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Regional water resource assessments in the SADC region

DENIS HUGHES
Institute for Water Research, Rhodes University, Grahamstown 6140, South Africa
e-mail: denis@iwr.ru.ac.za

ANDRE GÖRGENS
Ninham Shand Inc., PO Box 1347, Cape Town 8000, South Africa

BRIAN MIDDLETON
SRK, PO Box 55291, Northlands 2116, South Africa

BRIAN HOLLINGWORTH
Development Bank of Southern Africa, PO Box 1234, Halfway House, South Africa

Abstract The paper outlines a proposed study to assess the available water resources of the South African Development Community (SADC) region in a unified way. This is considered essential given the increasing need for integrated (across national boundaries and economic sectors) management of the regions water resources. The proposed assessment is based on the regionalization of rainfall–runoff model parameters (over about 10 000 sub-basins at scales of 100–2500 km^2) and modern database storage and retrieval methods and is expected to have a large capacity building component. While the project is ambitious, given the existing capacity within the region, the long-term benefits are considered to be more than worthwhile the effort.

Key words South African Development Community (SADC); rainfall–runoff modelling; databases; capacity building

INTRODUCTION

During 2000, the authors compiled a "terms of reference" document (WRC, 2001) that outlines the need for, and a possible structure of, a long-term study to quantify the surface water resources of the South African Development Community (SADC) region in southern Africa. The compilation of this document was funded by the Water Research Commission of South Africa as a contribution to the elaboration of the SADC Water Sector's PCN (Project Concept Note) 14. While the formal motivation for the compilation of the report was linked to PCN 14, the southern African FRIEND programme had also identified the need for a more unified approach to quantifying the available water resources of the region.

The overall aim of the long-term study is to improve the ability of the SADC member states to make water resource assessments that support environmentally sustainable development, through broad strategic water resource planning that is based on information and approaches that are reliable and mutually accepted within the region.

This aim would be supported by four main objectives:

(a) to generate monthly time series of naturalized streamflows at sub-basin spatial scales of 100 to 2500 km^2 (depending on information availability and intensity of water resource usage), as well as at major river and basin scales,

(b) to develop and distribute databases of streamflow and associated information (e.g. spatial data, rainfall and evaporation time series data, water use),

(c) to develop and distribute tools for applying the database information, and

(d) to build capacity within the SADC water resources community to make use of the developed information and tools.

This paper is designed to provide the background to and outline some of the structure of the proposed study, as well as illustrating how the study could provide an ideal vehicle for research results, from within the region and elsewhere, to be made more accessible to SADC water resource managers.

PERCEIVED NEED FOR THE STUDY

There have been a number of water resource assessments of the type proposed, but they have not usually been undertaken within a regional framework and therefore have rarely contributed to a common understanding between Member States. Such a common understanding would contribute to the implementation of the SADC Protocol on Shared Watercourse Systems, through an improved ability to reach agreements on the use of shared resources and the equitable apportionment of water between states or economic sectors. Many of the previous studies have been based on the use of rainfall–runoff models, while others have concentrated on the regionalization of indices of streamflow behaviour (indices of low flow, for example). Many of the modelling studies have been undertaken by consultants based outside the region and the technical capacity to update or expand the study to other areas has frequently not remained within the region. Some of the more regionally widespread studies have been based on a spatial resolution that is too course and not sufficiently flexible enough to satisfy future requirements.

Previous studies have nevertheless made significant contributions that can be incorporated into a future project. Some previous work has addressed problems with the application of models in the region (SMEC, 1991; De Bruine *et al.*, 1993; Hughes, 1995, 1997; Hughes & Metzler; 1998), while other studies have focused on the quantification of hydrological processes at the sub-regional scale (Mandeville & Batchelor, 1990; Görgens & Lee, 1992; Kafundi & Laisi, 1991; Andrews & Bullock, 1994). There have also been other regional studies at different spatial scales (Drayton *et al.*, 1980; Meigh *et al.*, 1998, 1999). The approach of Meigh *et al.* (1998, 1999), for example, has the potential to complement the proposed long-term study in that the information requirements for the regionalization of model parameter values will be very similar to those used for the previous grid-based approach. There are also many other documented experiences from sources that are less accessible than journals and published reports, but which can contribute to the objectives of the long-term study. Examples include the extensive hydrological modelling work carried out for the Lesotho Highlands Development Project, numerous basin study reports undertaken within the hydrological modelling study of the Limpopo River main stem for the national water agencies of Botswana, Mozambique, South Africa and Zimbabwe and the ongoing work that forms part of the Zambezi River Action Plan.

Within South Africa (and including Lesotho and Swaziland), the WR90 databases (Midgley *et al.*, 1994) have proved to be of enormous value for broad strategic water resource planning. They have also provided the default surface hydrology database for more detailed studies, including assessments of currently utilized or available water, instream flow requirements and others. While the WR90 type of approach can provide a broad template for the design of a SADC-wide water resources assessment, there are a number of other issues that will have to be addressed in the detailed design of the project structure:

(a) there are data availability, hydrological modelling and water resource problems in the other member states that are not found in South Africa,
(b) there have been recent advances in data (both spatial and time series) storage, retrieval, display and analysis software approaches that have the potential to greatly enhance the outputs from such a study (e.g. Hughes, 2002), and
(c) there are other parameter regionalization techniques (not used within WR90) that have been successful in other studies (Meigh *et al.*, 1998, 1999).

PROJECT MANAGEMENT AND STRUCTURE

While one of the most important aspects of a study with such a wide regional scope is the design of the project governance structures and the links between existing regional protocols (SADC Water Sector Coordination Unit), funding agencies and the project team, this paper will concentrate on the management of the technical implementation. The following realities of the SADC region were recognized in the project design:

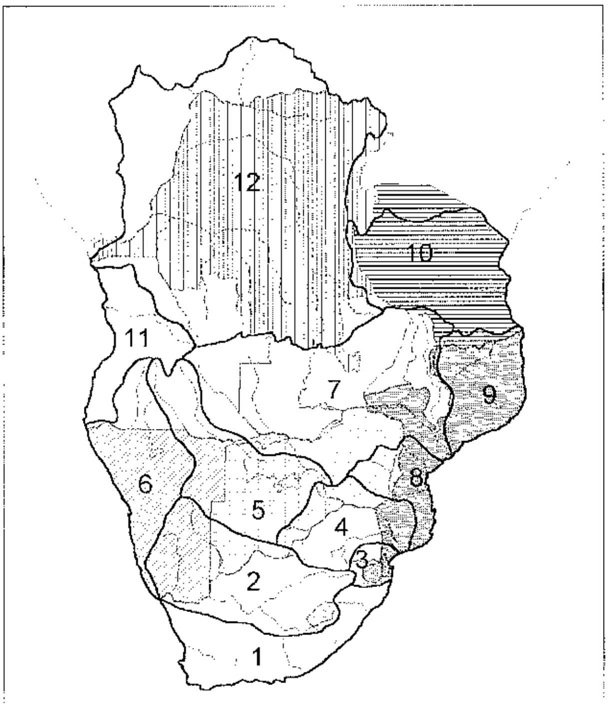
(a) the SADC region is made up of 14 independent countries,
(b) within the region there are local river basins (wholly within one Member State) as well as a number of large basins that are shared by two or more Member States,
(c) the water resources data collection, storage and management approaches differ between Member States, and
(d) there is limited existing capacity in some member states to contribute to such a study.

The proposed technical implementation of the project is based on an assumed duration of between 8 and 10 years and three main management components:

(a) A **Study-Wide Management Team** (SWMT) that will be responsible for the overall management of the project and reporting to the Implementing Agent, as well as any common activities such as software development, model selection and development, database design, coordination and supervision of model calibration and parameter regionalization, as well as the organization of training courses and capacity building activities.
(b) **Country Study Teams** (CST), responsible for the collection and initial processing of the data (time series and spatial) and for preparing and converting to a common format the information available within individual countries, for use by the Basin Study Teams. The CSTs will vary in both size and period of operation, depending on the size of the data collection task in each country, will be expected to have a

high level of local content and be based in, or strongly allied to, the national water agencies. Expertise may be seconded from outside organizations to assist in the development of capacity.

(c) **Basin Study Teams** (BSTs), responsible for the rainfall–runoff model calibrations, parameter regionalization, streamflow simulations and naturalization. The region will be divided up into approximately 15 major basins (or basin groups) in a way similar to Fig. 1 and, as with the CSTs, are expected to vary in size and period of operation depending on the scope of the modelling task for each basin. Local staff content will be a requirement for the BSTs, to encourage regional cooperation and develop capacity in the use of analysis and modelling methods.



KEY
1. Atlantic and Indian Ocean southern seaboard rivers (South Africa).
2. Orange River (Lesotho, South Africa, Botswana, Namibia).
3. Incomati, Umbeluzi and Maputo (South Africa, Swaziland, Mozambique).
4. Limpopo (Botswana, South Africa, Zimbabwe, Mozambique).
5. Okavango and Botswana rivers (Angola, Namibia, Zimbabwe, Botswana).
6. Cunene, Cuvelai and Namibian Atlantic rivers (Angola, Namibia).
7. Zambezi (Angola, Namibia, Zimbabwe, Zambia, Malawi, Tanzania, Mozambique).
8. Pungué, Buzi and Save (Zimbabwe, Mozambique).
9. Rovuma and northern Mozambique rivers (Tanzania, Malawi, Mozambique).
10. Tanzanian rivers (Tanzania).
11. Angolan rivers (Angola).
12. Congo basin (Angola, DRC, Zambia and non-SADC states).
13. Island rivers (Mauritius and Seychelles—not included on the map)

Fig. 1 South African Development Community region indicating member states (the shaded areas and excluding island members, Mauritius and Seychelles) and the identified basins.

Specific attention was given to some of the project activities in the Terms of Reference Document (WRC, 2001) where it was considered that more detailed recommendations on the direction that the project should follow were warranted. They can be divided up into four main categories: database design, rainfall–runoff model selection and application; development of application tools and capacity building.

Database design

The critical issues to address include ease of use, portability, efficiency of access and flexibility. It is essential that the spatial and time series data are integrated into a single system and the recommended approach is linking spatial databases (e.g. Arc/View Shape Files) with other database tables (e.g. Access, Paradox), where the time series data are stored as a single field (using BLOBs—binary large objects). Systems developed using Map Objects within either Delphi or Visual Basic programs offer a high degree of flexibility, straightforward links to existing spatial coverages and relatively low costs of distribution to a wide range of users. It will be necessary to consult with the national water agencies to ensure that their requirements are incorporated and that import and export routines are developed that cover the various raw data formats used.

Rainfall–runoff modelling issues

The model selected has to be suitable for simulating the range of basin responses expected in the region and related to differences in climate, topography, geology, soils and vegetation. The model should be able to operate in a semi-distributed (sub-area) format and include facilities to account for the types of modification to natural hydrological regimes that are found within the region (a variety of land-use changes, small and large dam impacts, direct run-of-river abstractions and return flows). It is envisaged that a limited amount of model development or improvement of an existing model will be necessary. The Pitman monthly model (Pitman, 1973) is considered to be suitable and there already exists an extensive experience base in the use of this model in southern Africa (Hughes, 1997). Several modifications should be considered to ensure that the model is able to address the requirements of the project. For example:

(a) A more flexible approach to the distribution of rainfall within the primary modelling period of 1 month to cater for differences between high rainfalls in semiarid zones (which typically occur over a few days), as well as in humid tropical zones (where rainfall is usually more evenly distributed over the month).
(b) A more explicit approach to groundwater recharge, storage and baseflow generation that will permit improved links to groundwater resource management.
(c) An improvement in the approach to channel transmission losses, which is an important issue in semiarid basins, large rivers and rivers with substantial alluvial beds and flood plains.
(d) Improvements related to modelling semiarid basin processes, such as allowing for non-seasonal dynamic vegetation cover responses, as well as non-symmetrical distribution of basin absorption rates.

The calibration and validation of the rainfall–runoff model involves the preparation of model inputs (basin rainfall, evaporation, land/water use, urban areas, streamflow, lakes, dams, wetlands and main stem losses) and the determination of parameter values for basins where adequate calibration data exist. Given that a degree of parameter interdependence is common to all hydrological models, it is possible to achieve similar outputs through different parameter sets and single optimum calibration solutions are generally not possible. Whether manual or constrained automatic calibration is used, to avoid inconsistencies it will be necessary to establish broad calibration guidelines with a limited data set drawn from the whole region before the remaining areas are dealt with by the BSTs. The guidelines may take the form of relatively simple qualitative statements, or could be quantitative parameter constraint ranges to use during automatic calibration.

There are two possible (and not necessarily mutually exclusive) approaches to parameter regionalization. The first is the more subjective approach of seeking similarity patterns associated with spatially variable basin characteristics (e.g. climate, topography, vegetation, geology, soils) that are expected to influence parameter values. This is more or less equivalent to defining hydrologically similar regions and assigning parameter sets to those regions (the procedure used in WR90). The second is a more quantitative approach of using multiple regression analyses of basin and climate characteristics to predict model parameters.

Development of application tools

These will include database access tools, modelling and data analysis tools, data visualization tools (time series and spatial data), and will provide the member states with a wide range of facilities for making water resource estimations at a variety of spatial scales. These tools should include:

(a) Data import and export facilities that allow transfers of time series data to and from the range of raw data formats used within SADC.
(b) Data display (tabular and graphical), editing and infilling facilities.
(c) Modelling facilities for assessing, for example, a variety of development scenarios.
(d) Data analysis facilities covering a wide range of options appropriate to monthly time series data that are typically used within the region (e.g. deficient flow duration–frequency analysis, reservoir yield analysis, impacts of streamflow reduction activities).

Training and capacity building

A complete section in WRC (2001) is devoted to this important topic and two main focus areas have been identified. The first is capacity building during the long-term study, which is expected to involve a range of possible options that can be followed. These may include on-site training of individuals (at their place of work), internships with project contractors to facilitate training and technology transfer and more formal courses for larger groups. The second focus area involves developing training manuals and courses in the use of the products of the study to ensure their rapid and effective transfer throughout the region.

CONCLUSIONS

The initiation of a project of this scope in a region where the lack of capacity has already been recognized by both the FRIEND programme and the SADC Water Sector Coordination Unit is clearly an ambitious task. However, the potential benefits are so great that the effort involved must be justified. Much of the research effort that is required for the proposed project to succeed has already been undertaken and merely needs to be consolidated and placed within a regional context. The difficult part of the project will be the coordination of group effort, involving many organizations from within the region, as well as others outside the region who have experience of the water resource issues of SADC.

The project is designed to make the most effective use of the existing capacity within the region (e.g. in national water agencies, universities, consulting companies), as well as developing further capacity. It is also designed to ensure that the results of the project are disseminated for use as quickly and as realistically possible. It is envisaged that there will be a number of secondary benefits associated with the project, ranging from improved ability to determine the environmental flow requirements of rivers, groundwater resources and drought susceptibility, to the identification of future hydrometeorological gauging network improvements. The existence of a regionally integrated, readily accessible water resource database and the associated analysis tools has relatively obvious direct benefits, but should also provide a "springboard" for further work where additional value is added to the information. Despite the limitations of the original WR90 database in South Africa (Midgley, 1994), this has certainly proven to be the case.

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