general principles have a broader application to transboundary resource issues. Obviously certain conditions, such as the type of climate, socioeconomic condition, political stability, and degree of cooperation between riparian states, need consideration when applying the results of this paper to rivers in other parts of the world.

On the basis of the present state and the future, a common understanding has to be developed on the desired development. In particular, the spatial distribution use, ecological effect, and supply are crucial, as downstream impacts of upstream activities is one of the main environmental, social and economic problems in river basin management. A prerequisite for a common view is a uniform information flow, which may diminish both the fragmentation and communication problems between the different management levels. An integrated set of indicators can provide more streamlined information flows. Furthermore, international agreement on indicators and their reference levels will increase the transparency in the decision-making process. The indicators will make the difference between scientifically proven and quantitatively described cause–effect relationships and societal trade-offs more clear. Riparian states can have different political preferences and economic, environmental, and social aims. More clarity and transparency on these aims is of major importance for the development of more integrated policies. The analysis in this paper may contribute to achieving the required transparency.

Acknowledgments

The authors would like to thank Prof. Nico van Straalen and Prof. Pier Vellinga for their comments on the manuscript. We also acknowledge the many comments, criticisms and suggestions of the four reviewers of this paper.

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