South African research in the hydrological sciences: 2003–2006

D.A. Hughes*

The principal activities of South African researchers in hydrology and water resources during the reporting period have been concerned with ground- and surface-water interactions, rainfall–runoff modelling, the establishment of improved regional water resource databases, the ecological Reserve, and investigating the likely consequences of climate change. Most of these studies have a strong emphasis on supporting the provisions of the National Water Act of 1998. Research programmes are benefiting from international and regional cooperation. In contrast, the lack of young scientists entering the field poses the greatest threat to hydrological research in South Africa.

Introduction

In hydrological and water resources research, there remains a strong emphasis on supporting the National Water Act (NWA) of 1998 and the implementation of the water resource management strategy for South Africa. Part of this research is focused on addressing previous imbalances in access to clean water, while work is also being undertaken on establishing improved institutional management systems at different levels (from communities through to national agencies). Figure 1 illustrates the balance of research funding, using information presented on new projects started during 2005, in the annual report for 2005/6 of the Water Research Commission (WRC), the main funding body supporting water resource and hydrological research in South Africa. This can be compared with a similar diagram presented in ref. 1 that covered the distribution of funding in 1981, 1991 and 2000. Water resource assessment as well as water supply and treatment technology clearly remain high priority areas. The water resource assessment category is equivalent to the combination of the previous groundwater, hydroclimatology and catchment hydrology groups, which enjoyed over 40% of the funding in the year 2000. It is noteworthy that the funding for projects focused on water use for poverty alleviation (and wealth creation) ranks third overall, while these were not represented at all in the earlier report.[1]

While the ongoing diversification of water-related research in South Africa has meant that more institutions are supported by research funding, most research in mainstream hydrology is still undertaken at a few university departments and by civil engineering consultancies. Unfortunately, it appears that there is a decreasing number of young hydrology scientists joining the established community. This is of great concern for the future sustainability of water research in South Africa. This observation was also made during the previous IUGG reporting cycle (1999–2003)[1] and it is clear that this issue has yet to be satisfactorily addressed.

A further indication of the type of research being undertaken in South Africa can be gained from the papers presented at the biennial SANCIAHS National Hydrology Symposia. The 2005 meeting attracted a wide mix of papers that covered studies of hydrological processes, model development and application in both hydrology and water resources, remote-sensing applications in hydrology, water quality, climate change issues, as well as water management and policy. There was a reasonable balance between development research and the application of hydrological and water resource analysis techniques in practice. This suggests that the current state of hydrological research in South Africa is healthy and that the long tradition of applied research is continuing.

The following sections highlight some of the research directions that have been dominant in the hydrological sciences in South Africa during the period 2003–2006, while the list of references includes some recent papers in international journals, the 2005 SANCIAHS conference and WRC scientific reports. Further information about past, current and future research programmes supported by the WRC can be found on its website (www.wrc.org.za), which also includes lists of publications.

Hydrology and the ecological Reserve

The ecological Reserve is the South African terminology for the water quantity and quality requirements of aquatic ecosystems (rivers, wetlands, ground water and estuaries) that are 'reserved' under the NWA for the purpose of sustaining the environment in a predetermined condition. Much research in the past has contributed to the refinement of the methods that are used to quantify these requirements. During the reporting period, major contributions were made to the methods of assessment for groundwater systems,[37] hydraulics issues related to Reserve determinations,[3] water quality methods[4] and scenario-based methods.[5] Many of the existing methods of assessment and data analysis have been incorporated into an integrated package based on spatial data visualization and database management tools.[6,7]

New WRC projects started during the reporting period and yet to be finalized include assessments of wetland integrity, devel-

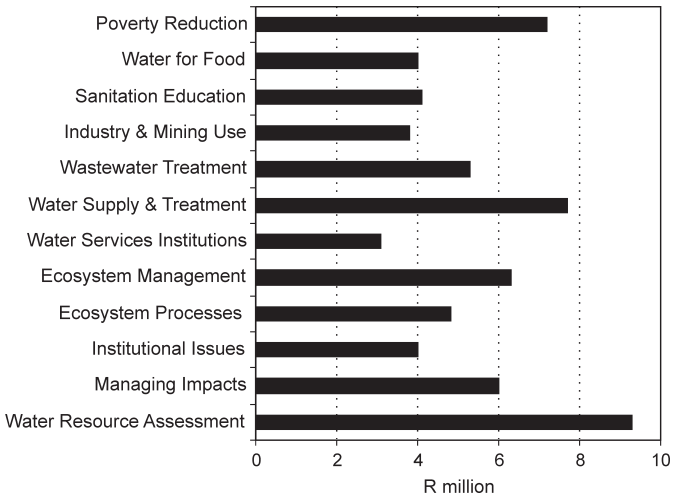

Fig. 1. Water Research Commission funding according to project topics identified in the WRC's annual report for 2005/6.

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

opment of real-time Reserve implementation methods,[8] and environmental water requirements of ephemeral river systems.[9,10] There are further initiatives supported by the Department of Water Affairs and Forestry (DWAF) that are designed to improve the application of existing methods and enhance the capacity of water managers to implement the provisions of the NWA.

Interactions between ground and surface water

The previous IUGG report[1] referred to the divide that has existed between the two disciplines of ground- and surface-water hydrology. With the emphasis on integrated water resource management, there has been some progress in bringing the two disciplines together.[11] As part of the development of the widely used Pitman monthly model, Hughes[12] incorporated some simple groundwater routines that allow the interactions between surface and ground water to be simulated at the catchment scale. While not designed as a substitute for more complex groundwater investigation tools, the changes have proved useful, particularly with respect to assessing groundwater contributions to streamflow.

Similar algorithms have been built into a commonly used model of water resource systems, so that yields from both sources can be simulated in an integrated manner. One of the critical issues in any model involving ground water is the accurate estimation of recharge and its variability.[2] Meyer[13] analysed the limited data on groundwater level available in the country and related it to patterns of rainfall variation.

Process studies in selected catchments contribute a great deal to our understanding of the interactions between surface and ground water, while isotopic tracer studies[14,15] appear to have much potential but have not been used extensively in South Africa.

Many rural areas of South Africa rely on groundwater supplies for domestic water and small-scale irrigation. At the same time the occurrence of ground water in the fractured rock systems of the country is frequently complex and difficult to assess accurately. A project started in 2005 is designed to improve our understanding of the occurrence and dynamics of these aquifers.

Rainfall-runoff modelling

South Africa has a long history of developing and, more specifically, applying rainfall–runoff models for estimating water resources. Both hydrological (rainfall-runoff) and water resource system models are frequently used for planning and managing operations. While there have been recent developments in the structures of some models used in South Africa, a greater emphasis has been placed on the practical application of the models, through the development of user-friendly and data-efficient interfaces, and the use of the models in ungauged situations (parameter estimation and regionalization of parameter sets). One current WRC project (referred to as WR2005[16]) involves updating the national surface-water database through the use of a revised version of the Pitman monthly model and the generation of natural, simulated time series for all 1946 so-called quaternary catchments. The project will provide a GIS and database interface to the raw data, as well as facilities to run the model for any future development scenario. Another project is designed to develop a hydrological decision support framework,[17] based on the SPATSIM modelling system[6] but incorporating new database design, the ACRU daily hydrological model, and the principles of OpenMI to facilitate the linking of models or sub-models.

Additional modelling research, often through postgraduate student projects, involves improvement of model sub-components,[18] estimating regional parameters, the identification and reduction of uncertainty in simulation results, and the application of models for the assessment of future water availability.[19]

Design rainfall and flood estimation

Flood estimation methods are widely used in South Africa for structural design purposes. Until recently there have been few changes in the methods that were developed during the 1970s and 1980s. Recent research, directed at improving flood estimation techniques, include new approaches to estimating extreme rainfall,[20] the use of continuous simulation models[21] and revisions to existing flood estimation methods.[22] Other work on the use of radar data for space-time analysis of rainfall is continuing.[23]

Land-use impacts on hydrology and evapotranspiration research

The assessment of the impact of various land-use practices on streamflow remains a focus area in hydrological research. Some of this research overlaps with the rainfall-runoff modelling theme, and the ACRU daily model has been used to regionalize the influence of different types of afforestation on streamflow, with a special emphasis on low flows.[24] Additional research is being undertaken on the effects of riparian vegetation management on water resources, as well as the impacts of commercial crops.[25] One of the critical issues associated with understanding the effects of changing land use on hydrology, is the effect on evapotranspiration loss dynamics. There are several active research projects designed to improve our understanding of the consumptive use of water by vegetation. Some of these involve field observations and monitoring networks,[36] while others focus on improving estimation techniques.

Satellite applications in hydrology

The estimation of soil moisture and rainfall data using satellite-derived information, although frequently used internationally, has not been much applied in southern Africa. Through international cooperation a project has been launched on the use of remote sensing to estimate soil moisture for various hydrological applications.[26] Recent research has also focused on the use of rainfall data from satellites[27,28] in hydrological models in view of declining ground-based observation networks.

Climate change research

No report on hydrological research would be complete without some mention of South African contributions to assessments of the impact of global climate change. Apart from climatology research on regional climate atmospheric models,[29] the WRC is supporting several projects on predicting the influence on water resources and secondary effects (water quality, such as nutrient recycling and temperature), as well as using a knowledge of climate variability to support water resource management. Some of these research programmes overlap with themes already referred to above, such as rainfall-runoff modelling.[19]

The topic of climate change, its causes and effects, is not without controversy, as in many other parts of the world. Some contributions have challenged the conventional approach to using global and regional climate models and have offered alternatives.[30,31] The scientific merits of these alternatives have been challenged.[32] The important issue from a hydrological and water resource estimation perspective is that many uncertainties associated with estimates of future patterns of rainfall and evapora-

tive loss (as well as effects on vegetation cover and land use) remain. There is a need to reduce these uncertainties so that predictions of future climate patterns can be used with confidence by hydrological scientists to make more reliable predictions of water availability that can subsequently be used by water resource managers.

Conferences and symposia

The first of the biennial national hydrology symposia was held in 1983 in Pretoria and published as a technical report by the Department of Environment Affairs.[33] These meetings remain one of the main local avenues for the dissemination of research results from the hydrological science community of South Africa. They represent ideal forums for the exchange of ideas and are especially valuable for younger scientists presenting the results of postgraduate research projects. The 12th National Hydrology Symposium was held at the Eskom Convention Centre, Midrand, Gauteng, in September 2005. The conference was well supported by researchers, as well as water resource practitioners from government departments and private consultancies. The 13th symposium was held in Cape Town in September 2007. Whereas the proceedings of earlier symposia were always published in hardcopy format, it has become normal practice to reduce costs and pre-publish full papers on CD.

Other important events on the local calendar are the annual WARFSA (Water Research Fund for Southern Africa) and SASAQS (South African Society of Aquatic Scientists) conferences. The former allows South African hydrologists to interact with their regional counterparts, while the latter provides opportunities for strengthening links with other aquatic scientists, whose focus is frequently on the biotic rather than the abiotic aspects of water resources. The Water Institute of South Africa (www.wisa.org.za/Home/Home) also regularly organizes conferences that are of potential interest to hydrologists, especially those who are working in areas that have strong links to practical management issues.

International and regional cooperation

Apart from links between organizations in South Africa and others throughout the world, South African hydrological scientists are actively engaged in various international research programmes including IAHS PUB (Prediction in Ungauged Basins: www.pub.iwmi.org) and the UNESCO HELP (Hydrology for the Environment, Life and Policy: www.unesco.org/water/ihp/help) and FRIEND (Flow Regimes from International Experimental and Network Data) initiatives. The Department of Water Affairs and Forestry was the main local organizer of an international HELP conference, held in Johannesburg in November 2006. Southern Africa FRIEND (www.ru.ac.za/institutes/iwr/friend/links) is a collaborative programme involving all Southern African Development Community (SADC) countries and a contribution to the UNESCO IHP international FRIEND programme. Despite good progress during the first and second phases,[34] it has subsequently been extremely difficult to identify sources of project funding and the programme has been relatively inactive. At the International FRIEND conference in Cuba during December 2006, a decision was taken to attempt to revive the activities of SA FRIEND and to focus attention on building research capacity through postgraduate studies. Several groups within South Africa are part of WaterNet, a regional network of university departments and research and training institutes specializing in water (www.waternetonline.ihe.nl).

Trans-boundary water issues will always be a major concern in southern Africa, where many rivers cross international boundaries.[35] While many of the issues lie within the realm of hydropolitics, it is important that there is consensus within the region on appropriate methods of estimating hydrological and water resource availability. This is an area where regional research cooperation (through PUB, HELP, FRIEND, WaterNET and others) can play a major role.

Conclusions

This report illustrates that hydrological research in South Africa continues to make significant contributions to the international body of knowledge, as well as to the solution of real problems in water resource management within the region. The availability of research funding and the decreasing number of young scientists entering the field are concerns that need to be addressed in the immediate future. It is inevitable, given the development needs of post-apartheid South Africa, that water resources-related research funding should be spread across many more fields than in the past and that this diversification would benefit research associated with social and economic upliftment. However, it is important that the solid base of research in hydrological science laid down over the last three to four decades is not eroded through a lack of funding. It is equally important that the present generation of experienced hydrological scientists encourage active participation in research by new members of the science community, so that there is no break in the continuity of expertise. The lack of younger scientists entering the field poses one of the greatest threats to the future of active hydrological research in the country.

1. Hughes D., Aston P., Görgens A., Jewitt G., Schulze R., Smithers J., Pegram G. and Dube R. (2003). South African research in the hydrological sciences: 1999–2002. *S. Afr. J. Sci.* **99**, 394–397.
2. Xu Y. and Beekman H.E. (Eds) (2003). Groundwater recharge estimation in Southern Africa. *IHP-VI Technical Documents in Hydrology*, No. 64, UNESCO, Paris.
3. Jordanova A.A., Birkhead A.L., James C.S. and Kleynhans C.J. (2004). *Hydraulics for determination of the ecological Reserve for rivers.* WRC Report No. 1174/1/04. Water Research Commission, Pretoria.
4. Palmer C.G., Scherman P-A., Muller W.J., Rossouw J.N., Malan H.L. and Jooste S. (2004). *Early development of water quality methods and approaches in ecological Reserve assessments.* WRC Report No. 1108/1/04. Water Research Commission, Pretoria.
5. King J.M., Brown C.A., Paxton B.R. and February R.J. (2004). *Development of DRIFT, a scenario-based methodology for environmental flow assessments.* WRC Report No. 1159/1/04. Water Research Commission, Pretoria.
6. Hughes D.A. (Ed.) (2004). *SPATSIM, an integrating framework for ecological Reserve determination and implementation.* WRC Report No. TT 245/04. Water Research Commission, Pretoria.
7. Hughes D.A. and Forsyth D.A. (2006). A generic database and spatial interface for the application of hydrological and water resource models. *Comp. Geosci.* **32**, 1389–1402.
8. Hughes D.A. (2004). Real time operation of environmental flows in South Africa. Poster and verbal presentation at the British Hydrological Society International Conference, Imperial College, London, July 2004.
9. Hughes D.A. (2005). Hydrological issues associated with the determination of environmental water requirements of ephemeral rivers. *River Res. Appl.* **21**(8), 899–908.
10. Roussouw L., Avenant M.F., Seaman M.T., King J.M., Barker C.H., du Preez P.J., Pelser A.J., Roos J.C., van Staden J.J., van Tonder G.J. and Watson M. (2005). *Environmental water requirements in non-perennial systems.* WRC Report 1414/1/05. Water Research Commission, Pretoria.
11. Parsons R.P. (2003). *Surface water–groundwater interaction in a South African context – a geohydrological perspective.* WRC Report TT 218/03. Water Research Commission, Pretoria.
12. Hughes D.A. (2004). Incorporating ground water recharge and discharge functions into an existing monthly rainfall-runoff model. *Hydrol. Sci. J.* **49**(2), 297–311.
13. Meyer R. (2005). *Analysis of groundwater level time series and the relation to rainfall and recharge.* WRC Report No. 1108/1/04. Water Research Commission, Pretoria.
14. Saayman I.C., Scott D.F., Prinsloo F.W., Moses G., Weaver J.M.C. and Talma S. (2003). *Evaluation of the application of natural isotopes in the identification of the domi-*

nant streamflow generation mechanisms in TMG catchments. WRC Report 1234/1/03. Water Research Commission, Pretoria.

15. Talma S. and Lorentz S. (2005). Isotopic composition of runoff in large catchments in southern Africa. Paper presented at the *12th South African National Hydrology Symposium,* Midrand, September 2005.
16. Bailey A.K. and Pitman W.V. (2005). The Water Resources 2005 Project (WR2005). Paper presented at the *12th South African National Hydrology Symposium,* Midrand, September 2005.
17. Clark D.J. and Smithers J.C. (2006). Hydrological decision support framework – initial design. *Water SA* **32**(4), 465–472.
18. Tewold M.H. and Smithers J.C. (2006). Flood routing in ungauged catchments using Muskingum methods. *Water SA* **32**(3), 379–388
19. Lumsden T.G. and Schulze R.E. (2005). Challenges associated with assessing the impacts of climate change on water resources in South Africa. Paper presented at the *12th South African National Hydrology Symposium*, Midrand, September 2005.
20. Smithers J.C. and Schulze R.E. (2004). The estimation of design rainfalls for South Africa using a regional scale invariant approach. *Water SA* **30**(4), 435–444.
21. Smithers J.C. and Chetty K.C. (2005). Design flood estimation using a continuous simulation modelling approach. Paper presented at the *12th South African National Hydrology Symposium*, Midrand, September 2005.
22. Parak M. and Pegram G.G.S (2006). The rational formula from the runhydrograph. *Water SA* **32**(2), 163–180.
23. Sinclair S. and Pegram G.G.S. (2005). Empirical mode decomposition in 2-D space and time: a tool for space-time rainfall analysis and nowcasting. Paper presented at the *12th South African National Hydrology Symposium,* Midrand, September 2005.
24. Blight J.J., Gush M.B., Le Maitre D. and Jewitt G.P.W. (2005). The impacts of afforestation on low flows: Paired catchments revisited. Paper presented at the *12th South African National Hydrology Symposium*, Midrand, September 2005.
25. Bezuidenhuot C.N., Lecler N.L., Gers C. and Lyne P.W.L. (2006). Regional based estimates of water use for commercial sugar-cane in South Africa. *Water SA* **32**(2), 219–222.
26. Nxumalo N.T. and Pegram G.G.S. (2005). Soil moisture from satellites. Paper presented at the *12th South African National Hydrology Symposium,* Midrand, September 2005.
27. Hughes D.A. (2006). Comparison of satellite rainfall data with observations from gauging station networks. *J. Hydrol.* **327**(3–4), 399–410.
28. Hughes D.A. (2006). An evaluation of the potential use of satellite rainfall data for input to water resource estimation models in southern Africa. In *Climate Variability and Change – Hydrological Impacts (*Proc. Fifth FRIEND World Conference held at Havana, Cuba, November 2006), *IAHS Publ.* 308, *75–80.*
29. Hewitson B.C. and Crane R.G. (2006). Consensus between GCM climate change projections with empirical downscaling: precipitation downscaling over South Africa. *Int. J. Climatol.* **26**, 1315–1337.
30. Alexander W.J.R. (2005). The development of a multi-year climate prediction model. *Water SA* **31**(2), 209–217.
31. Alexander W.J.R., Bailey F., Bredenkamp D.B., van der Merwe A. and Willemse N. (2007). Linkages between solar activity, climate predictability and water resource development. *J. S. Afr. Inst. Civil Eng.* **49**(2), 32–44.
32. Midgley G.F. and Underhill L.G. (2007). Is climate prediction model flawed? *The Water Wheel* **6**(2), 11–13.
33. Maaren H. (Ed.) (1983). *Proc. South African National Hydrological Symposium.* Department of Environment Affairs and Water Research Commission, Tech. Report No. TR 119, Pretoria.
34. Meigh J. and Fry M. (Eds) (2004). Southern Africa FRIEND Phase II 2000–2003. International Hydrological Programme, *IHP-VI Technical Documents in Hydrology,* No. 69, UNESCO, Paris.
35. Nkomo S and van der Zaag P. (2004) Equitable water allocation in a heavily committed international catchment area: the case of the Komati catchment. *Phys. Chem. Earth* **29**(15–18),1309–1317.
36. Savage M.J., Odhiambo G.O., Mengistu M.G., Everson C.S. and Jarmain C. (2005). Theory and practice of evaporation measurement, with special focus on surface layer scintillometry as an operational tool for the estimations of spatially-averaged evaporation. Paper presented at the *12th South African National Hydrology Symposium*, Midrand, September 2005.
37. Xu Y., Colvin C., van Tonder G.J., Hughes S., Le Maitre D., Zhang J., Mafanya T. and Braune E. (2003). *Towards the resource directed measures: groundwater component*. WRC Report No. 1090-2/1/03. Water Research Commission, Pretoria.