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Hydrological education and training needs in Sub-Saharan Africa: requirements, constraints and progress

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Abstract

This paper represents a perspective on the education and training needs related to hydrology and water resources science within the sub-Saharan Africa region and discusses the requirements of the region, some of the relatively recent developments and initiatives and some of the constraints that exist and remain difficult to surmount. The requirements include the development of academic research capacity and technical skill for both the private and public sector at a variety of levels. Some of the constraints that exist include a lack of adequate funding, lack of follow-up after short training courses, lack of institutional support to continue training, and competition for major water resources development projects from organizations outside the region. One of the main conclusions is that to sustain both educational and practical expertise in hydrology and water resources science within the region there is a need to build a "critical mass" of local expertise. Part of this could be achieved by increasing networking within the region and promoting the sharing of information, tools and expertise. There is also a need to promote institutional support.

1 Introduction

There have been a number of relatively recent publications that have questioned the way in which hydrologists are educated within the various educational institutions around the world (Nash et al., 1990; Salz, 1996; Wagener et al., 2007, 2010). Most of these publications refer to the diverse disciplinary backgrounds from which hydrologists originate, as well as the diversity of problems that need to be solved if hydrologists are to contribute to improved management of water resources. While hydrology is recognized by most as a geoscience, it has been dominated in the past by contributions from hydrologists who have a background in civil engineering (Muzik, 1996) and has been largely driven by the need to solve engineering problems. It is becoming increasingly evident that the demands on hydrologists are changing as they are

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required to understand the complexities of the global water system within an interdisciplinary framework (Wagener et al., 2007), but continue to develop their own discipline as a science (through improved conceptual understanding) and for applications in practice (through improved prediction methods). Some of the identified problems are related to diversity in the teaching and training material that is used and a lack of consistency that could be hindering the advance of hydrology as a science (Wagener et al., 2007). The dichotomy of the development of hydrology as a science and its practice, as either an applied science or an engineering sub-discipline, is also seen as limiting the application of research results in practice (Nash et al., 1990). Most of the background material that was used for these publications appears to have been derived from educational institutions in the developed world which generally have access to adequate resources in terms of educators (lecturers and post-graduate supervisors), text books and journals, as well as computer and laboratory facilities. Hence the focus is on the development of curricula, appropriate teaching material and instructor awareness of emerging trends in hydrological science. There are many educational facilities in the developing world where access to such facilities cannot be taken for granted and where there are additional challenges associated with creating an enabling environment for educating the future generation of hydrological researchers or practitioners.

There can be little doubt that the future economic and social development of sub-Saharan Africa relies to a large extent upon the sustainable management of the water resources of the sub-continent (Grey and Sadoff, 2002). Chapter 3 in the Africa Water Atlas (UNEP, 2010) refers to 9 "Water Challenges and Opportunities" which includes such issues as access to safe drinking water and sanitation, water for food security and managing water under potential threats related to global climate change. The final challenge referred to is "enhance capacity to address water challenges" and is premised on the lack of existing institutional, financial and human capacities for managing water. The chapter refers to the main constraints as an "insufficient knowledge base", no "effective research and technology base" and "weak institutional arrangements" for the "allocation and management of water".

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The author accepts that there are many challenges to developing the hydrological education and research base in Africa, but does not entirely agree with the UNEP (2010) report that there is no research or technology base. Recent personal experiences have also suggested that there is a large potential knowledge base that needs to be encouraged and better organized so that it can make a greater contribution to water management in the region and the science of hydrology internationally. The paper therefore attempts to look at some of the hydrological education and training requirements for sub-Saharan Africa (which will overlap with those from other parts of the world), together with the constraints and some recent progress that has been made. The main focus of the paper is on post-graduate education and training (the main experience base of the author), while it is recognized that undergraduate training needs cannot be ignored.

2 Hydrological issues in Sub-Saharan Africa

Many of the issues related to the approaches that can be used for hydrological analyses and water resources estimation in sub-Saharan Africa are different to some other parts of the world. This is largely because of the high variability in space and time that occurs across the region coupled with the general scarcity of hydrological observations and data (Hughes, 2006) and poorly quantified human impacts in terms of abstractions and land use change. Arguably, this is one of the areas of the world where the concepts of uncertainty analysis (Pappenberger and Beven, 2006) need to be fully embraced as part of both hydrological research (Hughes et al., 2010) and water resources management practice. A great deal of uncertainty has always existed in almost all of the hydrological estimates that have been used for designing water resource schemes, or making decisions about allocations for different users and for sustaining the natural ecological functioning of water bodies (rivers, wetlands, estuaries, etc.). However, there do not seem to be very many examples in the region where uncertainty concepts have been applied as part of research, and even fewer where decisions have been

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taken with uncertainty explicitly accounted for. The potential impacts of global change (Andersson, 2006; Lumsden et al., 2009) and the expanding population (together with the related water supply and food security concerns) of the region adds further impetus to the necessity of accounting for uncertainties in the future (Vörösmarty et al., 2000).

It is apparent therefore that the training requirements (see next section for further details) of the future generation of water scientists, engineers and decision makers, worldwide, should include the principles and methods of making uncertain hydrological estimates and how to deal with them in engineering design and water resources management decision making. This will almost certainly require a paradigm shift in the design of teaching, training and research methods and material. Wagener et al. (2010) summarise the key components of the required paradigm shift, but the question remains about how this can be achieved in poorly-resourced regions such as sub-Saharan Africa. These regions may have to rely initially on the development of the required approaches and materials from countries with greater research and educational experience and resources (e.g., Yadav et al., 2007). However, they will also have to be adapted to the local conditions and applied within the sub-Saharan Africa regional context (e.g., Kapangaziwiri et al., 2010).

3 Training requirements

The background to the training requirements in sub-Saharan Africa lies in the many water related problems that are experienced within the region coupled with a small (and shrinking) pool of qualified scientists and engineers and a relatively small academic community reliant upon a limited number of experienced staff. The first issue that needs to be considered is associated with aligning the training requirements with the needs of the region. There is no doubt that the sustainable management of water in sub-Saharan Africa requires multi- and interdisciplinary approaches that include specialist input from a number of natural sciences, engineering, economics and the social and political sciences. While it may be argued that one of the failings of the past

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has been the inability of single disciplines to come together in a truly multi-disciplinary manner, it should not be imagined that this can be achieved at the expense of adequate training in the individual disciplines. As noted by Metzger and Zare (1999) "strong interdisciplinary programs can only be built in circumstances in which strong disciplinary programs already exist. It makes no sense to sacrifice successful disciplinary efforts to appease perceived interdisciplinary needs".

From the perspective of the hydrological sciences, it is necessary to be quite clear in distinguishing between the training requirements of hydrologists (as scientists), water engineers and water resources managers (Kirshen et al., 2004). The author contends that there has been insufficient clarity in this distinction in the past and that the label "hydrologist" has been used too loosely and largely at the expense of hydrology as a science. This is not a situation that is unique to sub-Saharan Africa (Nash et al., 1990), but perhaps the impacts have been felt more strongly in this developing region because of the relatively small community of educators and practitioners. There is little doubt that the region needs expertise in all of the individual disciplines that contribute to integrated water resources management (IWRM). It is also desirable for the training to include the broader context of IWRM and the contribution that the individual disciplines can make to complex multi-disciplinary solutions.

A further issue related to training requirements is establishing a balance between academic and practical training, an issue that might also be referred to as the difference between a science-based approach versus a more engineering application approach. The emphasis in the region over the last few decades has almost certainly been on the engineering approach, partly because many of the students who have studied hydrology have been enrolled in engineering departments. More recently there has been a shift in some university departments toward a more science-based approach, but this has tended to occur within the South African universities where there are better resources. The region certainly requires expertise in the practical application of hydrological analysis methods and this may be considered to be justification for focusing on the engineering approach to training. However, there are two additional factors

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that have to be considered. The first is that without a sound scientific background to the various practical analysis methods (including hydrological models), users are at a disadvantage when it comes to their application in "difficult" situations, such as many of the completely ungauged catchments that exist throughout the region. Getting the right results for the right reasons (Kirchner, 2006) has often been neglected in practical hydrological modelling, partly because the right reasons are often not known in data scarce areas. A greater scientific, rather than mathematical, focus (Hughes, 2010) on modelling might go a long way towards solving these issues. The second is that if the training does not include the scientific basis for the methods it will always be difficult to create a new generation of researchers who can develop new and improved methods, as well as train the following generation of both scientists and engineers. Within South Africa this is already being experienced with relatively few young recruits to teaching and research groups within Universities and a rapidly aging cadre of experienced staff.

4 Existing resources

There are relatively few universities within southern Africa that offer either undergraduate or post-graduate training in hydrology and water resources science (Fig. 1). Many of these include hydrology as only a relatively small component of courses in other primary disciplines (e.g. civil engineering, geography or environmental science). As far as the author is aware there are only 3 universities where hydrology is taught at undergraduate level as a primary discipline and all of these are located within South Africa. At the MSc level there are a number of course-work degrees offered, but most of these are orientated towards water resources management and less towards the scientific aspects of hydrology, or more generally, water resources science. From a regional perspective, the courses offered through Waternet (http://www.waternetonline.ihe.nl – Love, 2011) are an excellent example of regional cooperation by many different institutions for the purposes of water resources management training, but may not fulfill the need for more science-based training.

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Some of the universities within the region offer opportunities for research-based MSc and PhD degree training, but are constrained by funding for student bursaries and a relatively small number of qualified and experienced project supervisors. Recent experiences suggest that the pool of potential post-graduate students is far greater than the existing capacity (in terms of financial and/or supervisory support). At the end of 2010 there was a call for applications for post-graduate opportunities in the SSAWRN (Sub-Saharan Africa Water Resources Network) project, a part of the Carnegie Foundation of New York funded RISE (Regional Initiative in Science Education) programme (http://sig.ias.edu/rise). This was the second phase of the project and the call was designed to add 10 more post-graduates to a group of 16 already supported by the first phase. A total of 120 applications were received and the vast majority of these were qualified to enter one of the four universities (Rhodes in South Africa, Makerere in Uganda, Okavango Research Institute in Botswana and Eduardo Mondlane in Mozambique – Fig. 1) that form part of SSAWRN. A more detailed examination of the backgrounds, educational qualifications and proposed research topics provided more evidence to support the contention that most of the training offered in the region is on water resources management, rather than water resources science. Very few of the students proposed projects that could be considered to be scientific development research and nearly all were related to the application of existing methods to solve specific water resources problems.

Apart from the university institutions that are currently recognized as having some resources and are therefore offering some form of post-graduate training, there are others where the potential exists, if some of the constraints can be over-come. Kyambogo University is situated in Kampala, Uganda (close to the better known and better resourced Makerere University – Fig. 1) and has an engineering department in which hydraulics, hydrology and water resources engineering forms part of the 3rd and 4th year curriculum. The 4th year students are required to do a project and out of the (approximately) 100 students, some 70 frequently express a desire to do a project in the field of water and sanitation. The main problem is that they lack basic equipment

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(computers and laboratories, etc.) as well as sufficient staff to support both the heavy lecturing load and student project supervision. It is therefore hardly surprising that the single permanent staff member in charge of water resources engineering is not able to develop his own research programme and generate the publications required to enhance his academic profile.

Kyambogo University is by no means a unique situation and there are other institutions that have substantial potential to develop their water engineering and water science departments if some of the capacity and resource constraints are overcome. The author has discussed similar issues with young academics who are working in, or soon to return to, the universities of Botswana, Malawi (Chancellor College) and the University of Kinshasa in the Democratic Republic of Congo (Fig. 1). These all represent existing resources that are not being used to their fullest advantage for the benefit of training hydrologists and water resource engineers and scientists.

There is little doubt that many of the resources available for post-graduate training are currently funded, and were partly initiated, from outside the region. Reference has already been made to the Waternet and RISE, SSAWRN programmes, while further examples that are contributing to the development of post-graduates are CLIVET (Impacts of climate change on water resources and agriculture and adaptation strategies in Tanzania – http://www.geus.dk/program-areas/common/int_tz03-dk.html) and NUFU (through the "Capacity building in water sciences for improved assessment and management of water resources" programme – http://espresso.siu.no/projects/?wicket:interface=:2:1:::). South Africa is probably the main exception to the dominance of foreign funded students. While there are some foreign funded South African students, many more are funded through the National Research Foundation (NRF) or research projects supported by the Water Research Commission (WRC).

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5 Main constraints

The majority of the constraints to the further development of training and research are related in one way or another to a lack of adequate funding. While there are a number of opportunities for students to obtain funding for bursaries (and some of them can be used to study within the region), the majority of these (outside South Africa) are financed from outside the region. A large proportion of these funding opportunities do not support the development of faculty staff members within the region's university institutions and only provide limited funds for the development of research infrastructure. One of the main discussion points at research and training meetings within the region is always the low level of financial support provided by most of the national governments in sub-Saharan Africa. The inevitable result is a strong reliance on outside funding which is rarely sufficient to address the related constraints of:

- Relatively low levels of academic remuneration.
- Inadequate staffing levels.
- Inadequate access to equipment and other resources such as computers, field and laboratory equipment, textbooks and scientific journals.
- Inadequate access to updated teaching material (and not enough time available to develop them in-house).
- Inadequate support for staff research project development.
- Inadequate support for attending scientific conferences.
- Inadequate resources to develop competitive research proposals for submission to major international funding agencies.

Figure 2 presents a comparison of national expenditure on R&D and the size of the research community for a sample of countries around the world (Blankley and Booysen, 2010). While some countries achieve greater success in attracting people into

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research for the same input costs than others, it is immediately clear that South Africa does not perform very well on either count. Blankley and Booysen (2010) also noted that a substantial proportion of the South African R&D expenditure is derived from the private sector. Given that South Africa has a higher relative R&D expenditure than other countries in the region, it is clear that a greater commitment is required from within the region to enable local scientists and engineers to improve their abilities to contribute to solving water related problems. It seems to be relatively easy to mobilise funds for ministerial think-tanks, the development of policy documents and inter-governmental discussion meetings on topics such as addressing the Millennium Development Goals and dealing with climate change threats. Unfortunately, it seems to be much more difficult to provide local scientists and engineers with the teaching and research infrastructure necessary to find solutions to some of these problems. Is it because the governments of the region don't have sufficient confidence in their own scientists, or is it because there are too few scientists to "shout loud enough" and promote their expertise and potential value, or is it simply because there is not enough political will to support the development and implementation of locally driven solutions? In reality, the answer is probably a combination of the above plus several other disabling factors.

There are also differences within the region in terms of the number of students who are interested in pursuing careers in hydrology and water resources. Within most of the region there appears to be a plentiful source of student interest. However, within South Africa, where there are frequently more resources, it is difficult to attract students to post-graduate degree programmes and even more difficult to retain them as future research or teaching faculty members. Part of the reason for this is the lower remuneration offered in academic institutions compared to the business (consulting) and government sectors. This is not unique to the water sciences sector and many science departments in South African universities have reached similar conclusions.

A further constraint to the development of local post-graduate programmes is the often held perception that it is better to pursue a post-graduate degree at universities outside the region that have more elevated academic reputations. While this may be

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an accurate perception, it is difficult for some of the poorly resourced local universities to compete. The result is that at least some of the graduates never return to the region, although the numbers involved and the potential impact do not appear to have been quantified.

One of the constraints to improved hydrological practice is the lack of capacity of local water resources managers (mostly employed as civil servants) to adopt new approaches. This means that even locally developed and applied research products are rarely used and there is a short-circuit in the processes associated with translating research into practice, evaluating the benefits and generating further research to continually improve both scientific understanding and practical applications. Gustard (2002) refers to the need for a greater emphasis to be given to the process of technology transfer, follow-up research and training in the use of appropriate software tools. While problems of transferring science into practice are certainly not unique to the developing countries of the world, the gap is arguably wider in developing countries due to communication problems between those involved in research, practice, management and policy development.

The overall result of these constraints is that all of the resources (including human, financial and materials) required to further develop teaching, training and research in hydrology and water resources science are stretched to the limit and there is a real fear that even the current situation is unlikely to be sustainable. The retirement of key individuals has the potential to cause the collapse of an institution's research and post-graduate teaching programme if there are no suitably trained and experienced persons to replace them. A further problem is that the termination of one or more foreign funding programmes can result in a substantial decrease in the number of post-graduate study opportunities – something that the region can ill afford, given the relatively small number that are currently available. Just as it appears to be very difficult for many of the countries of sub-Saharan Africa to emerge from the real (socio-economic) poverty gap, so it is equally difficult for them to emerge from the "research" poverty gap.

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6 The way forward

The previous section has painted a somewhat gloomy picture of the situation in the region, while it is true to say that there has been significant progress in recent years that has resulted in more research activity, specifically at the post-graduate (mainly PhD) level. The critical issue is therefore to find ways in which this progress can be sustained as well as removing some of the barriers that might be preventing even greater progress. There needs to be a concerted effort to pool the available resources and encourage the development of a critical mass (of facilities, human capacity and financial resources) that will contribute to a sustainable future. Given the overall socio-economic status of the countries in the region, and the fact that this seems unlikely to improve substantially in the near future, it will always be necessary to rely to a certain extent on support from outside the region. This issue has been recognized by many groups including the African Renaissance Institute of Science and Technology (ARIST – http://www.arist-edu.org/) whose objective is to foster the transformation of Africa through education, research, innovation, entrepreneurship, and community outreach'. The real issue is therefore how can outside assistance be used to effectively develop sustainable local capacity? The ultimate objective must be to create a situation where African water science and engineering groups can compete or collaborate on equal terms with their colleagues from more developed countries. What should be avoided is some type of scientific colonialism, where the outside organizations remain the dominant force.

There are many instances where major development projects in the region are undertaken by outside (the region) consulting companies, sometimes with local partners and a training component, but quite frequently without. Some organisations in the region have referred to the lack of follow-up activities once the initial training of local partners has taken place. This type of approach rarely develops effective capacity in research or practice within locally based institutions. Part of the reason for favouring outside consultants may be related to the lack of available local expertise, or the lack

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of awareness of the existence of local expertise and the lack of capacity of local qualified staff to bid for such contracts. The problem could also be related to assumptions by politicians that experts from developed countries are more skilled and can provide better solutions than local scientists and engineers.

There is little doubt that networks of potential collaborators in research, training or practice are not very well developed in sub-Saharan Africa. While there are a number of different collaborating groups (collaborating with each other and with organisations outside the region), they are frequently not very extensive, tend to be rather exclusive and often compete for funding opportunities with each other. There are many other groups who exist outside these rather limited areas of cooperation and have few opportunities of "breaking in". While the concepts behind establishing "centres of excellence" (not necessarily located in a single geographic location) may be sound, in practice they tend to favour those institutions that already have capacity at the expense of those that do not. This situation tends to be counter-productive when it comes to developing the capacity in the region as a whole. It is inevitable that there will always be some groups that have experience of working successfully together and these should be encouraged to continue. However, there appears to be a need for a broader "umbrella" network that can support established groups as well as encourage the development of emerging groups. The intention of such an umbrella network would not be to exercise control and add any additional administrative burden, but to add real value to existing initiatives in an attempt to ensure their sustainability and to make them more inclusive. An umbrella network approach might also be used to revive previous initiatives that were productive in the past but have recently become largely inactive. An example is the UNESCO Southern Africa FRIEND (Flow Regimes from International Experimental Network Data) programme that generated valuable regional research results during a 10 yr period up to 2003 (UNESCO, 1997, 2004), but has been largely inactive since then.

Lack of access to and awareness of research and teaching material is often quoted as being a stumbling block for research and developing new teaching programmes.

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This material includes textbooks, or other source material for lectures, journals and some of the global datasets that research organisations in other parts of the world take for granted. It is therefore encouraging that there are several existing and planned initiatives to improve the access to the material available for under-resourced universities in developing countries. One such programme is Research4Life (http://www.research4life.org), which is aimed at reducing the knowledge gap by providing affordable access to critical published scientific research. In a similar vein, the International Association of Hydrological Sciences (IAHS) initiated the Task Force for Developing Countries (TFDC) some years ago. This programme distributes IAHS publications free of charge to universities all over the developing world, including some 28 in Africa.

With respect to teaching resources, a US team of hydrology educators have recently initiated MOCHA (Modular Curriculum for Hydrological Advancement – http://www.mocha.psu.edu), designed to share the development of teaching material created by a range of experts in specific fields of hydrology. This type of resource could become invaluable to university departments in the sub-Saharan Africa region, particularly if some experienced lecturers can contribute material that has a strong local flavour and relevance. Similarly, a web-based portal of global and regional datasets (Watershed and Hydrologic Information Portal – WHIP) is under development by the University of Washington and others. This web portal will include links to data sources, the ability to search or filter by data type and region, primary references describing each dataset, guidelines on use of the data (inferences that can be made), and examples of how to use the data from published literature. It is, however, important to recognize that many sub-Saharan African universities still do not have adequately reliable and fast internet connections to be able to make the best use of web-based resources.

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7 Conclusions

A large part of the content of this contribution is based on the personal experience of the author combined with inputs of the opinions of others gleaned from discussions at conferences, workshops and other meetings. Many of the opinions are difficult to support with hard facts, but there are recurrent themes that emerge during discussions with hydrological scientists and water engineers who work within the region. These are related to a lack of financial resources and a feeling of being trapped in a "research" poverty gap that many individuals and institutions find difficult to emerge from. Table 1 summarises many of the constraints (and some of the reasons for their existence) and possible solutions that have been referred to in the sections above. There are overlaps amongst both the constraints and the possible solutions and it is apparent that many of them are related to funding.

While there is clearly a need to develop interdisciplinary research approaches to solving complex water resources issues, this should not be achieved at the expense of sound training in the individual disciplines (Metzler and Zare, 1999). Recent trends that focus on training in the broad issues of water resources management (through course-work MSc programmes and short courses for professionals) should not be seen as a substitute for training in scientific research, which is less than adequately developed in the region. Both are important and have roles to play in the further development of water-related skills in the region. However, the latter tend to be more attractive to both funders and students as they offer promises of training in "work-related" skills. This is quite an important selling point in a region where potential employment opportunities are a high priority. It is therefore important to establish an improved science agenda when looking at future possible developments in training and education to support improved water resources management in the region. This could then be used to support some of the existing programmes that focus on the integration of skills and their application in practice. Part of the training and research should include the concepts and methods that can be used to deal with uncertainty in science and practice, which

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represents a paradigm shift for most countries in the world (Wagener et al., 2010) and not only the sub-Saharan Africa region. These concepts should be applied to the individual disciplines (hydrology in particular), as well as to the cross-disciplinary links that should ultimately contribute to improved water resources management.

From a more optimistic perspective, there have been a number of positive trends that have resulted in the completion of some sound scientific research and the development of the careers of a number of locally based academics and practitioners (e.g., Kapangaziwiri, 2011; Kongo, 2008). While these are encouraging trends, the conclusion of this paper is that a "critical mass" has not been reached and the current system is too heavily dependent on outside support (financial and in terms of supervisory expertise) to be considered sustainable in the long-term. It is suggested that the sub-Saharan African community of water resource scientists and engineers involved in education and research need to establish improved networks in which they can share *inter alia* expertise, research resources (models, software, data sets, etc.), information about locally and globally available data as well as contacts with potential research partners and funders, within and outside the region. Many institutions are not even aware of the existence of others, or are not familiar with their expertise or potential to contribute to collaborative research projects. Improved networking could help to solve some of these problems and could even contribute to mobilizing the community to get its voice heard in the government departments of the region that control the education, research and development budgets.

Perhaps one of the critical questions to be asked is how international organisations, such as UNESCO and IAHS, can contribute to resolving some of the constraints and encouraging the development of hydrology teaching and research in developing regions such as sub-Saharan Africa? There is no doubt that both are already contributing through programmes such as TFDC (IAHS) and FRIEND (UNESCO), but what else needs to be done to try and establish the critical mass in hydrology research and bridge the research poverty gap?

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References

Andersson, L., Wilk, J., Todd, M. C., Hughes, D. A., Earle, A., Kniveton, D., Layberry, R., and Savenije, H. H. G.: Impact of climate change and development scenarios on flow patterns in the Okavango River, J. Hydrol., 331, 43–57, 2006.

Blankley, W. O. and Booyens, I.: Building a knowledge economy in South Africa, S. Afr. J. Sci., 106, 373, doi:10.4102/sajs.v106i11/12.373, 2010.

Grey, D. and Sadoff, C.: Water resources and poverty in africa: breaking the vicious circle. Paper Presented to the African Ministerial Conference on Water, Abuja, Nigeria, available at: http://www.africanwater.org/Documents/amcow_wb_speech.pdf, last access: 10 November 2011, 2002.

Gustard, A.: FRIEND: an international network for bridging the gap between research and practice, in: FRIEND 2002 – Regional Hydrology: Bridging the Gap between Research and Practice. Proceedings of the 4th International Conference on FRIEND held in Cape Town, South Africa, March 2002. IAHS Publ. 274, 3–10, 2002.

Hughes, D. A.: Water resources estimation in less developed regions – issues of uncertainty associated with a lack of data. in: Prediction in Ungauged Basins: Promises and Progress,

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Proceedings of symposium S7 held during the Seventh IAHS Scientific Assembly at Foz do Iguaçu, Brazil, April 2005. IAHS Publ. 303, 72–79, 2006.
Hughes, D. A.: Hydrological models: mathematics or science?, Hydrol. Proc., 24, 2199–2201, 2010.
Hughes, D. A., Kapangaziwiri, E., and Sawunyama, T.: Hydrological model uncertainty assessment in Southern Africa. J. Hydrol., 387, 221–232, 2010.
Kapangaziwiri, E.: Regional application of the Pitman monthly rainfall-runoff model in Southern Africa incorporating uncertainty, unpubl. PhD thesis, Rhodes University, South Africa, 2011.
Kapangaziwiri, E., Hughes, D. A., and Wagener, T.: Towards the development of a consistent uncertainty framework for hydrological predictions in South Africa. in: New approaches to hydrological prediction in data sparse regions, Proc. symposium HS2 at the joint IAHS & IAH convention, Hyderabad, India, September 2009. IAHS Publ. 333, 84–93, 2009.
Kirshen, P. H., Vogel, R. M., and Rogers, B. L.: Challenges in graduate education in integrated water resources management, J. Water Res. PI.-ASCE, 130, 185–186, 2004.
Kirchner, J. W.: Getting the right answers for the right reasons: linking measurements, analyses and models to advance the science of hydrology, Water Resour. Res., 42, W03S04, doi:10.1029/2005WR004362, 2006.
Kongo, V. M.: Balancing water for food and environment: hydrological determinants across scales in the Thukela River Basin, unpubl. PhD thesis, University of KwaZulu-Natal, South Africa, 2008.
Love, D.: Experiences from waternet in Southern Africa, Hydrol. Earth Syst. Sci., this issue, 2011.
Lumsden, T. G., Schulze, R. E., and Hewitson, B. C.: Evaluation of potential changes in hydrologically relevant statistics of rainfall in Southern Africa under conditions of climate change, Water SA, 35, 649–656, 2009.
Metzger, N. and Zare, R. N.: Interdisciplinary research: from belief to reality, Science, 283, 642–643, 1999.
Muzic, I.: Postgraduate education in hydrology today and future needs, in: Past, Present and Future of Post-graduate Education in Hydrology, edited by: Salz, H., IHP-V, Technical Documents in Hydrology No. 4, UNESCO, Paris, 169–175, 1996.
Nash, J. E., Eagleson, P. S., Phillip, J. R., and Van der Molen, W. H.: The education of hydrologists, Hydrol. Sci. J., 35(6), 597–607, 1990.
Pappenberger, F. and Beven, K.: Ignorance is bliss: or seven reasons not to use uncertainty

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analysis, Water Resour. Res., 42, W05302, doi:10.1029/2005WR004820, 2006.
Salz, H. (ed.): Past, present and future of post-graduate education in hydrology, IHP-V, Technical Documents in Hydrology No. 4, UNESCO, Paris, 1996.
Svoboda, A.: Postgraduate hydrology training in view of future needs of developing countries, in: Past, Present and Future of Post-graduate Education in Hydrology, edited by: Salz, H., IHP-V, Technical Documents in Hydrology No. 4, UNESCO, Paris, 189–194, 1996.
UNEP: "Africa Water Atlas". Division of Early Warning and Assessment (DEWA), United Nations Environment Programme (UNEP), Nairobi, Kenya, 2010.
UNESCO: Southern African FRIEND, Technical Documents in Hydrology No 15, UNESCO, Paris, 1997.
UNESCO: Southern African FRIEND Phase II 2000–2003, Technical Documents in Hydrology No 69, UNESCO, Paris, 2004.
Vörösmarty, C. J., Green, P., Salisbury, J., and Lammers, R. B.: Global water resources: vulnerability from climate change and population growth, Science, 289, 284–288, 2000.
Wagener, T., Weiler, M., McGlynn, B., Gooseff, M., Meixner, T., Marshall, L., McGuire, K., and McHale, M.: Taking the pulse of hydrology education, Hydrol. Proc., 21, 1789–1782, 2007.
Wagener, T., Sivapalan, M., Troch, P. A., McGlynn, B. L., Harman, C. J., Gupta, H. V., Kumar, P. Suresh, C. R., Basu, N. B., and Wilson, J. S.: The future of hydrology: an evolving scinence for a changing world, Water Resour. Res., 46, WO5301, doi:10.1029/2009WR008906, 2010.
Yadav, M., Wagener, T., and Gupta, H. V.: Regionalisation of constraints on expected watershed response behaviour, Adv. Water Res., 30, 1756–1774, 2007.

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Table 1. Summary of current constraints and possible ways forward (note that there will be overlaps between the constraints and solutions).

Current Constraint or Situation (& Reasons).	Possible Solutions.
Not enough faculty members to sustain training and research (Poor remuneration & lack of facilities).	Improved facilities & remuneration. Active recruitment drive, particularly of younger academics.
Too much reliance on foreign funding (Not enough R&D funding commitment from governments in the region).	Demonstrate the value of science training & research to national governments and lobby for additional local funding.
Not enough basic hydrological science education (Lack of resources & staff. Over-emphasis on water management).	Focus staff recruitment & educational resource development on science. Improve access to developing international teaching & research resources.
Focus on training in existing solutions to problems (Lack of resources to switch to new approaches or lack of awareness of new approaches).	Focus on emerging problems as well as new approaches to their solution.
Lack of access to, or awareness of existing research resources.	Need demonstration projects to illustrate the use and value of such as Earth Observation (EO) data and existing hydrological modeling software systems.
Not enough integration of science & practice (Lack of communication & commitment).	Improve communication between scientists, practitioners and managers within the region. Encourage water managers to use research outputs from the region.
Too little understanding of interdisciplinary approaches (Separation of disciplines).	Encourage interdisciplinary research & teaching, but not at the expense of adequate training in single disciplines.
Lack of integration of small research groups (Lack of adequate networking).	Encourage the development of an "umbrella" network that can support existing & new research groups.
Poor integration of local research with international research (Lack of access to, or awareness of international research programmes and funding).	Encourage network links between local & foreign groups (or individuals). Improve training in the development of research proposals.

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Symbol	University
EMU	Eduardo Mondlane Univ.
ORI	Okavango Research Inst.
Lesotho	Univ. of Lesotho
MAK	Makerere Univ.
RU	Rhodes Univ.
SWAZI	Univ. of Swaziland
UCT	Univ. of Cape Town
UDRC	Univ. of Kinshasa
UFS	Free State Univ.
UKZN	Univ. of KwaZulu-Natal
UNIB	University of Botswana
UNIZ	Univ. of Zululand
UM	Univ. of Mauritius
UP	Univ. of Pretoria
USDM	Univ. of Dar es Salaam
USB	Stellenbosch Univ.
UWC	Univ. of Western Cape
UZ	Univ. of Zimbabwe
UZAM	Univ. of Zambia
Venda	Univ. of Venda
WITS	Univ. of the Witwatersrand

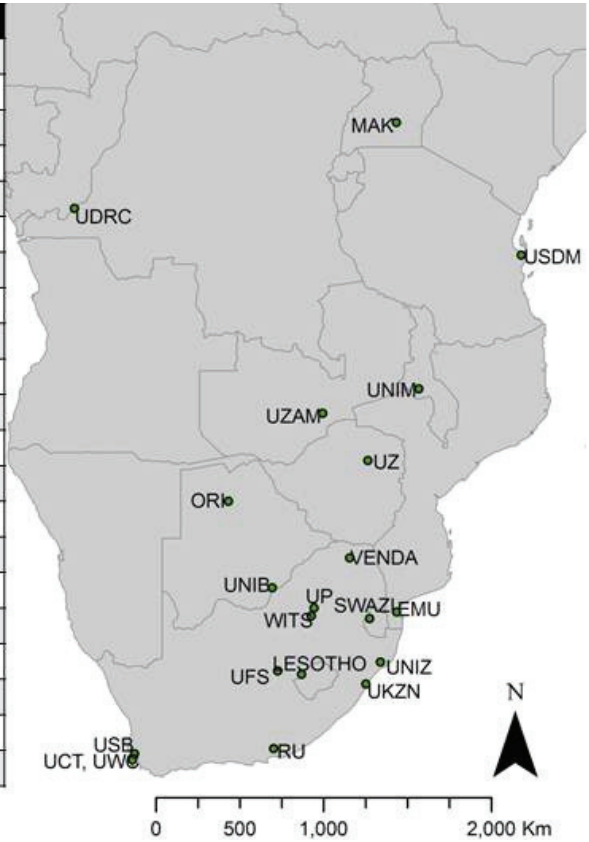

Fig. 1. Universities within continental Southern Africa with some involvement in hydrological training and research (Univ. of Mauritius is not shown).

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Hydrological education and training needs in Sub-Saharan Africa

D. A. Hughes

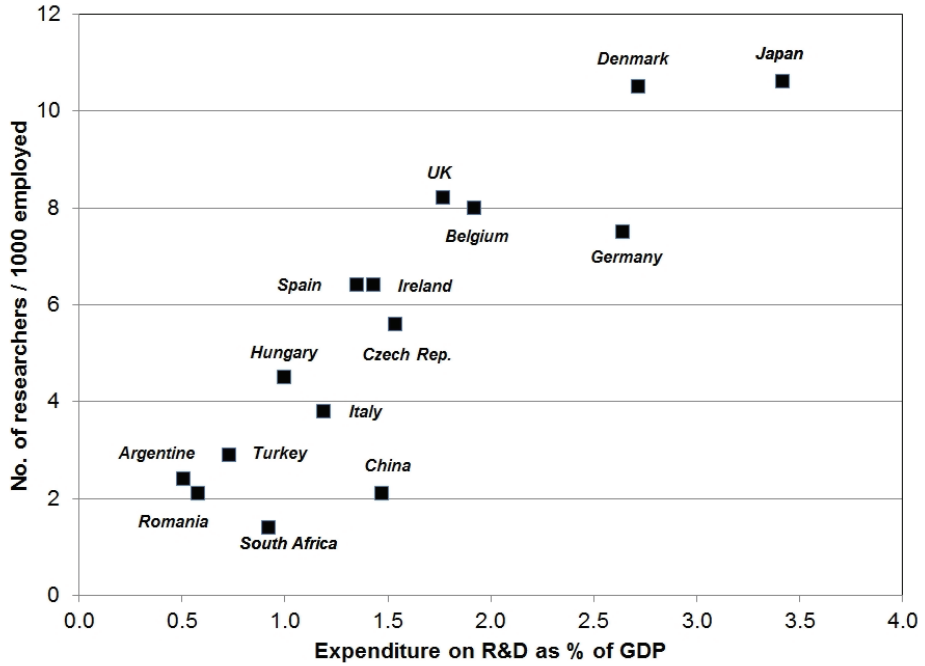

Fig. 2. Comparison of expenditure on R&D and number of researchers (in all fields) based on 2008 data presented in Blankley and Booyens, 2010).

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