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Framework for Measuring Sustainable Development in Catchment Systems

JAY J. WALMSLEY
Mzuri Consultants
PO Box 72847
Lynnwood Ridge
0040 Pretoria, South Africa

ABSTRACT / Integrated catchment management represents an approach to managing the resources of a catchment by integrating environmental, economic, and social issues. It is aimed at deriving sustainable benefits for future generations, while protecting natural resources, particularly water, and minimizing possible adverse social, economic, and environmental consequences. Indicators of sustainable development, which summarize information for use in decision-making, are invaluable when trying to assess the diverse, interacting components of catchment processes and resource management actions. The Driving-Forces–Pressure–State–Impact–Response (DPSIR) indicator framework is useful for identifying and developing indicators of sustainable development for catchment management. Driving forces have been identified as the natural conditions occurring in a catchment and the level of development and economic activity. Pressures include the natural and anthropogenic supply of water, water demand, and water pollution. State indicators can be split into those of quantity and those of quality. Impacts include those that affect the ecosystems directly and those that impact the use value of the resource. It core indicators are identified within each of the categories given in the framework, most major catchment-based management issues can be evaluated. This framework is applied to identify key issues in catchment management in South Africa, and develop a set of indicators for evaluating catchments throughout the country.

The term "sustainable development" has become one of the most widely used expressions in the context of economy, environment, and development. It describes an intended vision for development that provides solutions to current and future social, economic, and environmental problems (e.g., poverty, disease, unemployment, violence, environmental pollution, and loss of biodiversity). In essence it is about "improving the quality of life while living within the carrying capacity of supporting ecosystems" (Monro and Holdgate 1991).

In order to manage natural resources in a sustainable manner, decision- and policy-makers need information. Sustainable development is accepted as a vision for managing the interaction between the environment and economic progress, but experts are still struggling with the practical problem of how to implement and measure it. More often than not, they are faced with an information dilemma. On the one hand, information and information sources are proliferating at an astounding rate. On the other hand, they seldom seem to have the specific information required for good decision-making and effective resource management (Walmsley and Pretorius 1996).

One method of overcoming this dilemma is through the use of sustainability indicators. Indicators provide a means of communicating information about progress towards a goal (such as sustainable resource management) in a significant and simplified manner (Hammond and others 1995). Indicators have been used for many years by economists to explain economic trends, a typical example being gross national product. More recently there have been efforts aimed at developing indicators that are suitable for measuring sustainable development. Those involved include, among others: the World Resources Institute (Hammond and others 1995), the World Conservation Union-IUCN (Trzyna 1995), the Belgian government (Gouzee and others 1995), the OECD (1993) and its member countries, UNEP (Bakkes and others 1994), the UN Commission on Sustainable Development (Moldan and Billharz 1997), the Environmental Challenge Group of the United Kingdom (MacGillivray 1994), the UK Local Government Management Board (1995), and the World Bank (1995).

Most of these indicator initiatives have been aimed at providing information at a national level that would be useful for international comparisons. Few initiatives have been aimed at developing sectoral indicators, although some attempt has been made to develop sectoral indicators for agriculture, transport, and energy (Obst 2000). Most of the sectoral indicators have arisen from state-of-the-environment reporting (e.g., Ward 1990, OECD 1991, ANZECC 1998) or national and international initiatives to answer specific policy ques-

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tions (e.g., UNEP and WHO 1988, FAO 1992, Eeronheimo and others 1997). In a recent international survey by Walmsley and others 2001), 19 organizations from around the world were approached with regards to whether they had developed indicators of sustainable development for catchment management. Of these, only five organisations had developed indicator sets, of which only one addressed the issue of sustainability comprehensively. There is, thus, a recognized need for an understanding of how indicators can be used and developed in the catchment context.

This paper addresses the usefulness of sustainability indicators in the water sector, particularly with regard to catchment management. It highlights the characteristics of catchments that need to be taken into account when developing a set of indicators and presents a framework for developing a set of core indicators for catchment management information systems. A case study of the situation in South Africa is presented as a guide to using the framework in other countries.

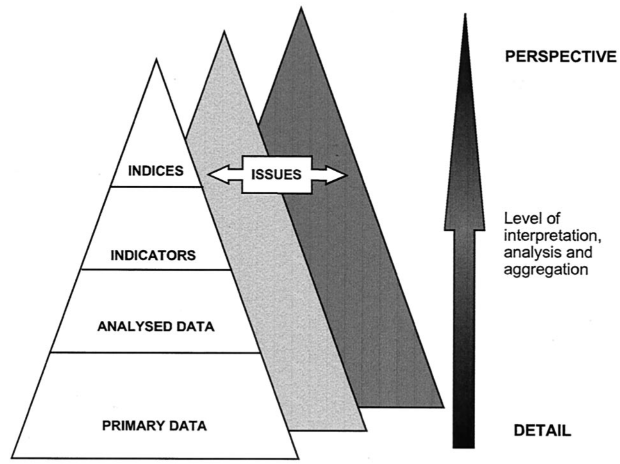

Figure 1. Information pyramid (adapted from Walmsley and Pretorius 1996).

Sustainability Indicators and Frameworks

Indicators of Sustainable Development

Agenda 21 (Chapter 40) states that "indicators of sustainable development need to be developed to provide solid bases for decision-making at all levels and to contribute to the self-regulating sustainability of integrated environmental and development systems". This has led to the acceptance of sustainability indicators as basic tools for facilitating public choices and supporting policy implementation (Von Meyer 2000). They provide information on relevant issues; identify development-potential problems and perspectives; analyze and interpret potential conflicts and synergies, and assist in assessing policy implementation and impacts (Von Meyer 2000). In essence, they allow us to better organize, synthesize, and use information. The main goal of establishing indicators is to measure, monitor, and report on progress towards sustainability.

Indicators have numerous uses and potential for improving environmental management. Some of these include (Hammond and others 1995, Walmsley and Pretorius 1996):

- Monitor and assess conditions and trends on a national, regional and global scale;
- Compare situations;
- Assess the effectiveness of policy-making;
- Mark progress against a stated benchmark;
- Monitor changes in public attitude and behaviour;
- Ensure understanding, participation and transparency in information transfer between interested and affected parties;
- Forecast and project trends;
- Provide early warning information.

Even though indicators are often presented in statistical or graphical form, they are distinct from statistics or primary data (Hammond and others 1995). Indicators, which may include highly aggregated indices, top an information pyramid, whose base is primary data derived from monitoring and data analysis (Figure 1).

Indicators should have three essential qualities. They should be "simple, quantifiable and communicable" (Walmsley and Pretorius 1996). The following criteria, as proposed by the OECD (1993), provide a useful guide to the selection of appropriate indicators.

With respect to policy relevance and utility for users, an indicator should:

- provide a representative picture of environmental conditions, pressure on the environment or society's response;
- be simple, easy to interpret, and able to show trends over time;
- be responsive to changes in the environment and related human activities;
- provide a basis for comparisons;
- be either national in scope or applicable to issues of national significance (e.g., catchment management); and
- have a target or threshold against which to compare it so that users are able to assess the significance of the values associated with it.

With respect to analytical soundness an indicator should:

- be theoretically well founded in technical and scientific terms;
- be based on international standards and consensus about its validity; and
- lend itself to be linked to economic models, forecasting and information systems.

With respect to measurability, the data required to support the indicators should be:

- readily available or made available at a reasonable cost;
- adequately documented and of known quality; and
- updated at regular intervals in accordance with reliable procedures.

Although the value of indicators to monitor progress towards sustainable development is widely accepted (OECD 1993), development of indicators has proved to be a daunting task. Many countries and international organizations have embarked upon projects involving research and consultation to develop indicators that are suitable for their own situations (Walmsley and Pretorius 1996). They have found that, to address the many issues and areas that pertain to sustainable development, frameworks are required to organise the indicators.

Frameworks for Sustainability Indicators

The use of frameworks is essential as they assist in developing and reporting on indicators in a logical fashion so that key issues can be readily identified and summarized. They suggest logical groupings of related sets of information and, thus, promote interpretation and integration. They can also help identify data collection needs and data gaps. Finally, indicator frameworks can help to spread the reporting burdens, by structuring the information collection, analysis, and reporting process across the many issues that pertain to sustainable development (Gouzee and others 1995, Walmsley and Pretorius 1996).

Two main types of framework are available, economic frameworks and physical environmental frameworks. The economic frameworks tend to favor "weak sustainability" (i.e., where manufactured capital can take the place of natural capital), while the physical environmental frameworks tend towards "strong sustainability," where spent natural capital cannot be replaced (Zinn 2000).

Economic frameworks. Several frameworks, based on the interaction between environmental, social, and economic elements have been developed, including frameworks such as the System of Integrated Environmental and Economic Accounting (SEEA); measures of wealth; and genuine savings (see OECD 2000). These economic frameworks are based on the concept of attempting to place a financial value on resources and assets. The basic framework on which all the others rest is that of the national system of accounts, which may be extended to include environmental resources and assets, and human and social capital (Obst 2000). However, the accuracy of any type of environmental accounting can be questioned, although the concept of including environmental considerations into the national accounting system is sound.

Physical environmental frameworks. Several frameworks have been developed to measure the interaction between humans and the environment. They are referred to here as "physical frameworks" as they tend to be systematic and are useful as a means of organizing and presenting physical data from various subject areas and sources (Alfieri 2000). The most commonly used of these frameworks are the Pressure–State– Response (PSR) framework developed by the OECD in the late 1980s (Walmsley and Pretorius 1996) and the Driving-Forces–Pressure–State–Impact–Response (DPSIR) framework, which is based on the PSR framework.

The PSR framework follows a cause–effect societal-response logic (Figure 2). Within the framework, the indicators are split into three categories:

- pressure indicators that measure the pressures that are exerted on resources and ecosystems from human activities (e.g., emissions, consumption, and utilization);
- state indicators that assess the condition of the resource or ecosystem as a result of the pressures, and
- response indicators that relate to the societal responses via policies, laws, programmes, research etc.

This framework was further developed by the United Nations into the DPSIR framework. There are two additional categories in this framework:

- driving forces, which are the human influences and activities that, when combined with environmental conditions, underpin environmental change; and
- impacts, which are the results of pressures on the current state.

Both the PSR and DPSIR frameworks have been used extensively in the development of state-of-the-en-

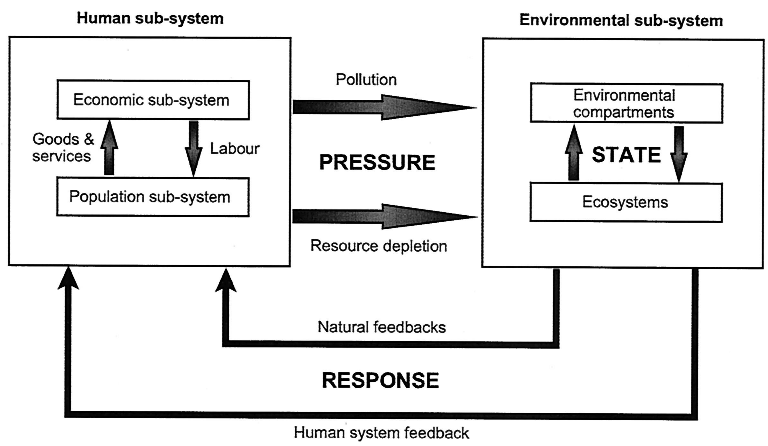

Figure 2. Representation of the pressure–state–response framework. Human activities and processes impact on the environment and exert pressure on it. Pressures can result in changes to the state of the environment. Measures of how society responds to these changes include institutional, legal, or financial measures or changes in management strategies and policy (Walmsley and Pretorius 1996).

vironment reports (DEAT 1999, UNEP 2000). These physical frameworks have tended to be used most often for identification of and reporting on environmental indicators, rather than the full spectrum of sustainability indicators. They deal more specifically with natural environmental issues and the influence of humans on the environment, rather than the economic aspects such as employment, empowerment, local needs, etc. However, if they are used in an innovative fashion, which includes economic aspects, they become valuable tools for assessing all aspect of sustainable development.

River Systems and Catchment Management

It is becoming increasingly apparent that the ability of nations and societies to develop and prosper is linked directly to their ability to develop, utilize, and protect their water resources (DWAF and WRC 1996). Water resources are the cornerstone of industrial development and agricultural production, as well as being useful in the transportation of goods, production of energy, and enhancement of the quality of life through recreational opportunities (DWAF and WRC 1996). Thus most economies rely on their river systems and underground water resources for their development.

A catchment, or drainage basin, is the total land area from which a river system receives its water, and the boundaries are demarcated by the points of highest altitude in the surrounding landscape (Hutchinson 1957, Reid and Wood 1981, DWAF and WRC 1996). A catchment encompasses the entire hydrological cycle, including atmospheric water (quantity, quality, and distribution of precipitation); subsurface water (soil moisture and groundwater reserves), surface water (rivers, lakes, wetlands, impoundments), the estuarine zone, and the coastal marine zone. DWAF and WRC (1996) define a catchment as a "living ecosystem" in which there is a large, interconnected web of land, water, vegetation, structural habitats, biota, and the many physical, chemical, and biological processes that link these. Minshall (1988) states that spatial and temporal dimensions provide the basis of river ecosystem structure. River systems, and thus catchment areas, have a four-dimensional structure, with changes occurring longitudinally, laterally, vertically, and with time (see Ward 1989). Superimposed upon this is the human system, which utilizes the water as an essential resource.

Integrated catchment management (ICM) represents an approach to managing the resources of a catchment by integrating all environmental, economic, and social issues within a catchment into an overall management philosophy, process, and plan (DWAF and WRC 1996). It is aimed at deriving the optimal mix of sustainable benefits for future generations, while protecting the natural resources, particularly water, and minimizing the possible adverse social, economic, and environmental consequences (DWAF and WRC 1996). In essence, it is managing for sustainable development at the catchment level, where water resources are viewed as the limiting factor.

One of the critical success factors for effective water resource and catchment management is the appropriate assessment of the diverse, interacting components of catchment processes, and the resource management actions that impact the water resources in a catchment (DWAF and WRC 1996). A systematic approach to this includes (DWAF and WRC 1996):

- Analysis of aspects of the catchment system that affect use and condition of the water resource;
- Assessment of the prevailing environmental, economic, and social values, together with the values arising from beneficial uses of the water resource

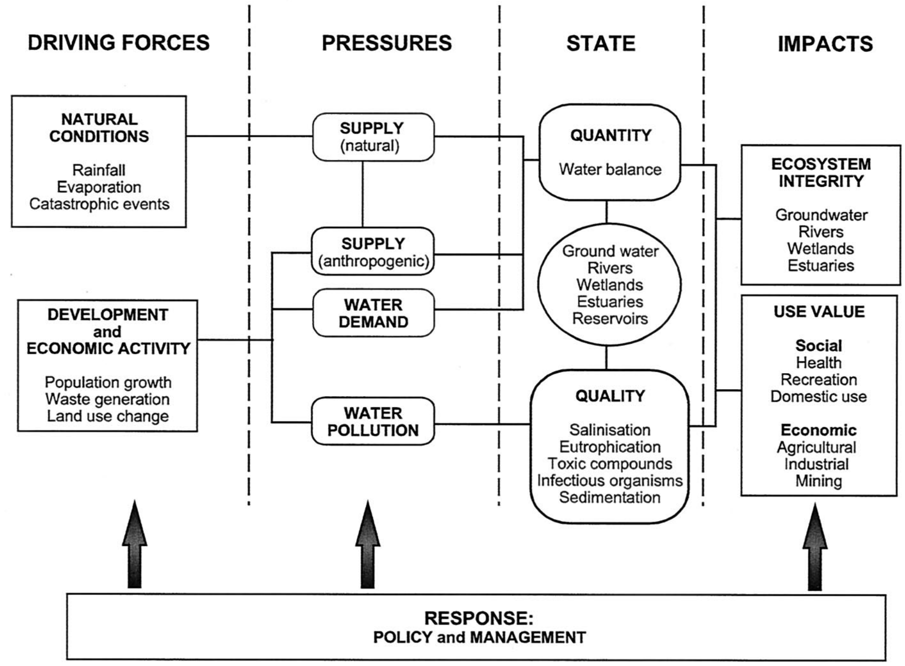

Figure 3. DPSIR linkage diagram showing functional interrelationships of water resource issues at a catchment level.

and the related impacts of management actions; and
- Monitoring of the environmental conditions and related socioeconomic factors.

This provides the basis for a management information system for catchments.

Indicators of sustainable development are invaluable when implementing this systems approach. A physical framework for identifying environmental indicators, such as the PSR or DPSIR frameworks, assists in the analysis of catchment systems; the indicators provide a method for assessing the current situation; and, once developed, the indicator system is ideal for both short- and long-term monitoring. The literature indicates that this approach has not yet been implemented in the catchment context.

Framework for Developing Indicators for Catchment Management

The DPSIR concept has been used here as a basis for a framework to identify and develop indicators for catchment management. The DPSIR framework identifies cause-and-effect relationships, allows for the separation of categories of issues, provides flexibility for usage and analysis, and provides a means by which monitoring can be systematically improved.

For development of catchment indicators, the DPSIR categories are defined as follows:

- Driving force indicators reflect pressures exerted by natural phenomena and anthropogenic activities that are not easily manipulated or managed within the catchment context, but provide essential information to understanding catchment processes;
- Pressure indicators measure the pressures that are exerted on the water resources of a catchment as a result of the driving forces (e.g., increased pollution from domestic waste due to increased population and poor sanitation; increased consumption due to increasing economic activity);
- State indicators assess the current status of the water resource, in terms of quantity and quality for each habitat/ecosystem type;
- Impact indicators assess the effect that a pressure has on the state of the water resource or on water-user groups;
- Response indicators relate to the social response via policies, laws, programes, research etc.

Within this framework a flow diagram was developed showing conceptual links and interrelationships between the DPSIR categories for a catchment-based situation (Figure 3). If core (or key) indicators for catchment management are identified within each of the categories present in the diagram, most major catchment-based management issues will be covered. Each of the elements within this causal diagram are discussed below.

Driving Forces

Natural conditions. The original definition of driving forces excluded natural phenomena, and only included human influence and activities. However, DEAT (1999) in the South African national state-of-the-environment report recommends that natural conditions be included as driving forces. Certainly, in the catchment context, driving forces in the form of climate, geology, and topography, etc., determine the underlying character of a catchment and its water resources. Without knowledge of these aspects, any anthropogenic impacts and changes cannot be monitored and managed. The natural conditions in a catchment can also be viewed as having a generally positive influence or exerting a positive pressure on the resource, while anthropogenic changes tend to be negative in character.

In the catchment context, the most important of these natural conditions is the climate, which directly affects the amount of water in the system. High precipitation and low evaporation ensures an abundance of water, while low precipitation and high evaporation will create arid conditions. Catastrophic events such as droughts and floods also have a major influence on the character of the catchment.

Development and economic activity. Over the last 50 years, the world has experienced an unprecedented growth in economic activity (Walmsley and Pretorius 1996), resulting in humans today using approximately 12,000 times more energy, mainly in the form of fossil fuels, than they did 400 generations ago (Munasinghe and Shearer 1995). For the purposes of developing indicators for catchment management, population growth, waste generation, and land-use change have been identified as the key consequences of development and economic growth within catchments. These, in turn, place pressures on the environment that have direct effects on the water resources.

Some people may argue that population growth is not a consequence of economic development, but a cause. However, most will agree that population growth and economic development are closely interrelated and both have a direct effect on the quantity and waste produced and on the type of land use that the catchment is experiencing.

Pressures

Natural supply. Like the driving forces, pressures on a resource can be either positive or negative. The natural supply of water to a catchment area is considered to be positive, although certain natural phenomena such as droughts and floods may have a negative effect on the quality of life of the human population in a catchment. From a natural environment point of view, the ecosystem is adapted to handle these fluctuations.

The natural supply of water in a catchment is provided by the precipitation on the catchment, which is stored as surface water in rivers lakes, reservoirs, wetlands, and estuaries, and as groundwater in aquifers. The quantity of the surface water available is reflected in the mean annual runoff (MAR), which is the amount of water that reaches the river after evaporation and soil absorption. In arid countries such as Australia and South Africa, this may be as little as about 10% (8.6% for South Africa and 9.8% for Australia) and rises to about 60% in wetter countries (e.g., Italy and Austria) (Allanson and others 1990).

Anthropogenic supply. In many countries in the world, the natural water supply in a catchment needs to be supplemented with water from outside. In most cases this is due to the development in a catchment outstripping the water resource availability. Importation of water takes different forms, the cheapest of which is interbasin transfer (IBT), where water is transferred via pipelines from one catchment to another (even one country to another). This has a negative effect on the water supply in one catchment, while fulfilling a need in another catchment. Other forms of water importation are desalinization of seawater and transportation of icebergs.

In determining indicators of anthropogenic supply, one must be careful of the syntactic difference between "availability" and "supply." The term "supply" is used specifically by hydrologists as the amount of water available for use and includes return flows. Although there is a fixed amount of water available in the catchment (availability = groundwater + MAR + IBTs), there is more available for use due to reuse of water in the form of return flows (supply = groundwater + MAR + IBTs + return flows). This can be confusing to the nonhydrologist and should be taken cognisance of when indicators are being developed.

Water demand. Water demand is the amount of water required by all water use sectors, including the mining, agriculture, industry, domestic, and environmental sectors. Previously the environment was not considered as a legitimate water user, but there is an international trend in recognizing the environment as a legitimate water user. In some countries (e.g., South Africa and Australia), water for the environment and drinking water are both considered basic needs and given priority in terms of water allocation. Sectoral water demand

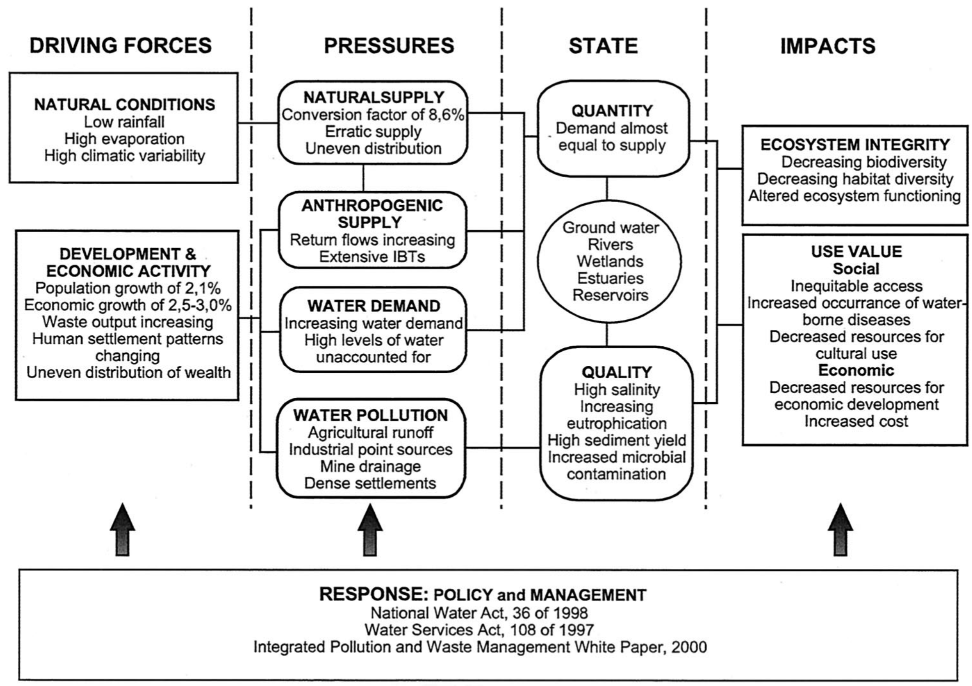

Figure 4. DPSIR linkage diagram for South Africa, showing key characteristics of South Africa's freshwater resources.

may be particularly important when considering policy development or catchment management issues.

As with the supply of water, both surface and groundwater demands should be taken into account. Some countries may rely heavily on their groundwater supplies, while others may rely on surface water resources. In both cases the demand for water needs to be seen in conjunction with supply to have any relevance.

Water pollution. Pollution is one of the greatest threats to water resources throughout the world. It is defined by Dallas and Day (1993) as "the presence of any foreign substance that impairs the usefulness of water." Freshwater pollutants originate mainly from industrial, mining, domestic, and agricultural sources. Those of greatest concern include organic and inorganic chemicals, plant nutrients, oxygen-demanding wastes, radioactive materials, sediment, and microbiological contaminants (DEAT 1996). The type and amount of pollution will vary from catchment to catchment, depending on the land-use and development patterns within each catchment. It is impossible to monitor all forms of pollution, and indicators will have to be chosen keeping in mind the dominant land use of a catchment.

State

The state of water resources in a catchment should be described in terms of both quantity and quality. Both the amount of water in the system and the quality of that water are essential in terms of ecosystem viability, as well as use value. It should be remembered that descriptions of "state" should provide information on the current status of a catchment. The three spatial dimensions of river systems need to be taken into account (longitudinal, vertical, and lateral), as well as short-term variations (i.e., seasonal changes).

Quantity. The state of a catchment's water resources is dependent on the right amount of water being available at the right time. All catchments undergo seasonal and long-term variations in water quantity. The natural system relies on these variations, to which they are adapted (including catastrophic events such as floods and droughts), to maintain ecosystem integrity. For instance, breeding seasons of the fauna are dependent on seasonal changes in the water level, while floods clear the system of weeds such as water hyacinth. On the other hand, humans prefer the system to be constant. To ensure sustainability, there should be a balance between the regulation of rivers and their natural flow regime.

All the ecosystems that make up the freshwater resources of a catchment need to be taken into account when describing water quantity. These include groundwater, rivers, wetlands, lakes, reservoirs and estuaries. Wetlands, estuaries, lakes, and reservoirs all form an important part of the whole river ecosystem, while the

Table 1. Indicators for catchment management in South Africa and their relevance to sustainable management of the country's water resources

Indicator	Importance/relevance
Driving forces	
Population density	A high or growing population can threaten the sustainability of water resources, particularly in South African catchments where freshwater resources are limited.
Urbanization	The number of people living in urban and rural environments has an impact on the infrastructure requirements, as well as waste management and pollution potential.
Proportion of households earning less than US$1000 per annum	Household earnings is an internationally accepted indicator of poverty. If a household in South Africa is earing less than US$1000 per annum, it suggests that the household is barely subsisting and lower order needs are the prime concern.
Gross geographic product per capita	Growth in the production of goods and services is a basic determinant of how the economy fares, as well as the level of development in a catchment. It measures income growth, and is an important indicator of consumption patters and the use of renewable resources.
Pressures	
Catchment population as a proportion of the maximum sustainable population	There is a certain minimum amount of water required for development, which can be expressed on a per capita basis (1000 m^3/yr, (Engelman and LeRoy 1993). If there is not enough water for the size of the population, development will not be possible and subsistence will predominate.
Population without access to piped water on site	Because of past imbalances, not all South Africans have access to water on site. This has implications for the control of water consumption in the catchment, as well as for future infrastructure development.
Population without access to toilet facilities	Not all South Africans have access to adequate sanitation facilities. This has implications for waste disposal and pollution potential in the catchment, as well as future infrastructure development.
Anthropogenic supply as a proportion of total available	In South Africa, there is a reliance in many catchments on importation of water from other catchments, or even downstream in the same catchment. If a catchment is too heavily reliant on water importation, the development of the catchment cannot be considered sustainable.
Reserve as a proportion of mean annual runoff	The National Water Act has legislated that a reserve shall be established for each catchment in South Africa. It consists of social requirements for essential use (minimum of 25 liters/day) and environmental requirements for the maintenance of the ecosystem. The higher the reserve requirement, the less water is available for development.
Total liquid waste discharged as a proportion of supply	Liquid waste generation depends on industrial and agricultural processes as well as the population size. The more liquid waste that is discharged into the system, the more pressure is exerted on the system to maintain itself.
Wastewater treated as a proportion of water care works' capacity	In South Africa, a single wastewater treatment plant will treat all effluents from domestic effluents through to industrial effluents. If the capacity of wastewater treatment plant is inadequate, this could provide a serious pollution threat to the resource.
State	
Total water available per capita	This is an internationally accepted basic indicator for water availability. It can be used at a catchment level and further split sectorally.
Demand as a proportion of supply	This indicator is a the core indicator of water balance. If demand is nearing supply, action with regard to water resource development is required. In many South African catchments, demand has exceeded supply and augmentation is required.
Proportion of groundwater utilized	In certain areas in the country, groundwater is a significant supply of water for domestic and agricultural use. If the demand for groundwater is higher than the safe yield, then groundwater usage will not be sustainable.
Proportion of boreholes contaminated	Groundwater supplies are particularly important in the more arid areas of the country. Good water quality is essential to development in these areas.
Reservoir water quality	Reservoirs are a reflection of what is occurring in the catchment. Particular water quality problems that pertain to South African catchments include salinization, eutrophication, microbiological contamination, toxic compounds and sedimentation. If receiving water quality objectives have been set, these can be compared to the ambient water quality.
Water quality at the downstream point	The downstream point is an indicator of the sum of all activities in the catchment. This indicator will complement water quality in reservoirs to provide an accurate picture of problem areas.
Reservoir capacity as a percentage of total water available	South Africa is a country prone to periodic droughts and floods. River regulation in the form of reservoirs mitigate against these catastrophic events, and this indicator shows the capacity for doing so. It could also be viewed as an indicator of the condition of the natural resource, where a highly regulated system would be viewed negatively.
Riparian zone with development	The riparian zone is the interface between freshwater and land systems. In the past, riparian land rights of landowners in South Africa have led to extensive degradation of the riparian zones of rivers, and irreparable damage to river ecosystems.
Impacts	
Biodiversity of wetland birds	Wetlands are some of the most endangered ecosystems in South Africa, with an estimated 50% of all South Africa's natural wetlands having been lost. The diversity of wetland birds, which require functioning wetland systems for their survival, is a good indication of the quality of wetlands in a catchment.
South African scoring system (SASS) for macroinvertebrate community health	SASS has been tested and is used widely in South Africa as a biological index of water quality. It rests on the basis that the structure of aquatic invertebrate communities is a sign of change in the overall river conditions and is a good indicator of river and habitat health.
Fish assemblage integrity index (FAII)	Fish, being relatively long-lived and mobile, are good indicators of long-term influences on rivers. The number of species, the size classes and health of fish give a good indication of river health.
Riparian vegetation index (RVI)	Healthy riparian zones maintain channel form and serve as filters for light nutrients and sediments. The status of riparian vegetation, including removal, cultivation, construction, inundation, erosion, sedimentation, and alien vegetation, gives an indication of the deviation from the natural, unmodified riparian conditions.
Index of habitat integrity (IHI)	Habitat availability and diversity are major determinants of aquatic community structure. The IHI is useful in assessing the impact of major disturbances on river reaches, including water abstraction, flow regulation, and bed and channel modification.

Table 1. (Continued)

Indicator	Importance/relevance
Recreational index for raw water	Poor water quality in catchments has related health risks. One of the important uses of water is for full- and partial-contact recreation. If water is too polluted for recreation, it will also be unacceptable for domestic use for informal settlements. It also has implications for access.
State of satisfaction of catchment population	Public opinion often influences the behavior of people. The level of cooperation of the community in water resource management and conservation depends, along with other factors, on their satisfaction with water management in their area.
Cost of water treatment	Water treatment costs rise with decreasing water quality. One of the major influences on water management decisions is the economic benefit of an action. If the cost of treating water exceeds the cost of pollution prevention activities, then pollution prevention will become the primary management thrust in a catchment
Responses	
Number of active hydrological monitoring stations per 100 km^2	Continual monitoring of water resources is important for immediate management. Rainfall in South Africa is irregular over many catchments, and constant surveillance is needed on the amount of water available in the catchment.
Number of water quality monitoring points per 100 km^2	Water quality information is important in the continual evaluation of pollution in a system and can be used as a warning system for spills.
Level of forum establishment in the catchment	Water forums have been established, or are being established, in many catchments in South Africa with the objective of allowing participative management in the catchment. They are viewed as essential to the successful establishment of CMAs. One of their primary roles is the establishment of receiving water quality objectives.
Establishment of catchment management agency	The National Water Act requires that CMAs are set up for all the major catchments in South Africa, within a reasonable time. If a CMA has been established, management in that area will be catchment specific.
Completion of catchment management plan	The National Water Act requires that each CMA develop a catchment management strategy for each catchment. The strategies must be in harmony with the national water strategy and should set the principles for allocating water taking into account the protection, use, development, conservation, management, and control of water resources in the catchment.

groundwater is continually replenished by surface waters. The balance between the availability of water and water removed from the system (supply and demand) will be crucial in the viability of these ecosystems. As with all the other categories, there are a large number of indicators that could describe the state of each ecosystem, and the choice will depend on the importance and character of the ecosystems within each catchment.

Water quality. The quality of water in a catchment obviously depends on the level and sources of pollution. The type of water quality problems will vary from catchment to catchment, but several generic problems have been identified (DEAT 1996):

- Salinization reduces crop yields, leads to salinization of irrigated soils, increases scaling and corrosion, and increases the need for pretreatment of water for industrial purposes. Sources include municipal, mining, and industrial effluents; irrigation return water; runoff from urban settlements; and seepage from waste disposal sites.
- Eutrophication causes taste and odor problems, limits recreational use, and can limit stock watering due to the presence of toxic algae. Sources of plant nutrients, which cause eutrophication, include agricultural and urban fertilizers, sewage, and effluent discharges.
- Sedimentation reduces the storage capacity of reservoirs, as well as affecting the ecological functioning of a system. Activities promoting erosion and increasing sedimentation include agriculture, forestry, construction activities, open-cast mining, and other disturbances of vegetation.
- Toxic inorganic compounds include heavy metals (e.g., mercury, lead, tin, cadmium), highly toxic elements (e.g., selenium, arsenic) and inorganic substances, such as acids, nitrates, and chlorine compounds, that become toxic in high concentrations. Sources include industrial processes such as metal finishing, mineral refining, plastics and chemical industries, and household solvents.
- Toxic organic compounds include pesticides, plastics, paints, colorants, pharmaceuticals, and many other products. Many are persistent and bioaccumulative toxins. The largest source of these is improper disposal of household and industrial waste.
- Infectious organisms, such as disease-causing microorganisms and parasites, are a major cause of health problems. Human settlements are the main source of these pollutants, which enter the water in the form of partially treated or untreated sewage, seepage from pit latrines, and runoff from settlements with inadequate sanitation and waste disposal facilities.
- Oxygen-demanding wastes, including sewage, paper and pulp effluent, and food-processing wastes, increase the oxygen consumption of bacteria and reduce the availability for other aquatic life.

Impact

Changes in water quality and quantity have two major impacts, one on the environmental subsystem, in the form of ecosystem integrity, and one on the human subsystem, in the form of use value.

Ecosystem integrity. Any anthropogenic changes to a natural ecosystem may have a negative impact on the balance of that ecosystem, i.e., it will affect the functional integrity of the system. This may take the form of invasion by alien species, increase in the numbers of pest species, decrease in biodiversity, and inability of the system to clean itself etc. In most of these cases, the result will have direct or indirect economic consequences. Once again, the type of environmental impact that is experienced will vary from catchment to catchment, depending on the sensitivity of the catchment and the level of disturbance.

Use value. If the resource is to be maintained for the purpose of human development on a sustainable basis, then the use value of the resource should not decline. Uses that need to be taken into account include social elements, such as health, recreation, and domestic use, and economic elements, such as agricultural, industrial (including power generation), and mining use.

The use value of a system is directly related to ecosystem integrity. If the ecosystem is not functioning properly, this will have a direct effect on use value. For instance, the introduction of plant nutrients will lead to eutrophication, which creates an imbalance in the system, causing algal blooms, which decrease the use value for industrial purposes that require clean water and for domestic use. In both cases, treatment costs will rise, negatively affecting the economic value of the water in the system. It may or may not be possible to pin a financial cost on a drop in use value.

Response

Responses in the context of the DPSIR framework generally apply to more long-term management actions, rather than emergency measures. They may include policy development in the form of international treaties, national and local legislation, and catchment management plans. A more indirect response may be the expansion of the knowledge base, in the form of research and monitoring.

Responses to a catchment problem may be applied anywhere in the causal chain outlined above. Generally, responses aim at adjusting anthropogenic pressures caused by development or by mitigating impacts. They are rarely able to make an impact on the driving forces.

South Africa: A Case Study

South Africa has introduced a new National Water Act (No. 36 of 1998) that will effectively dictate water resource policy and practice for at least the next ten years. A core feature of this act is the introduction of catchment management agencies (CMAs) that will be responsible for integrated water resource management of specific catchments. Catchment management strategies will be developed for each catchment in South Africa to ensure that the water resources are utilized in a sustainable manner. Additionally, the Act requires that the government establish a national monitoring and information system for water resources as soon as possible. This system should provide for the collection of appropriate data to assess the quantity, quality, use, and rehabilitation of water resources at catchment and national levels, as well as compliance with resource quality objectives, health of aquatic ecosystems and atmospheric conditions that may impact on water resources. With this in mind, the identification and use of effective indicators of sustainability for catchment management will be an important information management tool to assist in this aim.

Figure 4 summarizes the main characteristics of the South African water environment using the framework described in this paper. These core characteristics can be applied at any catchment level, from large basin catchments (such as the Orange and Vaal river basins), to quaternary catchments or hydrological units. In other words, it can be applied to any appropriate management unit.

From this, a set of key indicators has been developed by the author for South African catchments (Table 1). The main characteristics of these indicators are:

- They represent essential information that is required for catchment management in South Africa.
- They allow for comparisons to be made between catchments and over time.
- They are relatively simple and easy to understand, while remaining scientifically valid and analytically sound.
- They include all elements of sustainability, including social, economic and bio-physical aspects of catchment systems.
- The data are either readily available (e.g., water quality) or can be made available at a reasonable cost (e.g., state of satisfaction).

Conclusion

If carefully chosen, indicators of sustainable development can provide valuable information for catchment management. One of the main problems is limiting the vast array of indicators to those that are relevant, analytically sound, and measurable. Because the DPSIR framework is based on a cause-and-response logic, it lends itself to be used in identifying core indicators. Initially a comprehensive set of indicators can be identified using the framework described in this paper, and then these can be reduced to a set of core indicators that characterize a catchment using the minimum amount of information. For instance, it is easier collecting information on key water quality elements, than on waste production. Just by using key water quality parameters as part of the state of a catchment, the pollution pressures imposed on the catchment can be inferred.

The core indicators finally chosen will differ slightly depending on the catchment situation. The case study shows that indicators can be developed generically, in this case for catchment management in South Africa, but the framework also has relevance for developing indicators for a single catchment. In all cases, the framework presented here will ensure that the main management issues are covered for integrated water resource management in the catchment context.

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