Development of methodologies for setting integrated water quantity and quality objectives for the protection of aquatic ecosystems

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Abstract The recent reform of national water policy and law in South Africa has provided a unique opportunity to develop legislation which is founded on sound scientific principles as well as sound political, economic and social principles. This paper describes how links were made between law reform and the scientific development of methodologies for determination of the water quantity and quality requirements of aquatic ecosystems. The application of these methodologies within the larger processes of water allocation and water resource management in South Africa is briefly discussed.

Keywords aquatic ecosystems; water policy; South Africa; water resources management; environmental water requirements

BACKGROUND

The changing policy environment

After South Africa's first democratic elections in 1994, a process of reform of water policy and law was introduced. The essence of the Water Law Principles (DWAF, 1996b) can be summed up in the slogan which was adopted at the time by the

Department of Water Affairs and Forestry (DWAF): "Some for all for ever" and which "sums up the goals of: access to a limited resource (some), on an equitable basis (for all), in a sustainable manner, now and in the future (for ever)" (DWAF, 1997). This provided the starting point for subsequent development of water policy: A more detailed discussion of the history and process of policy development can be found in MacKay (2000).

Key elements of policy for protection of aquatic ecosystems

The South African water policy holds that aquatic ecosystems are the actual resource base from which water is derived (DWAF, 1996a; DWAF, 1997), and that in order to manage water in all its forms in the hydrological cycle, it is necessary to manage water resources as whole ecosystems. There is an implicit assumption that water resources do not have to remain in a pristine state: in fact water resources must be utilized for the benefit of people, but the sustainability principle requires that this is done in a way which does not lead to irreversible damage and loss of options for future generations.

The key to balancing sustainability and equity in water resources management lies in the provisions for the Reserve, and in our ability to quantify a Reserve for a water resource, as well as to manage water uses so as to meet the Reserve. The Reserve is defined in law as the quantity and assurance of water, as well as the quality of water, which are required to protect basic human needs and to protect aquatic ecosystems so as to secure ecologically sustainable development and utilization. (The component of the Reserve relating to basic human needs is commonly referred to as the "basic human needs Reserve", and the component relating to aquatic ecosystems as the "ecological Reserve".)

The water required to meet the Reserve is the only right remaining under South African law – all other water use is authorized through schedules, general authorizations or limited-period licenses with various conditions attached. The Reserve for a water resource must be determined and taken into account before any water use can be considered for authorization.

The need for transitional policy and regulatory tools

It was recognized that implementation of the National Water Act (NWA: Act 36 of 1998) should be carried out in a "phased and progressive manner", and the legislation makes provision for this. Hence, as a transitional measure, there was a need to develop tools for determining the Reserve which could provide answers relatively quickly, in order to meet initial demands, until such time as high-confidence Reserve determinations could be carried out.

A multi-disciplinary project team was established by DWAF in July 1997 to develop methodologies for preliminary determinations of the ecological Reserve. The team was under considerable pressure due to the schedule for national implementation of the NWA and the need to have regulatory procedures in place before final promulgation of key chapters of the NWA in October 1999. The project is usually referred to as “the RDM project”, since its overall purpose was to develop methodologies for determination of Resource Directed Measures (RDM), which include classification, the Reserve and resource quality objectives.

DESIGN CRITERIA FOR METHODOLOGY DEVELOPMENT

Design specifications for preliminary RDM methodologies

At the outset of the RDM project, the design specifications for preliminary RDM methodologies were (DWAF, 1999a):

(a) that they be legally defensible, since they had to serve as a basis for issuing legally valid water use licenses;

(b) that they be scientifically defensible, and based on sound ecological principles in line with the integrated ecosystem approach to water resource management;

(c) that they match administrative requirements for water use licensing in terms of scale and resolution;

(d) that they provide conservative estimates of the water quantity and quality required to meet the ecological Reserve, in line with the protection policy;

(e) that there be options for reasonably rapid determinations in order to meet projected demands for NWA implementation in the transitional period.

Desired characteristics of RDM methodologies

The following characteristics of preliminary RDM methodologies emerged in early discussions within the project team (DWAF, 1999a).

(a) The methodologies for preliminary determination should be derived from available technologies and understanding in South Africa or for southern hemisphere ecosystems.

(b) The methodologies should utilize a holistic ecosystem endpoint.

(c) Methodologies should rely on expert judgement applied within a very structured and consistent process, which could be initiated and administered by non-specialist staff of the DWAF, utilizing expert input at given points.

(d) All assumptions made at any stage in development and application of the methodologies should be verified by a group of specialists, and all assumptions should be fully documented and justified.

(e) Independent review would be integrated into the methodologies, to ensure quality control and consistency in application as far as possible.

(f) The methodology should allow for ongoing refinement of procedures and tools, and for refinement in the Reserve determination to improve confidence should this be desired.

SCIENTIFIC BASIS FOR METHODOLOGY DEVELOPMENT

The Water Law Principles (DWAF, 1996b) provided clear guidance which was reflected in methodology development. Several key concepts were derived directly from the Principles themselves and profoundly influenced development. These are discussed below.

Protection of ecosystem function and health

The water policy rests on the idea that water resources can be managed as renewable resources, providing goods and services for the benefit of people, within certain limits. A key assumption following on from this is that the sustainable provision of ecosystem goods and services relies on maintenance of ecological health and function, and to a lesser degree on ecosystem structure. Hence the methodologies for RDM determination are primarily focused on identification and protection of ecosystem functions, rather than ecosystem structure.

Integrated management on an ecosystem basis

There is an explicit requirement, arising from the Principles, that we should aim for truly conjunctive, integrated management of water resources. This requirement led to the inclusion of several very important legal definitions in the NWA, one of which is that relating to "resource quality". Resource quality has four critical components, to cover each of the aspects of resource quality which are necessary for protection of aquatic ecosystem function and health, and is defined in the NWA as -

"(a) the quantity, pattern, timing, water level and assurance of instream flow;

(b) the water quality, including the physical, chemical and biological characteristics of the water;

(c) the characteristics and condition of the instream and riparian habitat, and

(d) the characteristics, condition and distribution of the aquatic biota."

The NWA makes provision for the setting of Resource Quality Objectives (RQO), which must address the four components listed above, and which can also include requirements for "the regulation or prohibition of instream or land-based activities which may affect the quantity of water in or quality of the water resource". This definition gives legal substance to what are in effect management objectives for a water resource.

Other key definitions are those related to delineation of water resources: a water resource can include several linked components, including surface water (flowing or standing, in rivers, lakes, wetlands, or impoundments), estuarine and aquifer components. A water resource is defined as including the bed and banks of a watercourse, and explicitly includes riparian and instream habitat (for which there are specific legal definitions encompassing both physical structure and associated vegetation). Atmospheric water was not included. However, its impact on the hydrological cycle, particularly in terms of water quality, requires that co-operative governance measures be established with the other relevant regulatory agencies.

These definitions strongly influenced the design of the RDM project. Firstly, it was recognized that the methodologies must allow integration across the various components of the hydrological cycle. Hence sub-project teams were established for river ecosystems, wetland ecosystems, estuarine ecosystems and the groundwater component. Secondly, within each water resource component the methodologies must address, wherever relevant and in an integrated manner, all four aspects of resource quality (water quantity, water quality, habitat and biota) in order to ensure protection of ecosystem function and health. Thirdly, because water resources must be managed on an integrated catchment basis, the methodologies for each water resource component must be matched in scale and resolution such that they allow us to take account of upstream-downstream dependencies and physical, chemical, hydrological and ecological processes which act at the interfaces between water resource components.

A risk-based approach

The need for caution, and the desire to prevent unintentional exceedance of the limits of sustainable utilization, are recognized as cornerstones of the policy of protection. The approach which has been adopted is that of setting limits on the basis of acceptable risk of causing irreversible damage to a water resource. The extent of the risk which we will accept is related to the value or importance which we place on a specific water resource. The value of a water resource may be related to its economic importance, its ecological importance, social/cultural importance or a combination of these. However, the particular level of risk should be accepted by all stakeholders, including impacters and water users, with a clear and common understanding of the possible long term consequences.

A national protection-based classification system is currently under development, within which water resources can be grouped into classes representing different levels of protection and risk. Overall, the assignment of a specific class to a water resource gives a clear message to both users and impacters regarding the social, economic and ecological value of that water resource.

A quantitative risk-based approach is technically quite sophisticated and probably not achievable yet in South Africa, due to lack of ecological data and lack of expertise (Jooste *et al*, 1999). However, the policy tools currently in development are designed on the basis of a qualitative risk-based approach, so that as knowledge and understanding grow, policy and regulatory tools can be developed which a true risk-based approach.

Habitat as the endpoint

As a water resource management agency, DWAF has the mandate and authority to manage water quantity through regulated flow releases and/or control of abstractions, and water quality through control of discharges and pollution impacts on water resources. Water resource managers typically require information on the Reserve and RQO in a format and at a scale and resolution which will enable them to answer the questions "How much water, when, at what assurance, and of what quality ?"

Water quantity and water quality are the primary drivers of the biophysical template for aquatic ecosystems, and determine to a large extent the characteristics and condition of the instream and riparian habitat, although it is recognized that other land-based impacts such as erosion, deposition and disturbance of riparian vegetation must also be addressed in order to fully protect aquatic ecosystems. Hence habitat, at the river reach scale, is generally an appropriate endpoint for water resource management purposes. Three components of habitat must be considered in ensuring protection of the function and health of aquatic ecosystems:

(a) Hydraulic habitat, the key parameters of which are flow velocity, depth and wetted perimeter;

(b) Physico-chemical habitat, the key parameters of which are the typical water quality aspects such as inorganic constituents, nutrients, toxic substances;

(c) Geomorphological habitat, the key parameters of which are habitat types, substrate characteristics and vegetation types.

Identification of the interlinkages between habitat components and of the processes which act across the interfaces between water resource components has proved to be especially important in methodology development. Ensuring a common working language and a toolbox of technologies which are matched in spatial and temporal resolutions is the immediate challenge of the future for aquatic scientists in South Africa. However, it is becoming clear that the most important link between hydrological and ecological processes is through hydraulics: the emerging discipline of “eco-hydraulics” provides us with the key to translate ecological requirements (habitat extent, type, character and distribution) into the currencies of water resource management (how much water, when, of what quality), and vice versa.

Ecoregions as integrating units

The use of the concept of ecoregions has been of great assistance in promoting understanding and integration between different disciplines, and in moving towards matching of scale and resolution. Ecoregions within a catchment, which include geohydrological response units, can each belong to a specific "ecoregional type" or geohydrological response type, determined by a combination of major physiographic factors; geological, geomorphological and geochemical factors; regional natural hydrological characteristics; major natural vegetation types; biotic factors, including the natural occurrence of certain kinds of organisms such as fish, invertebrates, plants and algae.

Knowing the ecoregional type of a unit allows us to make some predictions about what kind of ecosystem could be expected to occur in that unit under natural or unimpacted conditions. That knowledge is then used to guide expert judgement regarding what the appropriate site-specific numerical water quantity and quality requirements might be for achieving different levels of protection of that particular water resource. (DWAF, 1999a; DWAF, 1999b)

DIFFERENT LEVELS OF METHODOLOGY

The RDM team designed a generic methodology, within which four different levels of RDM determination tools (desktop, rapid, intermediate and comprehensive) fit (see Table 1). Detailed discussion of each step in the methodology can be found in the relevant manuals (DWAF, 1999a). These various levels of tools are in different stages of development and testing. Both the desktop and rapid methods are likely to have a relatively short lifespan, since desktop and rapid determinations will progressively be replaced by higher-confidence intermediate and comprehensive determinations.

APPLICATION OF RDM IN WATER RESOURCE MANAGEMENT

The NWA provides for an integrated, adaptive process of water resource management. The various provisions of the core chapters of the NWA are arranged according to a fairly logical business process (MacKay, 2000), within which the Reserve and RQO provide crucial support to regulatory decision-making.

In many cases in South Africa, water resources are already stressed or over-allocated. We are likely to find that, once the Reserve has been determined, it has already been allocated for existing lawful water use under the previous water legislation, or else the water resource is so impacted from other sources that the Reserve can not immediately be met. The situation needs to be turned around, but this may take time. The Reserve and RQO can provide agreed, enforceable goals against which management of a water resource can be judged. A key aspect of water resource management is to establish not only what the target is (i.e. set the Reserve and resource quality objectives), but to develop a plan of action for reaching the target. The plan needs to set out strategies, time frames and responsibilities. The legal tool provided in the NWA for doing this is the Catchment Management Strategy, which provides a framework, agreed between stakeholders and agencies, for moving towards the desired balance between protection of the water resource and utilisation of the services provided by the water resource.

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Table 1: Various levels of determination of water quantity and quality requirements of aquatic ecosystems

Level	Characteristics & effort required	Basis for methodology	Output	Use
Desktop estimate	Very low confidence, about 2 hours per water resource	Regionalized hydrological method, based on previous determinations of ecological flow requirements	Proportion of MAR required under normal and drought conditions per quaternary catchment, distributed monthly according to regional seasonal patterns.	For planning purposes only.
Rapid determination	Low confidence; desktop + quick field assessment of present status, takes about 2 days	Hydrological method as for desktop estimate; water quality requirements set according to DWAF (1996a)	Proportion of MAR required under normal and drought conditions per quaternary catchment, distributed monthly according to regional seasonal patterns; target water quality ranges for selected variables.	Individual licensing for small impacts in unstressed catchments of low importance & sensitivity; compulsory licensing “holding action”
Intermediate determination	Medium confidence, specialist field studies, takes about 2 months	Hydraulic calibration method used to link habitat availability to site-specific hydrology; available data used to set site-specific water quality requirements according to DWAF (1996a)	Monthly average discharge at specified control sites within each ecoregion, for normal and drought conditions; peak flows and timing of freshes and floods; target water quality ranges for selected variables in each ecoregion.	Individual licensing for small to medium impacts in relatively unstressed catchments, of low to medium importance and sensitivity.
Comprehensive determination	Relatively high confidence, extensive field data collection by specialists, takes 8-12 months	Hydraulic calibration method used to link habitat availability to site-specific hydrology; available and new data used to set site-specific water quality requirements according to DWAF (1996a)	Monthly average discharge at specified control sites within each ecoregion, for normal and drought conditions; peak flows and timing of freshes and floods; target water quality ranges for selected variables in each ecoregion	All compulsory licensing. In individual licensing, used for large impacts in any catchment. Small or large impacts in very important and/or sensitive catchments.
Flow management plan	Acknowledges present operating constraints (mostly structural) on a river.	Modified operating rules are drawn up between the management agency and RDM study team, which will result in a more environmentally friendly flow regime, as far as possible.	Monthly to daily resolution of flows required at specific control sites under normal, drought and flood conditions; target water quality ranges for selected variables at control sites	For use in highly regulated systems where present flow control structures do not have outlets from which releases can be made to provide for the water quantity component of the Reserve.

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