Managing risk, mitigating drought and improving water productivity in the water scarce Limpopo Basin: highlights of some integrated water resources management solutions

David Love[1,2], Bekithemba Gumbo[1] and Washington Nyabeze[1,3*]

[1] WaterNet, PO Box MP600, Mount Pleasant, Harare, Zimbabwe
[2] ICRISAT Bulawayo, Matopos Research Station, PO Box 776 Bulawayo, Zimbabwe
[3] Makgaleng Projects, PO Box 27862, Sunnyside 0132, South Africa

Summary

This paper attempts to highlight how implementation of the integrated water resource management approach can reduce livelihood risk, either as a basis for an agricultural intervention, or as an essential planning tool. Three groups of studies are showcased. The first examines conservation agriculture and rainwater harvesting; the second evaluates the productivity, impact and sustainability of the current widespread distribution of low-head drip kits for irrigation at household level and the third case study considers aspects of climate change and livelihood risk. The basic principle illustrated in each of these three studies is that water in agriculture (although this is true in general) is best managed by considering the water cycle. This issue arises because the water cycle is a complex system and the implementation of a livelihood intervention that involves water use – whether in rainfed agriculture, irrigation, domestic supply or elsewhere – has to consider the impacts of that intervention across the whole cycle. If this is not done, the intervention may fail, prove unsustainable, or cause a conflict with other users. In integrating findings of this nature, the issue of scale is becomes a key challenge. While most of the initial investigative work is at plot or micro level up-scaling is required in order to see their impacts at decision-making level (water management areas and national provinces). At the same time, planning and policy issues developed at national and trans-national levels require down-scaling for their implications to be understood and implementable at farmer and user level. Methodologies to address these challenges are currently being developed on this project.

Keywords: integrated water resources management, livelihood risk, drought mitigation, water productivity, water cycle

Take home message: (i) In water scarce regions the water cycle in agriculture can be better managed to reduce risks, mitigate drought and increase water productivity without massive expenditure on irrigation schemes. (ii) Water resources evaluations are an essential pre-requisite to any livelihood intervention that involves water use, whether rainfed, irrigated, domestic or any other use.

* Corresponding author: Tel.: +27-11-3156791/2. Fax.: +27-11-8053875.
E-mail addresses: davidlove@science.uz.ac.zw / d.love@cgiar.org (D. Love); bgumbo@eng.uz.ac.zw / bgumbowits@yahoo.com (B. Gumbo); wedswrn@icon.co.za / washy@makproj.co.za (W. Nyabeze)

Introduction

The global food challenge requires a new green revolution with a focus on smallholder farming communities living in water scarce and ecologically vulnerable landscapes (Falkenmark and Rockström, 2003). The emphasis on smallholder farmers is based on an assessment that of the 850 million people living in serious and chronic hunger, approximately 50 % are smallholder farmers (FAO, 2004). For this reason, the Millennium Project recommendations on rural development and food security focuses on improving the production and livelihoods of smallholder farmers (UN Millennium Project, 2005a). It is increasingly understood that to unlock paths to sustainable development and food security, especially in improving the livelihoods of smallholder farmers, integrated water resource management (IWRM) is a basic requirement (Falkenmark and Rockström, 2003; van der Zaag, 2005). However, the new IWRM policies and structures, developed through water reforms since 1990, do not generally penetrate to the smallholder farmer (Jaspers, 2003; Nare *et al.*, 2005).

Smallholder farmers make up more than half the population at risk from hunger, and in southern Africa cultivate on poor soils, using unreliable rainfall as the main source of water (Twomlow and Bruneau, 2000). Crop yields are low and failures are frequent (Scoones, 1996), with more than one million people in the Limpopo basin depending on food aid in 2003 (Love *et al.*, 2004). Blue water resources for irrigation are over-committed in the Limpopo basin, while the bulk of agricultural produce sustaining lives of resource-poor farmers originates from green water flows in rainfed agriculture (Love *et al.*, 2004). However, the risk of failure of rainfed agriculture is very high, with potential evapotranspiration exceeding rainfall for more than 6 months of the year. Rainfall is seasonal and highly variable. Annual rainfall for a single site can vary by up to 1000 mm from year to year - although a drought year may easily record less than 250 mm, such as the 2004-2005 season in southern Zimbabwe and Mozambique (Love *et al.*, 2005a). By the end of the dry season, i.e. just before planting, the top 0.3 m of the soil horizon frequently holds negligible water content (Twomlow and Bruneau, 2000). Furthermore, a number of climate change models predict that southern Africa shall experience significantly reduced precipitation and runoff over the next fifty years (Arnell, 2003; Moyo *et al.*, 2005a) – resulting in food shortages(Cane *et al.*, 1994; Du Toit *et al.*, 2001).

Even where irrigation is considered, risk of crop failure is still high for the smallholder farmerbecause of the low conversion of rainfall to runoff and the precarious balance between available water resources and water demand (Mazvimavi, 2004). The water yield from the developed surface water resource in the Limpopo Basin frequently falls short of the demand, deficits being more evident during droughts (Nyabeze, 2004). Furthermore, demand from more powerful sectors, such as urban areas and commercial farming, is rising. It has been suggested that the expansion of the SADC regional economy – and especially the South African economy – will necessitate water re-allocation from agriculture to urban areas and industry (Taigbenu *et al.*, 2005). Where sufficient surface water can be apportioned and abstracted for smallholder irrigation schemes there are often management problems. In addition such schemes also tend to over-apply water (Senzanje *et al.*, 2003), for a variety of reasons such as design and pricing policies, leading to problems, especially during drought years (Munamati *et al.* 2005). Poor water management on such schemes also leads to reduced yields (Samakande *et al.*, 2004).

It becomes quite clear from this context that poor water management in southern Africa is linked to food shortages and poverty. In the same way, improving water management, both on-farm and at catchment level, could improve rural livelihoods and food security. This is the basis from which the overall research hypothesis of the WaterNet Challenge Program Project 17 "Integrated Water Resource Management for Improved Rural Livelihoods: Managing risk, mitigating drought and improving water productivity in the water scarce Limpopo Basin" was been developed. The hypothesis is that an integrated approach to water management can improve rural livelihoods, especially those of smallholder farmers, through managing risk and mitigating drought, and simultaneously increasing water productivity in agriculture. This paper seeks to highlight some of the key findings in the first year along the road in examining this hypothesis.

Highlights of some integrated water resources management solutions

Managing the full water cycle: conservation agriculture and rainwater harvesting

Conventional wisdom applied to agriculture in semi-arid areas holds that permanent irrigation is the solution to water scarcity and to food security in times of drought. This is reflected in the Millennium Project's recommendations on small-scale irrigation (UN Millennium Project, 2005b). However, access to irrigation water for the smallholder farmer in the Limpopo Basin is very limited (Love *et al.*, 2004). This can be attributed to a number of factors including lack of investment targeting such developments, lack of suitable sites to establish further dams, over-commitment of the available water resource in some catchments and poor coupling of possible dams sites with suitable soils. Furthermore, most southern African governments face a chronic shortage of funding for capital investments such as dams (Love *et al.*, 2005a). It should also be considered that application of scarce blue water resources in this fashion is often inherently costly and inefficient and what is needed is to improve the effectiveness of crop production in these marginal rainfall regions, by managing the full water cycle, not by simply tapping more river water. This can be done through culturally acceptable practices, which conserve and extend the period of water availability to the crop (Falkenmark and Rockström, 2003; Rockström, 2003; Twomlow and Bruneau, 2000). CP17 has undertaken a number of studies that examine such practices (Mucada, 2005; Mupangwa *et al.*, 2005; Mwenge-Kahinda, 2004; Woltering, 2005) and research in this area is in progress.

As an alternative to permanent irrigation, yields can be improved by short-term supplementary irrigation during dry spells (Falkenmark and Rockström, 2003; Nyamudeza, 1999; Rockström *et al.*, 2003). A study in Mozambique has shown that this can be required only in the third growth phase of maize (Mucada, 2005). As an alternative to dams, use can be made of rainwater harvesting technologies (Motsi *et al.*, 2004; Mwenge-Kahinda, 2004; Rockström, 2003) or accessing of alluvial aquifers (Dahlin and Owen, 1998; Moyce *et al.*, 2005). In rock outcrop water harvesting, in the Mzingwane Catchment, it takes a catchment area of approximately 4 Ha to provide supplementary irrigation for 1 Ha of maize. Farm sizes under such irrigation vary from less than 1 Ha to 10 Ha (Mwenge-Kahinda, 2004).

Figure 1. Rock outcrop water harvesting

Figure 2. Pumping from an alluvial aquifer

Supplementary irrigation and off-field rainwater harvesting are still accessing blue water. Good results can be obtained from better management of the rainfall that reaches the field naturally. Conservation agriculture groups water, soil and crop management practices, which focus on sustainable farming. Tillage is an important aspect, but the key to successful conservation farming is the integration of tillage within the total production system. This means that besides applying, for example, zero tillage, mulching or ridging, it is also important to focus on measures that increase the water uptake capacity of the plants, such as, pest management, crop rotations, weeding, etc (Woltering, 2005). In Zimbabwe water management under rainfed cropping systems has been the focus of several field studies encompassing effects of weeding on soil water regimes (Twomlow and Bruneau, 1998), tillage effects on soil water dynamics and crop yields (Nyakatawa *et al*., 1996; Nyamudeza, 1993), tillage effects on weeds (Dhliwayo *et al*., 1995) and soil erosion control (Chuma, 1993; Chuma and Haggmann, 1998).

Mulch ripping has been shown to give higher soil moisture in the topsoil especially at the beginning of the cropping season, since it protects the soil from erosion and promotes infiltration (Morse, 1996). Regrettably smallholder farmers have not taken up this technique. This is possibly because the technology was developed and tested in a non-participatory, top-down approach. The development approach did not address the competition for crop residue between crop and livestock enterprises common in the smallholder farming system (Mupangwa *et al.*, 2005).

Decreasing interception losses through minimum tillage increases the availability of water for transpiration and runoff. Water, which would otherwise have been lost through interception loss becomes available for plants uptake (Woltering, 2005). Minimum tillage has been explored as a soil and water conservation strategy for the semi-arid areas of Zimbabwe. Studies have been conducted on no till tied-ridges in the semi-arid areas (Vogel, 1992; Nyagumbo, 1999; Rusike and Heinrich, 2002; Twomlow and Bruneau, 2000). Significant observations made were that sorghum and sunflower crops under ridges showed less moisture stress than crops grown on flat ground. These studies also showed positive interaction effect of either fertilizer or manure with soil moisture conservation on crop yield.

Figure 3. Ripped field

Figure 4. Infiltration pit in a contour

Infiltration pits within contour ridges are being used as a soil water management technique (Mugabe, 2004; Mwenge-Kahinda, 2004). Water captured by the pits replenish soil water on the up and down slopes of the pit. Although the studies demonstrated the soil water benefits of infiltration pits, a significant proportion of water collected at 1 m depth could be lost through deep drainage (Mupangwa *et al.*, 2005).

Land fallowing has been explored as a soil moisture conservation strategy. However, for a farmer with limited land, the previously fallowed land should produce twice as much grain to compensate for time when it has no crop (Nyamudeza and Maringa, 1992).

It has been shown that best results are achieved where cultural practices are combined with soil fertility management (Mupangwa *et al.*, 2005). It has also been shown that the combined use of fertiliser and water harvesting systems can reduce crop failure risks from 20 % down to 7 %. Transpirational water productivity was improved with increased fertilization and supplemental irrigation. The results of the study show that water harvesting systems when combined with fertiliser (nitrogen) application, irrigation components and planned and integrated at catchment scale can achieve effective results (Mwenge-Kahinda, 2004).

There is evidence that only a few of the farmers who have been exposed to a number of soil water conservation technologies have actually continued to use them. There are a number of reasons that explain the lack of sustained uptake of such technologies that have a demonstrated potential to address challenges of the smallholder farming sector. One of them is the lack of appropriate and affordable equipment for some of the conservation techniques which has hampered uptake of these techniques as viable options to conventional practice (Mupangwa *et al.*, 2005). Limited labour resources and limited access to credit and markets also handicaps the use of technologies developed for smallholder farming communities (Woltering, 2005). The scarcity of necessary information and limited technical support from government and development agencies adds to the number of factors inhibiting uptake of these technologies (Mupangwa *et al.*, 2005).

Water demand management: case of drip kit usage and distribution

Water demand management is a key concept in IWRM, and is importance in the semi-arid tropics is rapidly increasing (Gumbo *et al.*, 2003; Lévite *et al.*, 2003; Gumbo *et al.*, 2005). Water demand management in agriculture is an obvious approach to consider, given the inefficiencies of irrigation systems (Munamati *et al.* 2005; Samakande *et al.*, 2004). From this perspective, the Millennium Project encourages the use of drip irrigation for smallholder farmers (UN Millennium Project, 2005a). There is significant growing interest in the use of these kits in the Limpopo basin (e.g. Chigerwe *et al.*, 2004; Maisiri *et al.*, 2005; Nkala, 2003; Polak *et al.*, 1997) and more than 20,000 kits have been distributed in Zimbabwe since the year 2000 (Moyo et al, 2005b). CP17 has undertaken studies to examine the benefits, impact and sustainability of drip kit distribution (Maisiri *et al.*, 2005; Moyo et al, 2005b) and research in this area is continuing.

Figure 5. Vegetable gardens using drip kits

A comparative study of water efficiencies and crop productivity at Zhulube irrigation scheme, in the upper Mzingwane sub-catchment, has shown a water saving of over 50% under drip compared to surface irrigation, but no significant differences in vegetable yield or labour (Maisiri *et al.*, 2005). Garden sizes vary, with some smallholder irrigation schemes using drip (generally around 10 Ha in size) and drip kits also being distributed to households, for irrigation of kitchen gardens of up to 1,000 m^2 and yielding up to 4 tons of vegetables or one ton of maize from that size (Chigerwe *et al.*, 2004).

A study was undertaken to assess the impacts and sustainability of drip kit distribution in the lower Mzingwane sub-catchment where it was found that only 2 % of the beneficiaries had used the kit to produce the expected 5 harvests over 2 years, owing to problems related to water shortage, access to water and also pests and diseases. Water is accessed mainly from boreholes and shallow wells. About 51 % of the respondents had produced at least 3 harvests and 86 % produced at least 2 harvests. Due to water shortages during the dry season 61% of crops produced with the drip kits occurred during the wet season. This suggests that most households use the drip kits to supplement rainfed agriculture. As uptake of the drip kit system is linked to access to water, it is not appropriate to offer drip kits as relief to the poorest of a community without improving their access to water (including reducing the distance that they must travel to obtain the water). Therefore low cost drip kit programs can only be a sustainable intervention if implemented as an integral part of a long-term development program, not short-term relief programs, and should include a detailed analysis of the existing water resources to assess availability, access and potential conflicts, prior to distribution of drip kits (Moyo *et al*., 2005b).

The protocol shown in Box 1 was developed for NGO's to form a better base for sustenance of drip kit programs.

Box 1. Protocol for drip irrigation kits distribution programs (after Moyo *et al*., 2005b)

For the programme to be sustainable, it is important that the NGOs to take aboard relevant government organs right from the inception of the program to the end so that by the time the NGOs conclude their work the programme can be handed over to such government institutions for continued support.

1.Distance of water source
<u>Objective: Ensure that the drip kit garden is close to the water source (borehole, well, etc.).</u>
Drip kit garden should be within 50m of the water source or
Provide wheelbarrow or simple water cart to assist with transport of water for distances up to 250 m

2.Reliability of water source
<u>Objective: Ensure that the beneficiaries have a reliable water source</u>
Before a kit is given the NGOs in collaboration with relevant Government Departments should make an effort to determine the reliability of the potential water sources.
The potential sources of water should be able to supply water for the kit all year round.

3.Follow up visits
<u>Objective: Ensure that the beneficiaries get prompt technical advisory service on the use of kit.</u>
During the year of inception the NGO should make high frequency follow-up visits to beneficiaries i.e. at least once every two weeks for the first crop, and then monthly.
During the second year follow-up visits should be made once every cropping season, and then once every year thereafter

4.Training
<u>Objective: Adequate training of beneficiaries</u>
The NGO in collaboration with Government Extension Services should undertake the training.
Training should be done in the following areas: Installation, repair and maintenance of drip kits
NB on maintenance of the kits training should take cognisance of quality of water available for the drip kit in different areas.
Cropping techniques including knowledge of the cropping calendar
Irrigation scheduling
Pest control using cheaper traditional methods
As a way of motivating the beneficiaries field days and exchange visits by beneficiaries especially during the inception year.

5. Targeting
<u>Objective: Recipients of the drip kits should be people who are able work in their respective</u>

Box 1. Protocol for drip irrigation kits distribution programs (after Moyo *et al*., 2005b)

gardens
NGO should ensure that the beneficiaries are able bodied persons who can work in their gardens
Provide water containers relevant to size and age of beneficiary – it is hard to lift and carry a 20 litre bucket full of water

6.Spares
Objective: Beneficiaries are able to carry out repair works in time on their kit without compromising their crop production
NGO should identify a local trader or storeowner willing to stock the necessary spares, so that the beneficiaries can purchase them when they need them.

This box illustrates an extremely important point in agricultural interventions that water resources planning and evaluation is required before and during implementing such interventions (whether conventional irrigation schemes, drip kit distribution, supplementary irrigation or conservation agriculture). It must be ascertained that the water supply assumed for an irrigation project is sufficient, sustainable and acceptable to the community and that the intervention proposed does not decrease water availability downstream or down-flow (especially for non-beneficiaries). It is essential that the agriculturalists and the water engineers should engage with each other; preferably at the local government and water management area levels (Love *et al.*, 2005a).

Towards evaluating water shortage risk: climate change and livelihood risk

Variations in climate have an obvious effect on the water cycle, whether the variations are natural or human-made, short term or long term. Climate variability is climatic fluctuations on time scales of less than a hundred years. The term is often used to denote deviations of climate statistics over a given period of time (such as specific month, season or year) from the long term climate statistics relating to the corresponding calendar period: the degree of climate variability can be described by the differences between long term statistics of meteorological elements calculated for different periods (Graciano *et al*., 2004). Climate change is projected to substantially increase the risk of annual water shortages (as reflected by decreasing projected runoff), as well as the incidence of extreme events such as droughts, in many of the water-scarce areas of the world (Houghton *et al*., 2001). Modelling runoff from rainfall and evaporation levels predicted in the Intergovernmental Panel on Climate Change Special report on Emission Scenarios (IPCC SRES) has shown that by the 2020s the effect of climate change on mean annual runoff will be greater than climate variability in two-thirds of the world, and in around 90% of the world by 2080 (Arnell, 2003). In the eastern part of southern Africa, runoff is expected to decline by between 10% and 40% (Arnell, 2003; Chenje and Johnson, 1996). The PN17 project has initiated some research in this area.

Examination of 70-year rainfall and runoff records for the Mzingwane Catchment (Limpopo Basin in Zimbabwe) showed declining total annual precipitation (around 2.5 % per decade) and runoff, and rising temperatures (around 1.8 % per decade) (Moyo *et al*., 2005a). Further statistical analysis is being performed.

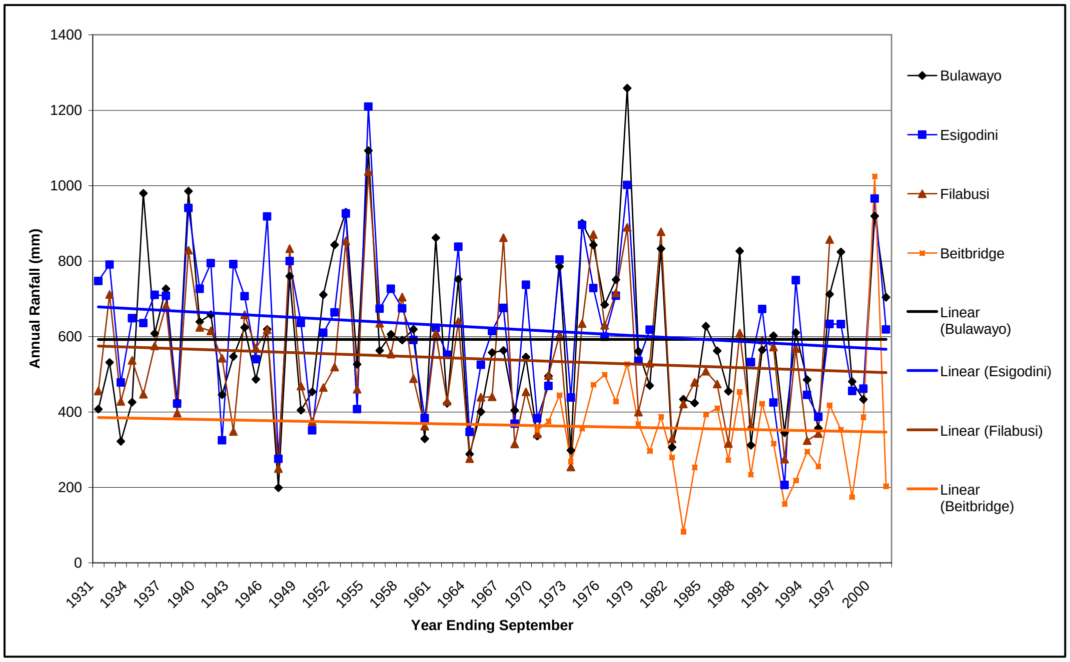

Figure 6. Annual rainfall, Limpopo Basin in Zimbabwe, 1930/31 to 2000/01.

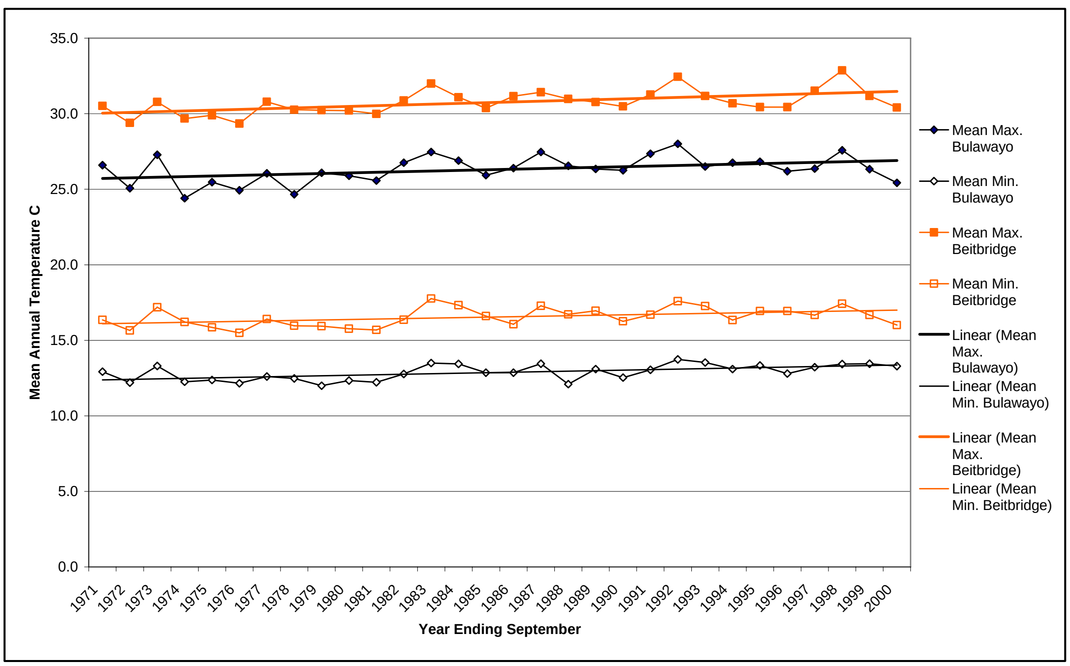

Figure 7. Annual temperatures, Limpopo Basin in Zimbabwe, 1970/71 to 2000/01.

Rainfall for the upper part of the Mzingwane Catchment, projected up to 2030 from these trends was found to be lower than predicted by global models, suggesting the possibility that the impact of climate change in southern Zimbabwe may be higher than predicted by global models.

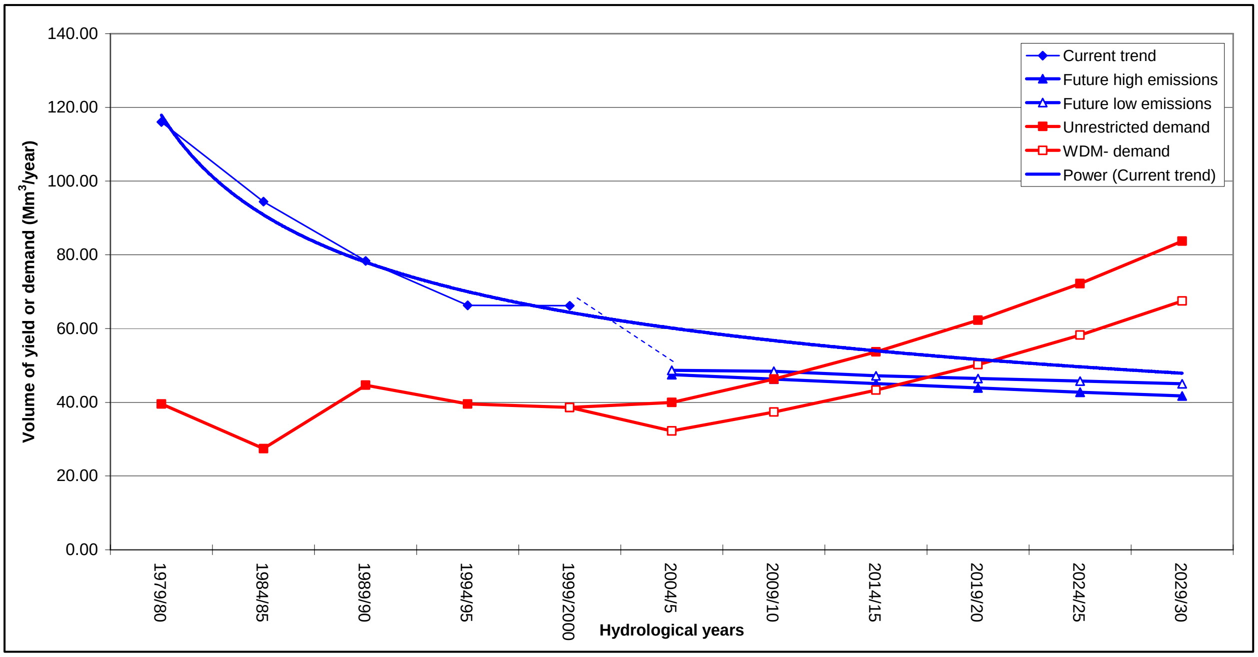

Figure 8. Recorded dam yields (blue) for the upper part of the Mzingwane Catchment and water demand (red) for the City of Bulawayo (1979-2000), and predicted dam yields and demand (2005-2030).

The implication of this is that future yields of dams supplying water to Zimbabwe's second largest city could decrease substantially. Based on avaerage conditions the city is expected to run out of water somewhere between 2009 and 2021, depending on the emissions scenario and on the extent to which water demand management strategies are implemented by the city (Moyo *et al.*, 2005a).

Other Research in Progress

In the preceding sections, we have chosen to highlight three research activities that have shown some interesting IWRM-based solutions. There is a wide variety of other research in progress as follows:

Preliminary water resource evaluation:

- Examination of 70-year rainfall and runoff records for the Mzingwane River, showed that the character of the upstream regime is related to climate and midstream regime to dam management. Downstream regime relates to both. Initial hydrological analyses show that the river is mainly ephemeral, but artificially semi-perennial below the major dams (Love *et al.*, 2005b).
- A small dam in Insiza District, upper Mzingwane sub-catchment, is currently supporting livestock and fishing, providing water for domestic purposes, and recharges a shallow borehole. Better use of existing dams, and improved catchment management may provide faster and more cost-effective returns to improving livelihoods than building new dams (Basima Busane *et al.*, 2005).

- Remote sensing applications are being developed for water resource characterisation, in a process led by PN46 but also involving PN17 (Moyce *et al.*, 2005; Sawunyama *et al*., in prep.).
- Alluvial aquifers are being evaluated and the high yields, good water quality and seasonal recharge of the aquifers give room for expansion for small scale irrigation along the river channel. Some of the unutilised alluvial water resources have areal extents ranging from 20ha to 175ha, with good soils on the alluvial plains and surrounding areas (Moyce *et al.*, 2005).

The main results of surveys of socio-economic conditions of smallholders are awaited, but some results are available as follows:

- In a survey of access to water for vulnerable children in Insiza District, upper Mzingwane sub-catchment, it was found that most (70%) of the children surveyed have adequate access to water, but almost half are accessing unsafe water sources. This figure increases during the dry season. More than half of the children surveyed do not get any income from water-related projects (Murata, 2005).
- In the Sekororo quaternary catchment in the Olifants Basin, a survey was carried out by a Masters Degree candidate from Limpopo University – the final report is currently awaited.

Land and water management practices:

- A study was carried out on water management strategies for vegetable production in Chókwè, when water is a limiting factor. The CropWat program was used and the study determined that in order to maximise production under water stress, the cultivated area must be reduced for tomatoes but increased for cabbages (Ibraimo, 2005).
- A Masters Degree student has been recruited and initiated his research on the influence of water budget allocation and water use efficiency quaternary catchment in the Olifants Catchment.
- On-farm agricultural water management practices in a sub-catchment of the Olifants Basin were surveyed and five different major cropping systems were described and analysed.
- A survey of agricultural water management practices in the Limpopo Basin in Mozambique has been carried out and the report is being compiled.

Water flow partitioning

- In a study of land use and hydrology in Insiza sub-catchment, results have indicated a decrease in flow rate at the sub-catchment scale but an increase in runoff coefficient at meso-scale. This can be related to increasing population and consequent intensification of agriculture, conversion of mixed impacted land into crop fields as observed during the 1990s (Kileshye Onema, 2004).
- In a study of the Insiza River, it has been shown that the frequency of occurrence of flows less than the average daily flow have been modified, and not the high flows. This is the opposite of the intention of the legislation used to grant water rights for development of large dams in Zimbabwe. The continuing managed releases from these dams are also beginning to become a source of conflict, with water release from one of the dams being the cause of a recent dispute between smallholder irrigators and a cement factory. A re-examination of the water permits and dam management rules is therefore required (Kileshye Onema *et al.*, in prep.).

- Using a simple rainfall-runoff model in the upper Mzingwane sub catchment, it was determined that conservation tillage can increase plant available moisture, but at the possible risk of decreasing river flow. However, these results are limited by the model's water balance estimation being performed at catchment scale, whilst conservation tillage is practised at farm scale (Woltering, 2005). This work is an initial study, prior to on-farm experiments.
- A Masters Degree student has been recruited and initiated his research on the influence of land use on a meso-scale quaternary catchment in the Olifants Catchment. The project seeks to provide a high resolution hydrologic model for selected quaternary catchments of the Olifants Catchment to aid the water sector in optimally using and planning water related projects, particularly the sectors that require models of a smaller time scale than has been previously provided (Ncube and Taigbenu *et al.*, 2005).

Institutional audit

- In a study of water allocation and management in small-scale irrigation schemes in the upper Mzingwane Subcatchment, shows that the irrigators do not have the same access to water or share the same view on how water should be managed. Social status, gender, power, institutional dynamics and group interests appear to determine accessibility to water and its management (Munamati *et al.*, 2005).
- A survey of stakeholder participation in water quality monitoring systems in the Mzingwane Catchment, results showed very limited stakeholder participation in and awareness of the established government systems. However, there is much indigenous knowledge of water quality surveillance, which could be incorporated into the formal systems (Nare *et al.*, 2005).
- The report of a Canadian student (University of Guelph) working on institutional aspects of water for domestic and productive uses in the Sekororo area, Olifants Catchment, is expected shortly.
- IWMI is in the process of compiling a book with mainly African case studies, including Zimbabwe and South Africa: 'Community-based water law and water resources management reform in developing countries' for the CGIAR Comprehensive Assessment.

Work by Ph.D. fellows is just starting, and includes:

- Modelling the effect of agricultural, climatic and land use changes and water resources in the Mzingwane Catchments, Limpopo Basin (David Love)
- Determining the water use efficiency and nutrient balance of selected soil-water conservation strategies in the semi-arid Mzingwane Catchment, Limpopo Basin, Zimbabwe (Walter Mupangwa)
- Investigating the challenge of salinity in the Chókwè Irrigation Scheme, Mozambique (Paiva Mungumabe)
- Modelling links between hydrology and socio-economics in the Olifants Catchment, South Africa (Manuel Magombeyi)
- Appropriate institutional models for water governance that strengthen institutions and policies for water productivity and risk mitigation (Collin Mabiza)

Discussion

In this paper, we have attempted to highlight how the integrated water resource management approach can reduce livelihood risk, either as a basis for an agricultural intervention, or as an essential planning tool. The basic principle illustrated in each of the three studies showcased is that water in agriculture (although this is true in general) is best managed as the water cycle. This issue arises because the water cycle is a complex system. A complex system could be described as consisting of a large number of components that are richly interconnected so that they can engage energy and/or information (Cilliers, 1998). These interconnections are non-linear. The characteristics of the system (emergent properties) are not primarily a result of the nature of the components, but of the nature of interconnections. This means that any attempt to give a complete description will disregard or violate some aspect of the system. Most importantly, to disregard the complexity of such a system in attempting to manage our interactions with it is not merely technical or descriptive error, it is likely to have unpredictable negative impacts on the system itself and on users. Thus the implementation of a livelihood intervention that involves water use – whether in rainfed agriculture, irrigation, domestic supply or elsewhere – has to consider the impacts of that intervention across the water cycle. If that is not done, the intervention may fail, prove unsustainable, or cause a conflict with other users.

Findings made at plot level require up-scaling in order to see their impacts at decision-making level (water management areas and national provinces). In integrating findings of this nature in this way, the issue of scale is becoming the key challenge. This is part of the work of Ph.D. fellows Love and Magombeyi. At the same time, planning and policy issues developed at national and trans-national level require downscaling for their implications to be realised and their functions implemented at farmer and user level. This is part of the work of Ph.D. fellow Mabiza. These scale issues raise critical challenges in:

- Hydrological and sociological modelling
- Heterogeneity and scarcity of data
- Penetration of stakeholder institutions
- Overlapping and conflicting jurisdictions and boundaries between institutions
- Cultural and political differences within a basin
- Technology transfer

Acknowledgements

This paper is a contribution to WaterNet Challenge Program Project 17 "Integrated Water Resource Management for Improved Rural Livelihoods: Managing risk, mitigating drought and improving water productivity in the water scarce Limpopo Basin", funded through the CGIAR Challenge Program on Water and Food. The opinions and results presented in this paper are those of the authors and do not necessarily represent the donors or participating institutions.

References

Arnell, N. 2003. Effects of IPCC SRES emissions scenarios on river runoff: a global perspective. *Hydrology and Earth System Sciences*, 7, 619-641.

Basima Busane, Sawunyama, T.,L., Chinoda, C., Twikirize, D., Love, D., Senzanje, A., Hoko, Z., Manzungu, E., Mangeya, P., Matura, N., Mhizha, A. and Sithole, P. 2005. An integrated evaluation of a small reservoir and its contribution to improved rural livelihoods: Sibasa Dam,

Limpopo Basin, Zimbabwe. In: Abstract volume, *6th WaterNet-WARFSA-GWP-SA Symposium*, Swaziland, November 2005, p32.
Cane, M. A., Eshel, G. and Buckland, R.W., 1994. Forecasting Zimbabwean maize yield using eastern equatorial Pacific seas surface temperatures. *Nature*, 370, 204-205.
Chenje, M. and Johnson, P. (Eds.), 1996. *Water in southern Africa*. SADC/IUCN/SARDC, Harare.
Chuma, E. 1993. Effects of tillage on erosion-related soil properties of a sandy soil in semi-arid Zimbabwe. In: Kronen, M. (ed.). *Proceedings of the Fourth Annual Scientific Conference of the SADC Land and Water Management Research Programme*, SACCAR, Gaborone, Botswana.
Chuma, E. and Haggman, J. 1998. Development of conservation tillage techniques through combined on-station and participatory on-farm research. In: Blume, H-P., Eger, H., Flieischhauer, E, Hebel, A., Reij, C. and Steiner, K.G., (eds.). Towards Sustainable land use. furthering cooperation between people and institutions, Vol. II. *Advances in Geoecology* 31. Catena Verlag GMBH Reiskirchen, Germany.
Cilliers, P. 1998. *Complexity and Postmodernism: Understanding Complex Systems*. Routledge, New York.
Dahlin, T. and Owen, R.J.S., 1998. Geophysical investigation of alluvial aquifers in Zimbabwe. In: *Proceedings of the 4th EEGS Meeting*, Barcelona, Spain.
Dhliwayo, H.H., Mabasa, S., Twomlow, S.J. and Riches, C.R., 1995. The effects of weeding methods and water conservation on weeds populations in dryland maize. *Brighton Crop Protection Conference – Weeds*.
Du du Toit, A.S. and Prinsloo, M.A. 2001. El Niňo-southern oscillation effects on maize production in South Africa: A preliminary study. In: Impact of El Niño and Climate Variability on Agriculture. *ASA Special Publication*, 63, 77-86.
Falkenmark, M. and Rockström, J. 2003. *Balancing Water for Man and Nature: The new approach in ecohydrology*. EarthScan, London.
FAO, 2004. *The State of Food Insecurity in the World: Monitoring progress towards the World Food Summit and Millennium Development Goals*. Food and Agricultural Organisation of the United Nations, Rome.
Graciano, P., Matondo, J. and Msibi, K. 2004. Evaluation of the impact of climate change on hydrology and water resources in Swaziland. *Physics and Chemistry of the Earth*, 29, 1181-1191.
Gumbo, B., Mlilio, S., Broome, J. and Lumbroso, D. 2003. Industrial water demand management and cleaner production: a case of three industries in Bulawayo, Zimbabwe. *Physics and Chemistry of the Earth*, 28, 797-804.
Gumbo, B., Forster, L. and Arntzen, J. 2003. Capacity building for water demand management as a key component to attaining the millennium development goals. *Physics and Chemistry of the Earth*, 30, 984-992.
Heinrich, G. 2001. Improving productivity and incomes for small-scale farmers in the semi-arid areas of Zimbabwe: on-farm participatory research in Gwanda. In: Twomlow, S.J. and Ncube, B., (eds.) *Improving soil management options for women farmers in Malawi and Zimbabwe: proceedings of a Collaborators' Workshop on the DFID-supported Project "Will Women Farmers Invest in Improving their Soil Fertility Management? Participatory Experimentation in a Risky Environment"*, International Crops Research Institute for the Semi Arid Tropics (ICRISAT), Bulawayo, Zimbabwe.

Houghton, J.T., Ding, Y., Griggs, M., Noguer, M., van der Linden, P.J. and Xiaosu, D. (Eds.) 2001. *Climate Change 2001: The Scientific Basis: Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).* Cambridge University Press, Cambridge.

Ibraimo, N.A. 2005. *Estratégias de gestão de água em situações de suficiência e insuficiência de água para a produção de tomate e repolho no regadio de Chókwè*. Licentiate thesis (unpublished), Faculty of Agronomy and Agricultural Engineering, Eduardo Mondlane University.

Jaspers, F.G.W. 2003. Institutional arrangements for integrated river basin management. *Water Policy*, 5, 77-90.

Kileshye Onema, J.-M. 2004. *A hydrological assessment of land use changes and human's effects on water resources in semi-arid Zimbabwe; the case of the Insiza sub-catchment*. M.Sc. thesis (unpublished), Water Resources Engineering and Management Programme, University of Zimbabwe.

Kileshye Onema, J.-M., Mazvimavi, D., Love, D. and Mul, M. in prep. Effects of dams on river flows of Insiza River, Zimbabwe. Paper submitted to *Physics and Chemistry of the Earth*.

Lévite, H., Sally, H. and Cour, J. 2003. Testing water demand management scenarios in A water-stressed basin in South Africa: application of the WEAP model. *Physics and Chemistry of the Earth*, 28, 779-786.

Love, D., Jonker, L., Rockström J., van der Zaag, P. and Twomlow, S. 2004. The Challenge of Integrated Water Resource Management for Improved Rural Livelihoods in the Limpopo Basin – an introduction to WaterNet's first network research program. In: Abstract volume, 5th WaterNet-WARFSA-GWP-SA Symposium, Windhoek, Namibia, pp106-107.

Love, D., Twomlow, S., Mupangwa, W., van der Zaag, P. and Gumbo, B. 2005a. Implementing the millennium development food security goals - challenges of the southern African context. In: Abstract Volume, 6th WaterNet-WARFSA-GWP-SA Symposium, Swaziland, p139.

Love, D., Uhlenbrook, S., Nyabeze, W., Owen, R.J.S., Twomlow, S., Savenije, H. , Woltering, L. and van der Zaag, P. 2005b. Analysis of hydrological change for IWRM planning: case study of the Mzingwane River, Limpopo Basin, Zimbabwe. In: Abstract Volume, 6th WaterNet-WARFSA-GWP-SA Symposium, Ezulwini, Swaziland, November 2005, p31.

Maisiri, N. Rockström, J., Senzanje, A. and Twomlow, S.J., 2005. An on-farm evaluation of the effects of low cost drip irrigation on water and crop productivity, compared to conventional surface irrigation system. *Physics and Chemistry of the Earth*, 30, 783-791.

Mazvimavi, D. 2004. *Estimation of Flow Characteristics of Ungauged Catchments: Case study in Zimbabwe*. PhD dissertation. Wageningen University and International Institute for Geo-Information Science and Earth Observation, Delft.

Morse, K., 1996. *A review of soil and water management research in semi-arid areas of Southern and Eastern Africa*. Chatham, UK, Natural Resources Institute.

Motsi, K.E., Chuma, E. and Mukamuri, B.B., 2004. Rainwater harvesting for sustainable agriculture in communal lands of Zimbabwe. Physics and Chemistry of the Earth, 29, 1069-1073.

Moyce, W., Mangeya, P., Love, D. and Owen, R. 2005. Alluvial aquifers in the Mzingwane Catchment: their distribution, properties, current usage and potential expansion and risk. In: Abstract Volume, 6th WaterNet-WARFSA-GWP-SA Symposium, Swaziland, p122.

Moyo, B., Madamombe, E. and Love, D. 2005a. A model for reservoir yield under climate change scenarios for the water-stressed City of Bulawayo, Zimbabwe. In: Abstract Volume, 6th WaterNet-WARFSA-GWP-SA Symposium, Swaziland, p38.

Moyo, R., Love, D., Mul, M., Twomlow, S. and Mupangwa, W. 2005b. Impact and sustainability of drip irrigation kits in the semi-arid Lower Mzingwane Subcatchment, Limpopo Basin, Zimbabwe. In: Abstract Volume, 6th WaterNet-WARFSA-GWP-SA Symposium, Swaziland, p115.

Mudaca, J.D. 2005. *Determinação do volume de água complementar a irrigação para agricultura de sequeiro na região de Chókwè*. Licentiate thesis (unpublished), Faculty of Agronomy and Agricultural Engineering, Eduardo Mondlane University.

Mugabe, F., 2004. Evaluation of the benefits of infiltration pits on soil moisture in semi-arid Zimbabwe. *Journal of Agronomy*, 3, 188-190.

Munamati, M., Mhizha, A. and Sithole, P. 2005. Cultivating livelihoods: an assessment of water allocation and management practices in small-scale irrigation schemes -case studies in Mzingwane Catchment. In: Abstract Volume, 6th WaterNet-WARFSA-GWP-SA Symposium, Swaziland, p120.

Mupangwa, W., Love, D. and Twomlow, S. 2005. Soil-water conservation and other rainwater harvesting strategies in the semi-arid Mzingwane Catchments, Limpopo Basin, Zimbabwe. In: Abstract Volume, 6th WaterNet-WARFSA-GWP-SA Symposium, Swaziland, p155.

Murata, R. 2005. *Access to water for Improved Rural Livelihoods: An investigation of the perspectives, experiences and strategies of orphans and other vulnerable children: a case study of Insiza District Mzingwane Catchment*. M.Sc. thesis (unpublished), Integrated Water Resources Management Programme, University of Zimbabwe.

Mwenge Kahinda, J.-M. 2004. *Water productivity and yield gap analysis of water harvesting systems in the semi-arid Mzingwane catchment, Zimbabwe*. M.Sc. thesis (unpublished), Water Resources Engineering and Management Programme, University of Zimbabwe.

Nare, L., Love, D. and Hoko, Z. 2005. Involvement of stakeholders in the water quality monitoring and surveillance system: the case of Mzingwane Catchment. In: Abstract Volume, 6th WaterNet-WARFSA-GWP-SA Symposium, Swaziland, p12.

Ncube, M. and Taigbenu, A.E. 2005. The impact of land cover and land use on hydrological response in the Olifants Catchment. In: *Proceedings of Special Colloquium: Water Research Showcase*, Universities of Johannesburg, Pretoria and the Witwatersrand, August 2005, pp 51-54.

Nyabeze, W.R. 2004. Estimating and interpreting hydrological drought indices using a selected catchment in Zimbabwe. *Physics and Chemistry of the Earth*, 29, 1173-1180.

Nyagumbo, I. 1999. Conservation tillage for sustainable crop production systems: Experiences from on-station and on-farm research in Zimbabwe. In: Kambutho, P.G. and Simalenga, T.E. (eds.). *Conservation tillage with animal traction. A resource book of the Animal Traction Network for Eastern and Southern Africa (ATNESA)*. Harare. Zimbabwe, 108-115.

Nyakatawa, E.Z., Brown, M. and Maringa, D. 1996. Maize and sorghum yields under tied ridges of fertilised sandy soils in semi-arid South-east Lowveld of Zimbabwe. *African Crop Science Journal*, 4, 197-206.

Nyamudeza, P. and Maringa, D., 1992. Effects of bare fallow and previous crop on residual soil water and yields of sorghum, maize and cotton in the South East lowveld of Zimbabwe. *Proceedings of the third annual scientific conference of the SADC-Land and Water Management Research Programme*, Harare, Zimbabwe, October, pp5-7.

Nyamudeza, P. 1993. The effects of growing sorghum (Sorghum bicolor) in furrows and on the flat at three populations and three row widths in a semi-arid region of Zimbabwe. 1. Grain Yield and Yield components. *Zimbabwe Journal of Agriculture Research*, 31, 1-10.

Nyamudeza, P. 1999. Agronomic practices for the low rainfall regions of Zimbabwe. In: Manzungu, E., Senzanje, A. and van der Zaag, P. (eds.), *Water for agriculture in Zimbabwe*. University of Zimbabwe Press, Harare, pp49-63.

Rockström, J. 2003. Resilience building and water demand management for drought mitigation. *Physics and Chemistry of the Earth*, 28, 869-877.

Rockström, J., Barron, J. and Fox, P., 2003. Water productivity in rain-fed agriculture: challenges and opportunities for smallholder farmers in drought-prone tropical agroecosystems. In: Kijne, J.W., Barker, R. and Molden, D. Eds. *Water Productivity in Agriculture: Limits and Opportunities for Improvement*. CAB International, London.

Rusike, J., Heinrich, G.M., 2002. Integrated soil water and nutrient management farmer field schools in Zimbabwe. *Proceedings of a Review, Evaluation and Planning workshop*,11-12 December 2001, International Crops Research Institute for the Semi Arid Tropics (ICRISAT), Bulawayo, Zimbabwe.

Samakande, I., Senzanje, A. and Manzungu, E. 2004. Sustainable water management in smallholder irrigation schemes: Understanding the impact of field water management on maize productivity on two irrigation schemes in Zimbabwe. *Physics and Chemistry of the Earth*, 29, 1075-1081.

Sawunyama, T., Chinoda, G., Love, D., Senzanje, A., Mangeya, P. and Matura, N. in prep. Characterisation of the hydrogeology and capacity of a small reservoir by remote sensing: Sibasa Dam, Limpopo Basin, Zimbabwe. Paper submitted to *Physics and Chemistry of the Earth*.

Scoones, I. 1996. *Hazards and Opportunities; Farming Livelihoods in Dryland Africa: lessons from Zimbabwe*. Zed Books, London.

Senzanje, A., Samakande, I., Chidenga, E. and Mugutso, D. 2003. Field irrigation practices and the performance of smallholder irrigation in Zimbabwe: case studies from Chakowa and Mpudzi irrigation schemes. *Journal of Agricultural Technology*, 5, 76-89.

Taigbenu, A.E., Ncube, M. and Boroto R.J. 2005. Resources management in agriculture: convergence of needs and opportunities. In: *12th South African National Hydrology Symposium*, Midrand, South Africa, September 2005, pp1-10.

Twomlow, S.J. and Bruneau, P.M.C. 1998. Soil-water regimes in semi-arid Zimbabwe. In: Wheater, H. and Kirby, C. (Eds.). *Hydrology in Changing Environment. Proceedings of the British Hydrological Society International Conference*, Exeter, July, 1998. Vol. II. British Hydrological Society. John Wiley & Sons. Chichester.

Twomlow, S. and Bruneau, P. 2000. Semi-arid soil water regimes in Zimbabwe. *Geoderma*, 95, 33-51.

UN Millennium Project, 2005a. *Investing in Development: A Practical Plan to Achieve the Millennium Development Goals*. Earthscan, New York.

UN Millennium Project, 2005b. *Halving Hunger: It can be done. Report of the Task Force on Hunger*. Earthscan, New York.

Van der Zaag, P. 2005. Integrated Water Resources Management: Relevant concept or irrelevant buzzword? A capacity building and research agenda for Southern Africa. Physics and Chemistry of the Earth, 30, 867-871.

Woltering, L. 2005. Estimating the influence of on-farm Conservation Practices on the Water Balance: Case of the Mzinyathini Catchment in Zimbabwe. M.Sc. thesis (unpublished), Delft University of Technology, the Netherlands.

Copyright