CPWF Project Report

The Challenge of Integrated Water Resource Management for Improved Rural Livelihoods: Managing Risk, Mitigating Drought and Improving Water Productivity in the Water Scarce Limpopo Basin

Project Number 17

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Project Partners:

Program Preface:

The Challenge Program on Water and Food (CPWF) contributes to efforts of the international community to ensure global diversions of water to agriculture are maintained at the level of the year 2000. It is a multi-institutional research initiative that aims to increase the resilience of social and ecological systems through better water management for food production. Through its broad partnerships, it conducts research that leads to impact on the poor and to policy change.

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Project Preface:

The Challenge of Integrated Water Resource Management for Improved Rural Livelihoods: Managing Risk, Mitigating Drought and Improving Water Productivity in the Water Scarce Limpopo Basin: Integrated Water Resources Management (IWRM) is a systems approach to water management, based on the principle of managing the full water cycle. It is required, not only to balance water for food and nature, but also to unlock paths to sustainable development. A global hotspot area in terms of water for food and improved livelihoods is in the poverty stricken rural areas of water scarce semi-arid tropics, such as in the Limpopo basin. The improvement in resilience that the IWRM approach can impart to rural livelihood systems has been shown by a series of case studies in the Limpopo Basin.

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EXECUTIVE SUMMARY

It is increasingly understood that integrated water resource management (IWRM) is required, not only to balance water for food and nature, but also to unlock paths to sustainable development. A global hotspot area in terms of water for food and improved livelihoods is in the poverty stricken rural areas of water scarce semi-arid tropics, such as in the Limpopo basin. Here, translating IWRM from concept to action still remains largely undone. Water policy and institutions are embedded in a conventional blue water framework, mainly concerned with (runoff-based) water supply for irrigation, domestic and industrial use. This water resource strategy has limitations. 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 crop and livestock production.

Integrated Water Resources Management (IWRM) is a systems approach to water management, based on the principle of managing the full water cycle (Twomlow *et al.*, 2008b). Green water is the source of runoff and percolation – and thus of blue water. The fundamental principles of IWRM are: (i) water is a vulnerable and finite resource requiring sustainable management, (ii) water is a special economic good, (iii) water management requires a participatory approach and (iv) sustainable water management requires the promotion of gender equity (ICWE, 1992; Savenije, 2002). The improvement in resilience that the IWRM approach can impart to rural livelihood systems has been shown by a series of case studies in the Limpopo Basin. Community or catchment water resource assessments must become an essential precursor to food security interventions, due to the convergence of water scarcity and food scarcity, and the constraints that water resource availability impose on development initiatives in basins such as the Limpopo (Love *et al.*, 2006b, 2010).

Access to green water in rainfed farming can be improved through a package of conservation agriculture techniques. Conservation tillage methods, such as planting basins, help to concentrate rainfall that falls in the field into the root zone of the crops and decreases runoff out of the field (Ncube et al., 2009). Best results are obtained when such methods are combined with fertility improvements such as manure, or micro-dosing with nitrogen fertilizer or with measures such as mulching that improve the use of water by crops and also decrease evaporation (Mupangwa, 2009). Yield improvements in rainfed farming translate very quickly into major improvements in green water productivity (Ncube *et al.*, 2007; Rockström *et al.*, 2007). The farming system's resilience is thus raised without industrial scale interventions.

Supplementary irrigation, using micro-catchment or runoff farming incorporates small-scale utilization of blue water into rainfed farming. It thus represents a nexus between rainfed and irrigated farming and conjunctive use of green and blue water. Studies in the Limpopo Basin (Mwenge Kahinda *et al.*, 2007; Magombeyi *et al.*, 2008) have shown that there is a substantial yield gap which supplementary irrigation can bridge. This is particularly the case especially during years with dryspells during the growing season, when conventional rainfed agriculture may fail completely.

A multi-stakeholder approach to decision-making, especially where gendered, builds resilience as negotiation processes between users result in new institutions, or new roles for existing institutions, such as school boards which take over borehole management. Such institutions often evolve and revolve around specific infrastructure (Mabiza *et al.* 2006). At the same time, these community-based institutions need linkage to formal water management structures (Dzingirai and Manzungu, 2009).

It should be emphasized that, as a network, WaterNet itself is a partnership organization. The Trust oversees, the secretariat coordinates but most activities are delivered by WaterNet members and partners. A key aspect of this project for WaterNet was building solid partnerships outside the university sector: with CG centres, government departments and NGOs. Many of these partnerships have outlasted the project. Individual project members built up their own partnerships, especially universities with CG centres, government departments and NGOs. This has led to cross-fertilisation and benefits to university curriculum, other research initiatives and so on. The methodology used by WaterNet as a network in developing the concept note and proposal, assembling the PN17 partnership and managing the project is serving as an excellent example as a way for us to facilitate our members to access international research programs. WaterNet is establishing other research projects in the same fashion.

A: INTRODUCTION

1 General Introduction

The main goal of the Challenge Program on Water and Food Project 17 (PN17) was to contribute to improved rural livelihoods of poor smallholder farmers in the Limpopo Basin. This goal was achieved through the development of an Integrated Water Resource Management (IWRM) framework for increased productive use of water flows and risk management for drought and dry-spell mitigation at all scales within the basin. The project also had a strong bias towards human capacity building which was fully integrated into all research activities. The research project was carried out in three pilot catchments using three approaches: Farmer Field Based Action Research (FFBAR) using technologies such as conservation farming and nutrient management to increase crop yields; Water Resources Research where rain, surface water and groundwater flow partitioning was characterized; and Institutional Research which developed appropriate institutional models for water governance and strengthened institutions and policies for water productivity and risk mitigation. The was implemented by 14 partners who were made up of two consultative groups of international agricultural research (CGIAR) centers, 10 national research centers (NARES), one agricultural research institute (ARI) and 1 non-governmental organization (NGO). The project covered three countries, South Africa, Mozambique and Zimbabwe. The project was originally planned to be carried out over four years. However, a no cost extension was granted for an extra year to allow for project completion.

Figure 1 shows the Limpopo basin and the location of the research sites where detailed studies were carried out. The basin covers mostly semi-arid regions with a mean annual rainfall of 530 mm (range 200 -1200 mm) (Harrington et al, 2004). Baseline data on water resources, agriculture and institutions was collected from some of the research sites using various methodologies. The main idea was to have background data for the main research studies. A few challenges were faced; hence some of the data was collected towards the end of the project.

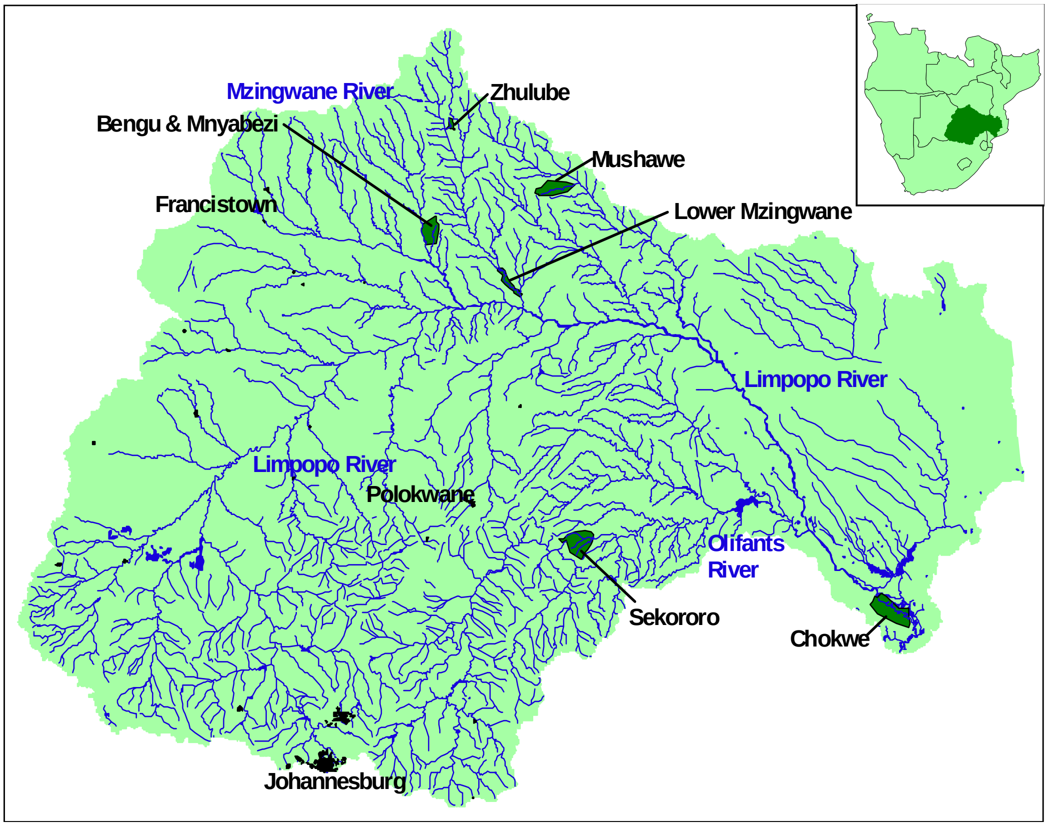

Figure 1: PN17 study sites in the Limpopo Basin. The research sites where detailed studies were done are shown.

2 Agriculture and Land Management Challenges

Agricultural production in the Limpopo Basin is hampered by poor soil fertility, poor access to water resources and low infrastructure development. Rainfall is unreliable making rain-fed farming very risky, and droughts are common during the crop growing season (Butterworth *et al.*, 1999; Twomlow and Bruneau, 2000; Unganai and Mason, 2002).

Access to water for agricultural production is poor due to unavailability of appropriate water sources, but at times the problem is that of unequal access to the resources, a case in point being large commercial farms having good access to water and infrastructure, while small holder farmers lack even drinking water.

Maize is the dominant crop that is grown under rain fed conditions in the basin despite the dryness. Other crops include sorghum, millet and legumes such as groundnuts and bambara nuts. An example of common farming systems in South Africa and the challenges that are faced are indicated in Table 1.

Table 1: Challenges facing rural farmers in South Africa

Farming Systems	**Challenges**
Emerging farmers	1. inadequate knowledge 2. shortage of capital 3. poor marketing arrangements
Irrigation schemes	1. shortage of water 2. dilapidated fences 3. uncontrolled livestock movements 4. shortage of farm inputs

Farming Systems	Challenges
	5. lack of draft power 6. Poor marketing arrangements 7. Pests
Hillside farmers	1. lack of access routes 2. destruction of crops by livestock 3. pests
Dryland farmers	1. low erratic rainfall 2. destruction of crops by livestock 3. shortage of draft power

The major agricultural issues that were addressed within the basin included improving crop productivity using low input systems such as conservation agriculture, improving water availability to crops through rainwater harvesting and supplemental irrigation. Farmer-Field Based Action Research involved the valuation of conservation agriculture, rainwater harvesting and field-testing of different nutrient and soil salinity management regimes in order to identify successful innovations and improve household food security.

3 Water Resources Management Challenges

3.1 Rainfall and Evaporation

Rainfall is seasonal, falling mainly between October and March. Rainfall is lowest in the upper Limpopo, with mean annual rainfall of 250 mm per annum in Botswana and 500 mm per annum in southwestern Zimbabwe. Within Zimbabwe, mean annual rainfall per hydrological subzone ranges from 415 to 633 mm per annum and mean annual evaporation from 1836 to 2034 mm per annum. The rainfall pattern is characterised by very high inter-annual variability. Data is generally scarce on the Mozambican side of the Lower Limpopo. However, the rainfall generally decreases from the coastline towards the inland. In South Africa, mean annual rainfall ranges from 481mm to 1316 per annum (Figure 2).

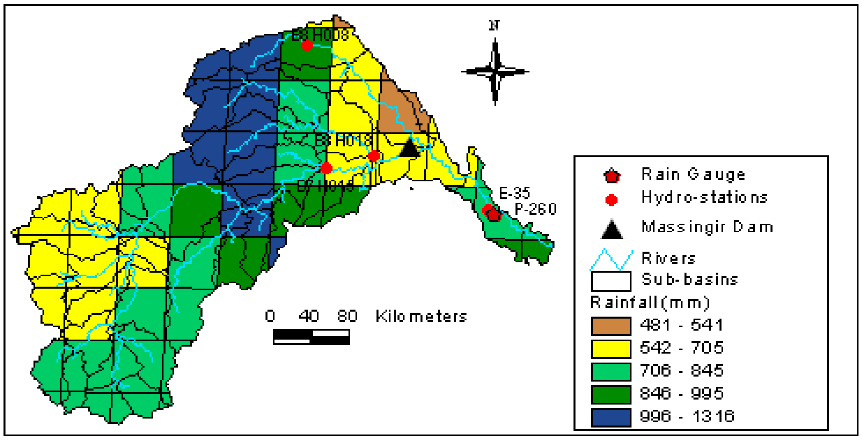

Figure 2: Spatial distribution of rainfall in the Olifants, a major sub basin of the Lower Limpopo.

3.2 Surface Water Availability

Rainfall is seasonal; as a result, greatest surface water flows occur between October and March. In the Mzingwane catchment, mean annual runoff is generally low (Figure 3), with high inter-annual variation. Most of the sub zones have low values of base flow index, less than 0.20, with almost all streams flowing during the wet season only. Figure 4 shows average annual runoff for Thuli River from 1959 to 2002.

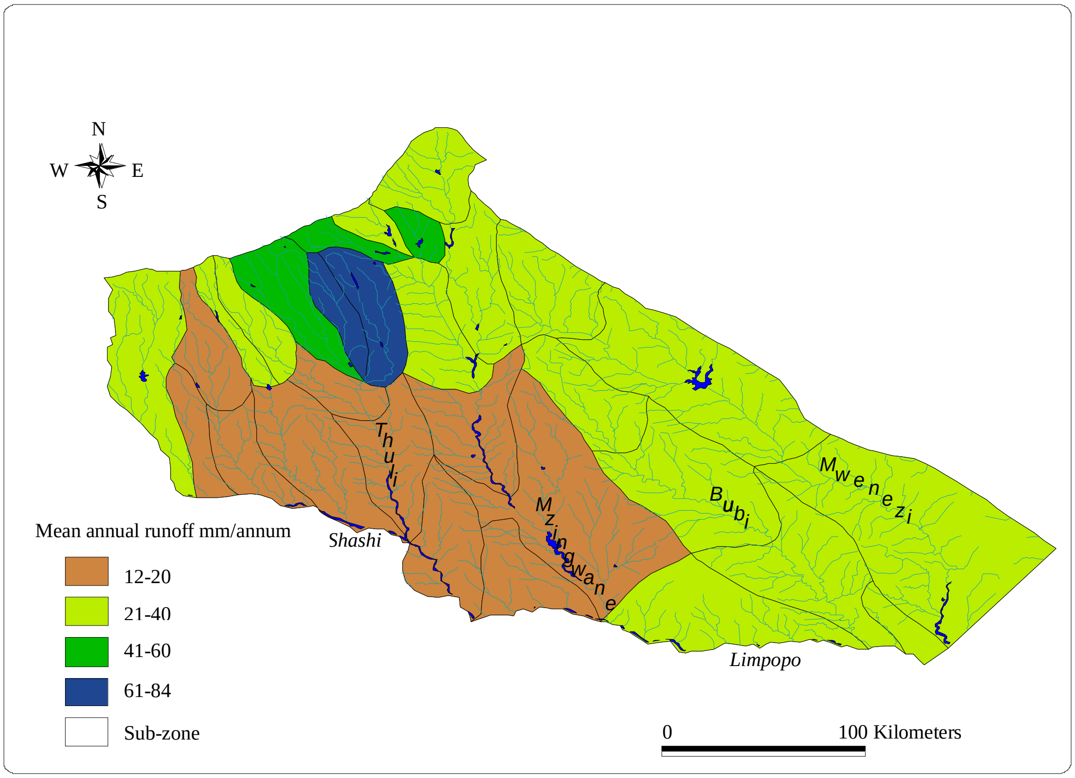

Figure 3: Mean annual runoff of sub-zones of the Mzingwane Catchment.

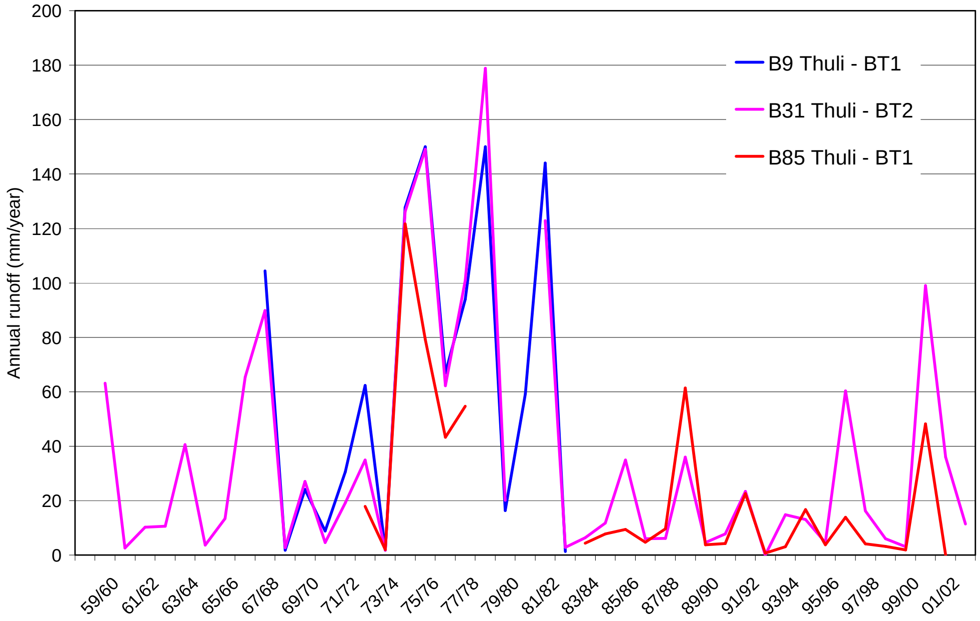

Figure 4: Variations of annual flow at three stations on the Thuli River in the Mzingwane Catchment.

3.3 Hydrogeology

The geology of the basin is dominated by the Limpopo Mobile Belt, a high grade metamorphic zone that lies in the collision zone between two Archean continental shield areas, the Zimbabwe craton to the north and the Kaapvaal craton to the south. Due to the metamorphism that resulted from the collision, these rocks have very limited primary porosity and permeability. Groundwater occurrence is largely restricted to secondary features such as fault zones, joints, lithological contact zones and regolith zones of deeper weathering that occur in favourable sites. Hence, limited groundwater supplies are available from these lithologies and no large scale development potential is anticipated.

The craton areas consist of a variety of ancient pre-Cambrian lithologies, including sediments; felsic, mafic and ultramafic igneous rocks. Most of these rocks have been metamorphosed to low grade metamorphic rocks. Groundwater occurrence in the craton areas is also restricted to secondary features as described for the Limpopo Mobile Belt rocks above, and yields are generally moderate. Occurrence in the individual rocks varies with rock type. In cases of mafic igneous rocks, the depth of the weathered regolith tends to be deeper, resulting in enhanced groundwater conditions. Meta-sediments and felsic igneous rocks, by contrast, generally have more limited chemical weathering, and the regolith tends to be thin and unproductive. However, particularly for the South Africa side of the basin, there are some limestone / dolomite sequences with the development of karst that can produce very high groundwater yields from sub-surface solution channels. In addition there are several brittle quartzite units within the sedimentary sequences that can provide a significant degree of secondary permeability and resultant high yields.

Overlying the two cratons and the Limpopo mobile belt are limited outcrop areas of Phanerozoic sediments from the Karoo and Kalahari groups. These sediments tend to have primary porosity and may be useful aquifers, depending on permeability considerations. Recent alluvial channel fill also provides an attractive exploitable groundwater resource in these areas.

To the east, the Mozambique part of the Limpopo basin consists almost entirely of younger sediments that have primary porosity and permeability. These include marine sequences, coastal dunes, as well as fluvial sands and argillites. The groundwater development potential of many of these units may be considered as high, although water quality issues have been reported in some cases, particularly high salinity.

3.4 Water Chemistry

The overall mineralisation of groundwater resources is not extremely high, but the variability is high, especially in the mining areas of the basin. The water chemistry problems are similar (salinity, nitrates and metals) throughout the basin due to the fact that the countries have similar hydrogeological units and similar activities taking place. The water quality in most places is related to the geology and variety of water chemistry observed is caused by various factors such as the chemistry of the host rock aquifer and residence time, which are mainly controlled by lithology and geological structure. In most of the cases, the hydrochemistry of alluvial aquifers is very similar to that of the surface water flowing above.

The main water quality problems in Zimbabwe and Botswana are natural salinity and localized fluoride, phosphorous from sewage and urban waste water and copper and cadmium from base metal mining. Mercury pollution from gold panning is a particular problem in Zimbabwe, although very localized. Mozambique shows major problems with salinity, as well as metal contamination in the lowland rivers. South Africa has similar problems to Botswana with natural salinity and localized fluoride, as well as major acid mine drainage (acid, metals and sulphate) in the coalfields. Elevated levels of cadmium in all four riparian countries are a cause for concern (Figure 5).

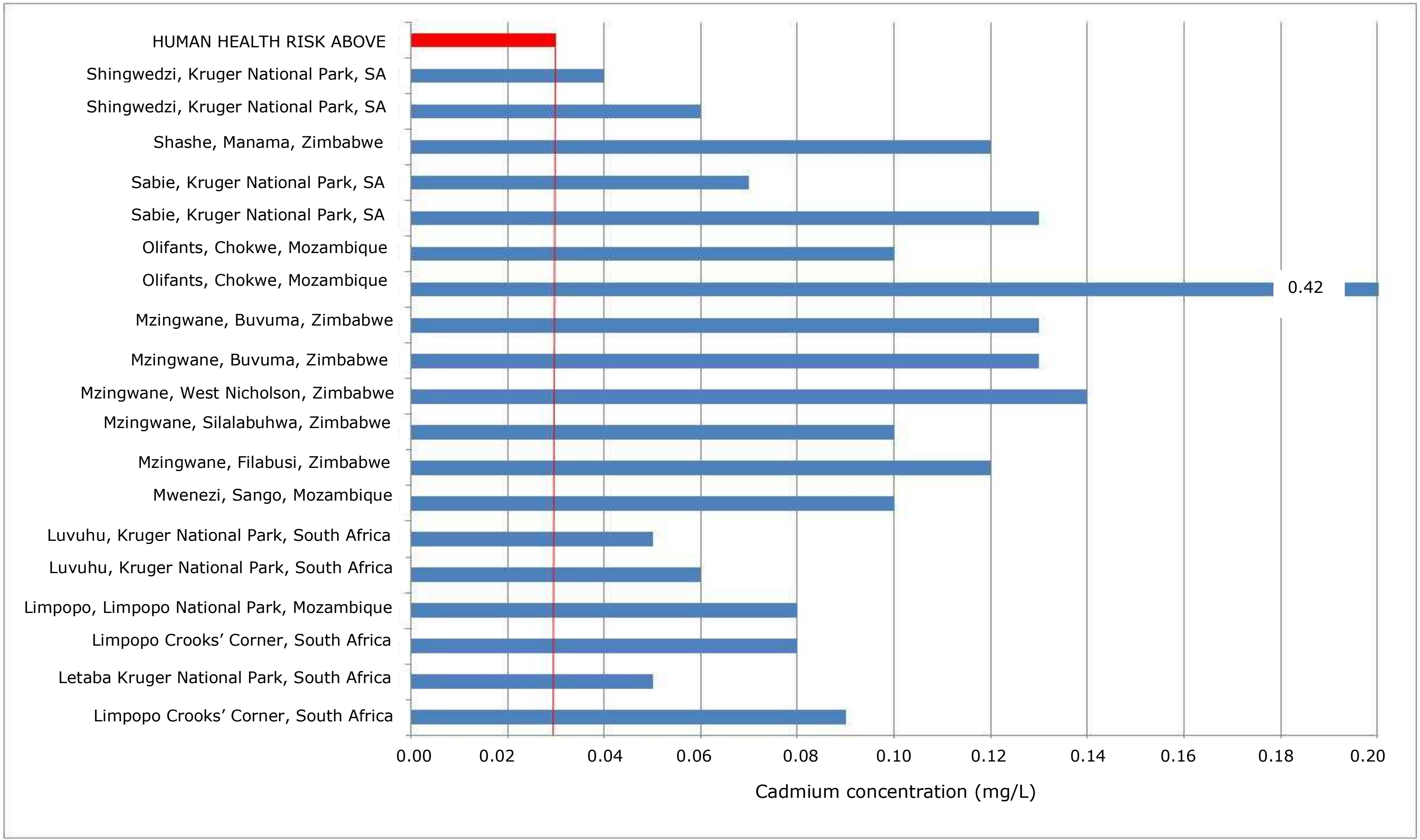

Figure 5: Summary of dissolved cadmium levels in the Limpopo Basin: sample locations identified by catchment, locality and country.

4 Socio-economic context of the Limpopo basin

4.1 Population

Population data was collected from three catchments within the Limpopo Basin, namely the Mzingwane in Zimbabwe, Olifants in South Africa and Chokwe in Mozambique. This was in line with objective 1.2.4 of the project proposal that required that a population data base covering the three selected catchments be completed, in recognition of the importance of water and land use planning management, livelihoods, development programs and research projects being based on current demographic features. The database was developed as part of the general baseline data that was undertaken by the Centre for Applied, Social Sciences (CASS), University of Zimbabwe.

At project formulation, there was a presumption that published population census and inter-census reports, among other secondary data sources would be used in order to fulfil the objective. It was also presumed that research partner institutions within PN 17 would work with the Centre for Applied Social Sciences in consolidating population data in the three catchments. Consolidating data from relevant partners proved to be a difficult task, more than was assumed at project formulation. Apart from Mzingwane Catchment data, it took unexpectedly more communication exchanges through electronic mail and telephone to gather relevant data, and when the data was finally made available it was not necessarily current data. The data was based on the 2001 census for the Olifants Catchment and the 2002 census for the Mzingwane Catchment.

As a result the researchers used whatever was available to generate the population database report. Out of the three catchments, only Mzingwane had complete population data on comparable population variables namely total population, male and female population and sex ratio. In the Olifants and Chokwe Catchments population data for other wards was absent. Unlike Mzingwane and Olifants catchment, shape files for the least geographical boundaries corresponding to population variables were not in polygon format. Available data for Chokwe Catchments could best be presented as a density map. The report therefore simplified population data presented in the Geographical Information System (GIS) format as a project with shape files, created maps and tables of population variables relating to the three Catchments. Figure 6 shows total population data for the three catchments, Mzingwane, Olifants and Chokwe.

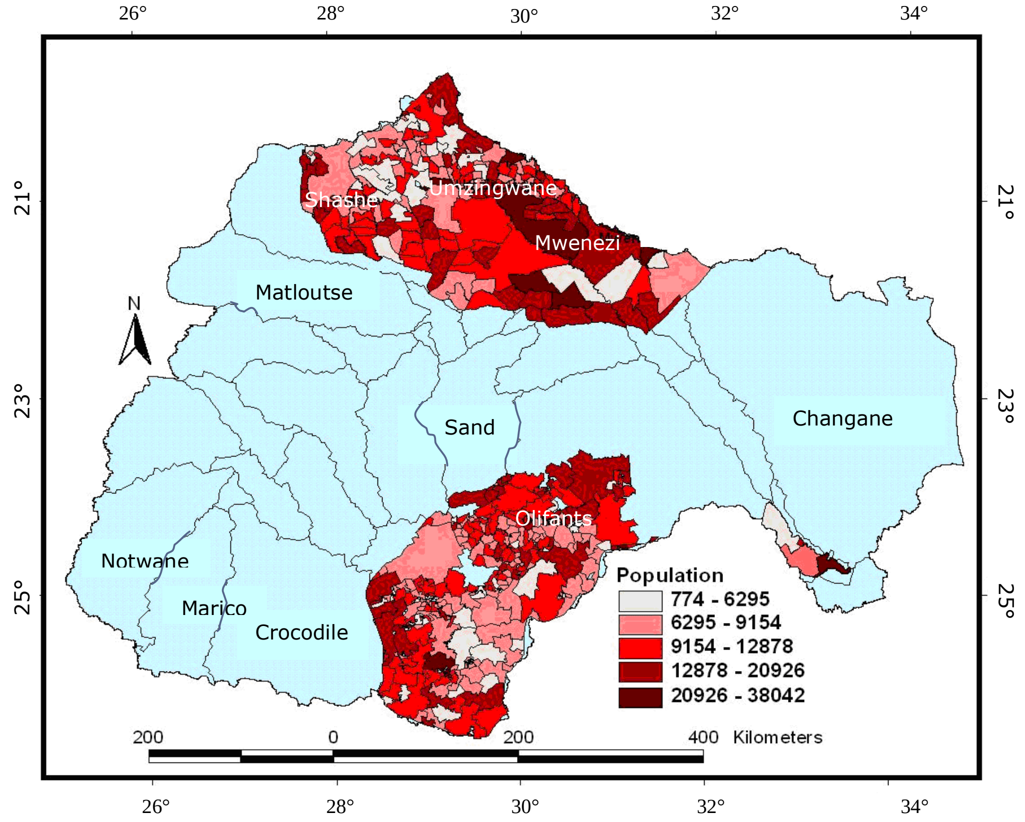

Figure 6: Population data for Chokwe, Mzingwane and Olifants Catchments

Total population was the only variable available for each of the three catchments. Areas of the highest population totals were found in the Mzingwane Catchment compared to Chokwe and Olifants.

Some variables could be compared between the Olifants and Mzingwane Catchments where more data was available. There were more females than males and the highest population fell within the 15-34 age categories in both catchments. Males constituted 48 % while 52 % were females. In the Mzingwane Catchment, 67 % of the wards had a sex ratio of less than 100 while 33% had a sex ratio of more than 100. Of the 2 763 375 people in the Olifants Catchment in 2001, 53 % were females while 47 % were males. 15 % of wards had a sex ratio of between 101 and 187 and while 85 % of the wards had a sex ratio ranging from 70 to 100.

More information on the population database can be found in the WaterNet website http://www.waternetonline.ihe.nl/.

4.2 Socio-economic constraints and opportunities for agricultural production

4.2.1 South Africa

A survey of socio-economics of smallholder farmers, complemented by secondary data that focused on an assessment of farming systems, land tenure and current agricultural water management practices, was undertaken in the quaternary catchment B72A of the Olifants basin. The study area incorporated the Maruleng local municipality in Mopani District Municipality, which is part of the Sekororo and Letsoalo tribal authorities. A large part of the catchment (80%) falls in the former Lebowa homeland. The area is estimated to have a total population of around 56 000 inhabitants, and is characterized by high population densities, poverty and unemployment. The main sources of income are state pensions and welfare grants. Small scale subsistence agriculture provides a small part of the food requirements.

Household size in the study area varied between 3.8 and 4.96-16. People under the age of 15 accounted for 43% of the population. Females outnumbered males across all age groups. Head of households had an average age of 54.4 years. Female headed households accounted for 64% of the sample, and constituted 68-70% of the farming population. However female-headed households were found to experience more poverty. For example a household headed by a resident male had a 28% probability of being poor whereas a household with a female head had a 48% chance; with a household with a *defacto* female head having a 53% chance. The main factors that explained the dire situation of female-headed households were the general poverty the rural areas, unemployment, skewed wage differences, fewer assets and low formal education, high incidences of HIV/Aids, and poor skill base.

4.2.2 Mozambique

Two socio-economic surveys were undertaken in the Lower Limpopo. The first survey was designed to identify the current agricultural and water management practices for food production used by smallholder farmers in Mabalane District and the Administrative Post of Combomune. The climate in the area is semi-arid with two distinct seasons: a rainy and hot season occurring from October to March; and a dry and cold season from April to September. The mean annual rainfall during the rainy and hot season varies from 360 to 470 mm. In the dry and cold season rainfall varies from 30 to 120 mm. Average temperatures ranges from 21-31^{o}C and 15-28^{o}C during the rainy and dry seasons, respectively. A total of thirty (30) families were randomly selected and interviewed. The survey covered issues such as farm characteristics, household characteristics, labour availability, main crops grown, agricultural practices, and water consumption patterns.

The average water consumption in the study area was found to be about 160 litres per day for a family of eight (8) members. Sources of water were located at 7.7 km from the homesteads. Rural water supply and sanitation are also a deficient in the region. The average number of farms per household is three (3) and no improved inputs are used. The use of animal traction in farm activities is common although mechanization is generally a major limitation. The major crops that are grown are maize, cowpeas, groundnuts, cassava and are mostly cultivated under a mixed cropping system. Pest and disease management during production and post-harvesting represents a threat. Besides agriculture, charcoal production constitutes the major source of income for the local communities. Dry climate conditions, including rainfall variability, increases the risk of crop lost due to occurrence of long dry-spells during the growing season.

The second survey had the same objectives as the first, namely to identify the current agricultural and water management practices for food production used by smallholder farmers in the Lower Limpopo. The study area covered the Administrative Posts of Chicumbane, Chonguene, and Mazivila. The climate is semi-arid with two distinct seasons. The rainy and hot season occurs from October to March while the dry and cold season is from April to September. The mean annual rainfall during the rainy and hot season varies from 650 to 760 mm. In the dry and cold season rainfall varies from 260 to 360 mm. Average temperatures ranges from 21-31^{o}C and 15-27^{o}C during the rainy and dry seasons, respectively. A total of thirty (30) families were randomly selected and interviewed (semi-structured interviews) according to their relative location in 13 areas of the Districts of Xai-Xai and Bilene. These families also matched the sub-areas high (i.e., sandy soils) and low (i.e., clay and organic soils "*machongo*[1]"). The survey covered issues such as farm characteristics, household characteristics, labour availability, main crops grown, agricultural practices, and water consumption patterns.

The average water consumption in the study area was found to be about 21 litres per day. Sources of water were located 2.6 km from the homesteads. The average number of farms per household was three (3). No improved inputs were used. There is evidence of use of animal traction and mechanization is a problem. The major crops that are grown include maize, cowpeas, sweet potato, banana, sugar cane, cassava and are mostly cultivated under a mixed cropping system. Pest and disease management during production and post-harvesting is a threat. Besides agriculture, fishing and charcoal production also constitute the major livelihoods activities.

4.2.3 Zimbabwe

A socio-economic survey was undertaken in Mangwe, Insiza, Mwenezi and Beitbridge districts. The sample consisted of 240 households. Data was collected through a questionnaire and PRA techniques. Most households were found to be involved in informal, petty trade. Low education levels were said to be a problem. The diverse cultural traditions as a result of the various ethnic groups present a set of challenge that has to be overcome. While women were found to participate in water and soil conservation measures and were better educated, they wielded little power in decision making.

Livestock rearing was identified as an important activity in the area and is more popular than crop production because it is affected less by inter and intra-seasonal variability. Cattle ownership was low with the majority of the population claiming to own 2 herds of cattle. This was in part attributed to the 1991/2 drought, as well as lack of markets.

Access to plots ranged from 0-5 hectares. Maize yields are low (2 300kg/tonne). Millet and sorghum are also grown. The popularity of these varied from district to district. In some areas farmers were not keen on growing drought tolerant sorghum and millet despite the low rainfall that characterized the area. Conservation agriculture (CA) was spearheaded by non-state actors such as Non-Governmental Organizations (NGOs). The CA message was very variable and was not an easy sale to farmers.

The participation of various NGOs intervened in agricultural production, while welcome, had the net effect of taking over poorly funded public extension services. Consequently there is a need to ensure the coordination of the various institutions that were in the area. Major water uses in the area included small and large irrigation schemes, gold panning, stock watering, tourism, fishing, and boating.

The sources of food in Table 2 show the different potential of agricultural products across the districts. The two districts where people produced their own food were wetter.

Table 2: Sources of food in Mzingwane catchment

District	**Source of food**
Beitbridge	Purchase
Mwenezi	Purchase
Insiza	Own production
Mangwe	Own production

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[1] In the Administrative Post of Chonguene these soils occupies a total area of about 4 500 ha.

5 Conclusions

Across all the countries it was clear that agricultural production and water management were affected by a combination of physical and socio-economic factors. Generally low precipitation levels limited rainfed agriculture more than soil type. Low levels of developed water resources resulted in low areas under irrigation. Irrigation could have changed the potential of agricultural production. Socio-economic factors that affected agricultural production and water management included widespread poverty as reflected by a low asset base and poor incomes, among other factors. The feminization of agriculture also contributed to poor agricultural production because of the cultural limitations society placed upon the women. Against such a background agriculture was not the main livelihood option. In South Africa government provided the bulk of income which was not the case in weak economies of Mozambique and Zimbabwe. All the socio-economic factors that were identified as limiting agricultural production and water use can be reduced to the absence of strong institutions. Generally there was poor coordination of institutions. In Zimbabwe lack of financial resources undermined public extension services, which contributed to Zimbabwe‵s smallholder agricultural revolution that was achieved in the first two decades of independence.

B: PROJECT OBJECTIVES

The main objectives of the project were:

1) Developing adoption and adaptation of water management practices among smallholder farmers that reduce risk, and which, together with integrated farm systems management (addressing particularly soil fertility and crop management) improve farm/household income and water productivity.
2) Development of appropriate catchment management strategies based on IWRM principles that incorporate sustainable use of green and blue water resources, which enables poor rural people to reduce risk of food deficits due to water scarcity, and to manage water for improved livelihoods.
3) Develop institutional models for water governance that aim at strengthening policies for water productivity and risk mitigation at catchment and basin scale.
4) Human capacity building among farmers, extension officers, water managers and researchers at local universities in the Limpopo Basin and in Southern Africa.

The research thrust of the project was to build evidence that improving water management through the IWRM paradigm has the potential to improve rural livelihoods from the basin (trans-boundary) scale down to the field scale (farmers).

1 Objective 1: Adoption and adaptation of water management practices among smallholder farmers that reduce risk, and which, together with integrated farm systems management (addressing particularly soil fertility and crop management) improve farm/household income and water productivity.

1.1 Introduction

1.2 Conservation Agriculture

1.2.1 Zimbabwe

1.2.1.1 Methods

Conservation agriculture (no till and reduced tillage) practices were studied as methods that simultaneously conserve soil and water resources, reduce farm energy usage and increase or stabilise crop production. In Zimbabwe the first conservation agriculture objective was to determine the interaction effect of tillage (single and double ploughing, ripping and planting basins) and nitrogen (0, 10 and 20 kg N ha^{-1}) on crop yields and soil water balance on farmers' fields (Mupangwa, 2009). In the second objective an on-station experiment was established to assess the effect of conservation agriculture practices on crop yields and soil water balance. Three tillage techniques (single ploughing, ripping and planting basins) and seven mulching levels (0, 0.5, 1, 2, 4, 8 and 10 t ha^{-1}) were combined factorially to assess their influence on maize, cowpea and sorghum yields, and soil water dynamics (Mupangwa *et al*., 2007; Mupangwa, 2009). The smallholder farmers also appraised the tillage systems at the end of the last growing season of the study. Lastly, the crop simulation model Agricultural Production SIMulator (APSIM) (Keating et al., 2003) was used to evaluate its capability in predicting effects of conventional, ripper and planting basin tillage techniques on soil water patterns; and to use the validated APSIM model to assess the long term (69 years) interaction effects of N fertilizer, and conventional and planting basin tillage systems on maize yields, surface runoff and deep drainage (Mupangwa *et al.*, 2008).

1.2.1.2 Results and Discussion

Results from the on-farm experimentation showed that the double conventional ploughing combined with nitrogen fertilizer outperformed the other three tillage systems regardless of the rainfall pattern experienced during the growing season. Nitrogen fertilizer increased maize yields and water productivity in each season across all four tillage systems tested. The planting basin system had higher maize crop establishment at most farms during the period of experimentation (Mupangwa, 2009). Surface runoff measurements indicated that planting basins gave the lowest seasonal runoff losses regardless of soil type and field slope (Figure 7). Despite the below average rainfall of 328-353 mm during the period of experimentation (2006/07 and 2007/08 seasons), planting basins consistently gave the highest soil water content particularly during the first half of the cropping period. However, the reduced surface runoff and higher initial soil water content was not translated into higher yields under the basin tillage system compared to the other tillage systems. There were no significant ($P > 0.05$) maize yield differences in the four tillage systems regardless of the different rainfall distribution each season (Mupangwa, 2009).

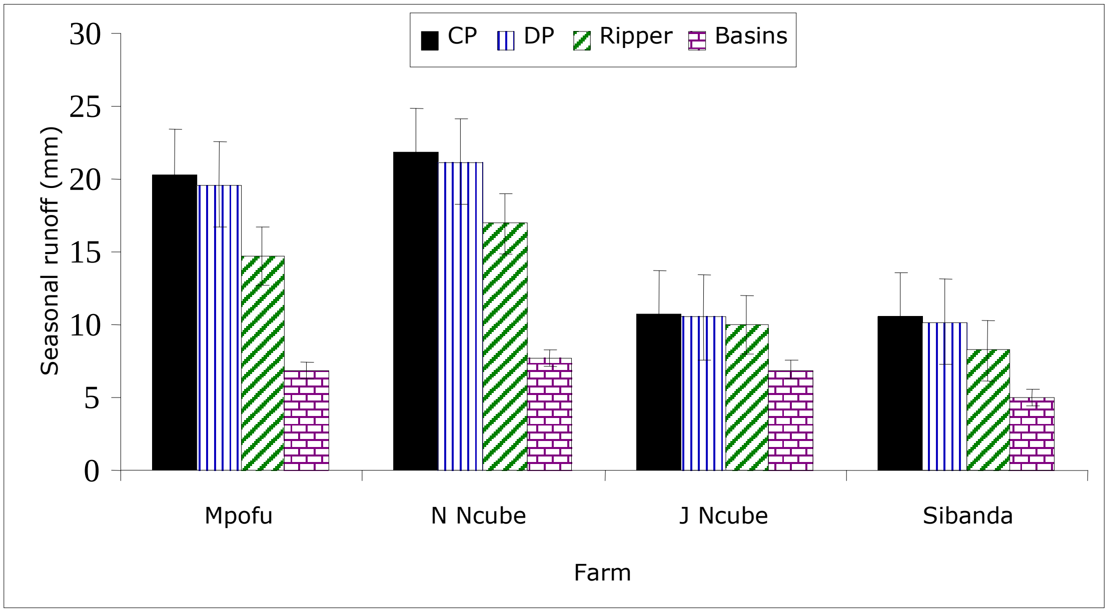

Figure 7: Seasonal runoff measured under each tillage treatment at Mpofu, N Ncube, J Ncube and Sibanda farms in Insiza and Gwanda Districts (adapted from Mupangwa, 2009). Data are means of 11 rainfall events that generated measurable runoff from each tillage treatment during the 2007/08 cropping period. Vertical bars indicate standard error of means. CP = conventional practice; DP = double ploughing.

The results from the study indicated that planting basins do have the potential to: i) promote infiltration of rainwater, ii) minimize soil, water and nutrient losses from the field, iii) reduce siltation and pollution (by agrochemicals) downstream of the fields, and iv) increase groundwater recharge as soil water is lost through deep drainage especially on sandy soils. However, during high rainfall seasons problems of water logging (depending on the soil type) might occur and affect yield. High surface runoff from each tillage system is likely during seasons with above-normal rainfall on the predominantly sandy soils of Gwanda and Insiza districts.

The on-station experiment showed that mulching had a significant influence on maize grain production across the three tillage systems in seasons with below average rainfall (Figure 8).

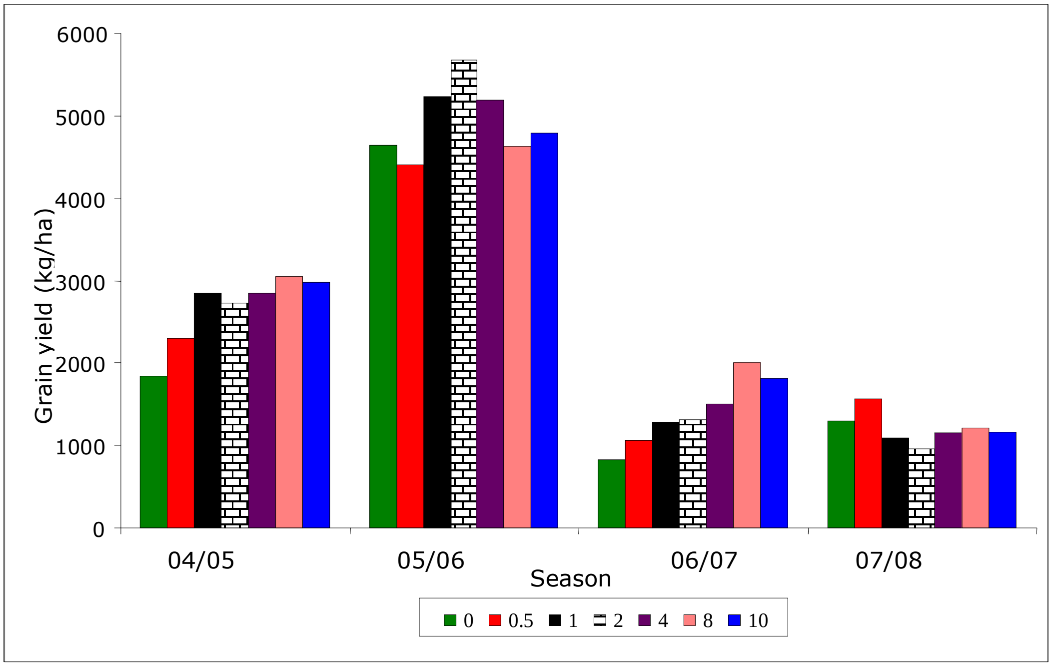

Figure 8: Seasonal and mulching effects on maize grain production averaged across three tillage systems (single ploughing, ripping and planting basins) on a red clay soil at Matopos Research Station. Mulch levels are in kg ha^{-1}.

However, tillage had no significant (P>0.05) influence on maize production and soil water dynamics over the four seasons the experiment was run. Figure 9 shows a comparison of water dynamics for conventional ploughing and basins under different levels of mulching during the 2006/07 cropping season (Mupangwa, 2009).

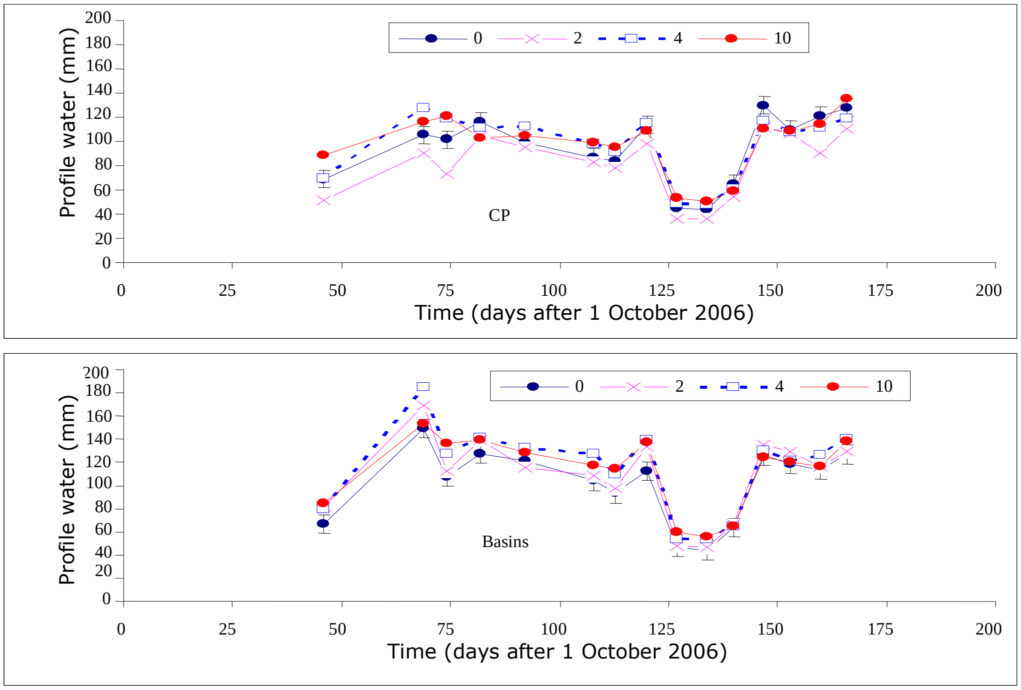

Figure 9: Profile soil water changes in the 0-0.55 m soil layer under single conventional ploughing (CP) and planting basins tillage systems and four mulching levels on a clay soil

during 2006/07 growing season. Error bars represent standard error of the means. Mulch levels are in kg ha^{-1}.

The evaluation of the tillage systems by smallholder farmers at the end of the study revealed that labour demand and crop yields are major factors considered by smallholder farmers when selecting a technology for adoption. The majority of the farmers achieved the highest crop yields from the double ploughing system; hence they ranked it as the most appropriate tillage system to use under their conditions (Mupangwa, 2009).

The long term assessment of the basin system through simulation modeling using the Agricultural Production SIMulator (APSIM) model revealed that basins give only marginal maize yield benefits over the conventional system regardless of the nitrogen level used. The long term simulation also indicated that crop failures can be experienced in both conventional and basin systems due largely to uneven distribution of rain events during the growing season (Figure 10).

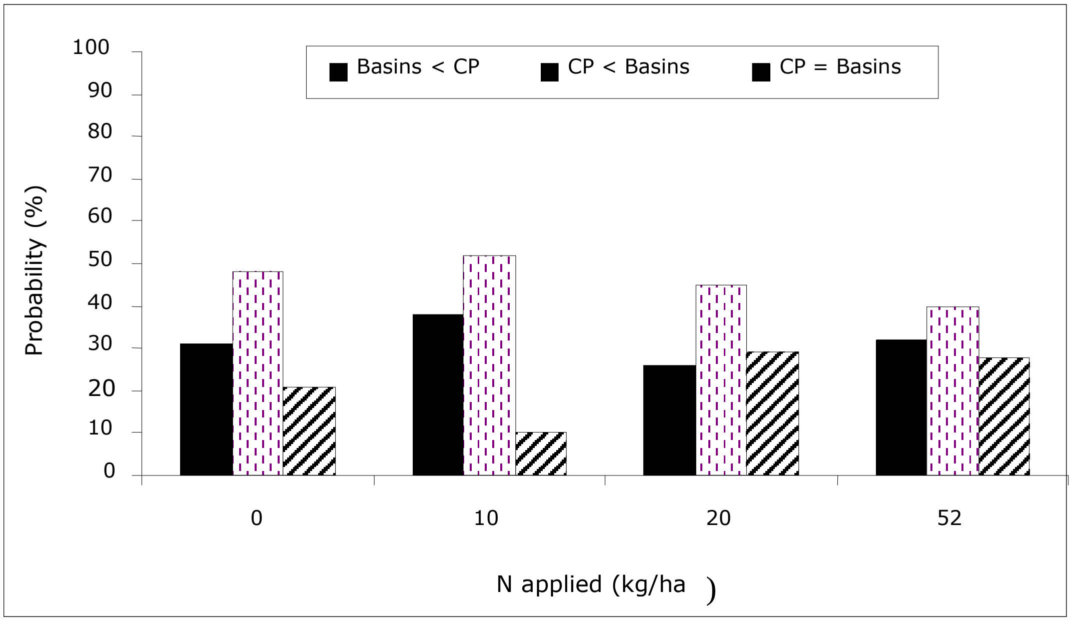

Figure 10: Probability of getting maize grain yield under two tillage systems (conventional ploughing and planting basins) and four N application rates (0. 10, 20 and 52 kgNha^{-1}) over a 69 year period on a sandy soil under semi-arid conditions

The basin tillage system had higher chances of giving yield than the conventional system regardless of N level used. There was a 48 % chance of getting grain yield without N fertilizer in the basin system compared with 31% in the conventional system. At 10 kgNha^{-1} the chances of getting higher grain yield from the basin system than the conventional system increased to 52%. The predicted grain yield suggests that the use of 10 kgNha^{-1} in both the conventional and planting basin systems is a good entry point for improving productivity in the cereal dominated semi-arid cropping systems of Zimbabwe. This confirms earlier results from the wide scale promotion of inorganic fertilizer which was conducted in semi-arid districts of Zimbabwe (Twomlow *et al.*, 2008a). The chances of getting similar maize yields from the conventional and basin tillage systems increase at N application levels greater than the microdosing rate (10 kgNha^{-1}) (Mupangwa, 2009).

1.2.1.3 Conclusions

The on-farm study demonstrated that double ploughing gives higher crop yield with similar soil fertility inputs than single conventional ploughing, ripper and basin tillage systems. The study clearly highlighted the fact that both soil water and fertility management are required at the same time in the smallholder cropping systems of southern Zimbabwe. The on-farm and on-station results indicated similar soil water dynamics in the tillage systems tested regardless of the soil type and mulching level applied. The planting basin system significantly reduced surface runoff water losses from cropped fields. Unfortunately the benefit of reduced surface runoff from the planting basin system was not translated into higher maize yield in the on-farm experimentation. Maize grain production was significantly influenced by mulching in growing seasons with below average rainfall. The farmer evaluation of the tillage systems promoted over three growing seasons in Gwanda and Insiza districts revealed that smallholder farmers considered labour demand and crop yields derived from the tillage systems. Smallholder farmers with draught animals were prepared to continue using the DP tillage system. The long term simulation of the promoted technologies suggested that a combination of planting basins and 10 kgNha^{-1} reduce production risk under semi-arid conditions of southern Zimbabwe.

1.2.2 Mozambique

1.2.2.1 Methods

Studies were carried out in three locations within the Chókwè District to assess maize and cowpea yields on Zai Pits (a variation of planting basins), in comparison with the same crops produced under farmers' practice (control), i.e. mixed cropping systems (maize intercropped with cowpea, cassava) using conventional tillage (Mamade, 2006). The dimensions of the Zai pits were about 0.6 m diameter and 0.3 m in depth. Four to eight seeds of maize or cowpea were sown in each pit. The planting density in the pits treatment was half that of the control.

1.2.2.2 Results and Discussion

The maize grain yield was 14 and 111 kg ha^{-1} for the control and pits respectively. Although the yields were very low in both treatments, the pits increased yield 8-fold. Grain yield of cowpeas was 92 kg ha^{-1} and 131 kg ha^{-1} for the control and pits, respectively. The Zai pits tended to increase water availability in the root zone especially in loam-clay soils. On sandy soils, the technique had some limitations probably due to poor soil structure (low water holding capacity). The surprising result from these studies was that 21% of farmers (including those who were already implementing before these studies) in the study area have adopted the pits despite the need for further study (Mamade, 2006).

1.2.2.3 Conclusions

Although the study showed a potential for increased rain water retention by Zai pits, effectiveness depends on rainfall patterns, soil type, crops and other agricultural practices like planting dates and density, and mulching. Further work is required to identify situations where the Zai pits are likely to be beneficial and associated crop management guidelines need to be developed.

1.3 Rainwater Harvesting

1.3.1 General Studies

Rainwater harvesting (RWH) is broadly defined as the collection and concentration of runoff for productive purposes (crop, fodder, pasture or tree production, livestock and domestic water supply etc) (Ngigi, 2003) or the process of concentrating rainfall as runoff for use in a smaller target area (Botha et al., 2003). The rainfall harvested can either be in-field (tillage techniques, pits etc.) or off-field (micro-catchment or runoff farming and supplementary irrigation). Two studies were carried out to assess the potential of rainwater harvesting (RWH) technologies in the Limpopo Basin (Mwenge-Kahinda, 2007; Ncube et al. 2009).

1.3.1.1 Potential impact of RWH on crop yields

The first study analyzed the agro-hydrological functions of RWH and also assessed the impacts (at field scale) on the crop yield gap as well as the Transpirational Water Productivity (WPT). A survey was carried out in six districts of the semi-arid Zimbabwe to assess the types of RWH technologies practiced in the six districts. The Agricultural Production Simulator Model (APSIM) was then used to simulate seven different treatments on crop yield (Control, RWH, Manure, Manure + RWH, Inorganic Nitrogen and Inorganic Nitrogen + RWH) for 30 years on alfisol deep sand, assuming no fertiliser carry over effect from season to season.

The survey results indicated that infield RWH is dominant in the six districts. The most common methods were infiltration pits, tied furrows, dead level contours, potholing and fanya juus. The combined use of inorganic fertiliser and RWH was the only treatment that closed the yield gap. Supplemental irrigation alone not only reduces the risks of complete crop failure (from 20% down to 7% on average) for all the treatments but also enhanced WPT (from 1.75 kg m^{-3} up to 2.3 kg m^{-3} on average) by mitigating ISDS.

1.3.1.2 Assessment of upstream-downstream interactions of rainwater harvesting

A synthesis of rainwater harvesting methodologies studied under PN17 was done by researchers who had carried out the studies (Ncube et al., 2009). The aim was to stimulate thinking on what the impacts of rainwater harvesting might be upstream and downstream of catchments. A methodology flow chart was proposed for systematically investigating the impacts of out-scaling in-field and ex-field rainwater harvesting techniques. The method proposed an analysis of levels of adoption to help identify optimum levels that will maximize land and water productivity while minimizing negative hydrological and ecological impacts at catchment or basin scales (Figure 11).

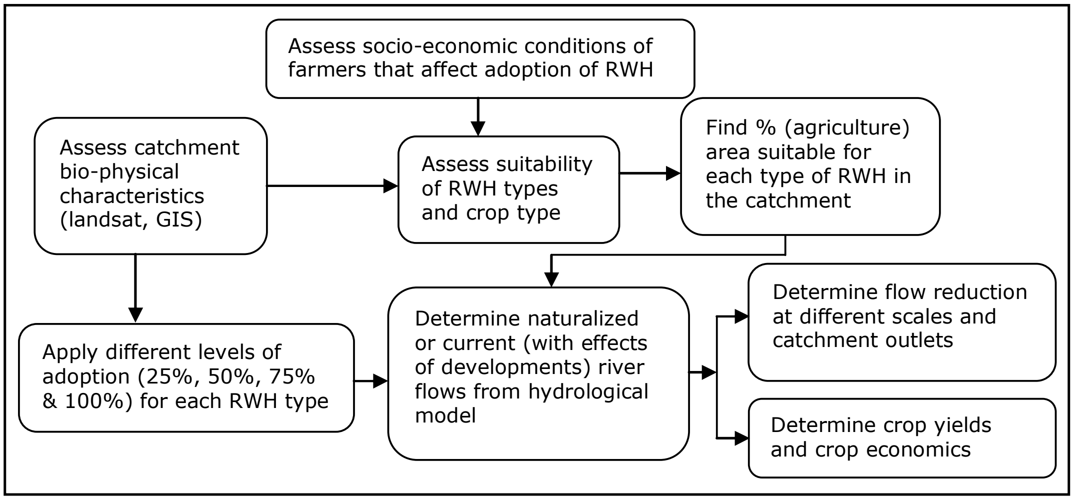

Figure 11: Proposed flow chart for assessment of the impacts of up-scaling rainwater harvesting technologies in the Limpopo River Basin. RWH is rain water harvesting**.**

1.3.2 Rainwater Harvesting Studies – Four Studies in Zimbabwe

1.3.2.1 Methods

In Zimbabwe work on rainwater harvesting technologies focused on the evaluation of contour ridges. The effects of the different types of contour ridges on rainwater harvesting and soil moisture storage were assessed in three separate studies.

The first study was conducted in four farms located in ward 17 of Gwanda district, southern Zimbabwe (Mupangwa, 2009). Two farms had dead level contours only while the other two had dead level contours and infiltration pits. In the 2006/07 growing season a single transect of access tubes was set up across the dead level contours and infiltration pits in conventionally ploughed fields which were under maize, sorghum, pearl millet and groundnut. In the 2007/08 growing season two transects of access tubes, one along a conventionally ploughed field and another along an unploughed field, were set up at each farm in order to separate the effect of tillage from that of contours on soil water measured at each distance from the dead level contour. The 15 mm PVC access tubes were installed at 2 and 7 m from the centre of the dead level contour with/without infiltration pit on the upslope side. On the downslope side of the dead level contour with/without infiltration pit access tubes were installed at 3, 8, 13 and 18 m from the centre of the contour. The access tubes were sunk to depths varying from 0.5 to 0.8 m across the four farms. Depth of access tubes was restricted by the presence of a stony layer in the profile at three of the four farms. At each farm access tubes were installed in October and maintained for the subsequent seasons. The dead level contours averaged 0.9-1.0 m wide and 0.3 m deep across the four farms. The infiltration pits averaged 1-1.5 m long, 0.5-1.0 m wide and 0.3-0.4 m deep across the two farms. During the two growing seasons volumetric soil water content was measured at 0.1m intervals fortnightly using a capacitance probe (MGPHR microgopher sensor, http://www.odysseydatarecording.com). Six to eight readings were taken from each access tube. Soil texture for each farm was determined using the hydrometer method (Anderson and Ingram, 1993). Soil water data were analyzed using the method of residual maximum likelihood (REML) in Genstat version 9 (ref). Data for each season was analysed separately because of differences in the rainfall patterns experienced during the 2006/07 and 2007/08 growing seasons.

Another study in the same area (Gwanda District) explored the importance of biophysical factors on the performance of the dead level contours. A two pronged approach was used, one using a questionnaire survey of 55 practising farmer respondents identified following community meetings, and 14 key informant interviews (Munamati et al, 2009). The other approach involved detailed pedological investigations of soils in the fields of 14 randomly selected farmers who were a subset of the respondent farmers (Nyagumbo et al, 2009). The study therefore sought to explore biophysical conditions (soil type, depth, slope and topographic conditions) that characterize successful *in-situ* water harvesting using dead level contours based on the experiences of practicing farmers in the district. Data analysis involved compilations of responses on roles of soil properties such as soil texture, depth and slope which were juxtaposed to corresponding pedological soil investigations data.

A third study is still in progress. The main objectives of the study are to compare the soil moisture benefits between the standard (graded) contour ridge design that was developed for soil erosion control, and the improved dead level contour design that retains water in the ridge (Mhizha 2009). The study is taking place in five farms in Zhulube (Insiza District). Two basic designs are implemented in each plot, one that prevents runoff water from leaving the field through a contour ridge constructed at a zero gradient and a second one that drains runoff water away from the field through contour ridges constructed at graded slope. There is also a third plot where there are no contours (control). Future studies aim to come up with the most beneficial design of the dead level contour using modelling approaches.

1.3.2.2 Results and discussion

In the first study the soil types at the four farms ranged from sand to loamy sand. The distance from the dead level contour had no significant (P>0.05) influence on profile water content recorded along transect during the 2006/07 growing season (Figure 12 and 13). The lowest profile water content was recorded at 7 m upslope of the dead level contour throughout the season particularly at farms with contours only (Figure 12). Soil water content recorded in the profile differed significantly (P<0.001) between the dates when soil water measurements were made indicating the occurrence of wetting and drying cycles during the growing season.

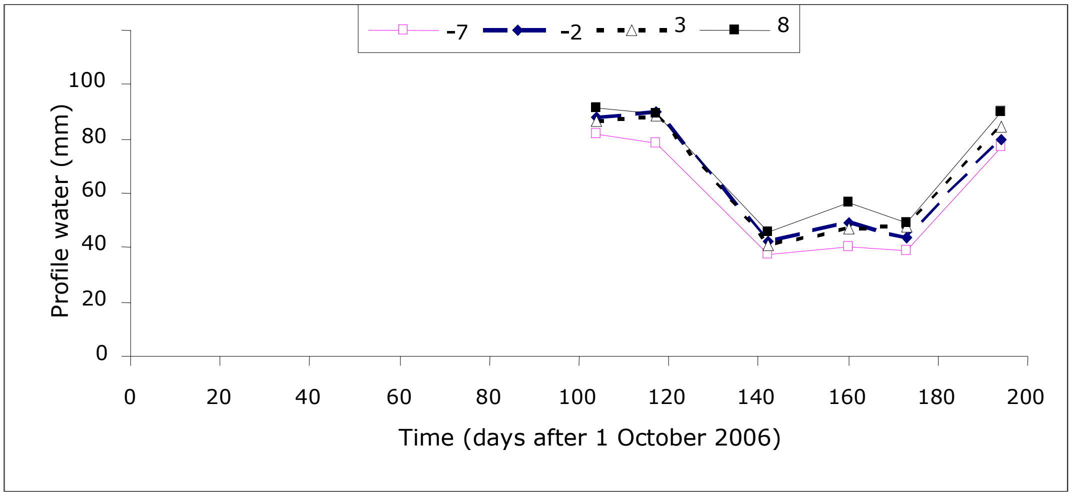

Figure 12: Profile soil water changes along ploughed transects averaged across two farms with dead level contours only along a ploughed transect during the 2006/07 growing season. Distance from the contour was measure in meters.

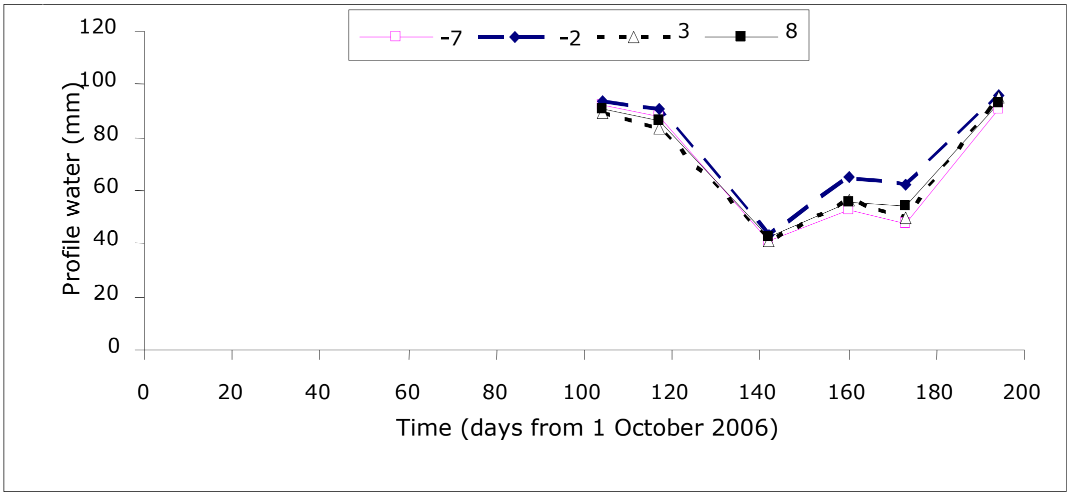

Figure 13: Profile soil water changes at different distances from the dead level contour with infiltration pit averaged across two farms along a ploughed transect during 2006/07 growing season. Distance from the contour was measured in metres.

During the 2007/08 growing season more profile soil water was gained downslope at farms with dead level contours and infiltration pits than at those farms with dead level contours only following a 60-70 mm rainfall event (Figure 14 and 15). This indicates that the dead level contours and infiltration pits at the farms farms captured more rainwater that moved laterally into the field than the dead level contours at the other two farms. The observations at the farms with dead level contours and infiltration pits were consistent with the findings of Mugabe (2004) that also indicated lateral soil water movement upslope and downslope of an infiltration pit measuring 7m long and 1m deep.

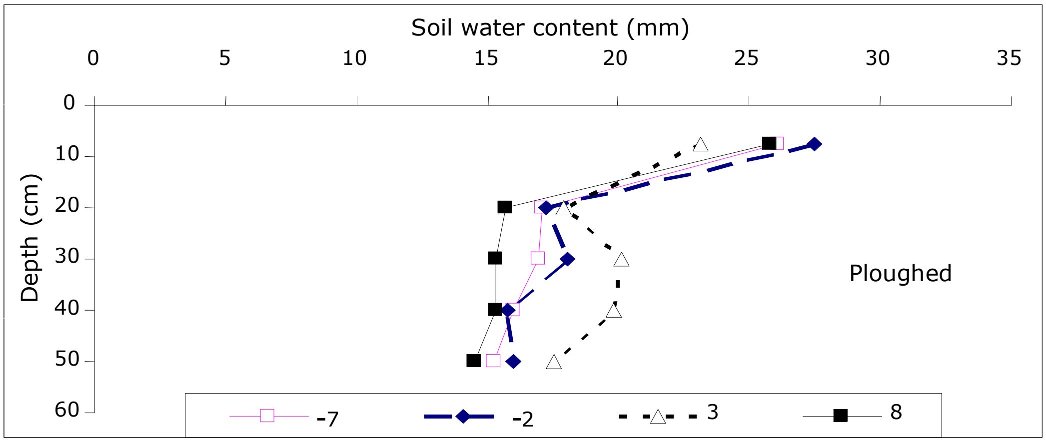

Figure 14: Soil water distribution with respect to depth at different distances from the dead level contour only averaged across two farms on wettest day along ploughed transect during 2007/08 growing season. Distance from the contour was measured in meters.

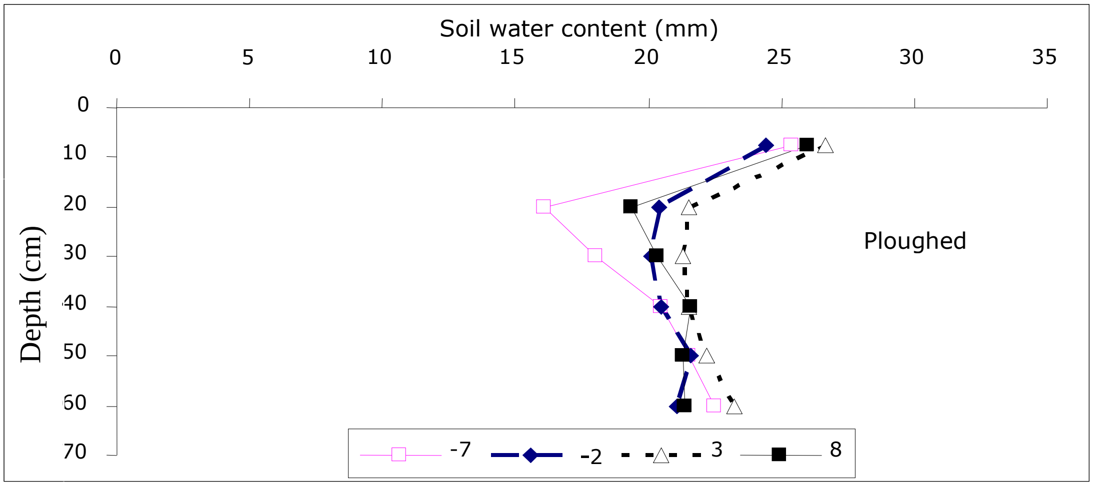

Figure 15: Soil water distribution with respect to depth at different distances from the dead level contour and infiltration pits averaged across two farms on wettest day along ploughed transects during 2007/08 season. Distance from the contour was measured in meters.

In the second study dead level contours were perceived as effective by 72% of key informants in Gwanda District, compared to standard graded contour ridges and other technologies (Figure 16).

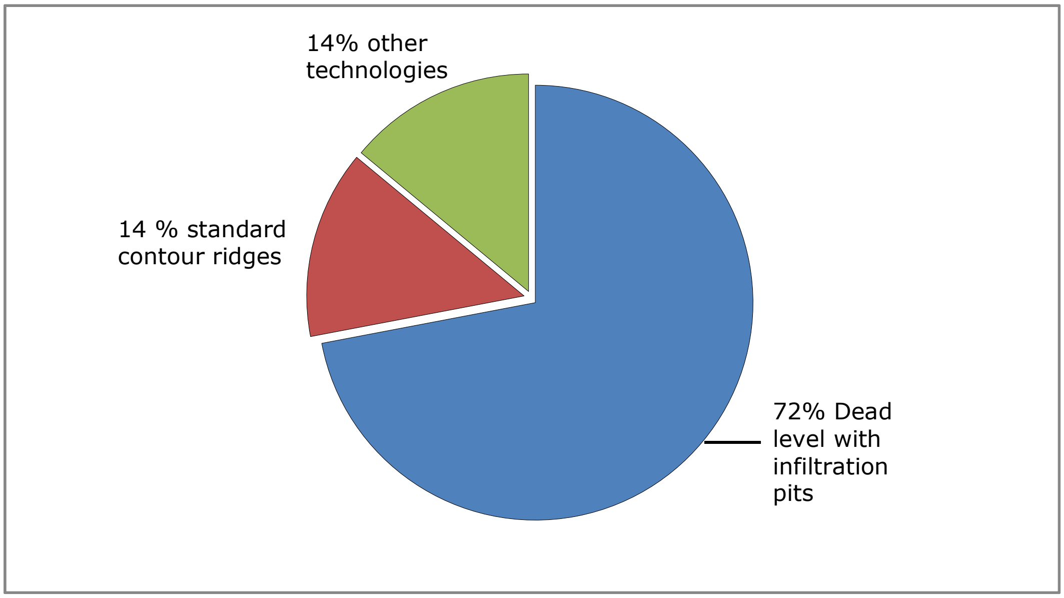

Figure 16: Key informant perceptions of effectiveness of various water harvesting technologies in wards 17 and 18 of Gwanda District, Zimbabwe in 2008. (N=14).

The dead level contour technology forms a significant part of the agricultural system in the study area. A significant linear relationship (r=0.84, *p* =0.000) was obtained between area under rainwater harvesting techniques (mainly dead level contours) and total arable area (Figure 17). Farmers with large arable areas also tended to put bigger proportions of their land to water harvesting thereby suggesting that farmers were now considering the technology an important component of their farming system.

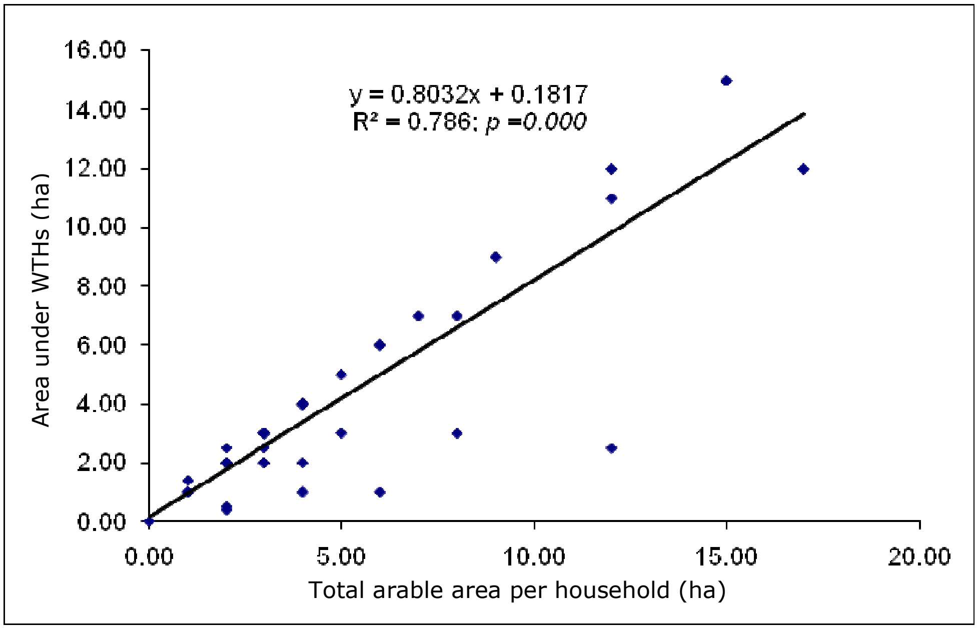

Figure 17: Relationship between area under water harvesting (WHT) and total arable area per household (ha) in wards 17 and 18, Gwanda district Zimbabwe.

A further assessment of the types of farmers who had adopted the dead level contours showed that well resourced farmers were the majority of those who had adopted the technology. The majority of the key-informants (93%) alluded that the more labour resources at one's disposal, the higher their chances of success. This is so because rain water harvesting technologies are time-consuming and labour intensive. The study concluded that resource ownership could be a key factor in farmers' ability to scale out the dead level contour technologies. Performance was significantly linked to resource status and gender (correlation was significant, p=0.039). Women headed households were performing rather poorly suggesting the need for special attention to gender in the promotion of rain water harvesting technologies (Munamati *et al*, 2009), mainly dead level contours in this study.

Preliminary results from the third study on contour ridges so far indicate that dead level contours store the largest amount of water when the data is presented using the soil water storage index (Figure 18).

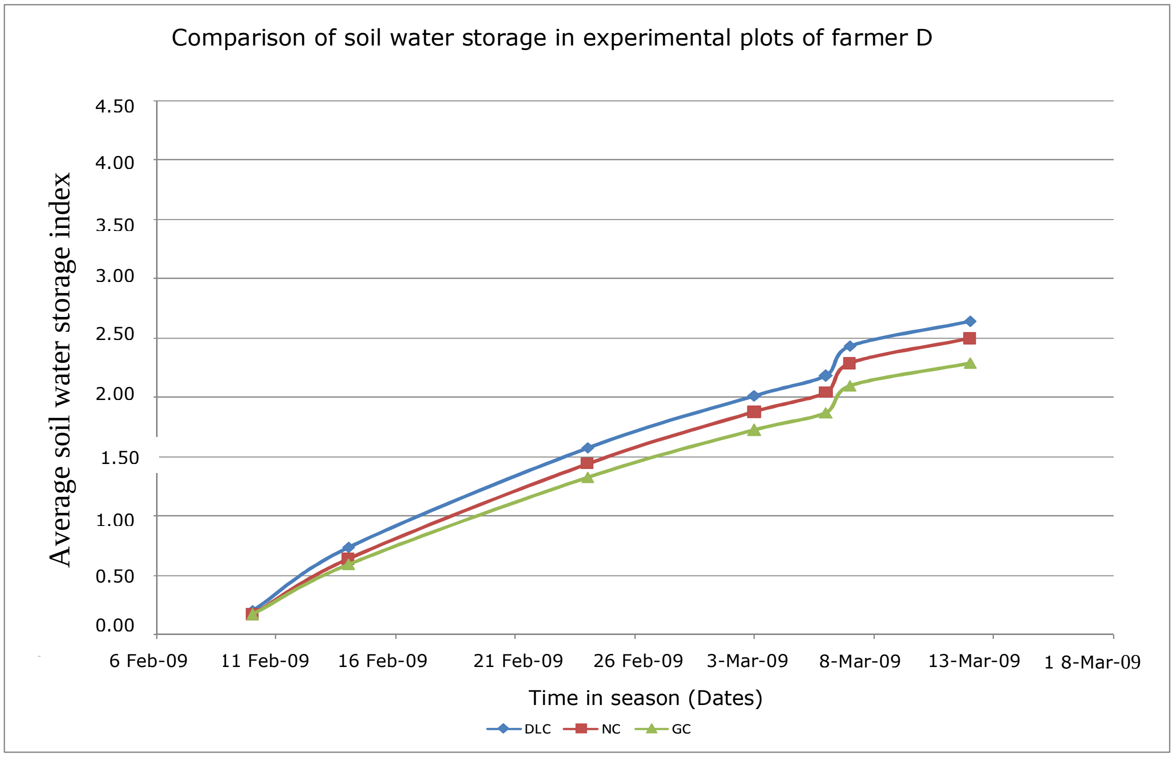

Figure 18: Example of soil water storage indices of dead level contours (DLC), no contour (NC) and graded contour (GC) in a farmer's field, Zhulube, Insiza.

According to preliminary results the graded contour (GC) plot performed the worst in three out of five measured plots. This could be because draining water away from the field using graded contours is likely to result in reduced soil water availability in the field compared to either having no contours or constructing dead level contours. In all the five fields under study a plot with no contours had less soil moisture storage index compared to a plot with dead level contours. This indicates that dead level contours retain moisture in the field.

1.3.2.3 Conclusions

From the first study it was shown that the upward side of the dead level contour with or without infiltration pit was drier than downslope on most occasions when soil water was measured, an expected result. The dead level contours with infiltration pits captured more rainwater following heavy rainfall events (60-70 mm). The soil layers that benefited most from the rainwater captured by the dead level contours with/without infiltration pit were in the middle (0.2-0.5 m) of the 0-0.6 m soil profile. Crops such as maize, sorghum, pearl millet and legumes commonly grown in semi-arid areas can access soil water from these soil layers. Results from the study suggest that the dead level contours have to be constructed at between 3-8 m spacing if they are to supply soil water to crops in the field. However, given the labour and time requirements for the construction of these structures and the limited soil water benefits observed so far, the study concludes it is not worthwhile investing in these rainwater harvesting structures using the current design in areas such as Gwanda district with a <1% slope and light textured soils. Contrasting results from the second study indicate that farmers believe in the dead level contour technology and they are convinced that dead level contours are beneficial (Munamati et al 2009; Nyagumbo et al., 2009). More conclusive results will probably come from further studies of the technology. The third study is therefore relevant as it would help improve the design of the dead level contours, hence give quantifiable benefits to the farmers, although other factors such as resource status are also important. Therefore, new designs of dead level contours and infiltration pits for different soil types and slopes could be explored as a way forward in the use of inter-field rainwater harvesting structures.

1.3.3 Rainwater Harvesting Studies - South Africa

1.3.3.1 Methods

In South Africa in-field rainwater-harvesting techniques were also tested in the Olifants Catchment, Quaternary Catchment B72A (Raisuba, 2007; Magombeyi and Taigbenu, 2008). The studies assessed conventional ploughing; Chololo pits/planting basins and ridges (Magombeyi and Taigbenu, 2008). Figure 19 shows pictures of a conventionally ploughed field compared to the two tested technologies (planting basins and ridges respectively).

Figure 19: Tillage methods used in Sekororo, from left to right conventional ploughing, planting basins and ridges ready for maize sowing

The main objectives of the studies were to evaluate water use efficiency and crop water productivity under prevailing rainfall patterns and the three farming practices The specific objectives were therefore to 1) to evaluate water use efficiency and crop water productivity under prevailing rainfall patterns and the farming practices, 2) to assess the impact of rainfall variability on crop yield and production. Studies were carried out to investigate the relationships between crop yield, field water balance and soil water storage capacity, based on four sites. The study evaluated the farming practices using crop yield, evapotranspiration and other parameters in a water balance (Raisuba, 2007). Data collected on field included soil moisture, rainfall and runoff. Other information was collected from the nearest Letsitele weather station. Soil nutrient analysis was also done in the research sites.

Field and crop description:

- No major diseases or damage occurred

- Sowing density was 44 000plants per hectare
- Sowing dates - Dec 2005 to April 2006; Dec 2006 to April 2007.
- Primary soil cultivation at all sites was the same, i.e. ploughing at 30 cm depth
- Dec 2005 to April 2006 and from Dec 2006 to April 2007.
- Daily rainfall - using manual plastic standard rain gauges for each particular maize plot site.
- irrigation water supplied to the farm
- runoff measurement-runoff collection catchment in each site was constructed
- Daily soil moisture content measurement by a Hydrosense instrument
- Particle size analysis – by mechanical and hydrometer methods; grain size is very much crucial because it can be used to predict soil water movement
- soil nutrients test analysis

Assumptions were:

- No evapotranspiration takes place when the water content is below the wilting point.
- Soil water content is limited by effective porosity and the wilting point (Wp).
- Drainage is negligible

Daily soil water budget equations

- $ET = (P + \Delta S) - (RO + D)$ Equation 1 rainfed
- $ET = (P + irrig + \Delta S) - (RO + D)$ Equation 2 supplementary irrigation

- P equals rainfall, Δ S indicates how much water has been lost from the soil column due to evapotranspiration (ET) and deep percolation (D) beyond root zone.

1.3.3.2 Results and discussion

The Chololo pits resulted in highest yield in comparison to conventional ploughing and ridges (Table 3). The highest yield was a result of the rainfall capture by the basins that increased infiltration and provided water to the roots.

Table 3: Partitioning under conventional ploughing, ridges and Chololo pits/planting basins (2007/2008).

Parameter	**Site**			
	Enable		**Worcester**	
	Ridges	Conventional ploughing	Chololo pits	Conventional ploughing
Rainfall (mm)	361	361	268	268
∆S (mm)	-24	-17	-111	-36
Runoff (mm)	46	129	21	69
Drainage (mm)	19	8	22	11
ET (mm)	320	241	336	224
Yield (kg)	335	0	585	0
Soil type	Loamy sand		Sandy loam	

Despite the higher yields it was however noted that the basins required the highest labour in the initial year, although the required labour decreases in subsequent years as the same pits from the previous season are used. The labour for the preparation of the planting basins can be spread over the dry period prior to planting season, thereby avoiding high labour demands when the rainy season commences. This has the advantage that the farmers sow at the right time as they avoid waiting or paying for draught power, increasing their chances of high yields. The study also found the importance of planting dates on yield in the catchment (Figure 20). The suitable dates were 15 December to 15 January. However, planting very late is not advisable as livestock that freely graze after 1st of June to the start of rainy season may destroy the crop before maturity.

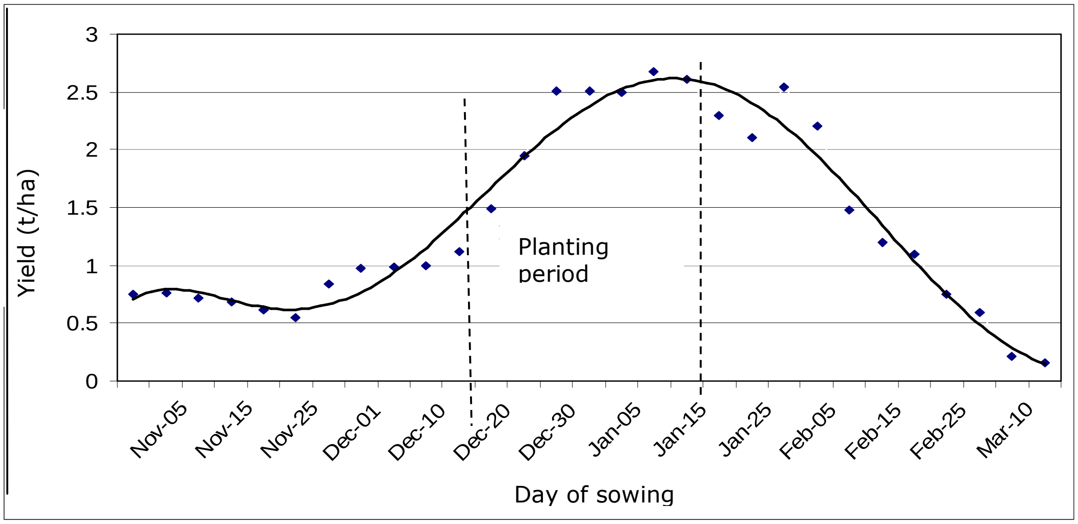

Figure 20: The relationship of planting date and yield in B72A quaternary catchment. The correlation coefficient, $R^2 = 0.96$).

Nutrients soil tests were used to evaluate fertility, measure the soil nutrients that are expected to become plant-available. To assess the soil nutrients status in the study area, some form of rating scale was adopted. The guidelines used in the soil nutrient management to interpret soil test results are shown in Table 4 (Marx et al., 1999).

Table 4: The guideline table to interpret soil test results (Source: Marx et al, 1999).

Nutrient level	**Potassium (K)**	**Calcium (Ca)**	**Magnesium (Mg)**	**Phosphorus (P)**	**Nitrogen (NH_4+N) -**	**Nitrogen (NO_3 -N)**	**pH**
Low	<150 ppm	<1000 ppm	< 60 ppm	< 20 ppm	< 2 ppm	< 10 ppm	6.6

The results from the soil nutrients tests are presented in Table 5 for the 2005/2006 in brackets for the cropping season. The macronutrients (nitrogen, phosphorus, potassium) levels for 2005/2006 were low according to a maize guideline by Marx et al, (1999), suggesting that less than 50–75% (Hanlon, 2001) of the crop yield was expected regardless of the improvement of other important required parameters like water, and weeding.

Table 5: Soil chemical properties for 2005/6 (in brackets) and 2007/8 for the study sites

Site	Phosphate-P mg/kg	Potassium-K mg/kg	Magnesium-Mg mg/kg	Calcium-Ca mg/kg	Nitrate-NO^-_3–N mg/kg	Organic C %	pH
Sofaya	11.2 (2.4)	207 (100)	311 (284)	2090 (1927)	12.3 (0.56)	1.33 (1.26)	6.02 (5.1)
Enable	26.2 (3)	96 (117)	98 (343)	1985 (3489)	4.9 (0.83)	0.86 (1.21)	8.15 (7.2)
Worcester	21.2 (0)	154 (145)	356 (428)	6098 (3505)	7.8 (0.62)	1.79 (1.32)	8.34 (5)

The Sofaya site nutrient levels increased from the 2005/6 season levels with an improvement in soil pH. For Enable and Worcester sites there was generally an increase in the nitrate and phosphorous levels, suggesting an improved soil nutrient status for improved crop yields.

1.3.3.3 Conclusions

- Nutrients status of the soil was very low (Marx *et al*, 1999).
- Apart from meeting water requirements nutrients have to be improved for higher yields.
- Crop failure - Moisture deficit was high at the moisture deficit sensitive stage of the maize crop.
- Greatest decrease in grain yields is caused by water deficits during the flowering, tasselling, silking and pollination, due mainly to a reduction in grain number per cob.
- Water deficits during the flowering period particularly at the time of silking and pollination may result in little or no grain yield due to silk drying (FAO, 2002).
- Rainwater harvesting improves soil moisture available to crops, during the extended dry spell periods.

1.3.4 Mozambique

1.3.4.1 Methods

In Mozambique the studies focused on using plastic material to harvest rainwater in the field. The approach comprised the use of polo vinyl chloride (PVC) plastic sheets in a gentle sloping (<2%) catchment area to increase the runoff to the cropping area (Figure 3.10). Under this technique the water is harvested in the plastic shields and directed to the root zone of the crop where it is stored and acts as a reservoir for the period that does not rain (Chilundo *et al.*, 2008). As a result the mitigation of dry spells is much better due to the deeper rooting system and the larger water holding capacity of the soil.

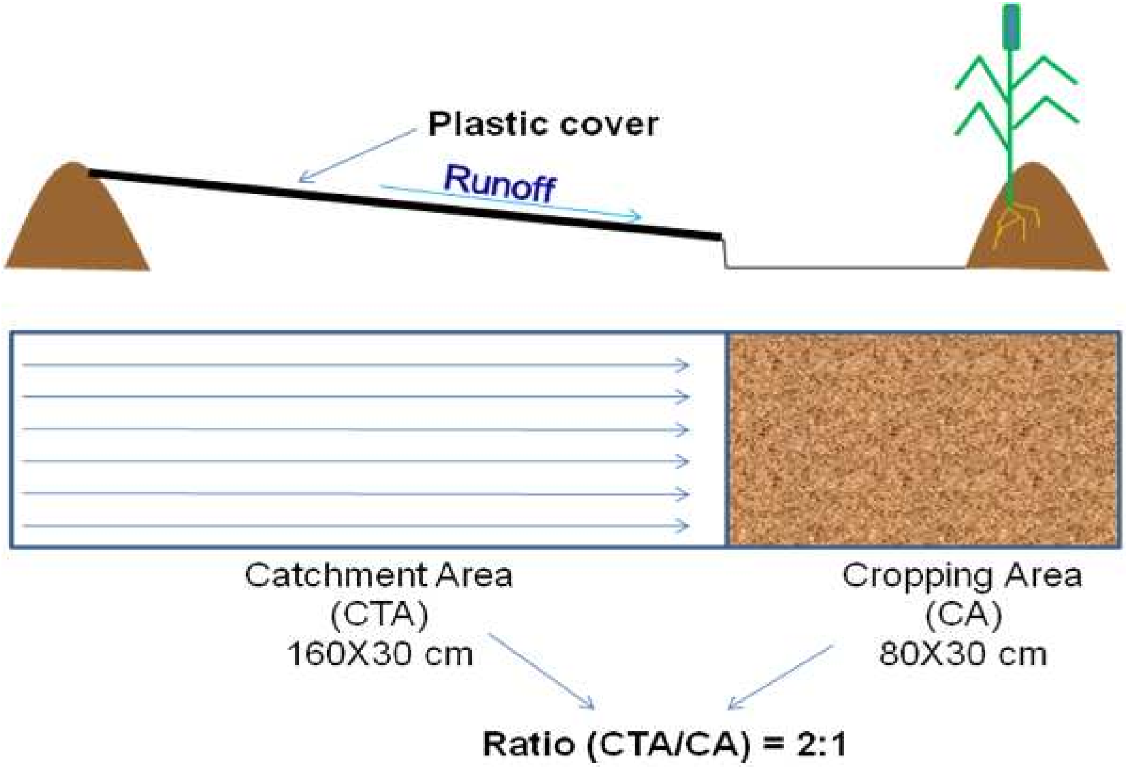

Figure 21: Schematic transversal cut and top view of the furrow (not to scale)

The method was evaluated through field trials carried out at the Chókwè Agricultural Station over two rainy seasons (2007/08 and 2008/09) (Chilundo *et al.*, 2008). During the two cropping seasons the total rainfall was 392 mm and 471 mm respectively. The treatments comprised two ratios *(i) ratio 2:1 (S160); and (ii) ratio 3:1 (S240).* The treatments were tested against a control treatment (S80) representing the conventional furrow system that is commonly used by smallholder farmers. Maize (cultivar Matuba) was planted and the planting density was 41 666 plants ha^{-1}, 20 833 plants ha^{-1} and 13 888 plants ha^{-1} for S80, S160 and S240 respectively (Chilundo *et al.*, 2008).

1.3.4.2 Results and Discussion

Table 6 shows the yield results obtained over the two cropping seasons. Maize grain yield under plastic cover for the S160 treatment (season 2007/08) was about 20% higher than the control (S80) treatment. However, there were no statistical differences ($p>0.05$) between S80 and S160 treatments. Opposite results were observed during the season 2008/09, where the S80 yields were higher and statistically different compared to S160. In both seasons the S240 treatment gave the lowest yield. Rainfall distribution, diseases and pest were the major factors affecting the yields in both seasons, especially for the S160 and S240 where fungal attacks were observed.

Table 6: Maize yields under plastic cover for two cropping seasons

	Maize yield (t ha^{-1})		
Season	**S80**	**S160**	**S240**
2007/08	2.32	2.77	1.69
2008/09	1.60	1.00	0.60

Results from this study are not conclusive therefore more work is planned for the future.

1.3.4.3 Conclusions

Plastic material might prove to be very expensive for smallholder farmers, therefore, there is a need to identify and test alternative material. The manual soil compaction method (in place of plastic) has shown promising results and the method is being adopted by smallholder farmers in Mozambique in a different semi-arid region. Climate effects such as seasonal rainfall variability patterns and thus changes in sowing dates also need to be assessed. There is need to consider integrated pest and disease management and fertilizers to increase water productivity and yields.

1.4 Supplemental Irrigation Using Blue Water

Supplemental irrigation involves the addition to essentially rain fed crops of small amounts of water during times when rainfall fails to provide sufficient moisture for normal plant growth, in order to improve and stabilize yields. Water is applied to rain fed crops, that would normally produce some yield without irrigation; since precipitation is the principal source of moisture for rain fed crops, supplemental irrigation is only applied when precipitation fails to provide essential moisture for improved and stabilized production and; the amount and timing of supplemental irrigation are not meant to provide moisture stress-free conditions rather to provide minimum water during the critical stages of crop growth to ensure optimal instead of maximum yield (http://www.ipcri.org/watconf/papers/mohammed.pdf).

1.4.1 Low Head Drip Irrigation systems – Zimbabwe

The first on-farm research on supplemental irrigation was carried out at Zhulube irrigation scheme. The aim was to determine how low cost drip irrigation technologies compared with conventional surface irrigation systems in terms of water and crop productivity (Maisiri et *al.,* 2005). A total of nine farmers who were practicing surface irrigation were chosen to participate in the study. The vegetable English giant rape (Brassica napus) was grown under the two irrigation systems with three fertilizer treatments in each system: ordinary granular fertilizer, liquid fertilizer (fertigation) and the last treatment with no fertilizer. These trials were replicated three times in a randomized block design. Measurements included biometric parameters of leaf area index (LAI) and fresh weight of the produce, water use efficiency (WUE) which was used to compare the performance of the two irrigation systems. A water balance of the inflows and outflows was kept for analysis of WUE. The economic profitability and the operation maintenance and management requirements of the different systems were also evaluated.

Results showed no significant differences in vegetable yield between the irrigation systems at 8.5 ton/ha for drip compared to 7.8 ton/ha in surface irrigation. There were significant increases in yields due to use of fertilizers. Drip irrigation used about 35% of the water used by the surface irrigation systems thus giving much higher water use efficiencies. The leaf area indices were comparable in both systems with the same fertilizer treatment ranging between 0.05 for surface without fertilizer to 6.8 for low cost drip with fertigation. Low cost drip systems did not reflect any labour saving especially when manually lifting the water into the drum compared to the use of siphons in surface irrigation system. The gross margin level for surface irrigation was lower than for low cost drip irrigation but the gross margin to total variable cost ratio was higher in surface irrigation systems, which meant that surface irrigation systems gave higher returns per variable costs incurred.

It was concluded that low cost drip systems achieved water saving of more than 50'% compared to surface irrigation systems and that it was not the type of irrigation system that influenced the yield of vegetables significantly but instead it was the type of fertilizer application method that contributed to the increase in the yield of vegetables. It was recommended that low cost technologies should be used in conjunction with good water and nutrient management if higher water and crop productivity are to be realized than surface irrigation systems.

The second study involved an assessment of the impacts and sustainability of the drip irrigation program that many nongovernmental organizations were implementing in Zimbabwe. The study involved interviewing representatives of the NGOs, local government, traditional leadership and agricultural extension officers in the Mzingwane Catchment (Gwanda and Beitbridge Districts). Focus group discussions with beneficiaries and other villagers were held at village level. A survey of 114 households was then conducted in the two districts, using a questionnaire developed from the output of the interviews and focus group discussions. The results from the study showed that the NGOs did not specifically target the distribution of the drip kits to poor members of the community. The main finding from the study was that low cost drip kit programs can only be a sustainable intervention if implemented as an integral part of a development program, not short-term relief programs and the programme should involve a broad range of stakeholders including donors, implementing NGOs and beneficiaries. A first step in any such program, especially in water scarce areas such as Gwanda and Beitbridge, would be a detailed analysis of the existing water resources to assess availability and potential conflicts, prior to distribution of drip kits. A protocol for the implementation of drip kit programs the semi-arid regions was developed (Moyo et al., 2006). Box 1 shows the protocol.

Box 1: Protocol for drip irrigation kits distribution programs

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

1. Distance of water source

Objective: Ensure that the drip kit garden is close to the water source
Drip kit garden should be within 50 m 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

Objective: Ensure that the beneficiaries have a reliable water source
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 water sources should be able to supply water for the kit all year round

3. Follow up visits

Objective: Ensure that the beneficiaries get prompt technical advisory service on the use of kit
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

Objective: Adequate training of beneficiaries
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 kit
NB. Maintenance of the kit training should take cognisance of quality of water available for the drip kit in different areas
Cropping techniques including 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

Objective: Beneficiaries are people who are able to work in their respective 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 a 20 l bucket

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 trade storeowner willing to stock the necessary spares, so that the beneficiaries can purchase them when they need them

1.4.2 Supplemental Irrigation studies - South Africa

1.4.2.1 Methods

Field experiment

In South Africa controlled plot experiments were conducted in collaboration with three smallholder farmers with two replicates per farm to determine various parameters for the water balance model in Sekororo. The field layout for the experiment consisted of one hectare plots, with two equal smaller runoff plots of dimensions 4 m × 2 m. The farmers were initially taught on daily field data capturing. The seasons studied were 2005/2006, 2006/2007 and 2007/2008. In the irrigated plots, water was supplied by gravity-fed furrow irrigation system from a weir built across a seasonal stream. Irrigation scheduling was left at discretion of the farmers but measured by a 90^0 V-notch weir. The farmers scheduled irrigation by a combination of two methods i.e. by intuition (when the maize crop showed signs of moisture stress) and calendar days since the last rainfall or irrigation (Shock et al., 2007). All plots were planted on the same day and farmers agreed on the same farm management strategies. Fertilisation treatment of 14 kg-N ha^{-1} per season (based on affordability and potential maize yields above average (0.5 t ha^{-1}) as recommended by ICRISAT (Kgonyane and Dimes 2007) from studies in the same area) was applied in all plots after the first weeding except for the 2006/2007 rainfed plot because of little rainfall. The first weeding was done 28 days after sowing. Soil moisture levels at 200 mm depth were measured on a daily basis during the growing season at 12 positions diagonally across the field using a hydrosense neutron probe (Campbell Scientific, Inc. 2001). Daily rainfall and runoff was also recorded from each field. The soil micronutrients were analysed towards the harvest in 2007/2008 season. The plots were harvested by hand and the grain yield recorded.

Water balance model

Using data on precipitation, supplementary irrigation, soil moisture, and runoff a seasonal root zone soil water balance over a daily temporal scale for three cropping seasons (2005/2006, 2006/2007 and 2007/2008) was constructed from Equation (1) (Walker and Ogindo 2003; Zhang et al. 2006).

$$D = (P + I) - (R + E_c + \Delta S) \qquad \text{(Equation 3)}$$

where D is the deep drainage beyond the 1 m (Ali et al. 2007) root zone (mm d^{-1}), P is the daily precipitation (mm), I is the irrigation water to the plot (mm d^{-1}), R is the runoff from the field (mm d^{-1}), E_c is the evapotranspiration (mm d^{-1}) and ΔS is the change in soil-water content (soil moisture at harvest minus soil moisture at sowing) in the root zone (mm d^{-1}). D was determined as a residual in Equation 1.

The maize crop actual evapotranspiration was estimated by Equation (4) (Chow and Maidment, D. 1988; Allen et al. 1998; Moroizumi et al. 2009):

$$E_c = K_s K_c E_0 \qquad \text{(Equation 4)}$$

Where E_c is the actual evapotranspiration (mm d^{-1}), K_s is the water stress condition, K_c is the maize crop coefficient, and E_0 is the reference evapotranspiration (mm d^{-1}). E_0 was calculated by the FAO Penman-Monteith equation (as a function of net radiation, air temperature, wind speed and vapour pressure). K_c values from SAPWAT for maize were used according to the maize growth stages.

SAPWAT is based on FAO, Penman-Monteith method (FAO 2002) developed to estimate crop water requirements (not a crop growth model) only for areas within South Africa (van Heerden and Crosby 2002). It uses local climate, irrigation systems and planting dates which represent the general production patterns found in the area. The K_s value was evaluated by Equation (35) (Moroizumi et al. 2009):

$K_s = 1$ for $\theta \geq \theta_t$

$$= \frac{\theta - \theta_{wp}}{\theta_t - \theta_{wp}} \text{ for } \theta_{wp} \le \theta < \theta_t \qquad \text{(Equation 5)}$$

Where θ is the soil water content at any day and θ_{wp} is the soil water content at the wilting point (9.5% in this study). The value of θ_t was calculated from Equation (6) (Moroizumi et al. 2009):

$$\theta_t = \theta_{fc} - p(\theta_{fc} - \theta_{wp}) \qquad \text{(Equation 6)}$$

Where θ_{fc} is the field capacity water content (20.7% in this study). A value of p= 0.43 for maize was adopted based on Allen et al. (1998) (θ_t = 15.9% in this study).

Water use efficiency or productivity (W_P) was calculated from the ratio of yield (kg ha^{-1}) to seasonal water evapotranspired (mm) (van Der Zel et al. 1993; Rockström et al. 1998; DFID 2003; Grove 2006; Zhang et al. 2006). Marginal supplementary irrigation water productivity (M_{SIWP}) was calculated from the ratio of change in yield to change in irrigation water applied (assuming no irrigation water loss to deep drainage), with other inputs held constant (Ali et al. 2007).

1.4.2.2 Results and discussions

Soil parameter analysis in 2007/2008 gave the following results: nitrate (12.3 ppm), phosphate (11.2 ppm), potassium (207 ppm), calcium (2 090 ppm), magnesium (311 ppm) and organic carbon (1.33 %). Compared to rating guidelines by Marx et al. (1999) of low nutrient levels (nitrate: < 10 ppm, phosphate: <20 ppm, potassium: < 150 ppm, calcium: < 1000 ppm and magnesium: < 60 ppm), phosphate levels in the study site are lower than recommended levels for maize. Hence, phosphate is the limiting nutrient in the soil. The 2007/2008 soil nutrient status showed an improvement from the 2005/2006 season.

The seasonal rainfall during the three seasons for maize varied from 388 to 1422 mm (Table 7). The 2006/2007 and 2007/2008 seasons were very dry below the long-term average, while 2005/2006 season received above normal rainfall. The average evapotranspiration (E_C) under rainfed and supplementary irrigation for the three seasons was 344 mm and 431 mm respectively. The observed E_C values are less than the general maximum (500 - 800 mm) required by a medium maturity maize crop for maximum yields (FAO 2002). Water balance components, maize grain yield and water use efficiencies (kg dry matter grain per mm rainfall) for the areas studied are shown in Table 7.

Table 7: Water balance components, water productivity, irrigation water productivity, marginal irrigation water productivity and yield reduction from the study area

Production system	Season	P (mm)	I (mm)	ΔS (mm)	R (mm)	D (mm)	E_C (mm)	Grain yield (kg ha^{-1})	W_P (kg mm^{-1} ha^{-1})	M_{SIWP} (kg mm^{-1} ha^{-1})
Rainfed with Supplementary Irrigation	2005/ 2006	1422	48	120	540	364	446	2000	4.5	16.7
	2006/ 2007	388	112	-54	82	56	416	1450	3.5	9.8
	2007/ 2008	611	96	-87	293	71	430	1700	4.0	11.9
Control – Exclusive Rainfed	2005/ 2006	1422	0	120	557	349	396	1200	3.0	0
	2006/ 2007	388	0	-66	105	42	307	350	1.1	0
	2007/ 2008	611	0	-30	257	56	328	556	1.7	0

The variation of grain yield with evapotranspiration (Figure 22) for rainfed and rainfed plus supplementary irrigation showed a strong correlation.

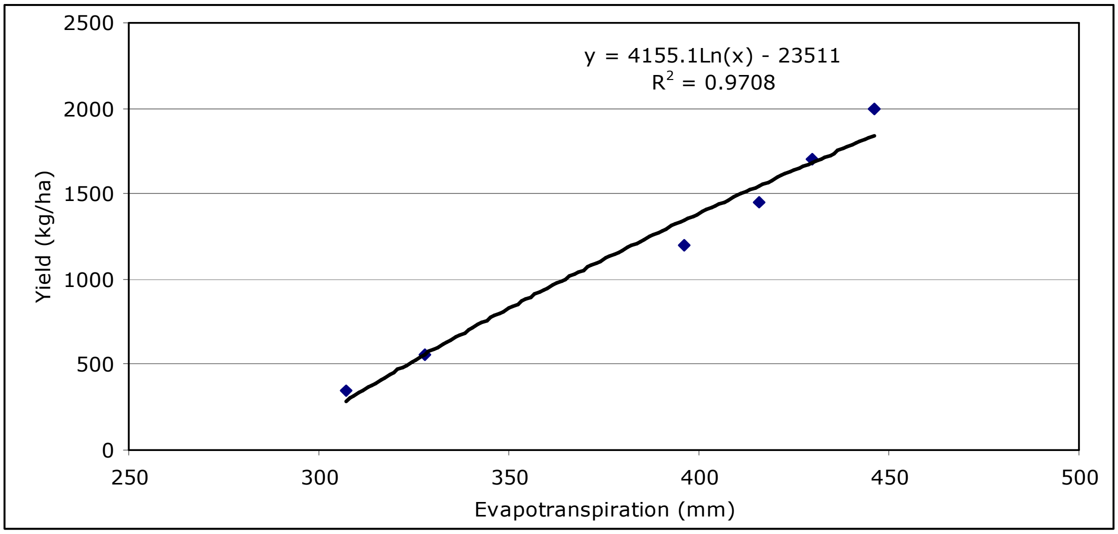

Figure 22: Correlation of yield variation with evapotranspiration in the study sites.

Maximum grain yields in fields with supplementary irrigation ranged from 1.45 to 2t ha^{-1}, while yields in exclusive rainfed field ranged from 0.35 to1.2 tha^{-1} (Table 7). Similar results were reported by earlier researchers working on maize in South, East and West Africa (Rockström et al. 1998; Oweis and Hachum 2003). Maize yield was affected by seasonal rainfall (Figure 23) and its erratic distribution throughout the growing season depicted by soil moisture changes in rainfed plots (Figure 25a–c). A good correlation of yield reduction with rainfall during the crop-growing period (Figure 23) suggested that lack of soil water during critical crop growing stages reduced maize grain yield.

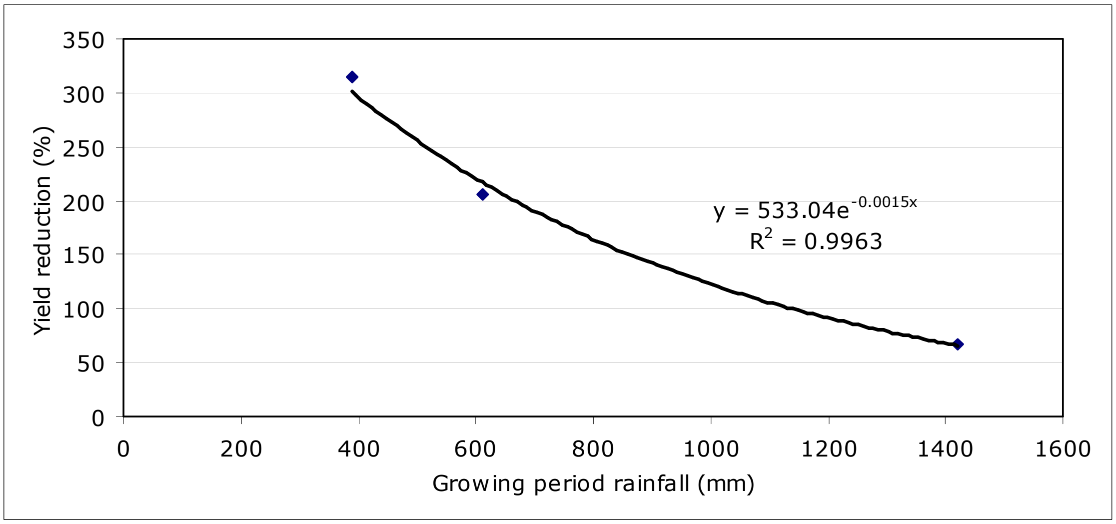

Figure 23: Correlation of yield reduction under rainfed compared to supplementary irrigation with rainfall during the growing seasons from 2005 to 2008.

Supplementary irrigation with added fertilisation of 14 kg-N/ha during dry spells increased yields on average by 196 %. Fox and Rockström (2000) reported similar result of 180 % yield increase in semi-arid Burkina Faso. During the dry seasons 2006/7 and 2007/8 the grain yield reduction without supplementary irrigation ranged from 206 % to 314 %, while for the wettest year (2005/2006) the yield reduction was 67 % indicating significant yield improvement with supplementary irrigation are realized during drier years. There was high potential maize yield due to more favourable high and evenly distributed rainfall in 2005/2006 season. Hence, the yield gap between rainfed and supplementary irrigation was smaller compared to drier seasons (2006/2007 and 2007/2008).

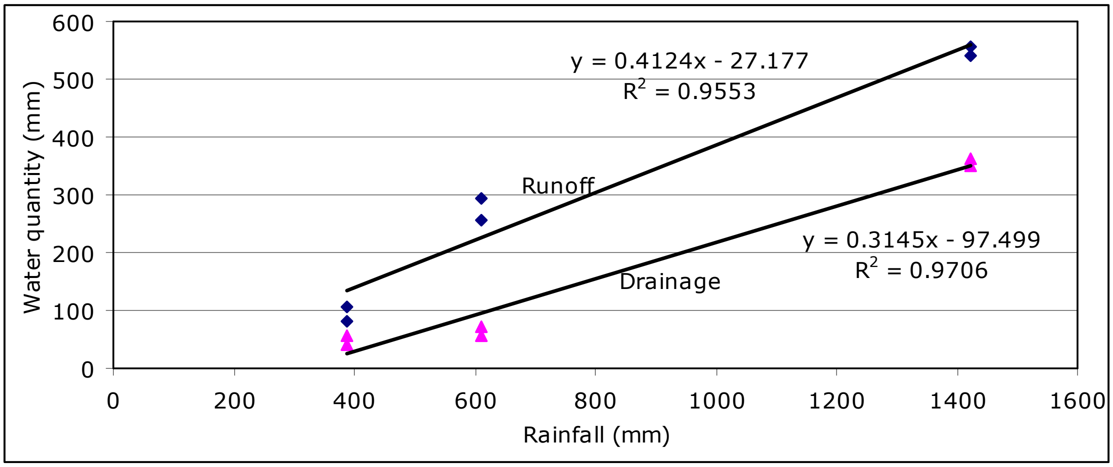

Figure 24: Correlation of surface runoff and deep drainage beyond the 1 m root zone with rainfall during the crop growing period

Surface runoff and drainage (Figure 24) from the field soil profile showed a strong linear relationship with seasonal rainfall. These results indicate the great potential for surface runoff water harvesting and groundwater recharging at study site as the quantity of rainfall increases. Runoff generated was high as the rainfall events occurred in pockets of 2–4 consecutive days which allowed little time for infiltration. The field results indicate that there is a significant scope for improving water productivity in rainfed farming through supplemental irrigation from local runoff harvesting, especially when combined with soil fertility management as reported in other parts of Africa (Rockström 1999; Fox and Rockström 2000).

Soil moisture variation and grain yield effects

Figures 25a –25c show the variation of soil moisture in the experimental sites for the three seasons from sowing to harvest. In some days the volumetric soil moisture content fell below the permanent wilting point of the sandy loam soil of 9.5 % volumetric soil water content (Mzirai et al. 2001), causing severe crop water stress. In addition, the sub-soil acidity (pH < 5) in the study area could have further restricted water uptake by the crop roots (Robertson et al. 2003). Despite high annual rainfall of 1422 mm in 2005/2006 season, the crop suffered from periods of water shortage, during the vegetative stage early in 2005/2006 (Figure 25a) (18–32 days after sowing) and flowering (50–70 days after sowing). In 2006/2007 season (Figure 25b) crop water stress at soil moisture contents less than 15.9% occurred in the vegetative and grain filling stages, while in 2007/2008 (Figure 25c) crop water stress was experienced from flowering through to grain filling (80–100 days after sowing) an observation also reported by Rockström et al. 1998.

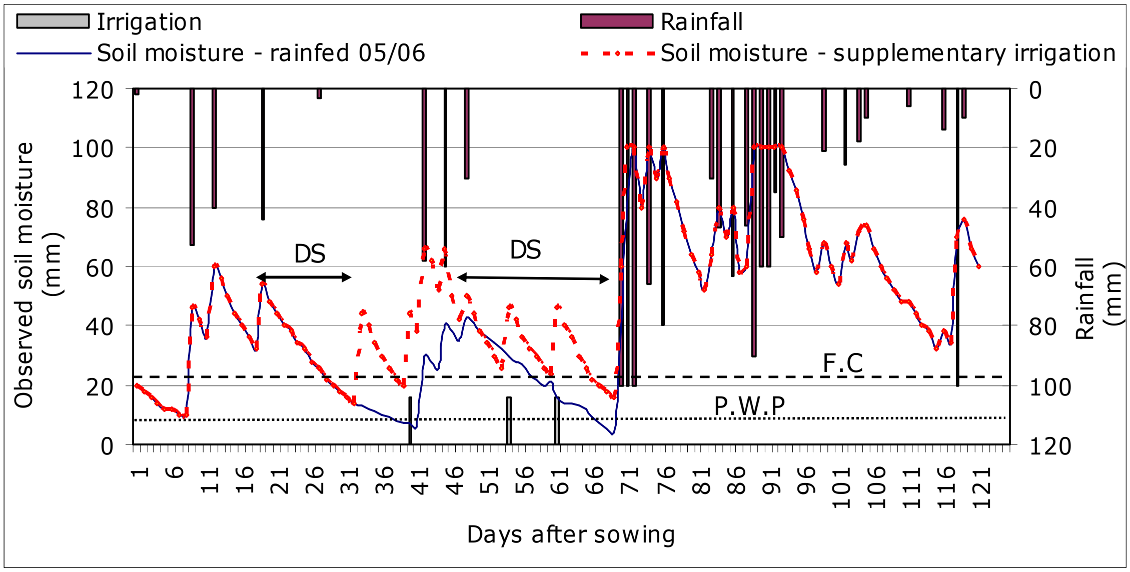

Figure 25a: Rainfall, irrigation and soil moisture changes monitored under rainfed and supplementary irrigation agriculture 2005/2006 season. DS = intra-seasonal long dry spells during the crop growing period. Dashed horizontal lines indicate average soil field capacity (F.C = 20.7% volumetric water content) and the permanent wilting point (P.W.P = 9.5% volumetric water content).

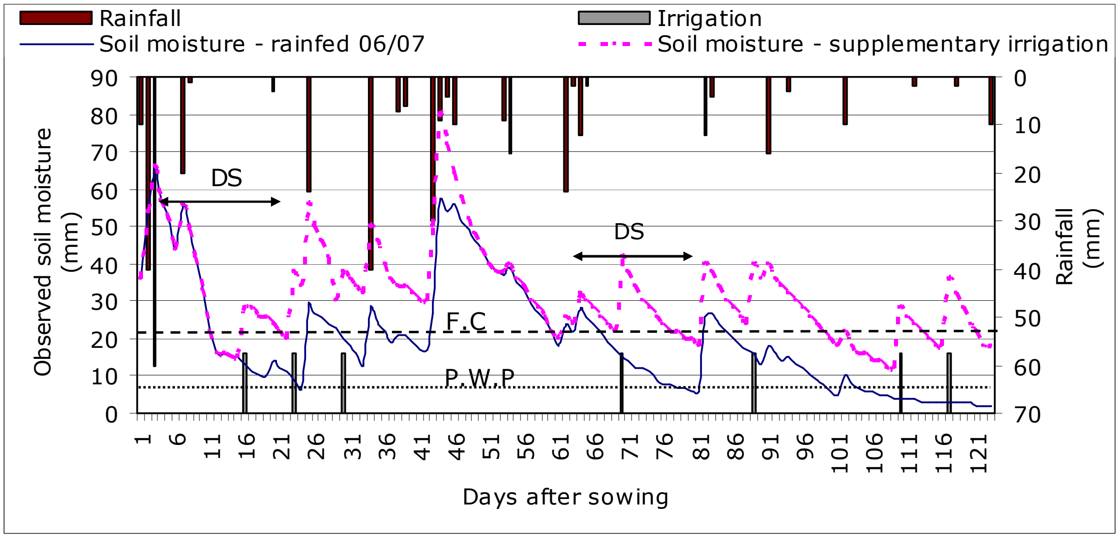

Figure 25b: Rainfall, irrigation and soil moisture changes monitored under rainfed and supplementary irrigation agriculture 2006/2007 season (DS = long dry spells during the growing season). Dashed horizontal lines indicate average soil field capacity (F.C = 20.7% volumetric water content) and the permanent wilting point (P.W.P = 9.5% volumetric water content).

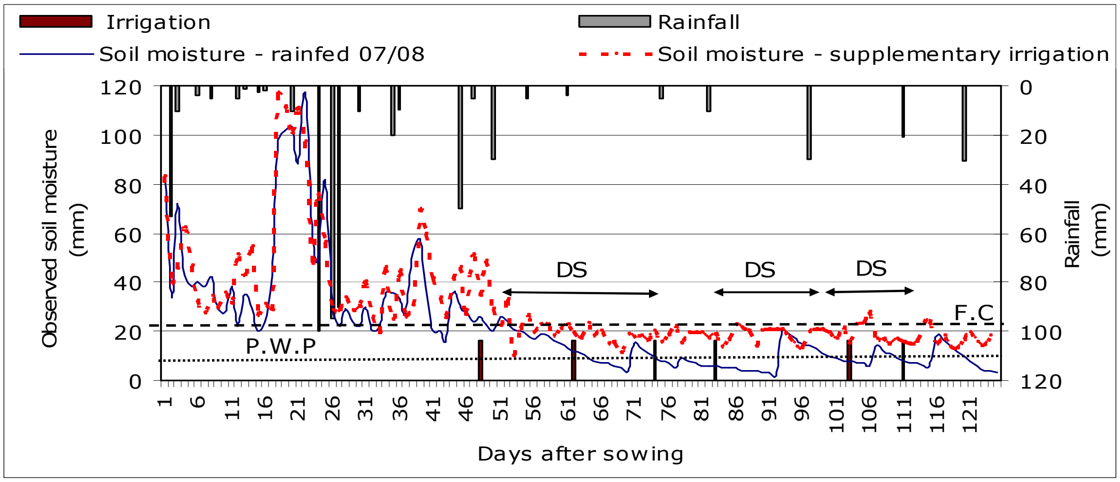

Figure 25c: Rainfall, irrigation and soil moisture changes monitored under rainfed and supplementary irrigation agriculture for 2007/2008 season (DS = dry spells during the growing season). Dashed horizontal lines indicate average soil field capacity (F.C = 20.7% volumetric water content) and the permanent wilting point (P.W.P = 9.5% volumetric water content).

Dry spells that were greater than 10 days resulted in volumetric soil moisture levels falling below 5 %. Soil moisture deficits adversely affected plant growth and yield attributes under rainfed plots due to increased total resistance in the soil-plant system resulting in reduced photosynthesis and growth (FAO 2002). In 2006/2007 the maize grain yield was drastically reduced to 350 kg ha^{-1} because the soil moisture stress experienced in the early growth stages (12–25 days after sowing) could have reduced the crop leaf area index and radiation use efficiency which have direct bearing on dry matter accumulation in plants (Rockström et al. 2002; Ali et al. 2007). The soil moisture levels could be used to determine the onset of crop water stress for the efficient utilisation of irrigation and precipitation (Abraha and Savage 2008). With improved timely and adequate supplementary irrigation coupled with good soil management, farmers could ensure minimum crop water stress to crops thereby enhancing families' food and income.

Marginal irrigation water productivity (M_{SIWP})

The M_{SIWP} is a good indicator for assessing the performance of supplementary irrigation management methods, to ascertain whether higher crop yields upset cost of supplying additional water (Rockström et al. 2002). The M_{SIWP} ranged from 9.8 to 16.7 kg mm^{-1} ha^{-1} (average of 12.8 kg mm^{-1} ha^{-1}) for 2005/2006, 2006/2007 and 2007/2008 seasons respectively (Table 7). The results are higher than 2.5–7.6 kg mm^{-1} ha^{-1} reported in Burkina Faso (Rockström et al. 2002) but on the lower side on comparison with 15 to 62 kg mm^{-1} ha^{-1} of supplemental irrigation (Tingem et al. 2008). With the current (2008) price of maize grain at South Africa Rand (ZAR) 2.0 per kilogram, on average 1 m^3 of irrigation water applied timely can produce ZAR 2.56 equivalent to US$ 0.26 (using 2009 exchange rate of 10 ZAR = 1 US$) worth of maize. The monetary return per m^3 of supplementary irrigation is five-fold higher than the cost of 1 m^3 water under full irrigation of ZAR 0.5/m^3. The values demonstrate the huge gains to be substantiated with timely and adequate supplementary irrigation to bridge dry spells.

Evapotranspiration water productivity (W_P)

Shifting from exclusive rainfed agriculture to supplementary irrigation agriculture in the study area increased average crop evapotranspiration (W_P) from 1.1 to 4.5 kg mm^{-1} ha^{-1} (or 309 % increase) (Table 7). The corresponding average yield increase was from 800 kg ha^{-1} to 1144 kg ha^{-1}. The results are comparable to average grain yield increases of

1.5 kg mm^{-1} ha^{-1} for rainfed to 3.5–10 kg mm^{-1} ha^{-1} for supplementary irrigation (Rockström et al. 2002). The yield improvement can be attributed to timely water application to crops to avoid severe water stress and availability of more soil water for the plant. Similar results from Burkina Faso reported tripling yields of 460 kg ha^{-1} to 1400 kg ha^{-1} by combining supplemental irrigation and fertiliser application (Rockström et al. 2002). On the other hand, for seasons with severe dry spells, e.g., 2006/2007 in Ga-Sekororo, the result was a complete crop failure for all treatments lacking dry spell mitigation such as supplementary irrigation. The results indicate that water harvesting for dry spell mitigation can play a critical role in mitigating the risk of crop failure during cropping seasons with severe dry spells.

1.4.2.3 Conclusions and recommendations

The daily soil moisture from the water balance can be used to estimate the impact of dry spells during the crop-growing season. Use of supplementary irrigation can help bridge the intra-seasonal dry spells in semi-arid tropics, thereby increasing crop yields. Huge benefits of supplementary irrigation are realised when rainfall is below average and unevenly distributed throughout the season. Ex-field rainwater harvesting from a river weir offers one way of realizing supplementary irrigation. More appropriate rainwater harvesting techniques should be employed to harness huge amounts of surface runoff generated in the study area. With the water productivity for rainfed agriculture lower than supplementary irrigation, the results demonstrate the great opportunities that exist for upgrading rainfed agriculture and ensuring food security in rural communities through timely and adequate supplementary irrigation to bridge and manage dry spells. Furthermore, low soil nutrients that characterise the study area can be improved through better soil fertility management with the overall result of higher water productivity. Improvement of the limiting soil phosphate nutrient in the study site is required to enhance crop yield. There is need to investigate the levels of nutrients at which supplemental irrigation perform best and improve supplementary irrigation water application efficiency.

The results have shown the importance of supplementary irrigation in bridging the intra-seasonal dry spells. The supplementary made the most impact in poorly distributed and low rainfall seasons. The yield improved by about two-fold (186%) under supplementary irrigation. However, people should not completely move to full irrigation as this result in significant increases in agricultural water use in the catchment.

1.5 Salinity Studies - Mozambique

1.5.1 Introduction

Salinity studies were carried out in the Mozambican part of the Limpopo Basin, in the Chókwè Irrigation Scheme. The Irrigation Scheme faces serious salinity problems which have rendered large parts of the irrigation scheme almost impossible to cultivate productively. The studies were conducted in order to provide additional knowledge to improve long-term agricultural water productivity, as well as better water and nitrogen management strategies. The research aimed to answer the question: *How to leach salts but conserve nitrogen on salt-affected soils of the Chókwè Irrigation Scheme (CIS)*?

1.5.2 Methods

Field trials were carried out in the Chókwè Irrigation Scheme (CIS) southern Mozambique, where the Limpopo River supplies water to irrigate about 23,000 ha of land. Three different salinity sites were selected to conduct the experiments. The *non-*

saline experiment was conducted on-station at the Chókwè Research Station[2] (24°22'S, 33°00'E, 33 m asl) of the National Agricultural Research Institute. The other two sites, the moderately and saline ones were conducted on-farm, and thus, managed by farmers. The experiments were conducted during the dry and rainy seasons of 2007-08. Treatments comprised water (soil water deficit & calendarization) and nitrogen (100 kg ha^{-1} and 200 kg ha^{-1}) application rates. Therefore, a 2x2 factorial design with three replications (RCBD) comprising twelve plots (maize PAN 67 cultivar) were established in each site to monitor nitrogen and salt leaching. A nitrogen treatment (control) was adopted in the on-station trial during the rainy season of 2007-08. Four Wetting Front Detectors (WFDs) were installed in each plot at depths of 20, 30 and 45 cm to collect the drained water to monitor nitrates and salt. A water-meter attached to a small motorized water pump was used to irrigate the plots under on-station trials. Under on-farm condition, flumes were used to monitor the irrigation water. Soil water contents measurements were taken daily and weekly using a time-domain reflectometer (TDR) and WinProbe. Yield, soil fertility, height of water table, salts and nitrate data were systematically collected. Climatological data was recorded in an AWS installed nearby the experimental sites. The analyses of variance were performed using Statistical Analysis System (SAS) software. Means were compared using the least significant differences (LSD) test at 5% probability level.

1.5.3 Results and discussion

Tables 8 and 9 provide the basic physical and chemical characteristics of the soils at the onset of the experiments. The soil texture differs in all the three experimental sites. The % of sand content is high in both saline and moderately saline sites compared to the non-saline site. However, the saturated hydraulic conductivity is higher under the non-saline sites which favour the movement of water throughout the soil profile. Under moderate and saline sites, the presence of a shallow watertable (<1.5 m) can probably explain the observed low conductivity. In addition, the exchangeable sodium percentage (ESP) values presented in Table 9 are greater than the threshold value of 15% in the saline site.

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[2] The mean annual precipitation is approximately 620 mm and evapotranspiration of 1500 mm.

Table 8: Soil physical characteristics of the three experimental sites prior to experiments

Depth	Clay	Silt	Sand	Textural Class	Bulk Density	Saturated hydraulic Conductivity
cm	------------- % -------------			-	g cm^{-3}	mm hr^{-1}
Non-saline: 2007-2008						
0-20	32.1	43.8	24.1	Clay Loam	1.3	22.5
20-40	32.7	39.5	27.7	Clay Loam	1.3	
40-80	35.7	43.8	20.5	Clay Loam	1.3	
Moderately saline: 2007-2008						
0-20	18.8	13.0	68.2	Sandy Loam	1.5	15.8
20-40	16.5	10.8	72.7	Sandy Loam	1.5	
40-80	30.0	11.7	58.4	Sandy Clay Loam	1.4	
Saline: 2007-2008						
0-20	25.4	21.7	52.9	Sandy Clay Loam	1.4	3.1
20-40	30.3	11.5	58.2	Sandy Clay Loam	1.4	
40-80	27.7	21.7	50.7	Sandy Clay Loam	1.4	

Table 9: Soil chemical characteristics of the three experimental sites prior to experiments

Depth	pH$_{H20}$	EC$_{1:2.5}$[x]	SOM[§]	N	Ca	Mg	Na	K	P	CEC[‡]	ESP[†]
cm		dS m^{-1}	--------- % ------- --		---------------------- meq 100 g^{-1} ------------------- -----						%
Non-saline: 2007-2008											
0-20	7.7	0.3	2.8	0.1	27.6	17.2	0.8	2.6	8.8	50.4	1.7
20-40	7.7	0.2	1.8	0.1	29.2	19.2	0.7	1.6	6.1	48.8	1.4
40-80	7.9	0.1	2.0	0.1	36.0	17.2	1.2	1.0	6.6	47.6	2.1
Moderately saline: 2007-2008											
0-20	7.1	0.7	0.8	0.0	13.6	10.0	2.0	1.3	3.3	20.8	8.0
20-40	7.0	0.8	1.4	0.1	11.6	10.8	1.8	1.0	1.9	28.8	7.8
40-80	8.3	0.7	0.5	0.0	14.0	12.4	5.2	1.2	2.1	28.0	19.0
Saline: 2007-2008											
0-20	8.1	3.6	0.4	0.0	33.2	21.2	10.5	1.7	8.1	30.8	18.7
20-40	8.3	1.4	0.6	0.0	48.8	20.0	5.7	1.4	4.4	35.2	8.2
40-80	8.3	2.0	0.3	0.1	57.2	24.0	4.9	1.4	2.2	34.0	5.9

[x] Electrical Conductivity (1:2.5); [§] Soil Organic Matter; [‡] Cation Exchange Capacity; [†] Exchangeable Sodium Percentage.

From Table 9 it can be seen that the N content in the soils of CIS is very low, and therefore, the need to carefully manage this nutrient.

Preliminary yield results after statistical analysis (ANOVA) show that yields tend to drop as one move from non-saline to saline soil conditions (Figures 26 and Figure 27). Yields of about 7 to 10 t ha^{-1} (no-saline), 3 to 7 t ha^{-1} (moderately saline) and 2-5 t ha^{-1} (saline) were recorded. Water treatments did not differ significantly ($p>0.05$), while the 200 kg ha^{-1} nitrogen application rate was statistically different from the 100 kg ha^{-1} in all the experiments.

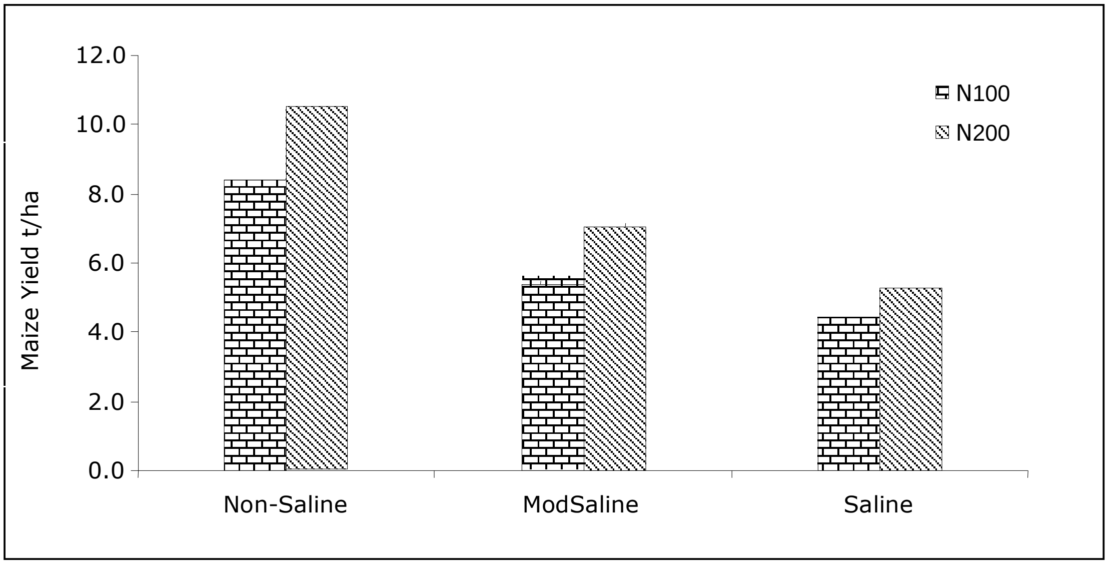

Figure 26: Maize yield response to salinity, water management and N application rates for the dry season 2007.

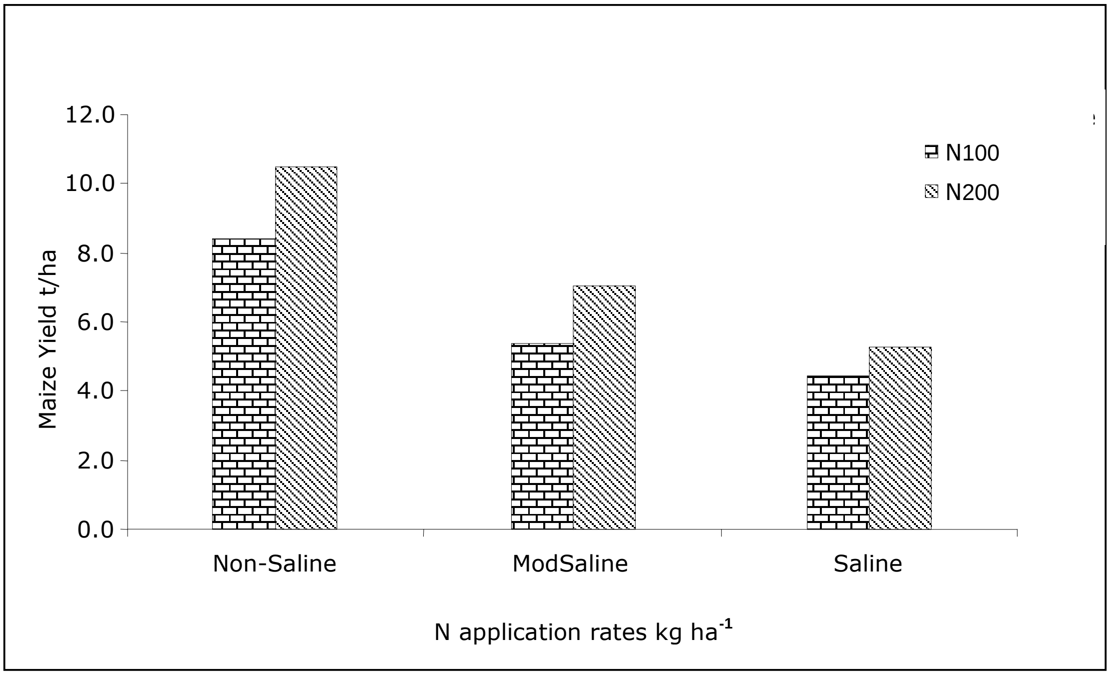

Figure 27: Maize yield response to salinity, water management and N application rates for the dry season 2007-08.

Other studies involved measurements of trends in the nitrogen and salts concentration throughout the dry growing season of 2007 for the three experimental sites. The challenge was to understand the dynamics of salts and nitrogen as affected by irrigation water including the presence of shallow water table under different soil salinity conditions (Figure 28).

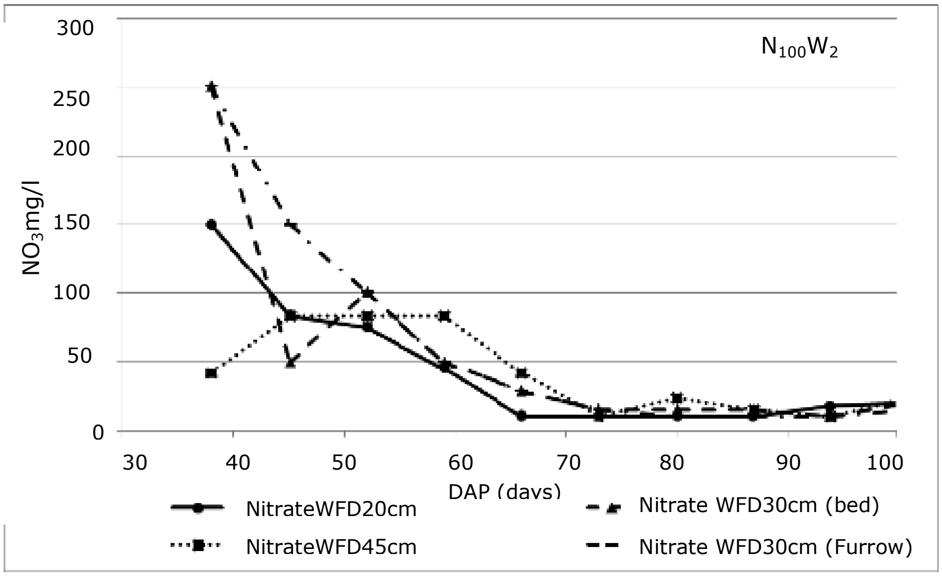

Figure 28: Concentration of N in drained water under 100 kg ha^{-1} of N (irrigation applied according to soil water deficit)

1.5.4 Conclusions

Generally the results so far indicate that nitrogen is crucial to boost maize production under saline conditions. Further work will include the modeling of the results to assess and identify the timing of application of nitrogen in order to reduce leaching of the nutrient.

1.6 Simulation of farming systems

1.6.1 Introduction

Simulation studies were done in B72A quaternary catchment in South Africa (Figure 29).

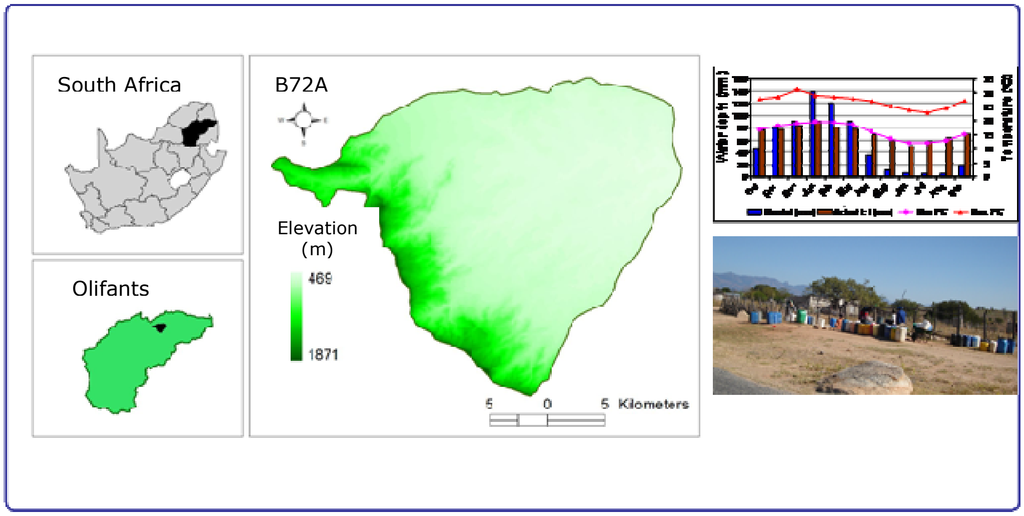

Figure 29: Location and characteristics of B72A quaternary catchment in South Africa

This study ascertains the effect of climate-induced risks and input/output price fluctuations on farm gross margin and food security for five smallholder farming systems. The results offer useful support to smallholder farmers and extension officers on how to achieve food security and profitability through alternative farm enterprises and/or management strategies.

1.6.2 Methods

1.6.2.1 Context

The risks of farmers to meeting food security under climate and market (maize grain, maize seed and fertiliser) shocks were evaluated using the framework shown in Figure 30. The rational is that the performance of the different smallholder farming systems is poorly understood. Furthermore, a clear understanding of the farming risk will help to adequately provide best bet improved farming practices and market solutions.

Five farm typologies were identified in the area that served as an input into the Olymple model. The typologies were built from the socio-economic surveys carried in the area. Principal component analysis and cluster analysis were applied to the data in sequential. The resulting typologies were further refined and validated in consultation with farmers and extension farmers in the study area prior to being applied in the Olympe model. Using Parched–Thirst an assessment of different (conventional versus planting basins) maize production systems was done. Furthermore, the impacts of maize grain (the main crop in the study area) and inputs (maize seed and fertiliser) price variations were evaluated. The price variations were guided by the historic trend and OECD-FAO (2008) outlook.

The lower and upper bound for maize high-price variations were selected from the lowest price under low-price variation (US$ 190 t^{-1}) and twice the lowest price, respectively. The lower and upper bound for maize low-price variations were selected from the lowest historical price (US$ 91/tonne) and twice the lowest historical price, respectively. The high and low price variations were derived from Monte Carlo simulation (van der Sluijs et al., 2004) using Microsoft Excel (Wittwer, 2004) based on historical trends. Maize grain price-variation is defined in relation to the current price US$ 228/tonne (2008) paid for maize grain to farmers without an increase in its quality or quantity.

1.6.2.2 Framework for the assessment of smallholder farming system risk

From the five identified farming systems under the homestead, the farming systems apply different agricultural management practices and give rise to different crop yields. The different crops yields and the family food needs (dependent on number, composition) are compared. The excess crop yield, above family needs may be sold to get disposable cash for buying other services. In the case of food needs exceeding available yield, the farmer has to argument the family food supply from other sources of income at homestead. Depending on levels of food production, disposable income and new knowledge of the farmers, they can change crop management practices in the next season to increase chances of high crop yield and disposable income. The cyclic nature of the framework is presented in Figure 30.

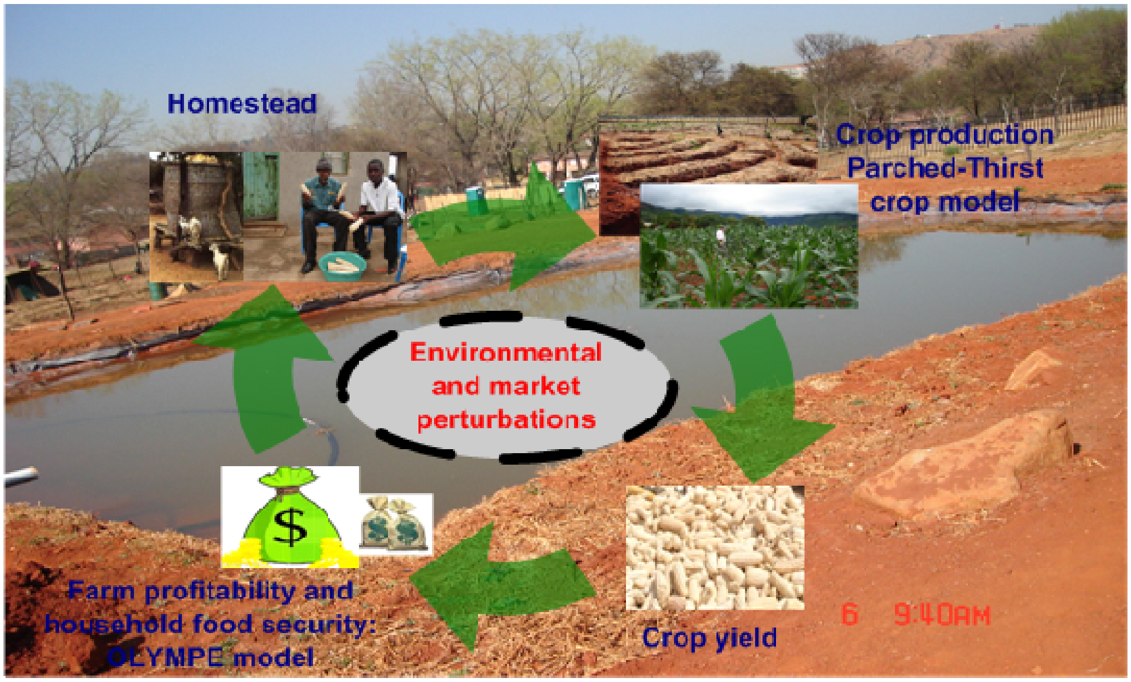

Figure 30: Framework for the assessment of smallholder farming system risk to climate and market shocks

1.6.3 Results and Discussions

The results of the farm typologies are presented in Table 10.

Table 10: Farming systems in the B72A quaternary catchment, Olifants River Basin; Data was derived from field surveys from 2005—2006

Variables	Average	Standard deviation	TYPE A	TYPE B	TYPE C	TYPE D	TYPE E	F-Statistic	F-TEST
Family Characteristics									
Age of farmer	**54.4**	14.1	49	52	57	50	67	3	**
Family members working on farm	**2.02**	1.99	2.67	1.90	1.94	1.80	1.33	0.82	no
Number of hired workers	**0.81**	1.12	1.17	0.85	0.49	2.40	0.67	8.90	***
Family labour/ha	**3.40**	6.2	4.6	5.3	2.5	1.3	0.8	2.07	*
Total labour/ha	**4.50**	6.6	6.5	6.1	3.3	4.3	1.5	2.12	*
Assets									
Household asset index	**1.27**	1.11	1.25	0.80	1.32	2.20	3.33	7.11	***
Land area (ha)	**1.30**	1.54	0.94	1.01	1.54	1.21	2.03	1.40	no
Livestock Units	**2.61**	3.59	1.20	1.12	3.23	3.99	12.09	11.09	***
Source of Income									
% Employment Income	**21%**	32%	73%	4%	15%	0%	91%	59.82	***
% Off farm Income	**3%**	14%	1%	4%	2%	21%	0%	4.87	***
% Livestock Income	**2%**	6%	0%	0%	4%	1%	1%	4.72	***
% Crops Income	**38%**	37%	12%	88%	18%	67%	4%	102.83	***
% Remit & grants	**5%**	14%	3%	0%	9%	0%	0%	3.17	**
% Pensions income	**31%**	35%	12%	4%	52%	11%	5%	27.06	***
Irrigation income / crop income	**54%**	38%	44%	49%	58%	67%	59%	1.03	no
Annual Crop income (US$)	**383**	430	219	613	295	596	325	5.85	***
Total family income (US$/year)	**1 925**	2 288	2 803	752	1 838	1 553	14 136	66.17	***
Agricultural Practices									
Fertiliser costs US$/ha	**9**	7	5	11	4	21	4	4.01	***
Seed costs US$/ha	**8**	6	2	7	4	11	18	0.89	no
Vegetables diversity	**2.25**	1.67	1.3	2.4	2.2	3.9	3.7	5.72	***

Notes:

1. *Sample size (N) = 159 farmers*
2. *1 US$ = 9 ZAR (2008).*
3. **** F test significant at 99 %, **; F test significant at 95 %, no: not significant at 90 %*
4. *Type A: Subsistence farmers with external jobs; Type B: Resource-constrained rainfed farmers; Type C: Social grants supported rainfed farmers; Type D: Intensive, diversified irrigation farmers and Type E: Rich, salaried entrepreneurs - very extensive farmers.*
5. *Off-farm income refers to income from self jobs such as hawking, craft work, brewing beer and excludes salaried employment*

6. The household asset index was calculated from standardized scores (0–5) based on the type, size, construction material of the house (s) at the homestead, farming implements and in-house items such as cooking stoves, furniture etc.
7. Vegetable diversity was calculated based on the number of vegetable crops grown by the farmer.

As Table 10 shows, the bulk of the family income for farm Types A, B, C, D and E comes from employment (73%), crops (88%), pensions (52%), crops (67%) and employment (91%) respectively. Farm Type E is least vulnerable. This is expected since most of the family income comes from employment and a buffer from accumulated high levels of assets compared to other farm types (Table 10).

From the survey, women constituted more than 60% of the farm household heads and were the most vulnerable households. Hence, programmes that uplift women will make greatest impact in the study area.

The OLYMPE model, which is a decision support system (DSS), considers a representative farming system (livestock, crops, tree plantation, management options and environmental externalities) and makes long-term simulations adequate to support policy impact analysis, including the cyclic weather conditions such as droughts.

Current crop management practices (labour costs of US\$ 58ha^{-1}) involve planting on level fields; while improved crop management includes planting basins (labour costs US\$ 168 ha^{-1}, initially). The planting basins improved the yields more than fourfold in good rainfall years while in poor rainfall seasons maize yield stabilised to about 76% (Figure 31a) of long-term average yield. Scenario results on seed, fertilizer, cattle and combined input/output price variations are presented in Figs 32–37.

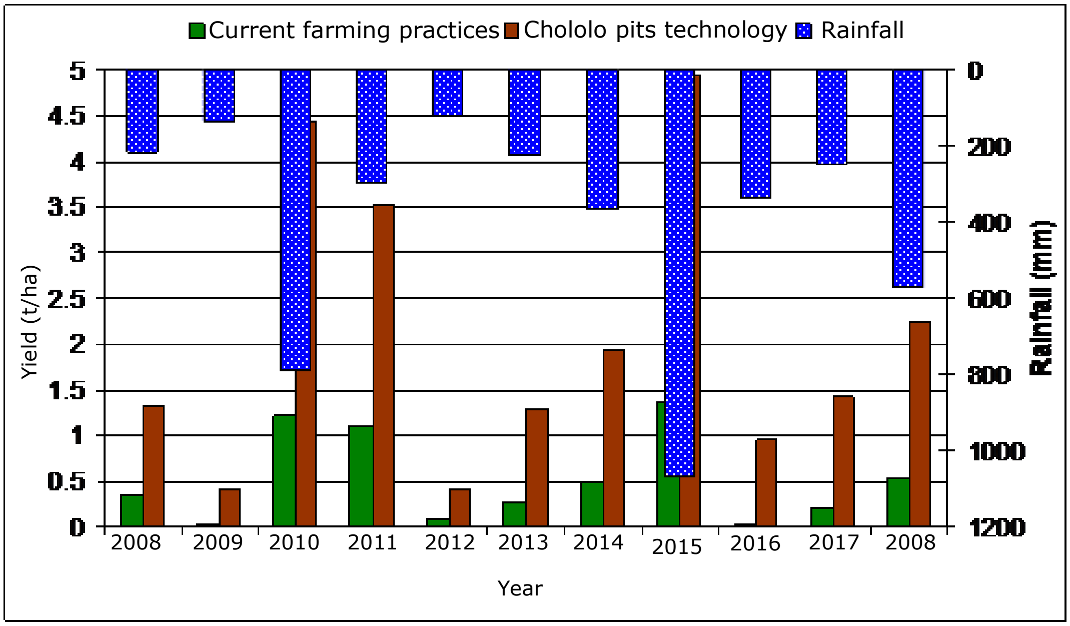

Figure 31a: Maize yield variation under current and *Chololo pits/*planting basins crop management. The average (n=10 years) yield is 0.5 t/ha and 2 t/ha for current and Chololo pits practices respectively. Rainfall was generated from Parched-Thirst model weather generator.

The conventional and planting basins structures are shown in Section 3.2.1 (Figure 17). The farmers received well the planting basins for maize production due to their capability of storing water for the crop for longer periods compared to conventional ploughing. Hence, the farmers expanded the technology to vegetables.

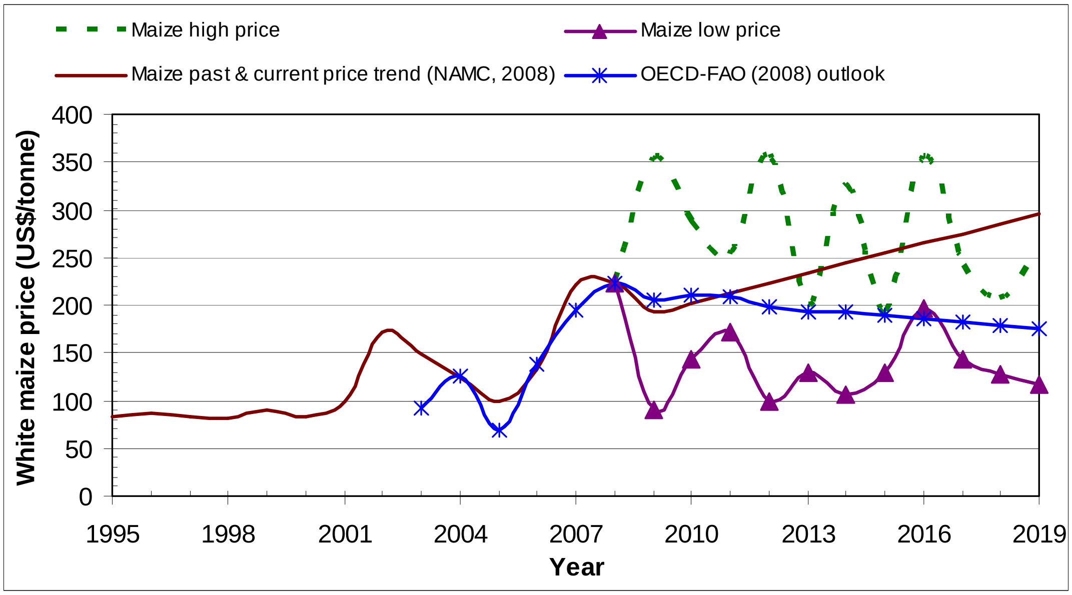

Figure 32a: Annual maize price variation scenarios under current trend, high price, low price and OECD-FAO (2008) outlook

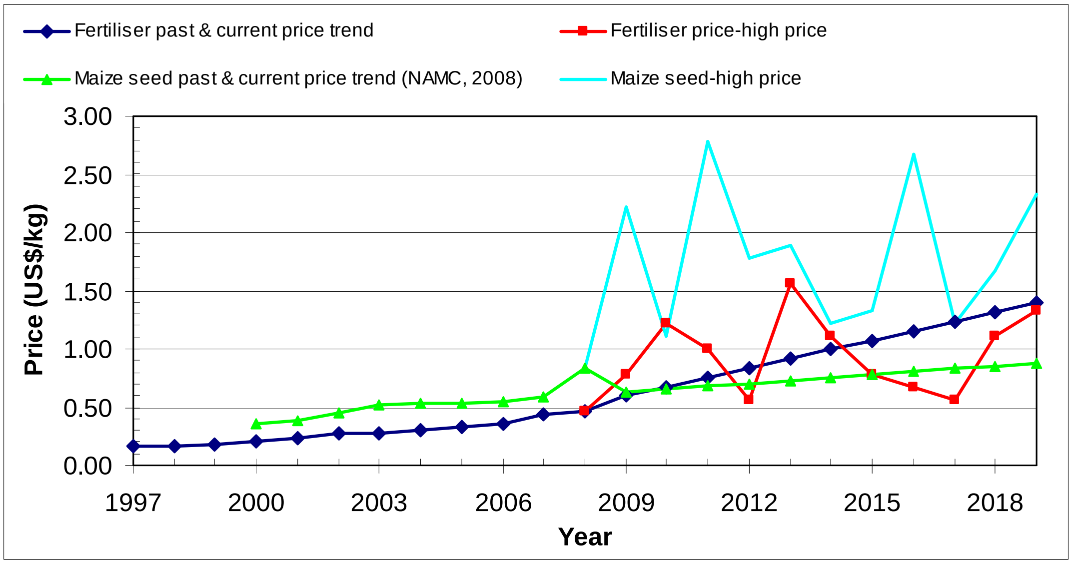

Figure 32b: Maize seed and fertilizer price scenarios for current trend and high prices.

The gross income and net income (Figure 33a) shows that types B and C farms are unsustainable. Types A and E are resilient. However, when other sources of income are considered, only type B is struggling to feed the family as show in Figure 33b.

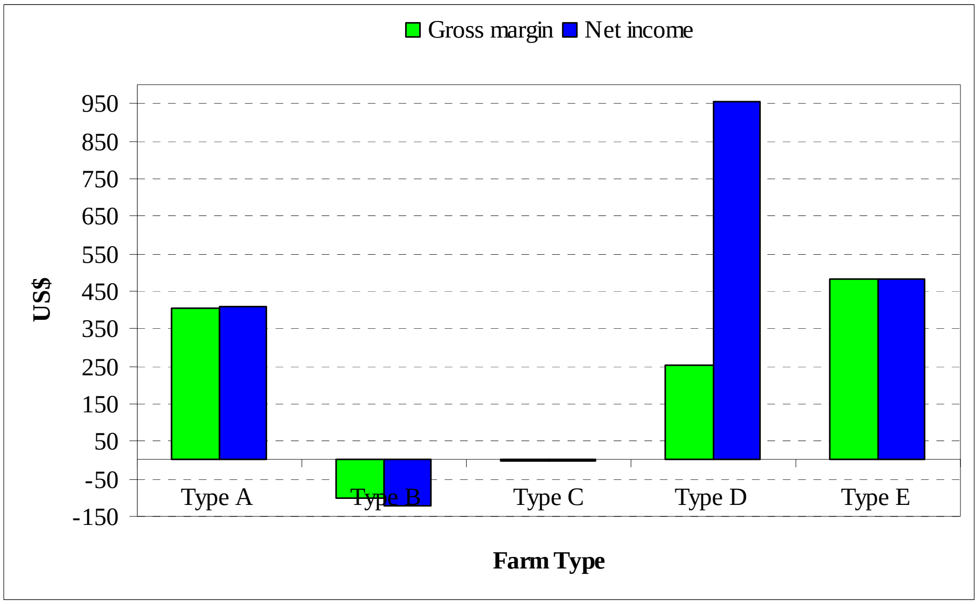

Figure 33a: Average (5 years) annual farm gross margin and net income.

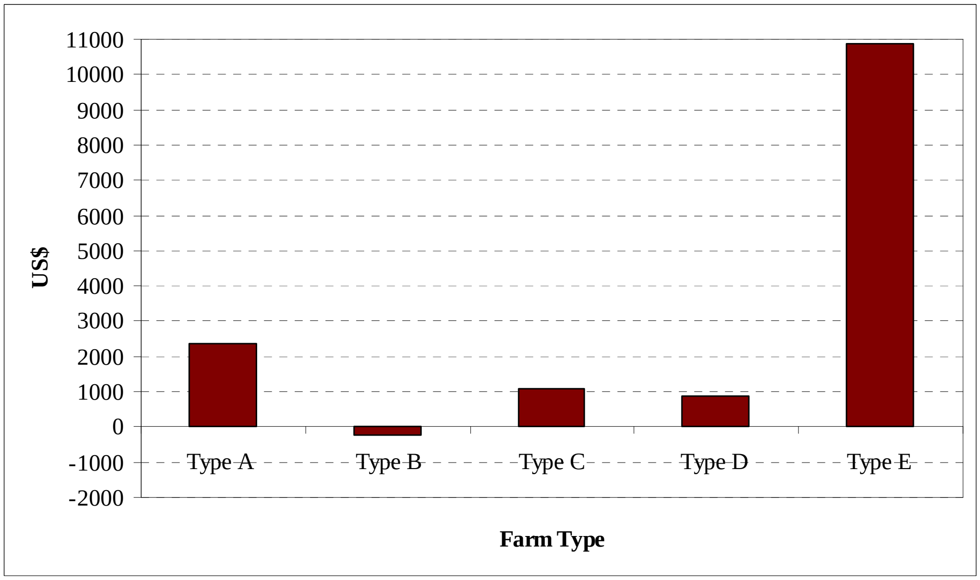

Figure 33b: Average annual (5 years) total family balance.

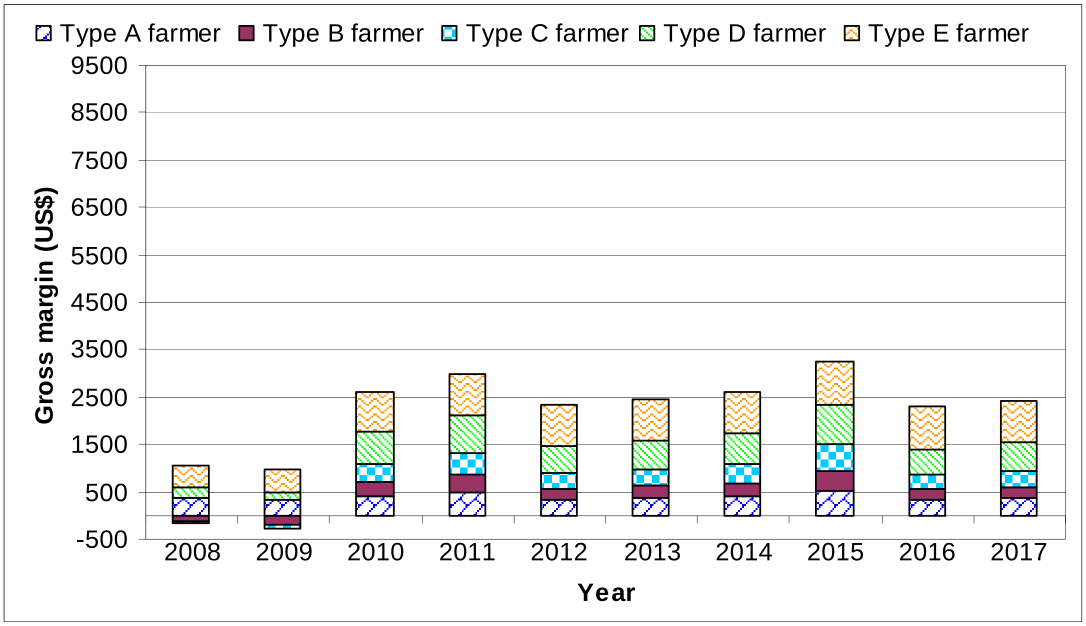

Figure 34a: Projected annual gross margin under current maize crop management and rainfall variation.

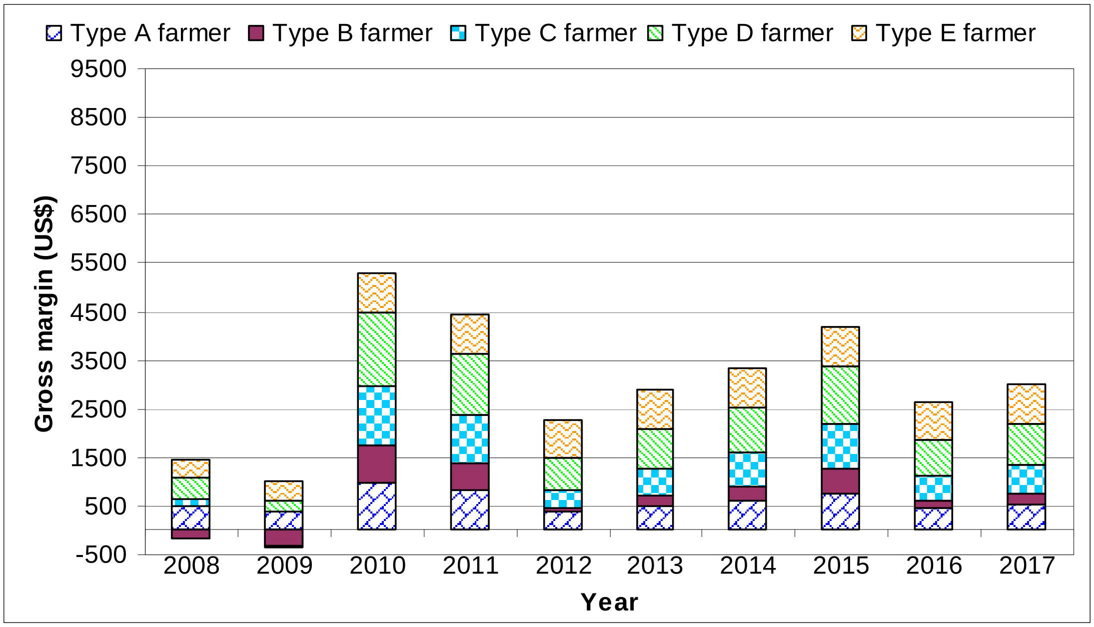

Figure 34b: Simulated farm gross margin under *Chololo pits/* planting basins technology and rainfall variation**.**

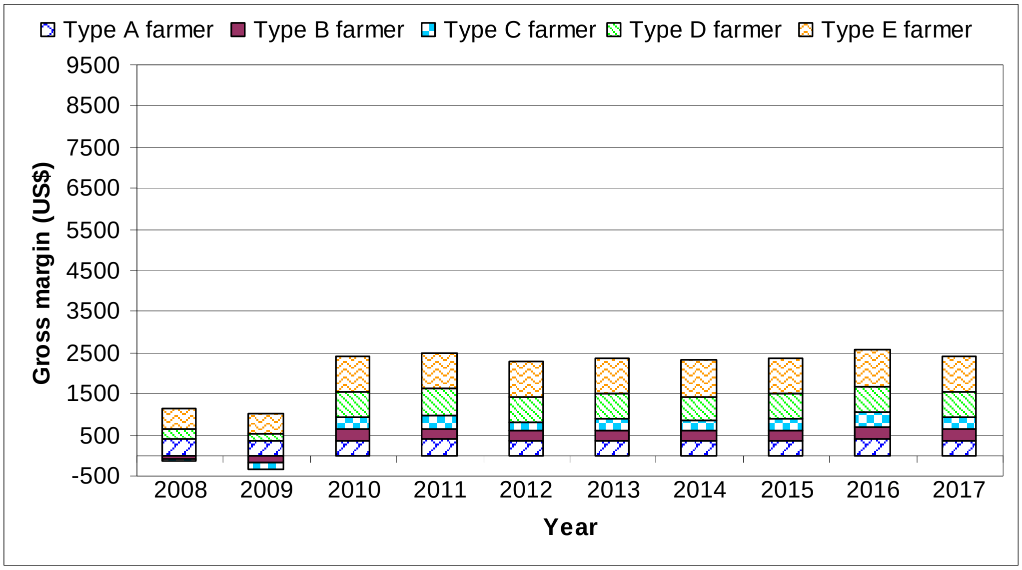

Figure 35a: Projected annual gross margin under low maize price variation.

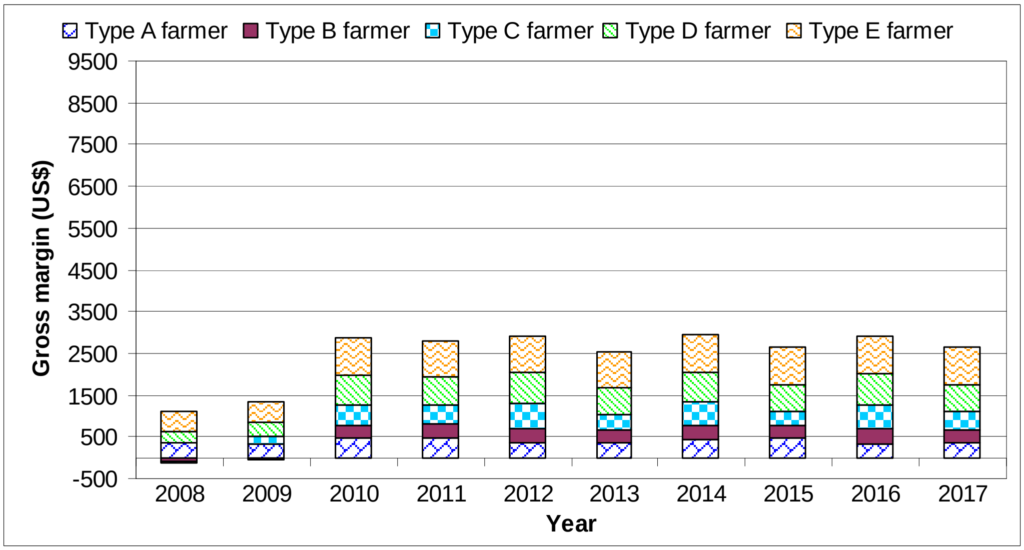

Figure 35b: Projected annual gross margin under high maize price variation.

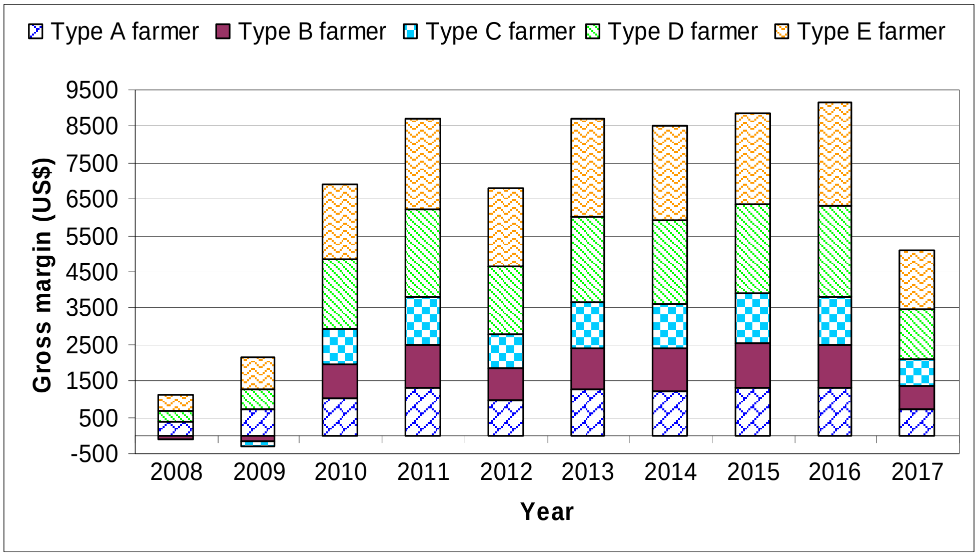

Figure 36a: Projected annual gross margin under cattle price variation scenario.

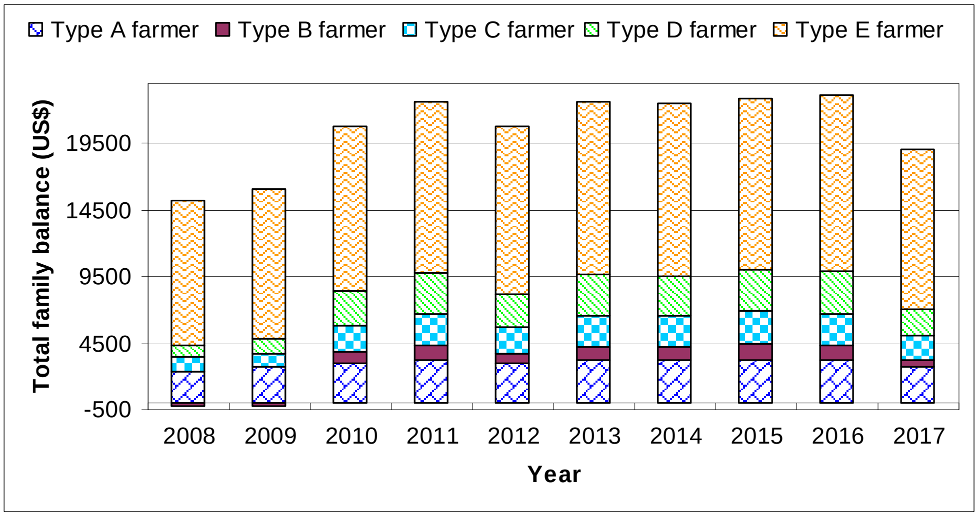

Figure 36b: Projected annual farm balance under cattle price variation scenario.

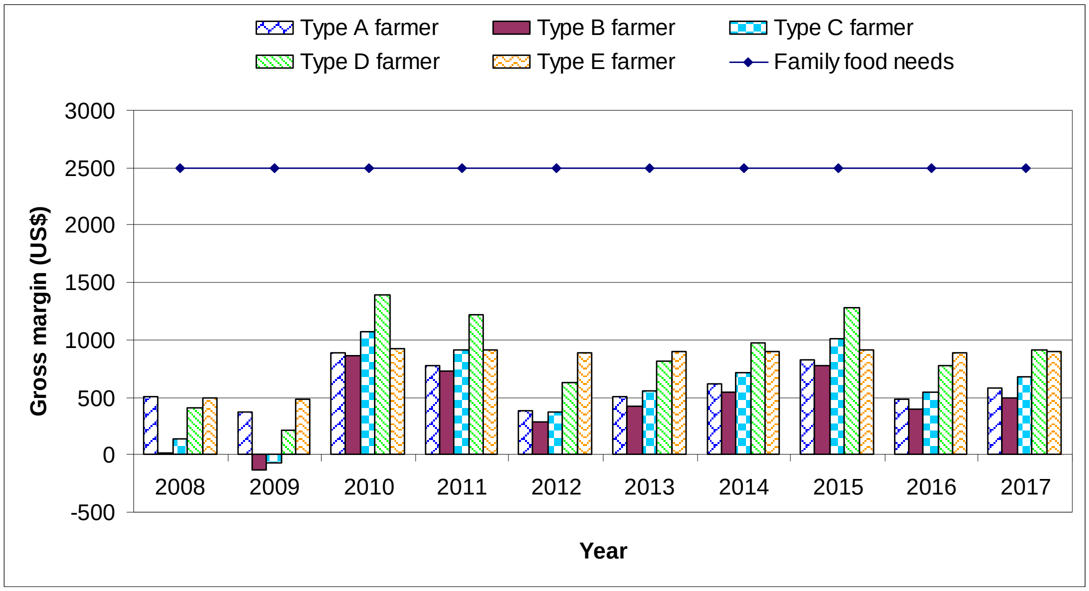

Figure 37a: Projected annual gross margin under combined scenario of planting basin technology, future rainfall variation, current trend in fertilizer and maize grain prices.

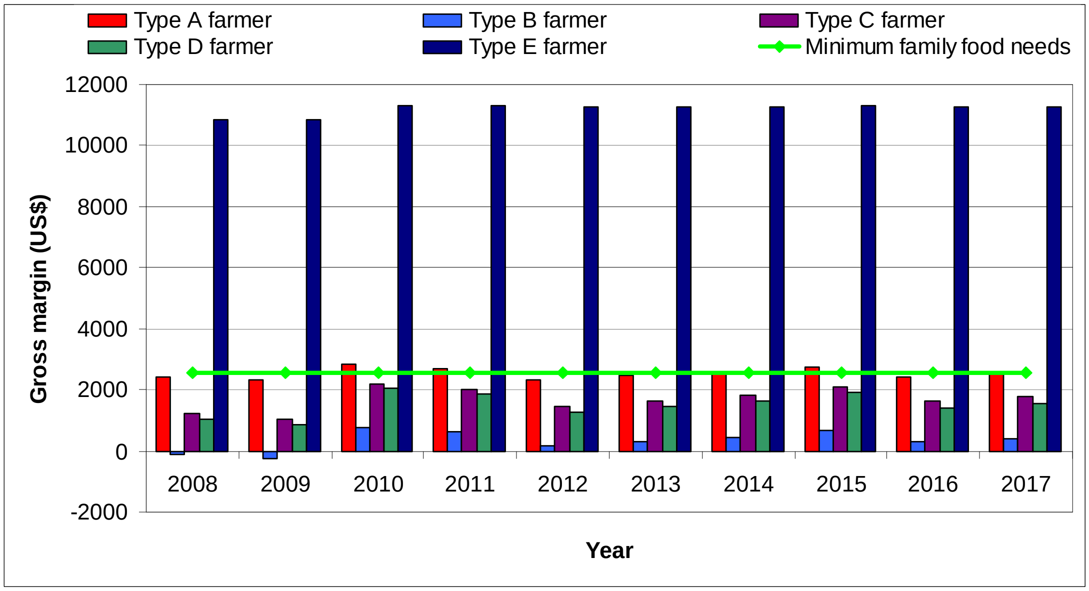

Figure 37b: Projected annual total family balance under combined scenario of planting basin technology, future rainfall variation, current trend in fertilizer and maize grain prices.

Maize price increases, enhance the purchasing power and farm production of small farmers given favourable weather conditions (Koch and Rook, 2008). In the wake of global bio-fuel agenda maize prices jumped to above US$200/tonne in the last three years. Unlike some countries, South Africa has already restricted the use of certain food commodities, in particular maize, for bio-fuels production to enhance the food security for the poor (Koch and Rook, 2008).

The study showed that the level of farm vulnerability and risk mitigation is strongly affected by farm resource endowment, in particular livestock units, crop management techniques, fraction of the area irrigated, farm area and labour availability per hectare.

The main stabilizer of farm income is the introduction of livestock (cattle, goats, and sheep) into the farming systems.

Based on the above results, it seems that the crop farming system is least resilient than the livestock and crop-livestock production systems. However, if externalities of the farming systems were evaluated the results could be different.

The model presented above is useful to:

- Supporting decisions by farmer on whether or not to shift from sole crop production into crop and livestock production,
- Policy-makers seeking to consider mixed and crop diversified farming productions.

Despite the technically feasible solutions derived from the model, policy-makers should take into consideration the costs to farmers and society of recommending or requiring uptake of the farming methods (i.e. economic efficiency).

1.6.4 Policy implications

- Promote planting basins in suitable conditions (rainfall, slope and soil) as a means of in-field rainwater harvesting technique
- Establish smallholder farmer water conservation committees with women as leaders
- Raise smallholder crop diversification levels to mitigate risk of a single crop failure
- Encourage mixed farm productions (crop and livestock) as a way of buffering livelihoods by livestock production in drought/flood years.

However, the above policies have their limitations as the farmers need to save money to invest in livestock, need of sufficient pasture and access to markets to sell the livestock at good prices.

Other farming improvement practices should entail the following:

- Introduction of high value crops;
- Improving extension and technical services;
- Land tenure reforms.

1.6.5 Conclusions

A farming simulation model for smallholder farmers is presented. The bio-economic simulation combined an agronomic model (PARCHED-THIRST) with a socio-economic model (OLYMPE), providing a realistic portrayal of agricultural reality. Farm risks evaluation through scenarios related to markets, crop management techniques and weather hazards on maize production were presented. The results demonstrate the great opportunities that exist to upgrading farming systems in the B72A quaternary catchment in Olifants, especially rainfed agriculture by use of *Chololo* planting basins to ensure food security and profitable farming in rural communities.

All farming systems except Type E could not satisfy the recommended minimum food requirements for an average family size of five persons.

- Consider various aspects of in-field water (basins) and soil (micro-dosing) management.
- Impact of input-price shocks is comparatively less than output price shocks on farm income. The impact of input-price increase is negligible to risk-averse smallholder farmers because of little quantities used and elasticity of the demand.
- Shocks of severe drought/flood and intra-seasonal dry-spells resulted in the highest reduction in farm returns, partly due to loss of production for family consumption.

- OLYMPE simulation with farmer involvement helps farmers to assess the impacts of farm systems and to make right decisions.

1.7 Crop Simulation Modelling in South Africa using the Agricultural Production SIMulator (APSIM)

Field experimentation was conducted in the 2007/08 cropping season in Sekororo in which crop and stover yield and water use of maize, cowpea, and groundnut were measured. The observed results were used to evaluate the performance of the crop-soil model crop□soil model APSIM in simulating the water balance, yield and water productivity of maize and legume crops in the Limpopo Province, RSA.

APSIM was able to simulate very closely the observed range of crop yields in terms of both total biomass (3750 to 7000 kg ha - 1) and grain yield (1250 to 2900 kg ha - 1). It also simulated the observed differences in soil water content over time under the 3 crops, reflecting differences in crop water use due to planting date and crop duration and soil water distribution patterns. Using in - crop rainfall, the water productivity (WP) of the 128 day maize (fertilized) and groundnut crops was the same (6 kg mm - 1 ha - 1) whereas it was 3.8 kg mm - 1 ha - 1 for the 94 day cowpea. Using model outputs to fill measurement gaps at the start and end of the crop cycle, WP with respect to total water input (rainfall plus soil water depletion), was reduced to 5.5 and 3 kg mm - 1 ha - 1 for maize/groundnut and cowpea, respectively. Including the total seasonal rainfall, which was above average, in the total water input reduced WP to about 4 kg mm - 1 ha - 1 for maize and groundnut and to only 1.8 kg mm - 1 ha - 1 for the short duration cowpea crop.

The model was able to provide estimates to fill measurement gaps in water balance components of the field experiments, thereby allowing more detailed and appropriate calculations for comparing the water productivity of the different crops.

2 Objective 2: Development of appropriate catchment management strategies based on IWRM principles that incorporate sustainable use of green and blue water resources, which enables poor rural people to reduce risk of food deficits due to water scarcity, and to manage water for improved livelihoods.

2.1 Introduction

Water resources, refers to water in its various forms of liquid, vapour and solid, and in various locations (atmospheric, surface and subsurface), which have potential value to man (United Nations, 2006). Water is indispensable to life, society's well-being and to sustainable economic growth. Plants, animals, ecosystems and humans are sensitive to fluctuations in the storage, fluxes, and quality of available soil, surface and/or ground water. In turn, these storage, fluxes and quality are sensitive to climate change (e.g. manifested through rainfall variations). Hence, the second key research achievement of the Challenge Program on Water and Food Project, PN17 was the development of appropriate catchment management strategies, based on IWRM principles that incorporate sustainable use of green and blue water resources, which enables poor rural people to reduce risk of food deficits due to water scarcity, and to manage water for improved livelihoods. To achieve this objective, water resources modelling to quantify (conventional and non-conventional water resources) and reveal any trends or fluctuations in quality or quantity were instituted in various catchments in the Limpopo Basin (Figure 1).

The Limpopo Basin is shared by Zimbabwe, Botswana (not part of this study), South Africa and Mozambique. Knowing potential water available and its quality in the basin helps to make informed decisions about water resources management such as rainwater harvesting systems, crop management practices and sustainable water allocation strategies to competing users, thereby enhancing livelihoods. This chapter gives an overview of various water resource studies carried out in the Limpopo Basin.

The chapter is divided into three sections. The first section briefly presents decision-making tools for catchment management including rainfall variation analyses (dry spells, wet days), rainfall-runoff modelling, impacts of dams on flow regimes, floods, water allocation, non-conventional water sources. The second section presents alluvial aquifers as sources of water especially for small communities including the rural population. The third section deals with the water quality issues. In all the sections, methodology, main results and key messages are presented. The chapter concludes by highlighting the key findings in all the studies.

2.2 Decision support tools for catchment management

2.2.1 Historic analyses of rainfall in Zimbabwe and South Africa

This section briefly describes three case studies carried out in Zimbabwe and South Africa in relation to rainfall variation impacts.

The first study characterised the changing regional and global trends in climate, such as global warming related declines in annual rainfall and discharge in Shashe and Mzingwane Rivers (Love et al., 2010). These trends are likely to have a strong influence on water resource availability, and increase livelihood risks. Comparisons of rainfall and runoff records at different locations within sub-basins were done. In addition, the Spearman rank test and the Pettitt test were used to analyse trends of temperature, rainfall and discharge from the northern portion of the Limpopo Basin in Zimbabwe. Statistical analyses of daily temperature, rainfall and runoff data from stations with a minimum of 30 years continuous data were carried out.

The results showed notable decline in rainfall and discharge in the study area since 1980, both in terms of total annual water resources (declines in annual rainfall and annual unit runoff) and in terms of the temporal availability of water (declines in number of rainy days, increases in dry spells and days without flow). The declining rainfall trend was related to the increased incidence and severity of El Niño events and to changes associated with global warming. Discharge reduction was attributed to declining rainfall input and runoff generation in headwater catchments due to impoundments in small dams and increased irrigation water abstractions (Love et *al*., 2010). The study suggested that as rainfall continues to decline a multiplier effect will be felt on discharge due to non-linear processes involved in rainfall-runoff conversion. Increased food shortages are likely because of declining water resources availability and uneven distribution indicated by increased dry spells on rainfed and irrigated agriculture. In addition, declining water resource availability will further stress urban water supplies, notably those of Zimbabwe's second largest city of Bulawayo.

Key message
There is a decline in water resource availability and uneven distribution, which has exerted pressure on urban, irrigated and rainfed agriculture. This has the potential to affect poverty reduction and sanitation provision.

In a second study, Mupangwa et al. (2009) assessed changes in the start, end and length of growing season and the pattern of 14 and 21–day dry spells during the growing season in the Mzingwane catchment portion of Limpopo Basin in southern Zimbabwe. The study provides information for planning of land preparation and planting activities for smallholder agriculture, dependant on seasonal characteristics of rainfall.

Daily rainfall data from five meteorological stations located in southern Zimbabwe was analysed. The study concluded that no significant changes in the start, end and subsequent length of growing season had occurred over the past 50–74 years along the Bulawayo to Beitbridge transect in southern Zimbabwe. In addition, the number of wet days per growing season had not changed significantly. However, high chances of 14 and 21–day dry spells during the peak rainfall months were noted, permitting scope of exploring rainwater management technologies to bridge dry spells in rainfed cropping systems.

The findings from this study (Mupangwa, 2009) concurred with those of Tadross et al. (2007) who reported increased dry spell lengths and reductions in wet day frequencies in Malawi, Zambia and Zimbabwe and in Sub-Saharan Africa in general (Usman and Reason, 2004). Furthermore, Magombeyi and Taigbenu (2008) reported return period of 2 years for droughts and 14–day intra-seasonal dry spells with a probability of 0.52 in the growing season, in the Olifants sub-basin in South Africa.

A third study, assessed dry spell impacts on crop yields in South Africa (Magombeyi and Taigbenu, 2008). The study evaluated the vulnerability and risk to water resources and food security of smallholder farmers under exclusive rainfed and supplementary irrigation agriculture in the Olifants sub-basin. It was noted that soil-water deficit at critical growth stages may reduce yields by up to 62 %, depending on the length and severity of the moisture deficit. The study affirmed the need to invest in rain and soil-water management technologies to prolong the period of soil-water availability to crops in smallholder cropping systems if increased rainfed yields are to be attained in semi-arid areas (Mupangwa, 2009; Love et al., 2010).

Key message
Crop production is threatened by increased incidence and severity of El Niño events and changes associated with global warming as they trigger high frequency of severe dry spells.

Understanding historic changes, or projecting future changes in streamflow conditions will require evaluation of precipitation and temperature changes as well as the role of land-use change on streamflow. These issues further reinforce the importance of maintaining adequate nationwide and basin networks of precipitation and streamflow gauges for use in predicting changes in average streamflow and streamflow variability.

The reported changes in regional and global trends in climate and discharge are likely to have a strong influence on water resource availability, agricultural practices, floods and increased food security risk. In the Limpopo River Basin, an increase in extreme precipitation events is considered likely as evidenced by floods experienced in 2000.

In the next section, a study on flood forecasting and potential human and property impacts in Mozambique is presented.

2.2.2 Flood forecasting in Mozambique

This section briefly describes a flood-forecasting tool developed and applied in data scarce areas in Mozambique. The tool is based on advances in integrated technologies including Geographic Information Systems (GIS).

A study aimed at improving flood forecasting and management options of potential inundated areas with limited climatic data was carried out in the Olifants sub-basin of the Limpopo River Basin, which is under constant threat from floods (Vilanculos, 2008).

The methodology employed the latest developments and advances in integrated technologies of Geographic Information Systems (GIS), remote sensing and hydrological modelling. Geophysical properties (soil and topography) and time series data obtained from satellite images and historical records were used to parameterise the model. The spatial and temporal attributes were stored and analysed through GIS, which was linked to a Geo-spatial Stream Flow Model.

The calibrated model performed well, with regression coefficients ranging between 94 % and 98 %. A flood wave was predicted to take two days to reach Chókwè, after leaving Massingir Dam. Furthermore, the study showed that flood prediction at Chókwè was possible three to five days prior. Thereby enable issuing of an early flood warning to downstream communities. At highest flood level, with water stages between 8.5–10.5 m, which were above historic levels, prior to 2000, the floods may affect up to 130,000 people, 27 primary schools, a secondary school and seven hospitals.

Key messages
The flood forecasting model produced reliable flood forecasts with up to 3–5 days lead time, comparable with superior methods that achieve up to 7 days (Markar et al., 2005).

Flood risks are a function of many factors, including populations exposed to floods, the nature and extent of structures within river floodplains, the frequency and intensity of hydrologic events, and kinds of protection and warning available. Therefore, decision support tools that enable flood prediction in data limited areas can save lives and property, and reduce poverty.

Owing to the large catchment scale and heterogeneity in topographic characteristics, more accurate geospatial data and distributed modelling are crucial for more accurate and reliable hydrologic predictions.

The next section presents water generation and allocation modelling studies carried out in Mzingwane sub-basin of the Limpopo Basin.

2.2.3 Mzingwane Basin modelling in Zimbabwe

This section presents eight studies including rainfall-runoff and water allocation from dams and streams with their associated impacts on water management for improved livelihoods.

2.2.3.1 Rainfall-runoff modeling with HBVx

In the first study, a dynamic, semi-distributed model HBVx was developed to analyse the rainfall-interception-evaporation-runoff relationships of a meso-catchment in the semi-arid Zhulube catchment in the Zimbabwe portion of the Limpopo Basin (Love et al., in press). HBVx is an improvement of HBV (Hydrologiska Byråns Vattenbalansmodell) (Seibert, 2002) with interception volume introduced and runs in parameterised and semi-distributed mode in two or more sub-basins. Understanding of the hydrological processes occurring in a catchment is essential in building resilience to water resource availability (Lange and Leibundgut, 2003) or developing trade-offs between food and ecosystem services (Falkenmark et al., 2007). Interception, one of the hydrological components is a major driver of the magnitude and speed of catchment response to rainfall, especially for semi-arid catchments with limited rainfall frequency and depth (Beven, 2002; De Groen and Savenije, 2006).

Daily rainfall for each sub-catchment was computed by use of Thiessen polygons, from the 2005–2008, while daily reference evaporation was calculated by Hargreaves formula (Allen et al., 1998).

The results showed that observed runoff events were disjointed, with short or no observable recession curves, probably caused by the shallow soils (graph/diagram). Floods showed longer recessions associated with higher antecedent precipitation. In the catchment water balance, interception accounted for 32 % of rainfall in the 2007–2008 season but increased to 56 % in the drier 2006–2007 season. After calibration, HBVx simulations satisfactorily showed the disjointed nature of the flows, as observed. The incorporation of interception into rainfall-runoff substantial improved the objective function values from Nash-Sutcliffe coefficients (C_{NS}) of 0.296 without interception to C_{NS} of 0.556 for the model with interception, both in semi-distributed mode. The best HBVx simulation supported by field observations suggested that discharge in the Zhulube Catchment was driven mainly by flow from rapidly-draining shallow groundwater, with little or no overland flow. Nonetheless, the HBVx model was unable to address temporal variability in soil characteristics and storages that are more complex such as bank and wetland storage. The model suggests episodic groundwater recharge with annual recharge of 100 mm a^{-1}, which is comparable to another study reported in Zimbabwe (Larsen et al., 2002). Higher temporal resolution data such as rainfall and discharge at sub-hourly time-steps would give better model results.

Key message
Interception quantification is important in catchment response to rainfall events, especially for semi-arid catchments. Discharge in the Zhulube Catchment was driven mainly by flow from rapidly-draining shallow groundwater.

The last study dealt with model regionalisation in Zimbabwe. Love et al. (2009) regionalised HBVx, derived from the conceptual hydrological model HBV (Bergström, 1992; Seibert, 2002), in the heterogeneous semi-arid Mzingwane sub-basin, Limpopo Basin. Regionalisation process transfers small-scale (or meso-scale: scale of approximately 10^1 – 10^3 km^2 (Blöschl and Sivapalan, 1995) measurements to a large scale (or basin or regional > 10^4 km^2) model, or from gauged catchments to ungauged catchments. Despite several past attempts, no single regionalisation procedure has been developed that yields universally acceptable results (Ramachandra Rao and Srinivas, 2003). The study presents opportunities for streamflow prediction in ungauged and data constrained catchments.

Fifteen meso-catchments were considered, including three that were instrumented during the study. The parameter sets that performed best in the regionalisation are suggestive of slow infiltration with moderate/fast overland flow. These processes appeared more prevalent in degraded catchments, suggesting that benefits can be derived from soil-water conservation techniques that increase infiltration rate and runoff harvesting (in-field and ex-field). Faster, and possibly greater, sub-surface contribution to streamflow is expected from catchments underlain by granitic rocks. The study noted that calibration and regionalisation were more successful at the dekad (10 days) time step than when using daily or monthly data. Nevertheless, none of the parameter sets regionalised yielded (Nash-Sutcliffe Coefficient) $C_{NS} \geq 0.3$ for half of the catchments. In agreement with Ramachandra Rao and Srinivas (2003), the study concluded that without more reliable and longer rainfall and runoff data, regionalisation in semi-arid ephemeral catchments would remain a challenge.

Key message
Regionalisation methods, though still under development, presents opportunities for streamflow prediction in ungauged and data constrained catchments. Time step and spatial heterogeneity play important roles when hydrological processes change from a small to large scale.

2.2.3.2 Modelling upstream-downstream interactions and water allocation with a spreadsheet-based model

In the third study, a spreadsheet-based WAFLEX (Savenije, 2005) model was applied to analyze upstream-downstream interactions, dam management options, water allocation and development options in the lower Mzingwane and Thuli River sub-basins of the Limpopo Basin, Zimbabwe (Love et al., 2008a).

In lower Mzingwane, the WAFLEX model showed that management of water releases from Zhovhe Dam, which is currently underutilized, could satisfy an agro-industry, town of Beitbridge and irrigation water for smallholder farmers along the river, where soils are poor and rainfall is unreliable. For the Thuli River sub-basin, an inter-basin water transfer to satisfy water requirements to Bulawayo City in Zimbabwe was proposed from Mtshabezi Dam. Furthermore, the construction of Moswa and Elliot Dams is essential to satisfy Greater Thuli Irrigation Scheme water needs. WAFLEX model identified underutilized water resources and showed the feasibility of equitably sharing scarce water resources among several users and with minimal negative impacts.

A fifth study evaluated the effects of upstream water demand scenarios on downstream users in the Thuli River sub-basin in south-western Zimbabwe (Khosa et al., 2008), since surface water resource availability is a constraint. Currently, the basin is more developed in its upper than lower reaches. Thuli River is a tributary basin to the Shashe River, which is a tributary of the Limpopo River (Khosa et al., 2008). Modelling water demand scenarios can be used to plan supply and demand for a particular water use (Shnaydman, 1993) or evaluate water policies (Gómez-Límon et al., 2002).

WAFLEX, a flexible spreadsheet based model (Savenije, 1995) was applied to simulate the impacts of different water demand scenarios on downstream water availability. The water demand scenarios tested were based on government recommendations and future water resources development, drought risk mitigation, implementation of environmental water requirement and implementation of inter-basin transfer to Bulawayo City water supplies.

WAFLEX model simulated well the observed flows in most of the years, with regression coefficient of 0.7 at $p < 0.05$. The results showed that implementing inter-basin transfer increased downstream water shortages, whereas provision of environmental water requirements, implementation of water resources development plans by government and drought risk mitigation decreased downstream water shortages. The study emphasised the need for a holistic simulation approach (including up- and down- stream users, other stakeholders and potential water development options) by the Thuli River basin management institution in selecting sustainable water development and water allocation trade-offs.

Key message
Dynamic reservoir operation rules will likely become more appropriate than traditional rule curves as complexity of water allocation increases due to competing uses and water scarcity. Depending on the state of the river system being managed, water supply impacts to competing users can be dampened by planned release regimes, increased water use efficiency and construction of new storage.

The seventh study applied WAFLEX model for optimisation of water use and storage to provide for more equitable water allocation, in the lower Mzingwane aquifer (Love et al., 2009c). The aquifer is currently underutilised and recharged by managed releases from Zhovhe Dam (capacity 133 Mm^3). The study is important as Lower Mzingwane valley currently support commercial agro-businesses (1,750 ha irrigation) and four smallholder irrigation schemes (400 ha with provision for a further 1,200 ha).

WAFLEX model was adapted to incorporate alluvial aquifers into the water balance, including recharge, baseflow and groundwater flows (Love et al., 2009c). WAFLEX modelling results suggest that there is surplus water available in the lower Mzingwane system, and thus water conflicts should not be there. Water resources were better shared through more frequent timing of releases from the dam and maintaining the alluvial aquifers permanently saturated. In addition, sand dams augmented the aquifer storage system and improved access to water. The alluvial aquifers upstream and downstream of Zhovhe Dam have an estimated average water storage capacity of 0.37 $Mm^3\ km^{-1}$ of which 0.35 $Mm^3\ km^{-1}$ is below evaporation extinction depth. Therefore, a 137 km length of aquifer could potentially store 50 Mm^3 of water, 38% of the capacity of Zhovhe Dam. This stored water would be sufficient to irrigate a belt 100 m to 180 m wide along each bank, with total area of 3,000 to 4,500 ha, depending on irrigation efficiency. Such a system would be decentralised; farmer or family owned to benefit a larger population than is currently served.

Key messages
WAFLEX is a simple and user-friendly model (Love et al., 2009c) ideal for institutions such as the water management authorities in Zimbabwe, challenged by capacity shortfalls and inadequate data. Increased water use efficiency is a key solution to the increasing stress on water supplies. More crop-per-drop in both rainfed and irrigated agriculture has become a new paradigm in water (blue and green) use efficiency (Comprehensive Assessment of Water Management in Agriculture, 2007). Innovative ways to address water scarcity such as exploration of non-conventional water resources (sand dams) constitutes a huge potential for the protection of highly claimed aquifers.

To further address water allocation, a fourth study dealt with the impacts of Zhovhe Dam on the lower Mzingwane River channel by comparing upstream and downstream flow regimes in a daily water balance (Love et al., 2008b). The construction and management regime of dams change the downstream natural flow regime of a river leading to either siltation or erosion of riparian zones (World Commission on Dams, 2000).

Data collection involved geomorphology and vegetation surveys. Managed releases from the dam supplied commercial agro-business and Beitbridge town. Changes in channel morphology were observed, such as the decline in active riverbed width and abandoned portions of the river channel on either side, attributed to changes in flow regime, indicate that the extent of the alluvial aquifer is likely to decrease. The change in grain size from coarse sand (1995) to fine gravel (2008) could result in a lower specific yield that would negatively impacts the water storage capacity and supply potential of the Lower Mzingwane alluvial aquifer to current users including the environment.

Key message
Dam construction alters the downstream flow regime; requiring planned releases to mitigate water allocation impacts to the environment and the downstream users.

A sixth study compared river flows with instreamflow requirements downstream of dams in the Insiza catchment, in line with the new Zimbabwean and South African Water Acts that of recognises the environment as a user (Kileshye Onema et al., 2006). The three dams studied were Upper Insiza Dam, Insiza Dam and Silalabuhwa Dam. These dams account for 90% of the total storage capacity in the Insiza catchment. Silalabuhwa Dam was developed mainly for urban water supply to the City of Bulawayo.

The study concluded that impacts of dam construction on exceedence of low flows should be studied as lack of flows during the dry season has considerable adverse effects on aquatic and non-aquatic ecosystems that depend on these flows.

Key messages
The design of dam operating rules and allocation of environmental flows should take into account possible changes in low flows in order to minimize adverse environmental effects and surprises.

2.2.4 Olifants Basin Modelling

This section describes two catchment modelling studies consisting of hydrological and water allocation performed to improve water management in Olifants sub-basin, South Africa. The first study assessed the impacts of human-environment interactions on streamflow by application of a semi-distributed, Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998) model to the B72A, E, F, G and H quaternary catchments in the Olifants sub-basin in South Africa as demands on the water resources increases (Ncube and Taigbenu, 2008; Ncube, 2006).

Rainfall data was obtained from a database by Lynch (2004) and other climatic data were obtained from the South African Weather Services. Department of Water and Forestry (DWAF) now Department of Water Affairs provided the daily streamflow data at four gauging stations (DWAF, 2006). A sensitivity analysis (incorporated in SWAT) based on the LH-OAT (Latin Hypercube – One-factor-At-a-Time) method was performed to identify the driving parameters for the hydrology.

Results showed a correlation between land cover and the hydrologic response, as an increase in land cover corresponded to streamflow reduction. SWAT was able to adequately represent, characterise the relative effects of different land cover conditions and provide streamflow time series in the catchment. Highest streamflow reduction was observed under range grass, followed by forestry. While arid land resulted in highest streamflow increase. Best model parameter values for the B72E – H catchment from auto-calibration (van Griensven and Meixner, 2004) were applied to an ungauged B72A quaternary catchment, with similar biophysical properties to gauged catchments. A mean annual runoff of 68 mm was obtained in B72A catchment that is about 20% less than the virgin streamflows reported in Schulze (2003).

Key message
Good land management practices are important in sustainable water resources management as they affect the catchment hydrology. Application of SWAT model to ungauged catchments is promising.

The second study assessed future water demands and resources in the water-stressed Olifants sub-basin, South Africa (Arranz and McCartney, 2007; McCartney et al., 2005) using the Water Evaluation And Planning (WEAP) model (Yates et al., 2005; SEI, 2001) in conjunction with scenario analysis. The assessment is critical to decision-making, planning and implementation of development projects as different competing water users (i.e., rural, urban, mining, subsistence and commercial irrigated agriculture, commercial forestry, industry and power generation) are present in this sub-basin, which is considered “closed”. The ongoing and future land distribution and water re-allocation, population growth, mining industry growth, implementation of environmental flows and the need to meet international flow requirements are going to exacerbate the complexity of future water resources management in this water-stressed sub-basin.

Using scenario approach, impacts of possible water demands on the water resources of the Olifants sub-basin in 2025 were compared to 1995 values (taken as the baseline). Hydrological and water demand data came Water Resources 1990 study and Water Situation Assessment Model database, respectively.

The model enabled analyses of unmet water demands, streamflows and water storage for each scenario. For the different scenarios considered in the study, the implementation of the Environmental Reserve (an instream requirement to guarantee the health of the riverine ecosystems) increased the deficits for other users. For instance, application of the Environmental Reserve to the 1995 baseline condition increased the average unmet demand by 65 %, up to 43.8 Mm^3 (i.e., 5.6% of the total demand). For the high growth scenario (total demand increased by 50% from 1995 baseline condition), the Environmental Reserve increased the average annual shortfall to 135 M m^3 (12.1% of the total demand) with irrigated agriculture sector most affected. There were water shortages in 1995 baseline condition in the Olifants sub-basin, which increased in all the 2025 scenarios. Construction of new water storage infrastructure in conjunction with the application of Water Conservation and Demand Management practices reduced the unmet demands and deficits to levels lower than, or similar to, those experienced in the 1995 baseline condition. However, these interventions were insufficient to satisfy fully the demands of all the users. Hence, the study recommended a tight control of future water demands, although this may be difficult in a rapidly developing country like South Africa.

Key messages
Assessment of catchment’s ability to satisfy its future water demands is crucial in order to plan and make wise decisions. Olifants sub-basin cannot satisfy its future water demands even after construction of new infrastructure and implementation of water conservation and demand management. Application of the Environmental Reserve,

intended to ensure the sustainability of the resource base, results in more water flowing in the rivers, but less water available to meet direct human demands.

2.2.5 Coupled Decision-support tools for catchment management

The Innovative Coupling of Hydrologic and Socio-Economic Aspects model (ICHSEA) couples SWAT (hydrology; Arnold and Foster, 2005; Neitsch et al., 2001a; 2001b; Arnold et al., 1993), PARCHED-THIRST (agricultural water management; Young et al., 2002) and OLYMPE (socio-economics; Penot and Deheuvels, 2007). The ICHSEA interface was developed in avenues language in ArcView, to take advantage of the mapping capability of ArcView. PARCHED-THIRST (Predicting Arable Resource Capture in Hostile Environments During the Harvesting of Incident Rainfall in the Semi-arid Tropics) is a process-based model, crop model capable of simulating rainwater harvesting systems. OLYMPE model enables analysis of farming systems and their relationships with the physical and economic environment.

In ICHSEA, SWAT generates streamflow from rainfall, soil, landuse and other climatic data. The generated streamflow series, together with rainfall then serve as the primary input into PARCHED-THIRST where rainfed, full or supplementary irrigation crop management options are simulated to give crop yields. The changes in landuse or crop type and area (e.g. as a result of different soil-water conservation or rainwater harvesting practices) in PARCHED-THIRST are feedback into SWAT to re-calculate the runoff and sediments generated. The crop yields subsequently serve as input into OLYMPE model where crop gross margin, family food needs, non-farm income, farm family potential savings and other socio-economic parameters are calculated. If family savings are inadequate, the farmer/modeller may decide to change crop or crop management practices, which will be captured in SWAT and consequently in PARCHED-THIRST, completing the sub-models dynamic feedbacks.

The sensitivity analysis results from ICHSEA indicated 13 ranked sensitive parameters in SWAT, with the first three most sensitive parameters in decreasing order being CN2 (SCS runoff curve number for moisture condition II), GWQMN (Threshold depth of water in the shallow aquifer (mm) required for return flow to occur), and ESCO (Soil evaporation compensation factor). The parameter rankings from sensitivity analysis were unchanged with and without observed streamflow, suggesting that SWAT sensitivity module is robust enough to identify hydrological important parameters in ungauged catchments. Other ICHSEA sensitivity results are presented in Table 11.

Table 11: Elasticity index of the important model output parameters in 2007/8

	Initial model output	**Elasticity index (e_{10})**	
Model output		**E_{-10}**	**E_{+10}**
Maize yield (t/ha) sensitivity to rainfall	0.35	-1.25	+0.63
Maize gross margin (US$/season) sensitivity to yield	92	-1.16	+1.16
Maize yield sensitivity to Plant population	40 000	-0.29	+0.57
Maize yield sensitivity to Initial soil moisture (mm)	57	-0.26	+3.33

Time step of a model is related to scale of water storage that buffers water stress: for rainfed crop production, soil-water storage provides the buffer, and is depleted over a time step of five to seven days. For this reason, SWAT and PARCHED-THIRST in ICHSEA run at a daily time step, while the OLYMPE model uses seasonal time step. For water allocation for irrigation and urban use, reservoirs and alluvial aquifers provide the buffer. The former are depleted over a (supra-) annual time step and the latter over a dekad to month time step. Thus, HOWZIT runs at a dekad time step.

In conclusion, a change in runoff generated by hydrological models can be linked to the landuse, catchment management practices (such as crop management practices) and ultimately food security. Using sensitivity analysis identified important hydrological parameters for runoff generation in SWAT model either with or without using observed streamflows, suggesting applicability of SWAT model to ungauged catchments. Much effort must be invested in obtaining good quality data of the sensitive parameters. The study noted that a decision support model should run at the time step of the system resilience.

Key message
Coupled catchment models provide flexible and holistic impacts assessment tools to support management decisions and policy-making. However, sensitivity and uncertainty analysis of results need to be communicated to the decision-makers.

In the next section, a synthesis of all the studies presented in the first part of this chapter is presented.

2.3 Water Quantity – General Conclusions

This section describes a synthesis of the water quantity related studies.

Different hydrological models and water allocation models were applied in South Africa and Zimbabwe portions of the Limpopo Basin. The main criteria used to choose the hydrological models were availability of input data at appropriate resolution and model support from the model experts and developers. In South Africa, data availability and quality is much better than in Zimbabwe. Hence, a more data intensive hydrological model, SWAT was selected for application in South Africa (Ncube and Taigbenu, 2008; Ncube, 2006), while a less data intensive spreadsheet based model, HBV and HBVx (an improvement of HBV) were applied in Zimbabwe (Love et al., in press). Despite the different models used in the different contexts, the studies from the two countries concluded that the models were able to give satisfactory results to inform water resources planning at catchment level. However, in ungauged catchments, distributed models or semi-distributed models such as SWAT would give better results.

Water allocation and planning models to simulate of anthropogenic activities superimposed on the natural system used in the Limpopo Basin studies were WEAP in South Africa (Arranz and McCartney, 2007) and WAFLEX in Zimbabwe (Khosa, 2007; Love et al., 2008a; 2009c). The models assisted in identifying equitable water sharing rules from underutilized and overstressed water resources in the catchments. Other augmentation solutions identified included demand management, use of alluvial aquifers, inter-basin transfers, construction of new infrastructure and use of non-conventional water sources such as the sand dams.

Implementation of environmental water requirements intended to ensure the sustainability of the water resource base would ensure that more water flows in the rivers, but less water available and reduced assurance to meet direct human demands. However, the studies noted the need of a holistic approach, with stakeholder participation in assessment of water allocation and development options to avoid negative impacts. In an endeavour to address the need for holistic approaches, coupled models (HOWZIT and ICHSEA) were development to aid management and decision-making at catchment level.

In the next section, alluvial aquifers are described as potential water sources in dry areas, especially for rural small communities.

2.4 Alluvial Hydrogeology Case Studies in Zimbabwe

The temporal and spatial unreliability of rainfall and potential evaporation exceeding rainfall in semi-arid areas requires an intra-annual storage to secure water supplies for domestic and agricultural use. The water yield from developed surface water sources often falls short of the demand especially during droughts (Nyabeze, 2004). For this reason, relatively cheap groundwater in the form of alluvial aquifers is an attractive water source in the northern Limpopo Basin (Love et al., 2008c). An alluvial aquifer is an unconfined groundwater unit that is located in horizontally discontinuous layers of sand, silt and clay, deposited in a river channel, banks or flood plain (Love et al., 2009c). This section briefly presents four case studies on alluvial aquifers as potential sources of water supply to small communities and augments surface water supplies in the Mzingwane sub-basin, Zimbabwe.

The first study assessed the potential water supply for the upper-Mnyabezi catchment in southern Zimbabwe under current conditions and after implementation of two storage capacity measures (de Hamer et al., 2008). These measures are heightening the spillway of the 'Mnyabezi 27' Dam and constructing a sand storage dam in the alluvial aquifer of the Mnyabezi River as water supply shortages exists.

The potential water supply in the Mnyabezi catchment under current conditions ranges from 2107 m^3 (5.7 months) in a dry year to 3162 m^3 (8.7 months) in a wet year. The maximum period of water supply after implementation of the storage capacity measures in a dry year is 2776 m^3 (8.4 months) and in a wet year, the amount is 3617 m^3 (10.8 months). The reservoir stores water for approximately five weeks longer after heightening the spillway to a height of 1.0 m. The sand storage dam can only be used as an additional water resource, since the storage capacity of the alluvial aquifer is small. However, when an ephemeral river is underlain by a larger alluvial aquifer, a sand storage dam is a promising way of water supply to smallholder farmers in southern Zimbabwe.

In a second study, surface water and groundwater resources water balance was applied to determine the potential for irrigation expansion and water allocation options along the water-stressed Mzingwane River in the Limpopo Basin, Zimbabwe (Love et al., 2009c). The data sources were limited and included a combination of existing data, field and laboratory investigations and remote sensing. A spreadsheet-based model, WAFLEX with module to compute water balance of alluvial aquifer was employed.

A substantial water volume of 38 Mm^3 can be stored in the lower Mzingwane alluvial aquifers, suggesting tripling of current water usage without construction of new reservoirs. This potential water stored can supply an additional 4,883 ha, with few shortages (Figure 38). Most of the additional area is located along the riverbanks. This arrangement could cause downstream impacts, as nearly a third of inflows are not released to downstream uses.

Key message
Alluvial aquifers in semi-arid areas in Africa provide access to shallow and relatively good quality groundwater from sand infiltration in an efficient way. The additional water available can be used in agriculture to enhance local livelihoods and contribute towards regional food security. The construction of sand dams or gabion weirs increases storage potential of alluvial aquifers.

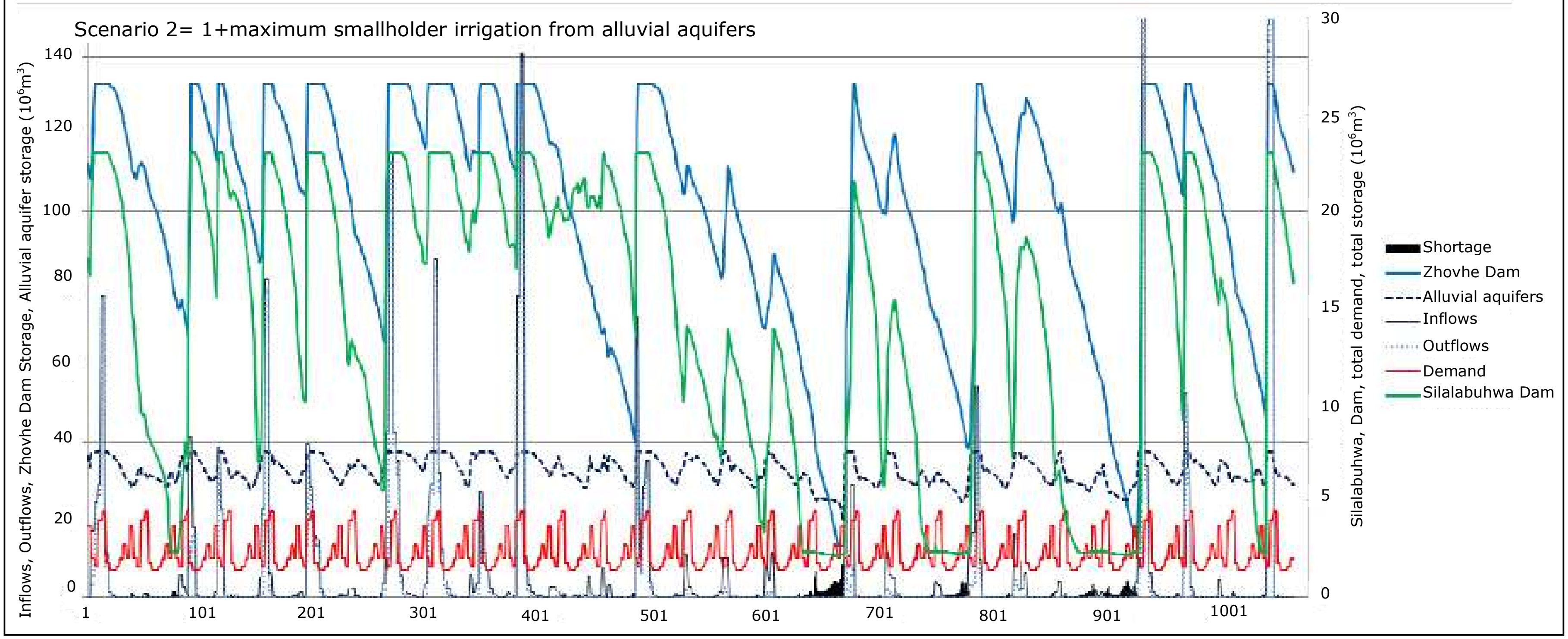

Figure 38: Major annual fluxes and storage levels in lower Mzingwane catchment under maximum smallholder water use from WAFLEX model (Love et al., 2009c).

A third study employed a finite difference model, MODFLOW to model Mushawe meso-alluvial aquifer behaviour (Harbaugh, 2005). Data collection involved channel width and slope surveys. The depth of sand was determined by physical probing with a steel probe, while a global positioning system tool (GPS) was used to survey the riverbed surface. Composite samples of alluvial material were collected from various depths of the aquifer to determine grain size distribution. Water depths were determined by piezometers. Classifications of Mzingwane sub-basin alluvial aquifers based on seepage were performed from satellite imagery.

Results showed that Mushawe River changes from a discharge water body in the dry season, to a recharge water body during the rainy season. The aquifer was fully saturated by December 2007 (5,425 m^3) but drops to 4,000 m^3 as the 2008 dry season begins. Alluvial aquifers hosted on older gneisses such as those in Beitbridge gneisses have higher levels of seepage, while those hosted on North Marginal Zone bedrock such as Chilimanzi granites are likely to have lower levels of seepage. Mushawe alluvial aquifer is suitable for small-scale domestic, livestock and small irrigation (gardens) water supply. Sand dams increased the storage capacity of alluvial aquifers by minimising downstream groundwater flow.

The last study identified alluvial aquifers' distribution, properties, current usage and potential groundwater expansion from literature and LandSat TM imagery in sand filled channel rivers in Mzingwane catchment (Moyce et al., 2006). The aquifers are considered to have potential to support significant additional irrigation development.

The alluvial aquifers form long ribbon shaped aquifers and are enhanced at lithological boundaries. Furthermore, the alluvial aquifers are more pronounced on gentler (1:500) slopes that allow for more sediment accumulation. These alluvial aquifers extend laterally outside the active channels, with areas ranging from 45–723 ha and 75–2196 ha in the channels and on the plains, respectively. The corresponding water resources potential in the channels and plains are 0.175–5.430 million m^3 and 0.08–6.92 million m^3, respectively. Such a water resource potential, depending on crop type and irrigation efficiency can support irrigation areas ranging from 18–543 ha and 8–692 ha for channel and plain alluvial aquifers, respectively. The water quality of the aquifers in general is fairly good. However, water salinity, especially in water abstracted from wells on the alluvial plains was found to increase significantly in the end of the dry season and in drought years. Currently, the aquifers provide water for domestic use, livestock watering and dip tanks, commercial irrigation and market gardening. It was concluded that integrated water resource management is needed to monitor abstraction rates and water quality and to conjunctively utilise the plains and river channel aquifers to avoid salinity problems. In addition, the study suggested construction of artificial alluvial dams to increase the storage capacity of the aquifer and thereby store enough freshwater for the dry season.

Key messages

A simple bedrock classification based on seepage can assist in targeting favourable reaches for sand rivers for further evaluation and possible water supply development.

Understanding of the aquifer's geology, including characteristics such as location of impermeable layers and the direction of water flow, is necessary in designing appropriate management options.

Mzingwane sub-basin alluvial aquifer potential is underutilized. If fully exploited, for instance by construction of artificial alluvial dams to increase the storage capacity of the aquifer, could provide substantial irrigation water to smallholder farmers, thereby improving local food security.

Conjunctive use of groundwater and surface water to meet demand is only sustainable if the groundwater supplies are periodically recharged using surplus surface water.

In the next section, water quality studies and associated ecosystem impacts in Zimbabwe, South Africa and Mozambique are presented.

2.5 Water Quality Case Studies in Zimbabwe, South Africa and Mozambique

This section gives a brief overview of water quality case studies carried out in Zimbabwe, South Africa and Mozambique. Problems associated with water quality are also presented.

2.5.1 Zimbabwe case studies

Water quality reflects the chemical inputs from air and landscape and their biogeochemical transformation within the water (Murdoch, 2000). Atmospheric processes and movements of chemicals through various hydrologic flow-paths of water in the watershed influence the inputs. Furthermore, the chemical nature of the soils within the watershed also influences water quality. Water quality is also broadly defined to include indicators of ecological health such as sensitive species of fauna and flora.

The lack of sufficient surface water quality is more pronounced in many arid and semi-arid regions, necessitating groundwater augmentation. Poor quality water poses health risks to humans, livestock and crops as well as impairs aesthetic water values, thereby affecting livelihoods. This section reports water quality in two river catchments (Thuli and Mzingwane) that lie in the low rainfall areas of south-western part of Zimbabwe in the Limpopo Basin (Love et al. 2006).

The first study enumerated water quality risks, and their possible impacts on livelihoods in the two catchments (Love et al. 2006). Thirty-six water samples were collected from rivers, dams and alluvial aquifers in the Mzingwane and Thuli River catchments. The samples were analysed for chemical and physical parameters including cadmium, copper, iron, manganese, nickel, arsenic, zinc, calcium, potassium, sodium, magnesium, nitrate, nitrite, chloride, phosphate, sulphate, alkalinity, total dissolved solids and pH.

The results revealed varied catchments water quality, dependent on the catchments geology. Water quality parameters such as arsenic, calcium, chloride, copper, potassium, magnesium, sodium, nitrite, nitrate, nickel and sulphate in the sub-catchments did not pose risks to humans, livestock and crops. Human health risks were associated with cadmium, nitrates and manganese, while risks to livestock and crops were associated with chloride and iron. Furthermore, impairment of aesthetic values and taste were associated with manganese, iron, total hardness and total dissolved solids. The potential risks posed by nitrates, chloride, iron, total hardness and total dissolved solids were localised in the catchments, facilitating easy remediation whilst manganese and cadmium risks were observed throughout the catchments. Nitrate, chloride, total hardness and total dissolved solids risks were associated with groundwater whilst cadmium risks were associated with both surface and groundwater. Iron risks to crops were associated with groundwater water whereas iron aesthetic problems were associated with surface water and boreholes proximity to the riverbanks.

The observed alluvial aquifers baseline chemistry has important implications for water supply development as these aquifers provide the main water source for rural communities in the study area (Nare et al., 2006). Communities and households in Mazunga Range area and the area around Bengu were identified as the most vulnerable to water quality threats.

Key messages

Local communities should protect both surface water and groundwater from pollution, due to their interconnectedness and interdependence. IWRM advocates recognise that groundwater is intrinsically linked to surface water; hence, it is important to couple surface and groundwater management within IWRM processes.

Limpopo River is a transboundary river that passes through Zimbabwe, Botswana, South Africa, and Mozambique thus it is imperative for the countries to have a common water quality guideline through joint efforts. However, it was noted that there are no common water quality guidelines for these basin countries.

The authors recommended a follow-up study of cadmium in the catchment as well as mercury analysis, not analysed in this study but found in an adjacent Zhulube catchment by Tunhuma et al. (2007), presented in the next paragraph.

A second study by Tunhuma et al. (2007) assessed the impacts of small-scale natural resource exploitation: gold panning in the Zhulube catchment in the portion of Limpopo Basin in Zimbabwe (Tunhuma 2006; Tunhuma, et al., 2007). Small-scale gold panning has become rampant as a drought shock coping strategy in the poverty-stricken rural areas of the catchment, where rainfed agriculture (Rockström et al., 2004), susceptible to droughts and dry spells is the main livelihood strategy. An estimated 2 million people (about 13 % of the Zimbabwean population) depend on small-scale mining located close to water sources (Figure 2.3) for their livelihoods (Maponga and Ngorima, 2003). Small-scale mining is located close to water sources due to large amounts of water requirements for mineral concentration, performed by gravity separation through a water medium (Babut et al, 2003; Hinton et al., 2003). Gold concentration and amalgamation are accomplished by use of cyanide and mercury, which are poisonous to humans, animals and aquatic life directly or indirectly through bioaccumulation in the food chains (Tunhuma, 2006). These environmentally unfriendly activities by the rural poor concurs with Cunningham et al. (2005) who depicted the poor as both the victims and agents of environmental degradation, forced to engage in unsustainable activities to meet short-term survival needs.

Other livelihood strategies include irrigated market gardening, wildlife hunting, wood harvesting, wood sculpturing and mat making using tree bucks and reeds. These small-scale activities either gradually (as in forest harvesting) or rapidly (as in mining) change the native vegetation cover and the natural landscape affecting the catchment hydrology responses (Tunhuma, 2006; Hope et al., 2004).

The methodology involved environmental impact assessment using the pressure-state-impact-response approach. The state was evaluated based on the researcher observation; water quantity was estimated using rainfall and siltation was estimated using two weirs in the catchment together with suspended solids in river water. Chemical water quality analyses of samples collected from the rivers in the catchment was done. For quality control, 10% of the sample where collected in duplicates, two in the first campaign and three in the second (Tunhuma, 2006). Furthermore, a survey and informal interviews were carried out to assess the response.

The results showed negative environmental impacts of water resources from uncontrolled small-scale gold panning, land clearance, erosion and sedimentation in Zhulube catchment (Figure 39). Gold panning contributed most, followed by agriculture to increased sediments entering water bodies. Furthermore, gold panning introduced sulphates and toxic metal, mercury into the aquatic environment. These extensive environmental impacts were attributed to limited enforcement and compliance with national laws at local level, poor resource use practices, lack of sense of ownership and alternative livelihoods among users. In addition, a number of institutions found at local level in Zhulube catchment to implement environmental protection and monitoring lacked work force, instrumentation and in some instances not well coordinated.

Coordinated efforts by these institutions may increase resources and efficiency of operations.

It was recommended that illegal forms of small-scale resource exploitation such as gold panning should be formalised and a wider stakeholder participation to include local communities in policy-making and environmental protection. The study also advocated for cleaner production techniques (Babut, et al., 2003; Ghose, 2003; Hinton et al., 2003) to be used in the purification of gold to reduce impacts on gold panners and environment. Furthermore, a continuous and systematic environmental (land use and water quality) monitoring system at catchment and basin scales should be set up to inform decision-makers.

The limitations of the study were omission of biological indicators in water quality assessment and limited sampling time of half a season (Tunhuma, 2006). A longer sampling period of more than two rainy seasons would have been ideal. To further evaluate water quality and address these limitations, Chilundo et al. (2008a) embarked on a more extensive water quality assessment in Mozambique, presented in the next section.

Figure 39: Stream morphology degradation due to gold panning. First picture shows holes dug in a stream and second picture shows processed sediment on the river (Tunhuma, 2006).

2.5.2 Mozambique case study

An extensive water quality assessment study by Chilundo et al. (2008a), proposed a water quality monitoring network to characterise stream health for the portion of the Limpopo River Basin (LRB) in Mozambique (see Figure 40), a region prone to severe droughts. Chilundo et al. (2008a) argue that anthropogenic and natural driven processes, exacerbated by the increased water demand by the four riparian countries (Botswana, South Africa, Zimbabwe and Mozambique) are responsible for surface water degradation and impairment of water uses in the basin. The design and establishment of water quality programmes for the Limpopo River will contribute to improved management of water in Mozambique and in the region.

The physico-chemical, biological and microbiological characteristics at 23 sites (in-stream and effluent point discharges) were assessed in November 2006 and January 2007. The physico-chemical and microbiological samples were analyzed according to American Public Health Association (APHA) standard methods, while the biological monitoring working party method (BMWP) was used for biological assessment. Site indices based on Lincoln Index (BMWP scores), Physico-chemical Index and Heavy metals Index were derived using the Mozambican standards for receiving waters and the WHO guidelines for drinking water quality. The worst scenario approach, which assigns the worst class, indicated by one of the three indices was used for assigning the overall water quality index of a site (Chilundo et al., 2008a).

Heavy metals water contamination at sites located at proximities to the border with upstream countries (Botswana, South Africa and Zimbabwe) were noted. These results confirmed earlier conclusions in the portion of the Limpopo Basin in Zimbabwe (Love et al., 2006a; Tunhuma, 2006; Tunhuma et al., 2008). Elephants sub-catchment had a relatively better water quality, while the Changane sub-catchment together with the effluent point discharges in the basin were polluted, indicated by the low dissolved oxygen and high total dissolved solids, sodium adsorption ratio and low benthic macro-invertebrates taxa. High counts of fecal coliforms (>2500 CFU/100 ml) contamination were associated with effluent discharges from urban areas. The study proposed monthly water quality monitoring because of the significant water quality differences ($p < 0.05$) found for some parameters when the concentrations recorded in November and January were compared.

It was concluded that a systematic water quality (focusing on ambient, early warning, operational and effluents) monitoring network composed of 16 stations at an estimated total cost of US $56,000 per year would suit the conditions of the Limpopo River Basin. Additional research at a basin scale was recommended to identify the major sources of pollution, their transportation and impacts to the downstream ecosystem.

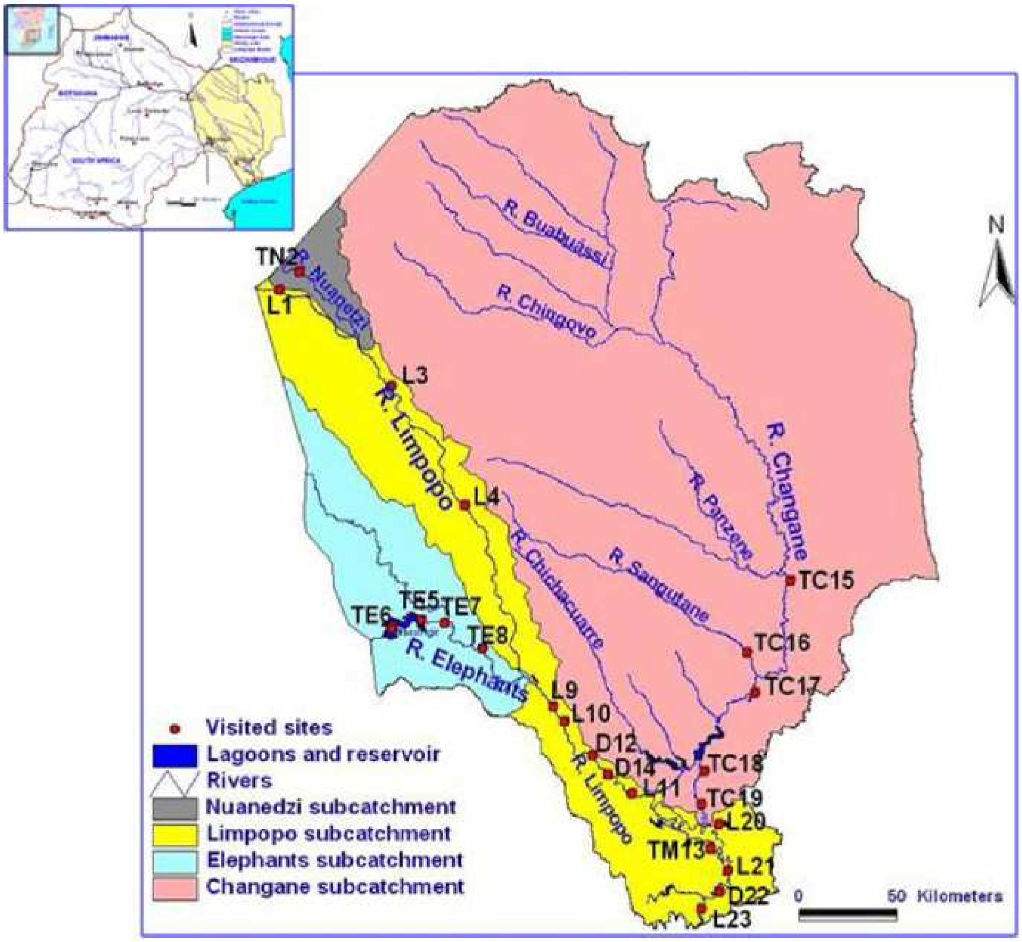

Figure 40: Location of sampling points in the Limpopo Basin (Chilundo et al., 2008a)

Key message
The results show high levels of pollution. However, the results cannot be conclusive due to the limited number of observations.

2.5.3 Cadmium synthesis study in Zimbabwe, South Africa and Mozambique

In another important study on transboundary water quality issues, cadmium a transition metal that occurs naturally at low concentrations (Love et al., 2009a) was evaluated. Dissolved cadmium is considered a human health risk at concentrations above 0.03 mg/L in drinking water. Furthermore, cadmium is a known teratogen, associated with birth defects, prostate and kidney cancer, and is a probable carcinogen. Smoking, ingestion of trace cadmium in foodstuffs or water, especially contaminated with phosphate fertilisers are the major routes for cadmium intake in humans.

Two independent water chemistry studies were carried out led by WaterNet. These studies pointed to elevated cadmium levels in surface water and groundwater in many locations within the Limpopo Basin in Mozambique (Chȯkwé, Sango, Limpopo National Park, Massangir) and Zimbabwe (Buvuma, Filabusi, Manama, Silalabuhwa, West Nicholson). Another recent study at the University of Johannesburg (not part of the project) showed similar problems from several locations within the Limpopo Basin in South Africa (Kruger National Park, Crook's Corner). Most of the results from the three studies were above the 0.03 mg/L, maximum safe level recommended by the WHO, signifying a potentially serious health risk to rural communities and ecosystems in the study areas. The residents may suffer from cumulative cadmium poisoning from their drinking water.

Key message
Elevated levels of cadmium (> 0.3mg/l) are a serious potential health hazard to the local communities and ecosystem. Hence, corrective actions by basin countries to identify cadmium sources and remediation efforts are required immediately.

2.5.4 General Conclusions on water quality studies

Physico-chemical and biological parameters were assessed in the Mozambican side of the Limpopo Basin, while in Zimbabwe only physico-chemical parameters were assessed. All the studies reported in the Limpopo Basin depicted heterogeneous water quality results. However, most of the parameters where found to be above country and WHO water quality standards posing a health risk to humans, animals, aquatic life and crops.

2.6 Key findings and Recommendations

Runoff generated and the associated uncertainty in a catchment is a driver in planning water use and allocation in ungauged and gauged catchments as it indicates potential available water for allocation to different water users.

More pressure on surface water supplies is likely to come from population shifts, land use practices and changes in water right allocations to accommodate environmental flows and water rights of former disadvantaged smallholder farmers and groups. This situation is likely to worsen due to long-term decreases in precipitation and increased frequency of dry spells (Mupangwa, 2009; Love et al., 2010) that will reduce water resources availability and possibly decrease recharge rates in some areas. Hence, climate change is likely to complicate and increase stress on water supply systems. This will compel exploration of non-conventional water resources (e.g. sand dams) as potential water supplies (Love et al., 2009b).

Projecting future changes in streamflow conditions will require more evaluation of the complex role of changing precipitation and temperature patterns as well as the role of land-use change on streamflow.

Aquatic and riparian ecosystems may be damaged under low precipitation, and increased dry spells (Mupangwa, 2009; Love et al., 2010) due to higher air temperatures and reduced summer flows. Furthermore, warmer, drier conditions promote mineralization of organic nitrogen thereby increasing chances of water pollution (Murdoch et al., 2000).

Groundwater storage is affected by seasonality, volume, persistence of surface water inflows and discharges from groundwater to surface water. Groundwater-surface water interactions are poorly understood in most areas, hence the need for further study in Limpopo Basin.

Concerning urban sanitation, treating urban pollution benefits health (saves lives), economy and ecosystems. For instance, reduced medical care expenditure, time and energy spent by women who care for the sick, all serve as economic incentives to treat and prevent water pollution and empower women. Locally and basin wide, corrective measures including monitoring efforts supported by basin wide institutions are therefore required to mitigate water quantity and quality impacts.

There is need to improve or develop a new Flood Forecasting System as a key component of the new decision support system tools for Limpopo Basin to improve the reliability, accuracy and lead times of forecasting flood discharges and flood levels along the Limpopo River.

Monitoring should be enhanced from a strategic perspective in order to integrate groundwater conditions, surface water quality, and biological factors in key habitats. Water quality changes that result from existing climatic variability, and the impacts of extreme events on ecosystems, need further evaluation.

There is a need for flexible basin wide institutional arrangements to guide water policy decisions in adaptation to changing conditions in climate and multiple current water stresses. Currently there is no common legal framework for water rights in the basin countries (Chilundo et al., 2008; Tunhuma et al., 2008). Devising new legal water institutions through institutional models to introduce the necessary flexibility (to respond efficiently to changing socio-economic and environmental conditions) into water management is a significant challenge that is addressed as the third key research achievement under PN17 in section 3.

Policy implications:
- Encourage exploitation of non-conventional water sources to augment current water supplies
- Encourage efficient use of green and blue water in catchments
- Encourage soil-water techniques to prolong soil moisture residence time in order to bridge dry spells, especially for smallholder farmers
- Encourage basin-wide joint dam operations to ensure floods and ecosystem are well managed
- Establish basin-wide monitoring network for water quantity and quality
- Establish basin-wide studies and water quality standards
- Establish basin-wide agreements on instreamflow quantities based on joint basin-wide studies.

3 *Objective 3: Develop institutional models for water governance that aim at strengthening policies for water productivity and risk mitigation at catchment and basin scale*.

3.1 General Introduction

The third major research area of the Challenge Program on Water and Food Project 17 had the objective of developing institutional models for effective water governance[3] so as to strengthen policies for enhancing water productivity and risk mitigation at the catchment and basin scale. This was against a backdrop of new water management institutions, based on hydrological rather than administrative boundaries, having been or in the process of being created in all the four Limpopo basin countries (Botswana, Mozambique, South Africa and Zimbabwe) in line with Integrated Water Resources Management (IWRM), which was adopted as the founding water management framework in southern Africa under the auspices of the Southern African Development Community (SADC), a regional political and economic bloc to which all the southern African countries belong. The main instruments that were crafted and adopted were the SADC Protocol on Shared Watercourses, the Regional Water Policy, the Regional Water Strategy, and the Regional Strategic Action Pan on Integrated Water Resources Development and Management (RSAP-IWRM) (Manzungu and Mpho, 2008). Individual countries crafted national laws and policies to operationalise IWRM.

It was envisaged that good water governance was to be achieved through the creation of multi-stakeholder platforms (MSPs) to ensure the participation of all stakeholders in the way water resources are managed. The degree to which the IWRM-based institutions have succeeded in promoting effective stakeholder participation at a regional, basin, national and local level has not been fully investigated (Fatch et al, 2009; Manzungu, 2004). More importantly for this project, the degree to which the new institutions have/are affected/affecting the livelihoods of the rural population, which represents well over half of the total population, remains unknown and uninvestigated (Mabiza et al, 2006; Sithole, et al, 2009). In this section institutions are understood as 'rules of the game' that are interpreted and acted on differently by people, are dynamic and evolve and change over time (North, 1990). A related term is organization which refers to groups of people with shared goals and some formalized pattern of interaction often defined in terms of roles (Merrey et al, 2007). In this study the focus was more on the organizations, with a view to understand the relationships between and among the various actors. The idea was to go beyond a mere description the relationships as contained in policy and legal documents, but document and understand as things were on the ground. This is because there tends to be a difference between the 'rules of the game' and the 'state of the play' as people does not always act according to stated rules (Shah. et al, 2005). Consequently effort was made not to view institutions as things (rather than as relationships and processes) as this can result in unproductive engineering metaphors and approaches being ascribed to them, which does not shed light on how institutions work in practice (Merrey et al, 2007). It is, however, important to remember that water-related institutions are not the only institutions that are found at the local level nor are they the only ones that affect and influence rural livelihoods. Another point that needs to be highlighted is that institutions are embedded in the political, social and economic context in which they are found. As such it is important to highlight the different water reform trajectories that individual SADC countries have followed (Manzungu, 2004; van Koppen, 2008) before discussing the various specific

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[3] Governance can be understood as comprising the traditions, institutions and processes through which power is exercised, citizens are given voice, and decisions are made on public issues (Warner et al, 2008). It is not clear whether the aim was to study the institutional modes that existed, help to establish institutions or both. All the same it is only in Zimbabwe where there was an attempt to engage stakeholders on possible institutional configurations as reported in later paragraphs.

institutional arrangements. This is undertaken below with the exception of Botswana, which was not part of the study.

3.2 Background: overview of water reforms

3.2.1 Mozambique

During the Portuguese colonial period (1505-1975) water could either be private or belong to the state. This changed after independence when water became state property owned and regulated by the state. Under the current law private water is distinguished from common water use which refers to water use that does not use a siphon, or other mechanical means to abstract water, to satisfy the domestic, personal and other needs including the watering cattle. Any other use falls under the category of private use. In practice common water use is defined as water use which is equivalent or less to irrigating 1 hectare. It is not paid for so as to enable low income families to access water, which is critical for improving livelihoods.

Water law 16/91 of 3 August 1991 created different institutional bodies that are responsible for water management. The Ministry of Public Works and Housing was given the mandate of planning and management of all the country‛s water resources. The Ministerial diploma 25/87 of 13 January created the National Directorate for Waters (DNA), which is responsible for coordinating water related activities at the national level while water supply in the rural areas falls under the responsibility of the Department of Rural Water (DAR) that was created in 1992. While the Ministry of Housing and Public Works is the line ministry responsible for water management, the law provides for institutional coordination among different stakeholders. The National Water Council, an advisory body for water policy and issues on water management, comprises different ministries such as agriculture; fisheries; foreign affairs and cooperation; industry, trade and tourism; mineral resources and energy; state administration; health and coordination for environmental affairs.

Decree 26/91 of 14 November created the Regional Administration for Water (ARA) as a vehicle to decentralize water management to the regional and basin level. Under this arrangement water resource management is organised on the basis of river basin and regional boundaries (ARA), which are public institutions with a legal persona, and enjoy administrative and financial autonomy under National Directorate of Water. Consequently the country was a divided into the following regions:

- ARA Sul, that covers the south border of the country to the Save river basin.
- ARA Centro, that covers Save river basin to the basin of the Zambezi River;
- ARA Zambezi that covers the basin of the Zambezi River basin;
- ARA Centro Norte - that covers the region from the Zambezi river basin to Lurio river and
- ARA Norte - that covers the Lúrio river basin to the northern border

Regions are empowered to collect and maintain all hydrological data at river basin level. Decree 25/91 of 14 November established the CNA (National Commission for Water), a consultative body of council of ministries, which facilitates inter-ministerial coordination relating to policy and implementation aspects. In 2007 the Government put in place mechanisms to allow river basin water users to interact with water management unity through basin committees (see Box 2).

Box 2: Institutional framework to facilitate delegated water management in Mozambique

- The Ministers of Public Works and Housing, of Planning and Finance, and of State Administration;
- The National Directorate of Water;
- The Coordinating Forum of Delegated Management;
- The Investment and Assets Fund for Water Supply (FIPAG);
- The Regulatory Council for Water Supply (CRA);
- City councils, and
- Operator.

Decree 72/98 of 23 December provides for a coordination forum as follows:

- One representative from the Ministry of Public Works and Housing, who shall be the Chairman;
- One representative from the Ministry of Planning and Finance;
- One representative from the Ministry of State Administration;
- The Director of FIPAG;
- The Chairman of CRA; and
- One representative of each city council.

Representatives of consumer associations or of other local consumer organizations may be invited to the Coordinating Forum by decision of the respective city councils.

3.2.2 South Africa

Inequalities in water and sanitation services, a consequence of apartheid policies, which disadvantaged the majority black population, led to the promulgation of the National Water Act of 1998 (RSA, 1998), and the Water Supply Services Act (RSA, 1997). The National Water Act enhanced the role of the state in water resources management, a role that is spearheaded by the Department of Water Affairs and Forestry (DWAF) (now the Department of Water Affairs).

The National Water Act in the first instance recognises water rights that pertain to basic human and ecological needs for water, termed the 'Reserve'. These enjoy priority in water allocation. All other uses are regulated through 'registration' and different types of 'authorizations'. The three types of water authorizations are Schedule One, General Authorizations and Water Use Licenses. Schedule One refers to permissible uses of water that do not require a license, and do not have to be registered because the water l quantities are small and do not have a big impact on the resource. General Authorizations allow slightly larger volumes of water use from less stressed sources, such as rivers and aquifers. People are allowed to use water without a license provided that the quantities are within the conditions stipulated in the General Authorizations. Schedule one water use and General Authorizations are used as strategies to cut down on unnecessary administrative efforts. It is important to note that there are no official definitive figures for these types of uses (Manzungu et al, 2009a). On the other hand water licenses are mechanisms for regulating water use that exceeds the limits outlined in Schedule One and General Authorizations. They also give existing and new water users formal authorization to use water for productive and beneficial purposes, and specify the conditions under which the water can be used. Licenses are issued by 'responsible authorities' namely, the Department of Water Affairs and Forestry (DWAF) or Catchment Management Agencies (CMAs). Currently, the licensing procedure requires new and potential water users to apply for a license or to register their water use with the responsible authority namely, the Regional Office of DWAF. This regulatory function is envisaged to devolve to CMAs when they become fully operational.

Another significant development was the requirement that all water users should participate in decision making. This was to be achieved by decentralizing water to catchment/basin based water management institutions in the form of Catchment Management Agencies (CMAs) and Water User Associations (WUA). Accordingly the country was divided into 19 Water Management Areas (WMAS) largely on the basis of hydrological boundaries. It was provided that Catchment Management Agencies (CMAs) would preside over water management areas (WMAs) and would replace state run regional offices which were organized on administrative boundaries. The Minister acts as the CMA where one has not been established. Where there are capacity constraints, an advisory committee may be appointed to develop the necessary capacity in the interim. WUAs were designated as the second tier water management institutions that are supposed to execute local management of water resources.

A number of challenges have been encountered in the establishment of both CMAs and WUAs. As far as CMAs are concerned there has been a rethinking of the whole concept. For example, in an e-mail to the author on 22 July 2009, Eiman Karar suggested that the number of CMAs should be reduced to 9 CMAs, or one national CMA supported by three sub-CMA. There have been also suggestions to drop altogether hydrological-based institutions in favour of administrative ones. By the end of 2008, eight CMAs had been formally established, but only two Governing Boards and two Chief Executive Officers were appointed. The fact that each regional office was free to choose its desired process towards the establishment of CMAs was another problem. As far as WUas are concerned, more than 200 WUAs have been established to date with most of these being transformed white run Irrigation Boards. The state of play regarding the state of the new water management institutions shows a disappointing state of affairs:

> “Following the standoff in the establishment of CMAs, the experience gained from the Inkomati CMA and the institutional realignment debate, there is a need for a collective wisdom to think about where we are at and where to from here with regards to the who will do management of water resources? We…have a collective responsibility to take a pause and share our thoughts at this point”. (Eiman Karar, email 22 July 2009)

It is true to say that black local water users in South Africa to a large extent remain uninfluenced by the new water management institutions.

3.2.3 Zimbabwe

In 1998 the Government of Zimbabwe promulgated the Water Act. According to the Act water use other primary water use (which refers to water used for domestic and other uses such as livestock watering, brick making as long as they are not labeled as commercial which is frequently a source of contention with the catchment councils which have the legal right to determine the amount of primary water) requires a water permit that stipulates the amount of water used over a given time. This replaced permanent water rights which had privileged white commercial farmers who had had applied for water first whose water security had been guaranteed under the perpetuity clause (Manzungu et al, 2009a; Manzungu and Machiridza, 2008).

In addition the Act, among other things, replaced water management institutions that were based on administrative boundaries in favour of those based on hydrological boundaries (Zimbabwe, 1998a). Accordingly the country was divided into 7 catchment management areas based on the major river systems (Fig. 41). Catchment areas are presided over by catchment councils while sub-catchment councils have responsibility over sub-catchment areas. To safeguard public interest, a state agency, Zimbabwe National Water Authority (ZINWA), retained a strong operational management and oversight role (Zimbabwe, 1998b). A small Department of Water Development (DWD) has the mandate over policy issues.

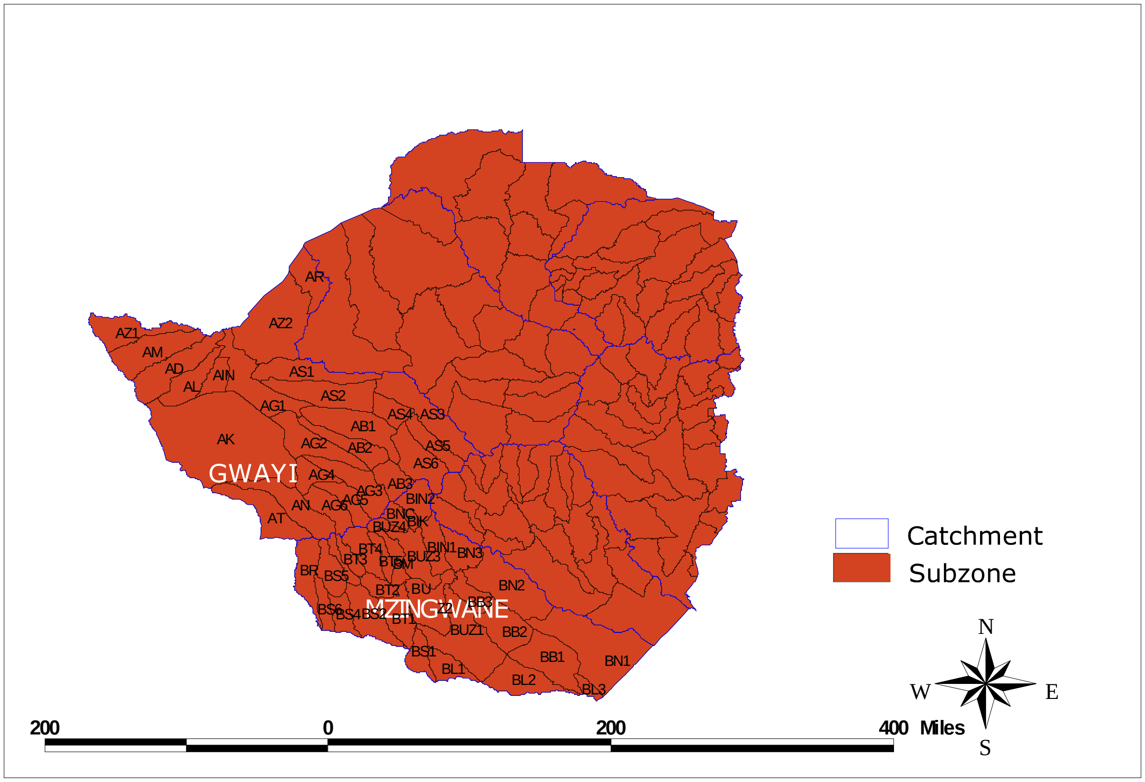

Figure 41: Catchment and sub-catchment areas of Zimbabwe

The new water institutions were established six months after the promulgation of the Act, in the hope that the institutions would learn by doing (Manzungu, 2004). Since their establishment in 1999 the water management institutions have experienced conceptual and operational problems relating to:

- Poor stakeholder identification especially among the rural black population, which resulted in continued marginalization of some stakeholders such as smallholder farmers and omission of others e.g. rainfed farmers;
- Limited interest on the part of some sectors such as urban authorities, mining and tourism;
- Domination of the process by powerful stakeholder groups such as white farmers early in the process, and later on by black elites who replaced the former, thanks to the fast track land reform programme;
- Almost exclusive focus on water resource management rather than on water development which tended to alienate rural communities (where water infrastructure development is seen as an essential component of water management);
- Financial constraints because of withdrawal of donor funds which had filled in the financial void left by state 's disengagement from the water sector;
- Human capacity limitations due to staff exodus to neighbouring countries and even beyond;'

- State agencies' lack of capacity to facilitate the process as reflected by poor institutional coordination, and failure to champion the cause of weak stakeholders; and
- Failure to operationalise the subsidiarity principle as illustrated by institutions that did not strike a chord with local level water issues (Manzungu et al, 2009a; Manzungu, 2002; Manzungu and Kujinga, 2002)

3.3 Materials and methods

In Mozambique the study relied mainly on document review as a source of information. The main documents that were reviewed were legal documents, locally known as decrees and ministerial diplomas, as well as policy documents. This was complemented by interviews held with key informants that were conducted between July and September 2009. In South Africa the study drew insights from ongoing PhD research work in the Sekororo communal lands which are located in the Limpopo basin. A study was conducted in the four villages of Enable, Lorraine, Sofaya and Worcester (see Sithole et al, 2009; Manzungu et al, 2009b).

In Zimbabwe the research was done in the Zimbabwean portion of the Limpopo basin, which is locally known as the Mzingwane Catchment area and is divided into four sub-catchment areas (Fig. 42). The Mzingwane Catchment Council presides over the entire Mzingwane catchment area while sub-catchment councils preside over sub-catchment areas bearing the same names. In the first instance the research team identified problems that were encountered by the Mzingwane Catchment Council, which included a general lack of information and awareness on the objectives of the water reform and the operational modalities, lack of participation by some water users e.g. rainfed farmers, irrigators, domestic water users), and an unworkable two-tier water management system (that incorporated the catchment and sub-catchment level). Given the failure of the state-defined approach that had given rise to the hydrologicaly-based water management institutions an action research was undertaken to find out how local people understood the problems and the solutions they had. The specific questions that were posed were who were the water users, how could the water users best be organized, and how could water users/stakeholders best represented at all levels (local, sub-catchment, catchment and basin level)? Participatory workshops were held in March 2009 in the Shashe sub-catchment area to obtain answers to these questions. Three wards were chosen to represent the main water management situations in the catchment area, namely a) ward in which smallholder irrigators obtained from a state dam (Ward 8), b) ward where smallholder irrigators obtained irrigation water from a river (ward 14), and c) a ward where irrigators used water from locally-constructed dams without water permits (ward 6). At each ward people were divided into groups and assigned to discuss issues pertaining to local water sources, general water issues, pressing water problems, and water institutions respectively. Where the numbers allowed it the group on water issues was further divided into men and women. Each group made a presentation of its deliberations in a plenary session at which all the issues raised were discussed. The discussions at the local level were cross-checked with a catchment level meeting that was held in Bulawayo town in April 2009 in both plenary and group presentations that discussed the stakeholders involved in the water sector and how stakeholders could best be represented at the basin level.

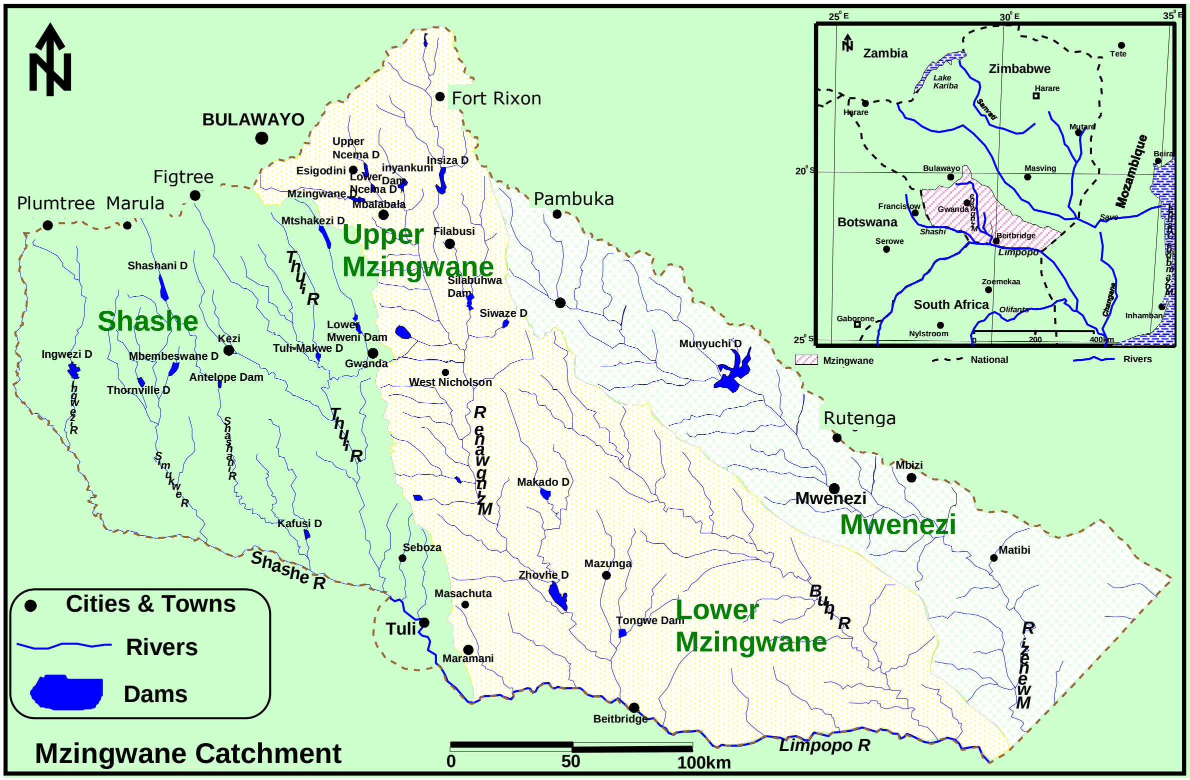

Figure 42: Sub-catchment areas of the Mzingwane Catchment

3.4 Results and Discussion

The results that are presented in this section (and the attendant discussion) differ in depth and coverage because of the specific activities that were undertaken in each country. Zimbabwe had much detail because of the type of research (action research) that was done there. In the concluding section an attempt is made to highlight the main differences and similarities.

3.4.1 Mozambique

In accordance with water law 16/91 water management in the Limpopo basin falls under auspices of ARA Sul which covers the south border of the country to the Save river basin. ARA Sul replaced the Unity of Directorate for Hidraulic Use (UDAH). The most important legal tool that affected water management at the lower management level in ARa Sul is the Ministerial Diploma 21/2007 of 28 February, which approved the Gross Water Tariff. The objective was that water tariffs would enable ARA-Sul to operate and maintain existing infrastructure. However, at the moment ARA Sul is facing the problem of how to effectively collect the money from the water users. A related activity is the water user registration process, meant to determine the water users and the quantity of water they use. This only applies to private water use.

ARA-Sul manages the greatest number of rivers basins through what are called Management Unities. The following are the unities under ARA-Sul Administration:

- Management Unity of Umbeluzi River Basin (UGBU), that includes also Maputo river basin, with an office in Boane;
- Management Unity of Incomati River Basin (UGBI) with an office in Corumana-Sabie with one branch office in Manhiça;
- Management Unity of Limpopo River Basin with an office in Chokwe and branches in Macarretane and Massingir districts; and

- Management Unity of Sabie River Basin (UGBS) with an office in Xai-Xai that includes small river basins from Mandlakazi up to Vila Nova Mambone in Inhambane excluding Limpopo River Basin, the office is located in Maxixe and in the future will have a branch in Vilanculos.

ARA-Sul also manages three major dams (Massingir, Corumana and Pequenos Libombos), a large weir at Macarretane on the Limpopo river basin, a number of smaller dams, dykes and other hydraulic structures, and a large hydrometric network. It executes all the activities in the Limpopo River Basin through UGBL (Unity of Limpopo Basin Management), which works under the auspices of a river basin committe. Rivers basin committees are also the advisory body for Management Unities Directors. Figure 43 shows the organization of UGBL.

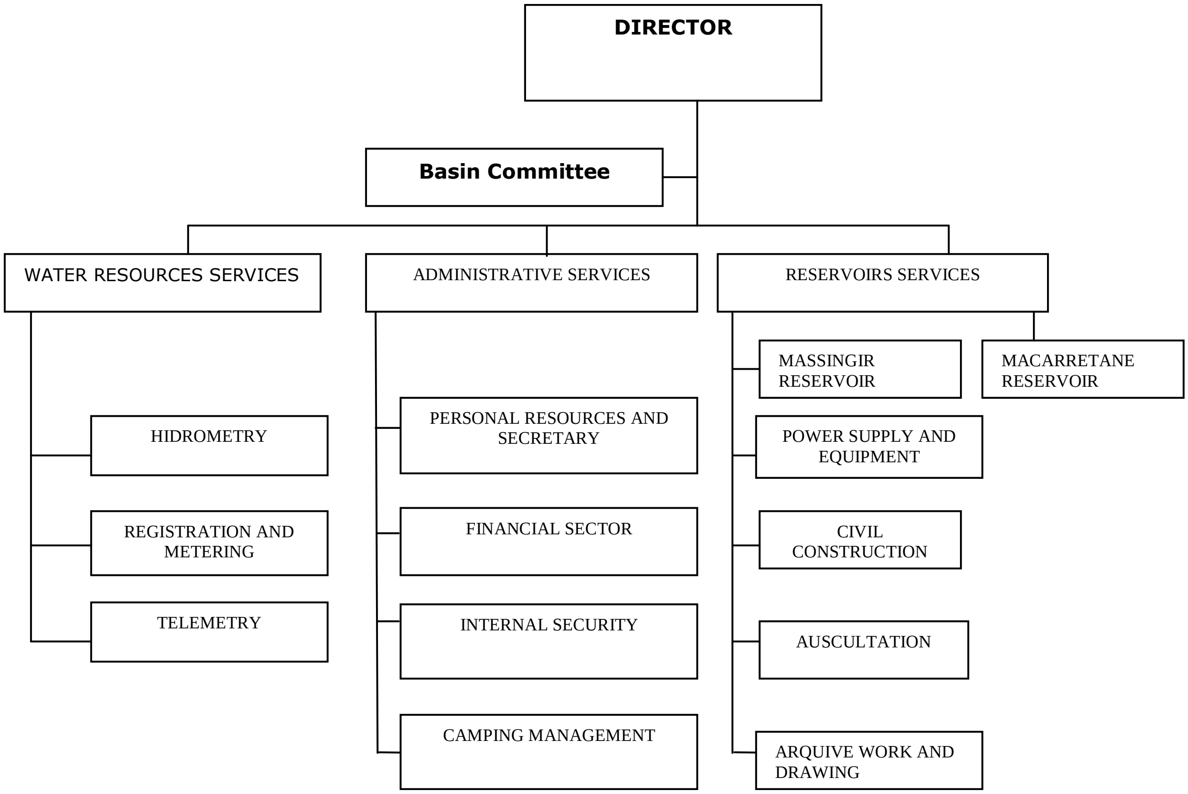

Figure 43: Structure of the Unity of Limpopo Basin Management

The river basin committee is one of the most important bodies in the UGBL, and collaborates with all sectors such as agriculture, industry and fisheries. It is a coordination entity that incorporates water users at river basin level, management unities of irrigation schemes, and other institutions related to water and land use under jurisdictional umbrella of UGBL. The Limpopo river basin committee has the following responsibilities:

- Promote the annual plan for public water supply, agriculture, power generation and water for environment;
- Monitor the water use and supply in order to guarantee the current use;
- Promote the adoption of operational measures for better management in the irrigation schemes to optimise the water use, the soil and infrastructures;
- Discuss river basin development programs;

- Pronounce about the performance of Management river basin Unity, and giving advice when needed;
- Look at the status of international agreements for water use between borders; and
- Have a say about the taxes for gross water.

In order to guarantee the representativeness of different water users and interested parties on water management, the Limpopo River basin committee is comprised by 12 members (Box 3).

Box 3: Membership of the Limpopo river basin committee

- The UGBL director
- One representative member of Provincial Government
- One representative from Ministry of Environmental Affairs (MICOA)
- One representative of provincial service of Rural Extension
- Two (2) representatives from association of irrigators
- Two (2) representatives of private farmers
- Two (2) representatives of Agrarian companies
- Two (2) representatives from Irrigation Scheme companies.

Positions in the committee are filled by a nomination process with names being formally communicated to the committee president. Members have a 3 year mandate which can be renewed, and are expected to attend all river basin committee meetings, submit issues of interest to be discussed, request river basin committee to call for extraordinary meetings, and vote as prescribed in the regulations.

The committee is led by the Director of Limpopo River basin Management unity (UGBL). The committee meets two times a year. An extraordinary meeting is called by the president when needed 15 days before for the meeting which can only changed if special request arise. The river basin committee is formally represented if there are more than half (50%) of the members in the first call, and by any number of members in the second call. The secretariat for all committee meetings is the administrative chief of UGBL, supported by two other members chosen from committee members. At each meeting the committee will elaborate the statement that have to be distributed to all members 7 days after that have to be discussed in the next meeting. All decisions from the Limpopo River Basin Committee have to be done by agreement of the members. If not, the decision will be carried by a simple majority.

Water management in the Limpopo river basin is managed subject to international agreements that the country is signatory to. These include resolution 31/2000 that ratified the Southern Africa Development Community (SADC) Protocol for Shared Water Courses, resolution 53/2004 of 1st December that create the Incomaputo, resolution 54/2004 of 31st December that created the Zambezi Commission (ZAMCOM), and resolution 67/2004 of 31st December that created the LIMCOM (Limpopo River Basin Commission). It remains to be seen how this will affect the livelihoods that are involved.

3.4.2 South Africa

In the Sekororo area the discourse around water management does not touch on CMAs and WUAs but was informed by local concerns about access to water for domestic and productive purposes (Manzungu et al, 2009b). The institutional arrangements varied depending whether the water source in question was communal/group, individual and

NGO-run. In communal water sources, which largely came about because of public investments in domestic and productive water sources, villagers elected representatives to a management committee. In some case like in Worcester village, some members were nominated by the local traditional leader. For individually-financed water sources institutional arrangements were determined by the owners according to their social networks (that took account of family, kinship ties, good neighborliness, and in some cases commodity relations where water is sold). NGO-supported committees, which presided over NGO-financed schemes, tended to be ad hoc, and drew their legitimacy from 'beneficiaries' with material and financial support acted as important incentives for participation. Such committees tended to lose their vibrancy when the project ended State agencies also existed side by side with local institutions.

As can be seem from Table 12 the institutions at the local level included those of a traditional, civic and public variety. There was, however, often no formal or even informal definition of the communication lines regarding how the various institutions should work with each other. This tended to be a disadvantage in relation to how water 'allocated' under Schedule one and General Authorizations could be accessed by local people.

Table 12: Water-related infrastructure and institutions in Sekororo

Category	**Structure**	**Legitimacy**	**Status**	**Mandates/Comments**
Traditional authorities	*Induna*	Hereditary	Very active	Land, water, livestock, woodlands and pastures
	Chief	Hereditary	Very active	Land, water, livestock, woodlands and pastures
Local government	District municipality	Elected committees	Not active	Water supply, infrastructure investment
	Local municipality	Elected committees	Active	Water supply, investment in infrastructure, maintenance
Government department	Department of Water Affairs (DWA)	Appointed	Not active	Water supply
	Limpopo Development of Agriculture (LDA)	Appointed	Not active	Agricultural development
NGOs	Sekororo Water Supply by Mvula Trust	elected committees	Active during Mvula presence & inactive after NGO left	Provision of infrastructure and capacity building support.
	Worcester Garden Committee	Elected committees	Very active	Provision of infrastructure, setting up committees, and other support
	Enable Garden	Elected committee	Very active in	Provision of infrastructure, setting

Category	Structure	Legitimacy	Status	Mandates/Comments
	Committee		the short term	up committees, and other support
	Sofaya Women's Group	elected water committees	Very active in the short term	Provision of infrastructure, setting up committees, and other support
	Matsivo Savings Group	Voluntary subscriptions	Active	Moral and material support for livelihoods and during bereavement

Source: Manzungu et al (2009b)

3.4.3 Zimbabwe

In the three wards that were studied that included domestic water sources (boreholes and wells) and productive water sources (irrigation schemes) there were efforts at introducing representative democracy as illustrated by the presence of water point committees for boreholes (the wells were not important enough to attract a committee) and irrigation management committees in the irrigation schemes. But as is true for such committees in the rest of the country the committees were, by the admission of the respondents, not effective for a number of reasons ranging from lack of adequate financial resources to lack of organisational capacity. These committees were also not concerned with water resource management and did not engage with the new water management institutions (catchment and subcatchment councils). It was for this reason that action research was undertaken (see above).

Both local (ward) and catchment level meetings disagreed with the predetermined list of stakeholder representatives produced by the state as captured in the statutory instrument. The perception was that stakeholder groups should reflect the actual water use in the catchment. The list was also considered out of date in relation to the new socio-political structure of the country. On the contrary the list produced by local people was very much aligned to actual water use while the state categorized stakeholders to broad social groups (Table 13).

Table 13: Comparison between top down and bottom up list of stakeholders

Stakeholders as identified by the top-down approach	Stakeholders as identified by a bottom up approach
Rural District Council Communal farmers Large Scale Commercial Farmers Indigenous Commercial Farmers Resettlement farmers Urban Authorities Large scale mines Small scale miners Any other stakeholder group	Primary water users, Miners, Irrigators, Commercial farmers, Livestock farmers, game ranchers, Recreational users (non consumptive use), Urban and rural authorities.

Figure 44 shows the institutional arrangements in Mzingwane catchment Council as stipulated by the government. According to this depiction the lowest level is the sub-catchment council. The structure, which is more or less the same throughout the country, did not provide for effective stakeholder representation at the local, catchment or basin level. The bottom up approach tried to address the issues in two main ways

(Fig. 45). First, the lowest water management level was identified as the ward upon which a Ward Water Users Association would be constituted. The ward, presided over by a popularly elected Water Development Committee, is the second basic organizational unit of local government in Zimbabwe. It has become an important organizing principle because of its functionality in relation to social and political activities. Most development activities that include local and national elections, extension services, and relief programmes, tend to be organised around the ward.

Participants recommended that at the ward level there would be one representative from primary water users, irrigators and miners, and any other group. Due to the large number of wards in the sub-catchment it was decided that a District Water Users Forum would provide a platform for electing three ward representatives to the sub-catchment council. Each district would contribute three ward representatives to the sub-catchment council. This means that representatives from the wards would take 12 slots out of the 15 that were available. The remainder would be taken up by other stakeholders such as local authorities, large scale mining and tourism. Although there were differences in the way women and men regarded water use (e.g. women identified more with domestic water sources while men more were interested in productive water use) there was no recommendation regarding gender-specific representation. Just as was the case with rainfed farmers it was felt that these would be captured during election of representatives of different water use categories. The present water point committees whose mandate is over specific water sources would be maintained.

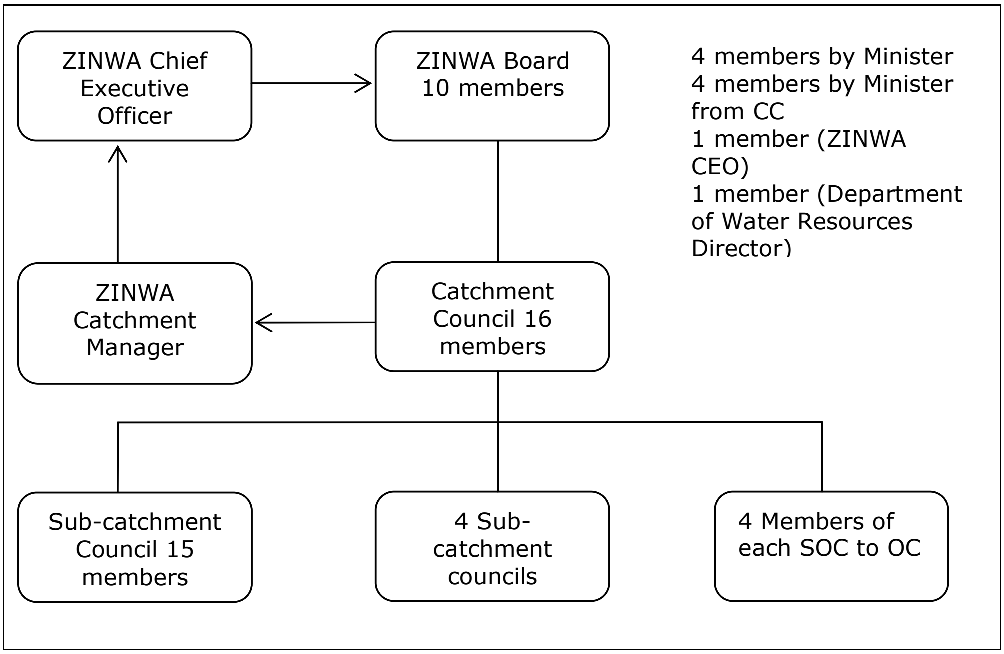

Fig. 44: State-defined stakeholder representation in the Mzingwane catchment area

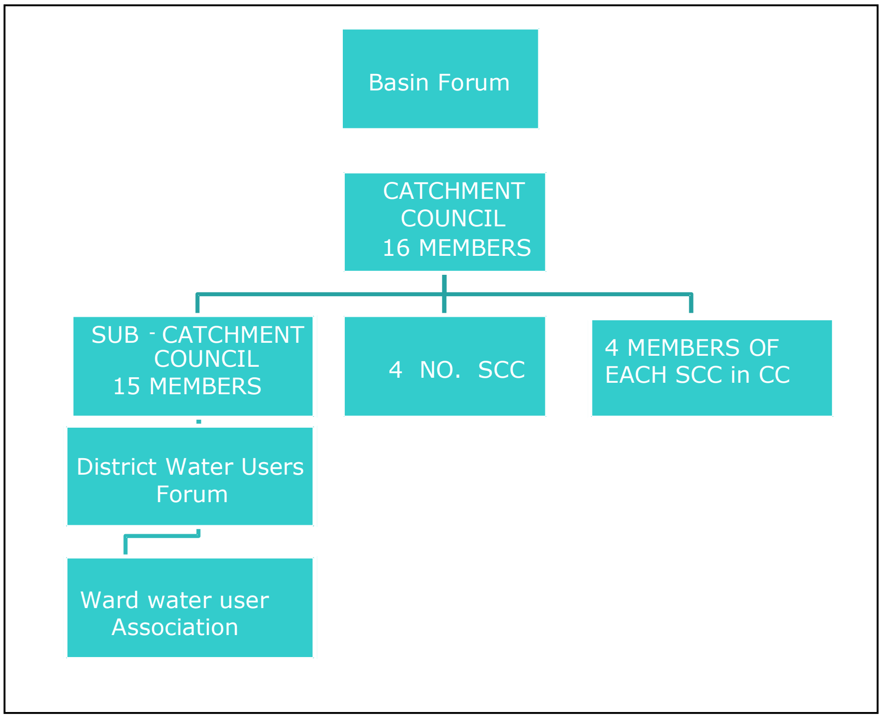

Figure 45: Locally-defined stakeholder representation in the Mzingwane catchment area

There was a strong feeling that the Chairman of the Mzingwane Catchment Council should attend the basin level meetings that took place under the auspices of the Limpopo Basin Permanent Technical Committee (LBPTC). Legally this was possible because of a provision that allowed member states to bring advisors. This recommendation stemmed from a feeling that there was no transparency and accountability regarding the discussions at the basin level. There was a lukewarm response to transboundary basin forum at which water users from the riparian countries would meet a model that is in use in the Okavango basin.

To make the relationships between Subcatchment Councils and administrative authorities simpler, and also to allow residents to more readily understand which Subcatchment they fall under, small boundary deviations were proposed (figure 46). These would mean that (with only three exceptions) every administrative ward would fall under only one Subcatchment Council.

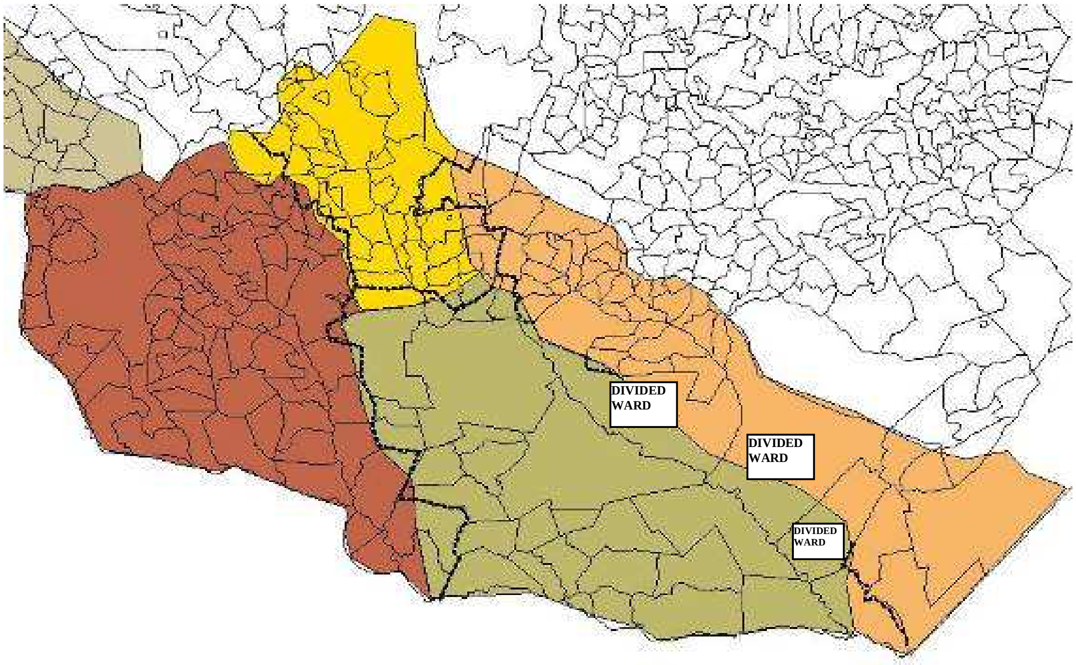

Figure 46. Possible deviation of Subcatchment Council (SCC) boundaries in the Mzingwane Catchment to follow ward boundaries. Existing SCC areas shown by a coloured background; ward boundaries by thin lines; proposed changes to operational boundaries of SCCs (and SCC electoral colleges) are shown by dashed black lines. Three wards within Mwenezi District must be divided between Mwenezi SCC and Lower Mzingwane SCC along farm boundaries.

3.5 Summary and conclusions

Before presenting the main conclusions across all the countries the main highlights for each country are given. The current institutional model in Mozambique does not provide a meaningful direct role to water users, which could be because of the country‘s centralization culture, a legacy which seems to persist. The degree to which these deficiencies affect local water uses and livelihoods remains to be determined. Another significant finding was the fact water management institutions were not defined according to hydrological boundaries but were based on a mixture of hydrological and administrative boundaries. Manzungu (2004) suggests that this could be because it was felt that there was no practical purpose that would be served by creating many hydrological-based institutions that would not only be expensive to run but would have relatively limited activities on account of limited development in some basins.

As far as South Africa is concerned there are questions as to whether the adoption of IWRM in South Africa has made a meaningful contribution to the development agenda in a country where, during apartheid, the water rights of millions of black majority population were systematically expunged due to unjust legislation and underinvestment in water infrastructure, and to what extent has the new water law has become a resource that the black population could use to their advantage. The fact that IWRM-based institutions such as CMAs are still to be agreed and operationalised as the water management organizing principle has complicated issues with the slow pace of reforms. While the current water laws and policies may not be discriminatory their implementation has reinforced the status quo. This also applies to financial incentives (subsidies, loans) for development of infrastructure. The individual investments in water infrastructure and the attendant institutional arrangements point to the vibrancy of local initiatives. In this regard the institutional framework, which is supposed to guide and regulate social action and interaction of actors that spanned from traditional authority, local government, Department of Agriculture, and Department of Water, needs to be restructured so that it could be responsive to local needs.

In Zimbabwe the state-defined institutional model designated the sub-catchment council as the lowest management level. This was found to be inappropriate since it did not provide for stakeholder representation at the local level where water was used or at national/basin level where policies were determined. The bottom up institutional model that local people suggested tried to address the issues by identifying the lowest water management level at the ward (at which a Ward Water Users Association would be formed), the second basic organizational unit of local government in Zimbabwe with a District Water Users Forum providing a platform for electing three ward representatives to the sub-catchment council with district representatives constituting part of the sub-catchment and catchment council.

In general we can say that in all the three countries IWRM-informed water laws and policies have resulted in efforts directed at ensuring participation in decision making processes as well as development activities, epitomised by policy of devolution of power and authority to sub-national institutions through a process of decentralization. While this was seen as critical to 'good water governance', it is the implementation of the approach that is important. One common legal instrument that could be used to improve the livelihoods of the people was the provision that local people could access reasonable quantities of water for domestic and other uses necessary for human sustenance. However the exact details differed from country to country as was the way decentralization was undertaken between countries. At the present time it does not appear that the new water management institutions in their present form affect local livelihoods. However this does not suggest that they are not relevant. What is important is to see how the institutions can be configured. In this vein the action research work that was done in Zimbabwe holds promise. Among other things, this work showed that 'hybrid' institutions that combined hydrological and administrative boundaries could be effective.

4 Objective 4: Human capacity building among farmers, extension officers, water managers and researchers at local universities in the Limpopo Basin and in Southern Africa

Note: Full details and statistics of the capacity building outputs of this project can be found in the Final Report.

4.1 Introduction

In improving global food production, the problem is not always due to the physical scarcity of water, but rather the lack of integrated land-water management approaches and weak institutional arrangements (Falkenmark and Rockström, 2003; Jaspers, 2003; Love *et al.*, 2006b; van der Zaag, 2005). An integrated approach to green and blue water management from the farmer's field to the river basin scale is required to promote and upscale smallholder rural livelihood improvements (Love *et al.*, 2004). This cannot be achieved though the introduction of innovations alone, but requires the building of appropriate capacity in land and water management at all the scales at which interventions are implemented, or management decisions are taken.

Too often capacity-building is seen as an add-on to research: a follow-up activity in which the main researchers are uninvolved or uninterested. As an alternative, WaterNet's approach is to integrate capacity building into the research activities from the planning stage onwards. This is show-cased through Challenge Program Number 17 (PN17), which from proposal stage has been integrated with WaterNet's capacity building programmes in Southern Africa.

4.2 Methods

WaterNet's approach is to integrate capacity building into the research activities from the planning stage onwards. PN17 was conceptualized with 6 PhD fellows and 21 Masters Students. In implementation key research in PN17 has been undertaken by the seven Ph.D. fellows, registered at WaterNet member institutions and supervised by scientists from universities and CGIAR centers within PN17. Each Ph.D. fellow was linked to Masters Students (a total of 31) who undertook their dissertation projects within PN17. Many of these students came from the WaterNet regional masters programme in Integrated Water Resources Management at the Universities of Dar-es-Salaam and Zimbabwe, supported by four other regional universities. Others came from programmes at other WaterNet member institutions. They were supervised by Ph.D. fellows and scientists from universities and CG centers in PN17. The project also involved capacity building at community, extension officer and water manager level. This included participatory on-farm pilot experiments (involving farmers and extension officers) and participatory development of institutional and water resources models (involving water managers). Direct training and extension were also provided in key areas.

Master students were funded primarily from WaterNet's Fellowship and Dissertation Funds, with some CPWF funding, whereas doctoral students were funded primarily from CPWF, with additional support from other agencies, including the WaterNet Staff Development Fund and Professional Training Fund.

4.3 Results and Discussion

Part of the impact of capacity building within PN17 can be seen in the number (more than the target) and distribution (half of SADC countries) of the Masters students (Figures 47 and 48).

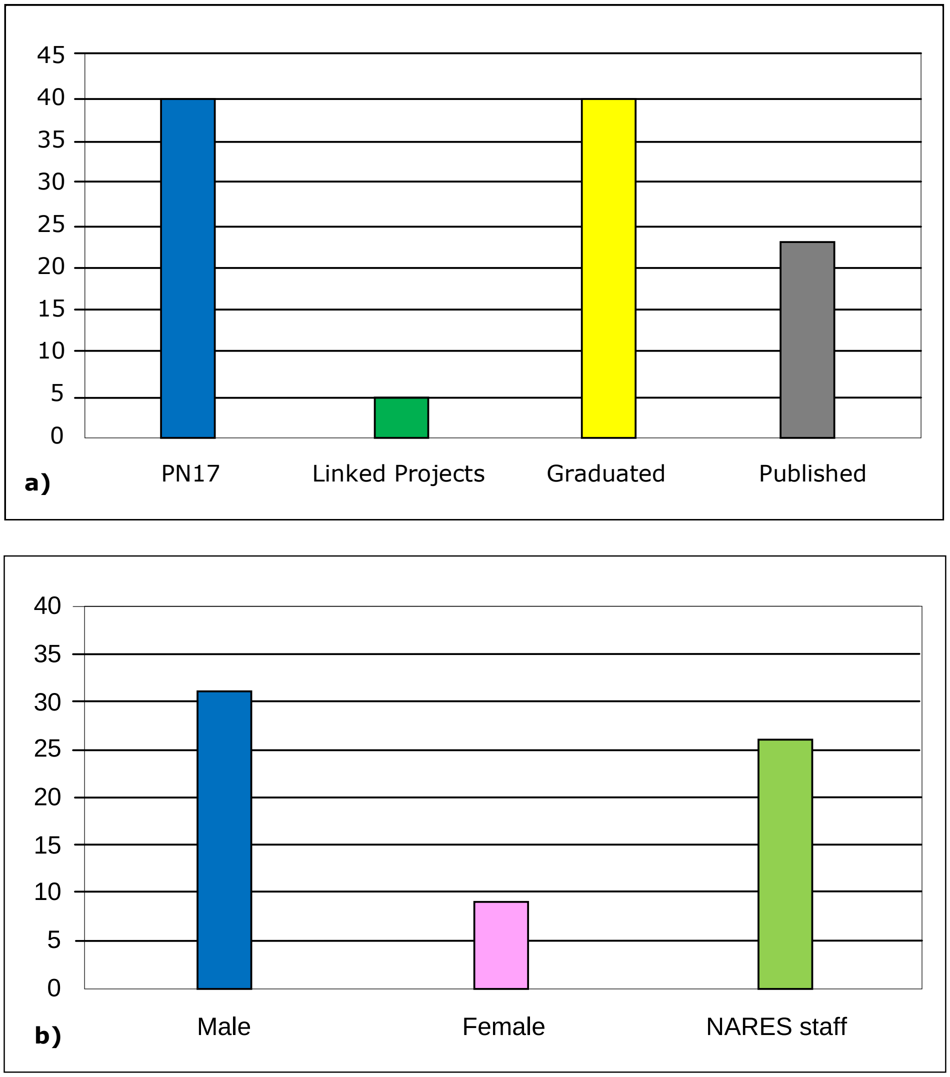

Figure 47: Masters Students sponsored by PN17. Please note that almost all have graduated and most have had their work published internationally **(a)**. Whilst staff from national agricultural (or water) research and extension services (NARES) is well represented, gender balance has not been achieved **(b)**.

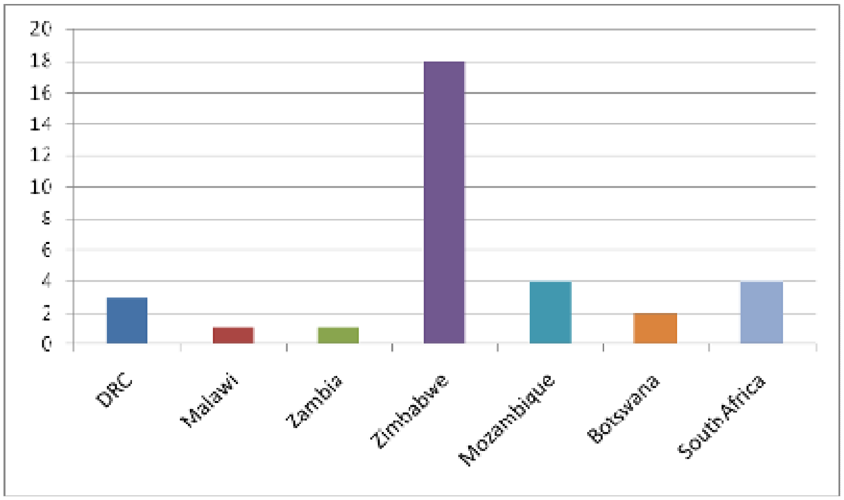

Figure 48: Distribution by nationality of the Masters students sponsored by PN17

The capacity building component of the project has influenced the project's research output, with 22 students publishing papers, articles or both (Figure 46). Contributions have been made in all major areas of PN17 research: Farmer-field based action research (Maisiri *et al.*, 2005; Dhliwayo *et al.*, 2006; Moyo *et al.*, 2006; Mwenge Kahinda *et al*, 2007), water resources research (Moyo, *et al.*, 2005; Kileshye-Onema *et al.*, 2006; Moyce *et al.*, 2006; Ngwenya *et al.*, 2006; Vilanculos *et al.*, 2006; Tunhuma *et al.*, 2007; McCartney and Arranz, 2008; Chilundo *et al.*, 2008; De Hamer *et al.*, 2008; Khosa *et al.*, in press; Masvopo *et al.*, 2008; Ncube and Taigbenu, 2007) and institutional research and development (Munamati *et al.*, 2005; Nare *et al.*, 2006; Svubure, 2007) as well as synthesis work such as where Basima Busane *et al*. (2005) integrated the research of four students who had been working on the same small reservoir.

Published research results have an impact in the broader scientific community. van der Zaag (2007) showed that articles published in the journal *Physics and Chemistry of the Earth* following the annual WaterNet/WARFSA-GWP-SA symposia (where most PN17 results have been presented) achieved an impact factor of between 0.3 and 0.8, with the water and land theme having an impact factor of 1.03. The paper by Moyce *et al* received the Phaup Award from the Geological Society of Zimbabwe, for the paper contributing most to the understanding of Zimbabwean geological science during the year 2006. The approach of Vilanculos *et al.* (2006) is being used for flood forecasting. The work of Maisiri *et al* (2005) Moyo *et al* (2006) on drip kits has been developed into a protocol on drip kit distribution which is now widely used in the NGO community in Zimbabwe. Initial steps have been taken for the work by Masvopo *et al.* (2008) to be developed in partnership with a private company, to supply water for smallholder citrus production. The results and model of Khosa *et al.* (2008) has been shared with the Zimbabwe National Water Management Authority for use in planning and at a stakeholder workshop. Recommendations by Svubure (2007) for rolling out water users associations and intermediate tier management structures were adopted by the Mwenezi Sub-catchment Council in Zimbabwe.

By a participatory approach, PN17 has trained communities, extension officers and water managers in a variety of interventions (Table 14).

Table 14: Intervention matrix for PN17: examples of interventions developed by a participatory approach

Intervention Package	**Community Beneficiaries**	**Organisational Beneficiaries**
Conservation agriculture	Communities in Insiza, Gwanda and Mwenezi (Zimbabwe) and Capricorn (South Africa)	Department of Agricultural Research and Extension (Zimbabwe) Limpopo Department of Agriculture (South Africa)
Rainwater harvesting	Communities in Sekororo (South Africa) and Chókwè (Mozambique)	Limpopo Department of Agriculture (South Africa) Chókwè District Agriculture Department (DDA) (Mozambique)
Low head drip kits	Communities in Insiza (Zimbabwe). But mostly this work was learning from the communities	Department of Agricultural Research and Extension (Zimbabwe) Many NGOs which distribute drip kits
Alluvial aquifers for smallholder irrigation	Communities in Matobo (Zimbabwe) (planned).	Zimbabwe National Water Authority
Improving flood forecasting	-	AraSul (Mozambique)
Modelling upstream -	-	Zimbabwe National Water

Intervention Package	Community Beneficiaries	Organisational Beneficiaries
downstream interactions		Authority
Building institutional sustainability	Communities in Sekororo (South Africa), Insiza and Mwenezi (Zimbabwe)	Zimbabwe National Water Authority

A particular benefit of the project was the development of transdisciplinary scientific teams for the supervision of students and the guiding of community training. This was made possible by the broad nature of the PN17 partnership, backed up by the wider WaterNet membership (Figure 49). The involvement of scientists in the supervision of research and capacity building projects at different scales, from farmer's field to river basin, results in the development of a core capacity with an appreciation of the challenges and linkages at the different scales within the basin. Methodologies, research tools and results are shared through integrative scientific and stakeholder workshops. Students are also required to present papers at symposia and encouraged to publish in journals. Quality control is conducted from conceptualisation of research ideas to implementation, publication of papers and synthesis of research findings.

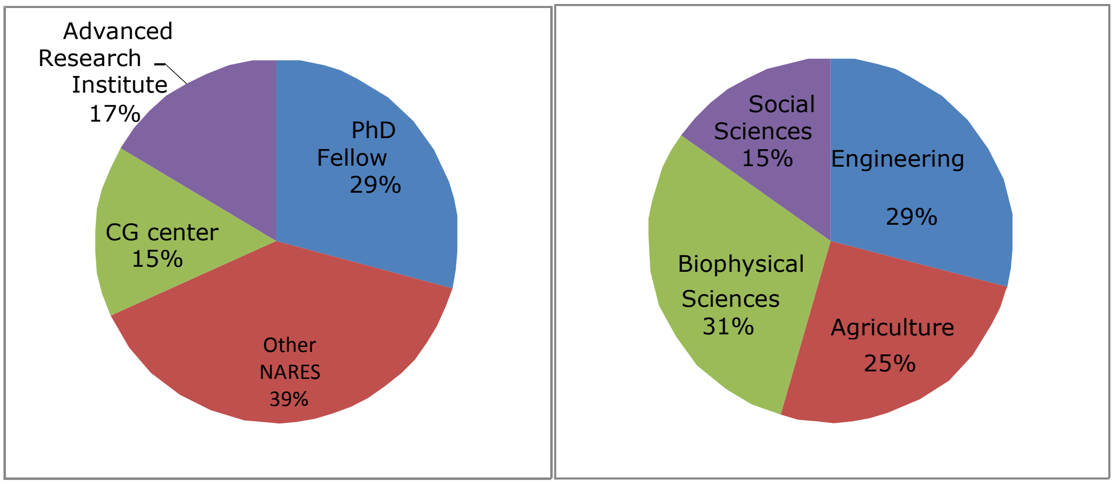

Figure 49: Affiliations and disciplines of supervisors of Masters Students. Most students had two or three supervisors. NARES = national agricultural (or water) research and extension services. PhD fellows who are also NARES staff are only recorded as PhD fellows. Institutional affiliation (left) shows the extent to which local scientists had ownership of MSc supervision. There is a good balance between disciplines of supervisors (right), making for good transdisciplinary teamwork.

4.4 Conclusions and recommendations

Integrating research and capacity building was a win-win scenario. At WaterNet, the MSc programme benefited as researchers from PN17 were brought into teaching, and as new research ideas from PN17 were integrated into the Masters curriculum. The Masters programme thus provided students who were well-equipped to begin their research projects, some of which were on water and food. Beyond this, WaterNet aims at training a new generation of water managers. By the integration of PN17 and the Masters programme, the new ideas and philosophies of more crop per drop were passed on to the students, who, returning to their home countries and workplaces in southern Africa, hopefully, implemented the new knowledge see Figure 50).

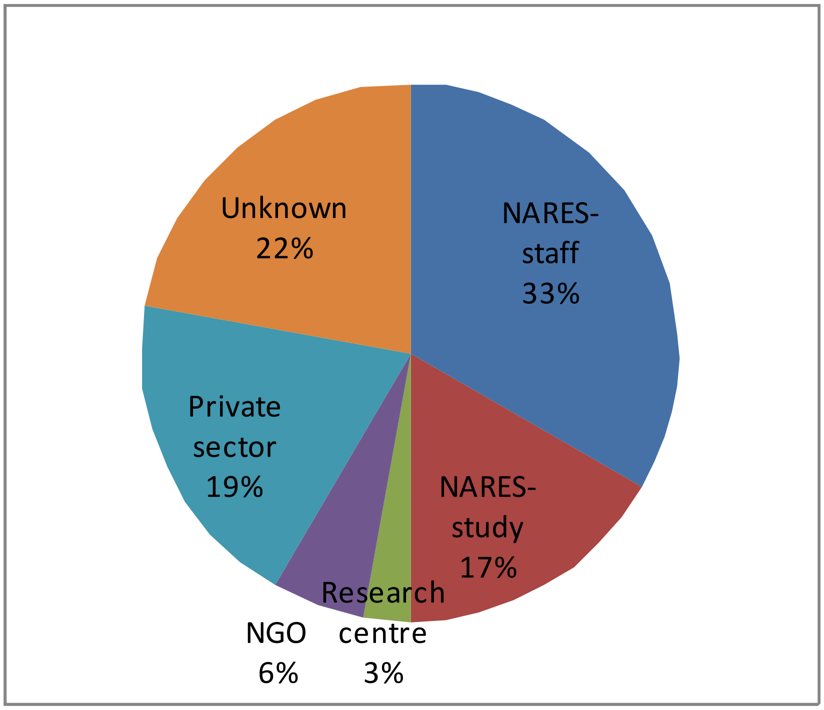

Figure 50: Deployment of Masters graduates from PN17, as at July 2009.

Half of the graduates worked in the state sector, in national agricultural or water ministries, universities or parastatals.

C: OUTCOMES AND IMPACTS

Note: in this section, frequent use is made of our project publication codes, eg A03, P78, D10. These codes refer to individual publications in the publications list (see section C5) and their file names on the publications DVD.

1 Outcomes and Impacts Proforma

Table 15. Summary Description of the Project's Main Impact Pathways

Actor or actors who have changed at least partly due to project activities	What is their change in practice? I.e., what are they now doing differently?	What are the changes in knowledge, attitude and skills that helped bring this change about?	What were the project strategies that contributed to the change? What research outputs were involved (if any)?	Please quantify the change(s) as far as possible
Farmers in the Zhulube and Mnyabezi areas, Mzingwane	Adoption of some of the conservation agriculture technologies	Farmers saw the benefits that those using conservation agriculture technologies obtained. Planned outcome	Farmer-field based participatory research approach A08, A15, A36, C12, P18, P76, PhD2	Two farmer groups were directly involved
NGOs	One NGO has outscaled the use of ripper tines and plating basins in Zimbabwe	NGO was impressed by research results.	A15, C12, WP09, PhD2	One international NGO working throughout Zimbabwe
NGOs	One NGO has upscaled the protocol for drip irrigation kit distribution.	NGO was concerned by findings of initial drip kit evaluation, upscaled it and adopted the protocol	A01, A02	One international NGO working throughout Zimbabwe
NGOs	One NGO is upscaling work on small alluvial aquifer hydrology and on cadmium contamination	NGO was part of research plan – planned outcome	A03, A11, A14, A24, A34, RB01	Regional NGO working in Botswana and Zimbabwe
Zimbabwe National Water Authority	The hydrological stations constructed in Zimbabwe will be taken over and used by the	Agreed as part of research plan – planned outcome	Hydrological research in Zimbabwe	Two stations

Actor or actors who have changed at least partly due to project activities	What is their change in practice? I.e., what are they now doing differently?	What are the changes in knowledge, attitude and skills that helped bring this change about?	What were the project strategies that contributed to the change? What research outputs were involved (if any)?	Please quantify the change(s) as far as possible
	Zimbabwe National Water Authority			
New institutional model and Ideas on stakeholder mobilisation at water user level	The Mzingwane Catchment Council is currently working towards outscaling this in the rolling out of and capacity building for Water User Associations.	Planned outcome Additional funding from WaterNet	A32, A06, RB03, P28, P87	Implemented in one catchment (water management area) and one subcatchment to date
Increased research capacity	Scientists from NARES and CG centres have obtained postgraduate qualifications. Scientists and staff from NARES and NGOs were involved in the surveys developments and implementation.	Planned outcome	C07	See section B4 of this report
Provincial administration, Matabeleland South	Provincial administration considering new sites for irrigation schemes	Provincial administrator attended project workshop	A26	Not yet funded
Juice producing company	Company wants to use smallholder farmers with access to alluvial groundwater as citrus outgrowers; will assist them start up	Company approached farmer who approached researchers	A26, P57	Not yet funded
Research consortium	Consortium assembled to apply IWRM/INRM nexus concept for	Consortium leader read paper	A13	Not yet funded

Actor or actors who have changed at least partly due to project activities	What is their change in practice? I.e., what are they now doing differently?	What are the changes in knowledge, attitude and skills that helped bring this change about?	What were the project strategies that contributed to the change? What research outputs were involved (if any)?	Please quantify the change(s) as far as possible
	natural resources management in the Zambezi Basin			
National government, South Africa	Input made into water services reform	Planned outcome	P52	
National government, South Africa	Input made into water law reform process	Planned outcome	A17, BK01, BK02, C06, C08, P71	
ARA-Sul	New GIS-based model incorporated into flood forecasting system in Mozambique	Planned outcome	P27	
Irrigated farmers, Chókwè	(work in progress still)			

Of the changes listed above, which have the greatest potential to be adopted and have impact? What might the potential be on the ultimate beneficiaries?

- Adoption of conservation agriculture by farmers
- Protocol for drip irrigation kit distribution influences effectiveness of very large relief programmes
- Use of large alluvial aquifers if adopted by provincial government can benefit thousands of people
- Changes to Zimbabwean water institutions and South African water laws should improve water management throughout those countries

What still needs to be done to achieve this potential? Are measures in place (e.g., a new project, on-going commitments) to achieve this potential? Please describe what will happen when the project ends.

See table above. Several of the changes require funding

Each row of the table above is an impact pathway describing how the project contributed to outcomes in a particular actor or actors.
Which of these impact pathways were unexpected (compared to expectations at the beginning of the project?)

Those not identified as "planned outcomes"

Why were they unexpected? How was the project able to take advantage of them?

Some of the outcomes were unexpected as the results were unexpected. In other cases, unanticipated users/stakeholders encountered the project's work.

What would you do differently next time to better achieve outcomes (i.e. changes in stakeholder knowledge, attitudes, skills and practice)?

Working to effect institutional change is the most complicated aspect and should start much earlier.

2 International Public Goods

Note: for a comprehensive account of project data, please see the completion report.

Table 16. Baselines

International Public Good	Project publication
Limpopo Basin geology baseline	WP11
Limpopo Basin soil baseline	WP12
Limpopo Basin hydrogeology baseline	AR24 (draft)
Agricultural system baseline, Mozambique	WP13, WP14
Limpopo Basin (Mozambique) profile	WP15
Socio-economic baseline, Mzingwane Catchment	AR12
Socio-economic and agricultural system baseline, Catchment B72A, Olifants Basin	AR14
Olifants Basin (South Africa) profile	AR15

Table 17. Methods and models

International Public Good	Project publication
Drip kit distribution protocol	A02
Method for reconnaissance mapping of alluvial aquifers	A03
Application of the *river basin game* in southern Africa	A19
Incorporation of interception routine into HBV model	A22,A25
Incorporation of alluvial groundwater into WAFLEX model	A26
Integrated coupled hydrological, agronomic and socio-economic model ICHSEA	A37

Table 18. Insights (selected)

International Public Good	Project publication
Double conventional ploughing can produce higher yields than ripping, basin tillage or conventional ploughing	PhD2
Basin tillage reduces in-field surface runoff and improves soil water availability, but not necessarily yields	A36, PhD2
Dead level contours have no significant effect on soil water availability	PhD2
Labour requirements are a major constraint in conservation agriculture	PhD2
For water management to achieve impact and stakeholder participation, consideration should be given to administrative boundaries, not just hydrological ones	A32
Seepage is often the largest constraint to sustainable	A34

International Public Good	Project publication
development of alluvial aquifers; seepage levels can be predicted from geology	
The yield gap in rainfed farming can be bridged by supplementary irrigation	C02, C11

3 Partnership Achievements

The research project has resulted in some major partnership building, between:

- WaterNet members who are partners in the project
- CG centres and NARES who are partners in the project and WaterNet members
- NARES and NGOs in the project, or operational in the project area
- WaterNet and national government structures

It should be emphasized that, as a network, WaterNet itself is a partnership organization. The Trust oversees, the secretariat coordinates but most activities are delivered by WaterNet members and partners. A key aspect of this project for WaterNet was building solid partnerships outside the university sector: with CG centres, government departments and NGOs. Many of these partnerships have outlasted the project. Individual project members built up their own partnerships, especially universities with CG centres, government departments and NGOs. This has led to cross-fertilisation and benefits to university curriculum, other research initiatives and so on.

The methodology used by WaterNet as a network in developing the concept note and proposal, assembling the PN17 partnership and managing the project is serving as an excellent example as a way for us to facilitate our members to access international research programs. WaterNet is establishing other research projects in the same fashion.

Most of the international public goods produced are the result of partnership efforts:

Table 19. Partnerships in achievement

International Public Good	Partnership
Drip kit distribution protocol	CG centre, NGO and university
Method for reconnaissance mapping of alluvial aquifers	University, ARI and government dept
Application of the *river basin game* in southern Africa	CG centre, NGO and university
Double conventional ploughing can produce higher yields than ripping, basin tillage or conventional ploughing	CG centre, NGO and university
Basin tillage reduces in-field surface runoff and improves soil water availability, but not necessarily yields	CG centre, NGO and university
Dead level contours have no significant effect on soil water availability	CG centre, NGO and university
Labour requirements are a major constraint in conservation agriculture	CG centre, NGO and university
For water management to achieve impact and stakeholder participation, consideration should be given to administrative boundaries, not just hydrological ones	University, ARI and government dept
Seepage is often the largest constraint to sustainable development of alluvial aquifers; seepage levels can be predicted from geology	University, ARI and government dept

A particular benefit of the project is the development of transdisciplinary scientific teams for the supervision of students and the guiding of community training – see section B4.3.

The new institutional model being developed and rolled out in the Mzingwane Catchment – essentially a model of hybrid administrative-hydrological boundary scales – is the result of an innovative partnership between the universities and the water management authority that continues beyond the end of the project.

4 Recommendations

- Baselines developed should be made widely available for future use
- Promote fertility amendments alongside conservation tillage – microdosing is best suited to farmers' risk management approach as higher dosage levels represent risky expenditure
- Always consider the labour costs of any conservation agriculture intervention
- Reconsider the promotion of dead level contours as a soil water intervention
- Low cost technologies (such as drip) should be used in conjunction with good water and nutrient management if higher water and crop productivity are to be realized than surface irrigation systems
- Drip kit distribution protocol should continue to be used
- With the water productivity for rainfed agriculture lower than supplementary irrigation, the results demonstrate the great opportunities that exist for upgrading rainfed agriculture and ensuring food security in rural communities through timely and adequate supplementary irrigation to bridge and manage dry spells
- Rising frequency of mid-season dry spells suggests scope in exploring rainwater management technologies and short-season varieties to reduce the impact of dry spells in rainfed cropping systems
- A follow-up study of cadmium in the Limpopo Basin is needed to determine the extent of the problem
- Additional research at a basin scale was recommended to identify the major sources of pollution to Mozambique
- Stress on water supply systems will compel exploration of non-conventional water resources (e.g. sand dams) as potential water supplies
- Use (existing) geological mapping to predict suitable (low seepage) areas for exploration of alluvial aquifers
- Illegal forms of small-scale resource exploitation such as gold panning should be formalised and a wider stakeholder participation to include local communities in policy-making and environmental protection
- Establish smallholder farmer water conservation committees with women as leaders
- Tight control of future water demands are needed in the Olifants Basin, which is closing
- Upscaling of the institutional model within the Mzingwane Catchment and elsewhere in Zimbabwe
- For water management to achieve impact and stakeholder participation, consideration should be given to administrative boundaries, not just hydrological ones – this is already happening in Zimbabwe (as a result of this project) and in South Africa

5 Publications

Title **JOURNAL ARTICLES**	**Activity Number**	**Date**	**Publisher**	**Authors**
A01. An on-farm evaluation of the effects of low cost drip irrigation on water and crop productivity, compared to conventional surface irrigation system	2.2	September 2005	*Physics and Chemistry of the Earth*, **30**, 783-791 doi:/10.1016/j.pce.2005.08.021	N Maisiri, J Rockström, A Senzanje, S Twomlow
A02. Impact and sustainability of low-head drip irrigation kits, in the semi-arid Gwanda and Beitbridge Districts, Mzingwane Catchment, Limpopo Basin, Zimbabwe	1.6	November 2006	*Physics and Chemistry of the Earth*, **31**, 885-892 doi:10.1016/j.pce.2006.08.020	R Moyo, D Love, S Twomlow, W Mupangwa, M Mul

Title JOURNAL ARTICLES	Activity Number	Date	Publisher	Authors
A03. Alluvial aquifers in the Mzingwane Catchment: their distribution, properties, current usage and potential expansion	1.3	November 2006	*Physics and Chemistry of the Earth*, **31**, 988-994 doi:10.1016/j.pce.2006.08.013	W Moyce, P Mangeya, RJ Owen, D Love
A04. Implementing the millennium development food security goals – Challenges of the southern African context	1.6	November 2006	*Physics and Chemistry of the Earth*, **31**, 731-737 doi:/10.1016/j.pce.2006.08.002	D Love, S Twomlow, W Mupangwa, P van der Zaag, B Gumbo
A05. Soil-water conservation and rainwater harvesting strategies in the semi-arid Mzingwane Catchment, Limpopo Basin, Zimbabwe	1.6	November 2006	*Physics and Chemistry of the Earth*, **31**, 83-90 doi:10.1016/j.pce.2006.08.042	W Mupangwa, D Love, S Twomlow
A06. Involvement of stakeholders in the water quality monitoring and surveillance system: the case of Mzingwane Catchment, Zimbabwe	1.3 3.1	November 2006	*Physics and Chemistry of the Earth*, **31**, 707-712 doi:10.1016/j.pce.2006.08.037	L Nare, D Love, Z Hoko
A07. Effects of dams on river flows of Insiza River, Zimbabwe	1.3	November 2006	*Physics and Chemistry of the Earth*, **31**, 870-875 doi:10.1016/j.pce.2006.08.022	JM Kileshye Onema, D Mazvimavi, D Love, M Mul
A08. Effect of mulching and minimum tillage on maize (*Zea mays* L.) yield and water content of clayey and sandy soils	2.2	November 2007	*Physics and Chemistry of the Earth*, **32**, 1127-1134 doi:10.1016/j.pce.2007.07.030	W Mupangwa, S Twomlow, L Hove, S Walker
A09. Rainwater harvesting to enhance water productivity of rainfed agriculture in the semi-arid Zimbabwe	1.6	November 2007	*Physics and Chemistry of the Earth*, **32**, 1068-1073 doi:10.1016/j.pce.2007.07.011	J Mwenge Kahinda, J Rockström, AE Taigbenu, J Dimes
A10. Changing rainfall and discharge patterns in the northern Limpopo Basin, Zimbabwe	2.1	April 2010	*Water SA*, **36**, 3	D Love, S Uhlenbrook, S Twomlow, P van der Zaag
A11. Potential water supply of a small reservoir and alluvial aquifer system in southern Zimbabwe	1.3.2	July 2008	*Physics and Chemistry of the Earth*, **33**, 633-639, doi:10.1016/j.pce.2008.06.056	W. de Hamer, D. Love, R. Owen, M.J. Booij, A.Y.Hoekstra
A12. DRAFT Application of the SWAT model to assess the impact of land cover and land use on the hydrologic response in the Olifants Catchment	2.1	2010	Article submitted to *Water SA*	M Ncube, AE Taigbenu
A13. The nexus between Integrated Natural Resources Management and Integrated Water Resources Management in Southern Africa	Synthesis	July 2008	*Physics and Chemistry of the Earth*, **33**, 889-898, doi:10.1016/j.pce.2008.06.044	S Twomlow, D Love, S Walker
A14. Design of a water quality monitoring network for the Limpopo River Basin in Mozambique	1.3.4	July 2008	*Physics and Chemistry of the Earth*, **33**, 655-665, doi:10.1016/j.pce.2008.06.055	M Chilundo, P Kelderman, JHO O'Keeffe
A15. The influence of conservation tillage methods on soil water regimes in semi-arid southern Zimbabwe	2.2	July 2008	*Physics and Chemistry of the Earth*, **33**, 762-767, doi:10.1016/j.pce.2008.06.049	W Mupangwa, S Twomlow, S Walker
A16. Building adaptive capacity to cope with increasing vulnerability due to climatic change in Africa– a new approach	Synthesis	July 2008	*Physics and Chemistry of the Earth*, **33**, 780-787, doi:10.1016/j.pce.2008.06.048	S Twomlow, FT Mugabe, M Mwale, R Delve, D Nanja, P Carberry, M Howden
A17. Redressing inequities from the past from a historical perspective: the case of the Olifants Basin, South Africa	3.1	April 2008	*Water SA*, **34**, 432-438	B van Koppen
A18. Crop yield risk analysis and mitigation of smallholder farmers at quaternary catchment level: Case study of B72A in Olifants river basin, South Africa	2.2	July 2008	*Physics and Chemistry of the Earth*, **33**, 744-756, doi:10.1016/j.pce.2008.06.050	MS Magombeyi, AE Taigbenu
A19. The River Basin Game as a tool for collective water management at community level in South Africa	5	July 2008	*Physics and Chemistry of the Earth*, **33**, 873-880 doi:10.1016/j.pce.2008.06.045	MS Magombeyi, D Rollin, B Lankford
A20. DRAFT Evaluation of the effects of different water demand scenarios on downstream water availability: The case of Thuli river basin	2.1	December 2010	Draft MS	S Khosa, D Love, ML Mul
A22. DRAFT Challenges of regionalising a conceptual model in semi-arid meso-catchments	2.8	June 2010	Article submitted to *Physics and Chemistry of the Earth*	D Love, S Uhlenbrook, P van der Zaag
A23. DRAFT Start, end and dry spells of the growing season in semi-arid southern Zimbabwe	2.1	December 2010	Draft MS	W Mupangwa, S Walker, S Twomlow
A24. DRAFT Water quality in the Thuli and Mzingwane catchments, Zimbabwe: implication for risks to human health, livestock and crops	1.3.4	December 2010	Draft MS	D Love, M Meck, R Owen, S Ravengai, W Moyce
A25. DRAFT Rainfall-interception-evaporation-runoff relationships in a semi-arid meso-catchment, northern Limpopo Basin,	2.1	June 2010	Article submitted to *Hydrological Sciences Journal*	D Love, S Uhlenbrook, G Corzo-Perez, S Twomlow

Title JOURNAL ARTICLES	Activity Number	Date	Publisher	Authors
Zimbabwe				
A26. DRAFT A water balance modelling approach to optimising the use of water resources in ephemeral sand rivers – the example of the Lower Mzingwane alluvial aquifer	1.3.2 2.8	June 2010	Article submitted to *River Research & Applications*	D Love, P van der Zaag, S Uhlenbrook, R Owen
A27. DRAFT Mercury pollution from gold panning, Zhulube Catchment, Limpopo Basin, Zimbabwe	1.3.4	December 2010	Draft MS	D Love, N Tunhuma, P Kelderman, S Uhlenbrook
A28. DRAFT Rainwater harvesting to cope with climate induced risks in smallholder farming systems in the Limpopo Basin	2.2	December 2010	Draft MS	R Brito et al.
A32. DRAFT Beyond fragmented realities: The quest for broadbased stakeholder participation in water resource management in Zimbabwe	3	July 2010	Draft MS	E Manzungu, V Dzingirai, J Fatch
A33. DRAFT Decision-making tools for catchment management: contrasting data-rich and data-scarce approaches	2.8 Synthesis	December 2010	Draft MS	D Love, M Magombeyi, A Taigbenu, S Uhlenbrook, P van der Zaag
A34. DRAFT The Mushawe meso-alluvial aquifer, Limpopo Basin, Zimbabwe and the development potential of small sand rivers	1.3.2	December 2010	Draft MS	D Love, R Owen, S Uhlenbrook, P van der Zaag
A35. DRAFT Rainfall Risk Analysis for Rainfed Agriculture in the Limpopo Basin	2.1 2.2	December 2010	Draft MS	W. Mupangwa, J. Dimes, S. Walker, E. Masvaya, M. Magombeyi, P. Munguambe and S. Mpandeli
A36. DRAFT Productivity of planting basin tillage system and nitrogen under highly variable rainfall regimes of semi-arid Zimbabwe: A modelling assessment	2.2	June 2010	Draft MS	W. Mupangwa, J. Dimes, S. Walker, S Twomlow
A37. DRAFT Simulation of farming systems in the Olifants river basin, South Africa	2.2	July 2010	Article submitted to *Journal of Agricultural Systems*	M Magombeyi, A Taigbenu, S Moradet, C Cheron
A38. DRAFT Uncovering hidden potential: Dynamics of local water investments in Sekororo Communal lands, Limpopo basin, South Africa	3	December 2010	Draft MS	P Sithole, E Manzungu, B Tapela, B van Koppen
A39. Micro-dosing as a pathway to Africa's Green Revolution: evidence from broad-scale on-farm trials	2.2	2009	*Nutrient Cycling in Agroecosystems*; doi: 10.1007/s10705-008-9200-4	S Twomlow, D Rohrbach, J Dimes, J Rusike, W Mupangwa, B Ncube, L Hove, M Moyo, N Mashingaidze, P Mahposa

Title BOOKS	Activity Number	Date	Publisher	Authors
BK01. Community-Based Water Law and Water Resource Management Reform in Developing Countries	3	2008	CABI publisher, ISBN: 1 84593 326 5	Editors: B van Koppen, M Giordano, and J Butterworth
BK02. DRAFT The basin development trajectory of the Olifants Basin in South Africa	3	August 2009	Submitted to Water Research Commission	B van Koppen

Title BOOK/PROCEEDINGS CHAPTERS	Activity Number	Date	Publisher	Authors
C01. Simulation of farming systems in the Olifants river basin, South Africa	2.2	November 2008	In: Humphreys *et al.* (eds.). *Fighting Poverty Through Sustainable Water Use: Proceedings of the CGIAR Challenge Program on Water and Food 2nd International Forum on Water and Food, Addis Ababa, Ethiopia, November 10 – 14 2008*, **I**. The CGIAR Challenge Program on Water and Food, Colombo	M Magombeyi, A Taigbenu

Title BOOK/PROCEEDINGS CHAPTERS	Activity Number	Date	Publisher	Authors
C02. Water availability deficit in rainfed farming for semiarid Mzingwane Catchment, Zimbabwe	2.1	November 2008	In: Humphreys *et al.* (eds.). *Fighting Poverty Through Sustainable Water Use: Proceedings of the CGIAR Challenge Program on Water and Food 2nd International Forum on Water and Food, Addis Ababa, Ethiopia, November 10 – 14 2008*, **II**. The CGIAR Challenge Program on Water and Food, Colombo	A Mhizha, B Chibulu
C03. Integration of germplasm and management for sustainable water productivity improvement in rainfed cropping	2.2	November 2008		J Dimes, P du Toit
C04. Modelling upstream-downstream interactions using a spreadsheet-based water balance model: two case studies from the Limpopo basin	2.8	November 2008	In: Humphreys *et al.* (eds.). *Fighting Poverty Through Sustainable Water Use: Proceedings of the CGIAR Challenge Program on Water and Food 2nd International Forum on Water and Food, Addis Ababa, Ethiopia, November 10 – 14 2008*, **III**. The CGIAR Challenge Program on Water and Food, Colombo.	D Love, S Khosa, M Mul, S Uhlenbrook, P van der Zaag
C05. Impact of the Zhovhe Dam on the lower Mzingwane River channel	2.1	November 2008		D Love, F Love, P van der Zaag, S Uhlenbrook, R Owen
C06. Understanding hydraulic property rights creation, re-creation and de-creation: A case study of Lorraine and Fumukwe villages, Limpopo basin (go to page181)	3.1	November 2008		P Sithole, B van Koppen
C07. Mainstreaming capacity building in food and water research in the Limpopo Basin: linking across scales and across disciplines (go to page128)	5	November 2008		D Love, B Ncube, B Gumbo
C08. DRAFT. The political, social and economic context of changing water policy in South Africa post-1994	3	2010	In: Schreiner and Hassan (eds). *Integrated Water Resource Management in South Africa*. Resources for the Future Publications.	B van Koppen, B Schreiner, S Fakir
C09. DRAFT. Mainstreaming gender in water management in South Africa	3	2010		B van Koppen and E Karr
C10. Methodologies and case studies for investigating upstream-downstream interactions of rainwater water harvesting in the Limpopo Basin	2.2	2009	In: Humphreys, L (ed). *Proceedings of the Workshop on Increasing the Productivity and Sustainability of Rainfed Cropping Systems of Poor, Smallholder Farmers, Tamale, Ghana, 22-25 September 2008*. The CGIAR Challenge Program on Water and Food, Colombo. [ISBN 9789299005347]	B Ncube, M Magombeyi, P Munguambe, W Mupangwa, D Love
C11. Maize yields under supplementary irrigation in the Olifants river basin, South Africa	2.2	2009		MS Magombeyi, T Rasiuba, AE Taigbenu
C12. Precision conservation agriculture for vulnerable farmers in low-potential zones	2.2	2009		S Twomlow, L Hove, W Mupangwa, P Masikati, N Mashingaidze
C13. Quantifying water productivity in rainfed cropping systems in Limpopo province, South Africa	2.2	2009		J Dimes, P du Toit
C14. Climate change impact on crop productivity in the semi-arid tropics of Zimbabwe in the 21st century	2.2	2009		J Dimes, P Cooper, KPC Rao

Title INSTITUTIONAL WORKING PAPERS AND RESEARCH REPORTS	Activity Number	Date	Publisher	Authors
RR01. Application of the Water Evaluation And Planning (WEAP) Model to Assess Future Water Demands and Resources in the Olifants Catchment, South Africa	1.6	May 2008	IWMI Research Report	R Arranz and M McCartney
WP01. An overview of the Mzingwane Catchment, Zimbabwe	1.2	February 2005	WaterNet Working Paper **1**	D Love and AE Taigbenu and L Jonker

Title INSTITUTIONAL WORKING PAPERS AND RESEARCH REPORTS	Activity Number	Date	Publisher	Authors
WP02. Short report on five masters projects from the Mzingwane Catchment, Zimbabwe	5.4	February 2005	WaterNet Working Paper **2**	D Love and L Jonker
WP03. Spreading the word on fertilizer	2.2	February 2006	ICRISAT GTAE Report **24**	S Twomlow and D Rohrbach and J Rusike and W Mupangwa and J Dimes and B Ncube
WP04. Short Report on Masters research in the Mzingwane Catchment, Zimbabwe, 2004/5 – 2005/6	5.4	September 2006	WaterNet Working Paper **3**	D Love
WP05. Short Report on Masters research cofunded by RELMA-in-ICRAF in the Mzingwane Catchment, Zimbabwe, 2004/5	5.4	November 2006	WaterNet Working Paper **4**	D Love
WP06. Short Report on Doctoral research within WaterNet Challenge Program Project PN17	5.5	November 2006	WaterNet Working Paper **5**	D Love and W Nyabeze
WP07. Short Report on Masters research in progress in the Mzingwane Catchment, Zimbabwe, 2006/7	5.5	May 2007	WaterNet Working Paper **6**	D Love
WP08. Application of the Water Evaluation And Planning (WEAP) Model to Assess Future Water Demands and Resources in the Olifants Catchment, South Africa	1.6	August 2007	IWMI Working Paper **116**	R Arranz and M McCartney
WP09. An assessment of the sustainable uptake of conservation farming in Zimbabwe	2.2	March 2008	ICRISAT GTAE Report **39**	Mazvimavi K, Twomlow S, Belder P, and Hove L
WP10. DRAFT Integrated water resource management (IWRM) research for mitigating drought and improving livelihoods within the Limpopo Basin	Synthesis	July 2010	Draft CPWF Working Paper	B Ncube, D Love, B Gumbo
WP11. Baseline Report on the Geology of the Limpopo Basin Area (data)	1.2	July 2009	WaterNet Working Paper 7	G Chinoda, W Moyce, N Matura, R Owen
WP12. Baseline Report on the Soils of the Limpopo River Basin (data)	1.2	July 2009	WaterNet Working Paper 8	C Bangira, A Manyevere
WP13. Report on Agricultural Surveys, Upper Limpopo, Mabalane District, Mozambique	1.5	July 2009	WaterNet Working Paper 9	R. Brito, P. Munguambe, N. Ibraimo, C. Julaia, A. Nhamatate
WP14. Report on Agricultural Surveys, Lower Limpopo, Xai-Xai and Bilene Districts, Mozambique	1.5	July 2009	WaterNet Working Paper 10	R. Brito, P. Munguambe, C. Julaia, A. Nhamatate
WP15. Profile of the Limpopo Basin in Mozambique	1.2	July 2009	WaterNet Working Paper 11	R Brito, S Famba, P Munguambe, N Ibraimo, C Julaia

Title RESEARCH BRIEFS	Activity Number	Date	Publisher	Authors
RB01. Risk posed by dissolved Cadmium in the transboundary Limpopo Basin	1.3.4	July 2009	WaterNet / CPWF PN17 Research Brief 1	M Chilundo, D Love, M Meck, B Ncube
RB02. Mid-season dry spells in the transboundary Limpopo Basin	2.1	September 2009	WaterNet / CPWF PN17 Research Brief 2	J Dimes, D Love, W Mupangwa, B Ncube, S Walker
RB03. DRAFT An institutional model for sustainable water resource management in the Limpopo basin, Zimbabwe	3	June 2010	WaterNet / CPWF PN17 Research Brief 3	E Manzungu

Title PAPERS	Activity Number	Date	Publisher	Authors
NP1. The Impact Of Land Cover And Land Use On Hydrological Response In The Olifants Catchment	2.1	August 2005	Special Colloquium, Water Research Showcase, Univ. of Johannesburg, Pretoria & The Witwatersrand	M Ncube, AE Taigbenu
NP2. Water resources management in agriculture: convergence of needs and opportunities	1.6	September 2005	12th SANCHIAS symposium	AE Taigbenu, M Ncube, RJ Boroto
P01. The Challenge of Integrated Water Resource Management for Improved Rural Livelihoods in the Limpopo Basin – an introduction to WaterNet's first network research program	Synthesis	November 2004	WaterNet/WARFSA/GWP-SA Annual Symposium, Namibia	D Love, L Jonker, J Rockström, P van der Zaag, S Twomlow
P02. An integrated evaluation of a small	1.3 3.1	November	WaterNet/WARFSA/GWP-SA	L Basima Busane, T

Title **PAPERS**	**Activity Number**	**Date**	**Publisher**	**Authors**
reservoir and its contribution to improved rural livelihoods: Sibasa Dam, Limpopo Basin, Zimbabwe		2005	Annual Symposium, Swaziland	Sawunyama, G Chinoda, D Twikirize, A Senzanje, D Love, Z Hoko E Manzungu, P Mangeya, N Matura, A Mhizha, P Sithole
P03. Influence of human activities on the hydrology of the Insiza River, Limpopo Basin, Zimbabwe - implications for catchment planning	2.1			JM Kileshye Onema, J Rockström, D Mazvimavi D Love, M Mul A van Rooyen, S Twomlow
P04. Implementing the millennium development food security goals - challenges of the southern African context	1.6 2.2			D Love, S Twomlow, W Mupangwa, P van der Zaag, B Gumbo
P05. Analysis of hydrological change for IWRM planning: case study of the Mzingwane River, Limpopo Basin, Zimbabwe	1.3			D Love, S Uhlenbrook, W Nyabeze, RJS Owen, S Twomlow, H Savenije L Woltering, P van der Zaag
P06. Alluvial aquifers in the Mzingwane Catchment: their distribution, properties, current usage and potential expansion and risk	1.3			W Moyce, P Mangeya, RJ Owen, D Love
P07. A model for reservoir yield under climate change scenarios for the water-stressed City of Bulawayo, Zimbabwe	1.3 2.1			B Moyo, E Madamombe D Love
P08. Impact and sustainability of drip irrigation kits in the semi-arid Lower Mzingwane Subcatchment, Limpopo Basin, Zimbabwe	2.2			R Moyo, D Love, S Twomlow, W Mupangwa, M Mul
P09. Cultivating livelihoods: an assessment of water allocation and management practices in small-scale irrigation schemes -case studies in Mzingwane Catchment	1.6 3.1			M Munamati, A Mhizha, P Sithole
P10. Soil-water conservation and other rainwater harvesting strategies in the semi-arid Mzingwane Catchments, Limpopo Basin, Zimbabwe	1.6 2.2			W Mupangwa, D Love, S Twomlow
P11. Involvement of stakeholders in the water quality monitoring and surveillance system: the case of Mzingwane Catchment	3.1	November 2005	WaterNet/WARFSA/GWP-SA Annual Symposium, Swaziland	L Nare, D Love, Z Hoko
P12. Managing risk, mitigating drought and improving water productivity in the water scarce Limpopo Basin: highlights of some integrated water resources management solutions	Synthesis	December 2005	CGIAR Challenge Program on Water and Food International Workshop on “Enhancing human and ecological well-being in Africa through sustainable increases in water productivity”, Uganda	D Love, B Gumbo, W Nyabeze
P13. Managing risk, mitigating drought and improving water productivity in the water scarce Limpopo Basin: highlights of some integrated water resources management approaches	Synthesis	February 2006	SADC Land and Water Management Applied Research Programme Scientific Symposium “Land and Water Management for Sustainable Agriculture”, Malawi	D Love, B Gumbo, W Nyabeze
P14. An evaluation of climate and runoff variability and associated livelihood risks in the Mzingwane Catchment, Limpopo Basin, Zimbabwe	1.3 2.1	May 2006	Water Institute of Southern Africa Biennial Conference and Exhibition, Durban, South Africa	D Love, S Uhlenbrook, E Madamombe S Twomlow, P van der Zaag
P15. Conservation farming by basins breathes new life into smallholder farmers in Zimbabwe	2.2	February 2006	SADC Land and Water Management Applied Research Programme Scientific Symposium “Land and Water Management for Sustainable Agriculture”, Malawi	S Twomlow, D Rohrbach, L Hove, W Mupangwa, N Mashingaidze, M Moyo, C Chiroro
P16. Alluvial aquifers as potential safe water storage in semi arid areas: case study of Lower Mzingwane Catchment, Limpopo Basin, Zimbabwe	1.3	August 2006	Stockholm Water Symposium World Water Week, Sweden	W Moyce, P Mangeya, RJ Owen, D Love
P17. Livelihood challenges posed by water quality in the Mzingwane and Thuli River Catchments, Zimbabwe	1.3	November 2006	WaterNet/WARFSA/GWP-SA Annual Symposium, Malawi	D Love, W Moyce, S Ravengai
P18. An on farm comparison of conservation agriculture practices and conventional farmer	2.2			C Dhliwayo, H Makurira, W

Title PAPERS	Activity Number	Date	Publisher	Authors
practices on soil hydrology and maize yield				Mupangwa, D Love, S Twomlow
P19. Effects of grazing management on rangeland soil hydrology, Insiza, Zimbabwe	2.2			PT Ngwenya, D Love, A Mhizha, S Twomlow
P20. Effects of dams on river flows of Insiza River, Limpopo Basin Zimbabwe	1.3	August 2006	Stockholm Water Symposium World Water Week, Sweden	JM Kileshye Onema, D Mazvimavi, D Love, M Mul
P21. Olifants river basin: the process of basin closure	1.3			W Nyabeze, B Gumbo, D Love
P22. Effect of mulching and minimum tillage on maize (Zea mays L.) yield and water content of clayey and sandy soils	2.2	November 2006	WaterNet/WARFSA/GWP-SA Annual Symposium, Malawi	W Mupangwa, S Twomlow, L Hove, S Walker
P23. Rainwater harvesting to enhance water productivity of rainfed agriculture in the semi-arid Zimbabwe	1.6			J Mwenge Kahinda, J Rockström, AE Taigbenu, J Dimes
P24. Spreading the word on fertilizer in Zimbabwe	2.2	February 2006	SADC Land and Water Management Applied Research Programme Scientific Symposium “Land and Water Management for Sustainable Agriculture”, Malawi	S Twomlow, D Rohrbach, L Hove, W Mupangwa, N Mashingaidze, M Moyo, C Chiroro
P25. Integrating hydrological and socio-economic aspects for sustainable catchment management: needs and opportunities	2.8	November 2006	WaterNet/WARFSA/GWP-SA Annual Symposium, Malawi	M Magombeyi, AE Taigbenu, D Rollin
P26. The use of the river basin game as a tool for the implementation of the Waternet CP project in South Africa	2.5			M Magombeyi, D Rollin, B Lankford
P27. Towards improving flood forecasting and early warning systems through integrated technology in the Limpopo Basin	2.1 2.8			A Vilanculos, A Mhizha, E Kaseke
P28. Community-based water resource management institutions: perspectives from the Mzingwane catchment	3.1			C Mabiza, P van der Zaag, E Manzungu, R Ahlers
P29. Institutional Mapping, Water Sources and the Politics of Access in Ward 17, Gwanda – Mzingwane Catchment	3.1			P Sithole
P30. Potential water supply of a small reservoir and alluvial aquifer system in southern Zimbabwe	1.3.2	November 2007	WaterNet/WARFSA/GWP-SA Annual Symposium, Zambia	W de Hamer, D Love, R Owen, M Booij, A Hoekstra
P31. A rainfall runoff model for two small ungauged catchment using the water balance of a reservoir for calibration	2.1			W de Hamer, D Love, R Owen, M Booij, A Hoekstra
P32. Application of the SWAT model to assess the impact of land cover and land use on the hydrologic response in the Olifants Catchment	2.1			M Ncube, A Taigbenu
P33. Environmental Impact Assessment of Small Scale Resource Exploitation: the case of gold panning in Zhulube Catchment, Limpopo Basin, Zimbabwe	1.3.4			N Tunhuma, P Kelderman, D Love, S Uhlenbrook
P34. Stream quality in a small rural catchment, Limpopo Basin, Zimbabwe	1.3.4			N Tunhuma, P Kelderman, D Love, S Uhlenbrook
P35. Response of semi-arid meso-catchments to rainfall at daily and monthly time steps	2.1			D Love, S Uhlenbrook, P van der Zaag, S Twomlow
P36. The lower Mzingwane alluvial aquifer: managed releases, groundwater - surface water interactions and the challenge of salinity	1.3.2			D Love, R Owen, S Uhlenbrook, P van der Zaag, W Moyce
P37. Case studies of groundwater – surface water interactions and scale relationships in small alluvial aquifers	1.3.2			D Love, W de Hamer, R Owen, M Booij, S Uhlenbrook, A Hoekstra, P van der Zaag
P38. The nexus between INRM and IWRM	Synthesis			S Twomlow, D Love, S Walker
P39. A crop yield risk analysis and mitigation of small-holder farmers at quaternary catchment level- Case study of B72A in Olifants river basin	2.2			M Magombeyi, A Taigbenu
P40. Conservation Tillage for Soil Water Management in the Semi Arid Southern Zimbabwe	2.2			W Mupangwa, S Twomlow, S Walker

Title PAPERS	Activity Number	Date	Publisher	Authors
P41. The art of irrigation on salt-affected soils in the Chókwè Irrigation Scheme, Mozambique	2.2			P Munguambe
P42. The making of a catchment plan: experiences of the Mzingwane Catchment, Zimbabwe	3.3			C Mabiza, E Manzungu, P van der Zaag, R Ahlers
P43. Design of a water quality monitoring network for the Limpopo River Basin in Mozambique	1.3 2.1			MNG Chilundo, P Kelderman, JHO O'Keeffe
P44. Land use dynamics in a small watershed of the semi-arid Zimbabwe	1.3	December 2007	American Geophysical Union, Fall Meeting 2007, abstract #B41B-0460	J-M Kileshye-Onema, A van Rooyen
P45. Changing rainfall and discharge patterns in the northern Limpopo Basin, Zimbabwe	2.1	April 2008	EGU General Assembly 2008	D Love, S Uhlenbrook, S Twomlow, P van der Zaag
P46. Integrated water resource management (IWRM) research for mitigating drought and improving livelihoods within the Limpopo Basin	Synthesis	April 2008	SADC Land and Water Management Applied Research Programme Scientific Symposium "Institutional Structures and Best Practices in Land and Water Management in Southern Africa – Towards Meeting the Challenges of Climate Change", Zambia	B Ncube, D Love, B Gumbo
P47. Quantifying water productivity in rain-fed cropping systems in Limpopo Province, RSA	2.2	October 2008	WaterNet/WARFSA/GWP-SA Annual Symposium, South Africa	J Dimes, P du Toit
P48. Applications of GIS and Remote sensing techniques in gully identification and assessment in the Zhulube Meso-catchment, Zimbabwe: Implications to Water Resources Management	2.1			F Dondofema
P49. Evaluation of the effects of different water demand scenarios on downstream water availability: The case of Thuli river basin	2.8			S Khosa, D Love, M Mul
P50. Storing and sharing water in sand rivers: a water balance modelling approach	2.1	May 2009	EGU General Assembly 2009	D Love, P van der Zaag, S Uhlenbrook
P51. The Mushawe meso-alluvial aquifer, Limpopo Basin, Zimbabwe	1.3.2	October 2008	WaterNet/WARFSA/GWP-SA Annual Symposium, South Africa	D Love, R Owen, S Uhlenbrook, P van der Zaag
P52. Large-scale and small-scale infrastructure Water for Growth and Development	3	October 2008	Water for Growth and Development Session Sunday 17 August 2008 Stockholm Water Week	B van Koppen
P53. Impact of the Zhovhe Dam on the lower Mzingwane River channel	2.1	October 2008	WaterNet/WARFSA/GWP-SA Annual Symposium, South Africa	D Love, F Love, R Owen, S Uhlenbrook, P van der Zaag
P54. Politics and water: insights from Bulawayo	3.3			C Mabiza, E Manzungu, P van der Zaag, R Ahlers
P55. Simulation of farming systems in the Olifants river basin, South Africa	2.2			M Magombeyi, A Taigbenu, S Moradet, C Cheron
P56. Rainfall variability impacts on farmers' management strategies and crop yields	2.2			E Masvaya, W Mupangwa, S Twomlow
P57. Evaluation of the groundwater-potential of the Malala Alluvial Aquifer, Lower Mzingwane River, Zimbabwe	1.3.2			T Masvopo, D Love, H Makurira
P58. Improving the design of contour ridges for water conservation	1.6			A Mhizha, J Ndiritu
P59. Managing Salinity: an Adaptive Approach to Balance Salts and Nitrogen Leaching	2.2			P Munguambe, M Chilundo
P60. In situ rainwater harvesting for improved maize production under semi-arid conditions: Case study of Chókwè, Mozambique	2.2			P Munguambe, M Chilundo, C Tamele, R Brito
P61. Cowpea (*Vigna unguiculata* L) yield and soil water responses to minimum tillage and mulching	2.2			W Mupangwa, S Twomlow, S Walker
P62. Characterisation of rainfall pattern for improved rainfed crop production in semi-arid southern Zimbabwe	2.1			W Mupangwa, S Twomlow, S Walker

Title PAPERS	Activity Number	Date	Publisher	Authors
P63. Integrated water resource management (IWRM) research for mitigating drought and improving livelihoods within the Limpopo Basin	Synthesis			B Ncube, D Love, B Gumbo
P64. Precision Conservation Agriculture for Vulnerable Farmers in Low-potential Zones	2.2			S Twomlow, L Hove, W Mupangwa, P Masikati, N Mashingaidze
P65. Quantifying water productivity in rainfed cropping systems in Limpopo Province, RSA	2.2	November 2008	2nd International Forum on Water and Food, Ethiopia	J Dimes, P du Toit
P66. Modelling upstream-downstream interactions using a spreadsheet-based water balance model: two case studies from the Limpopo basin	2.8			D Love, S Khosa, M Mul, S Uhlenbrook, P van der Zaag
P67. Impact of the Zhovhe Dam on the lower Mzingwane River channel	2.1			D Love, F Love, R Owen, S Uhlenbrook, P van der Zaag
P68. Methodologies and case studies for investigating upstream-downstream interactions of water harvesting	2.1 2.2	September 2008	CGIAR Challenge Program on Water and Food Workshop on Increasing the Productivity and Sustainability of Rainfed Cropping Systems of Poor, Smallholder Farmers, Tamale, Ghana	Ncube, B., Magombeyi, M., Love, D., Mupangwa, W., Munguambe, P.
P69. Mainstreaming capacity building in food and water research in the Limpopo Basin: linking across scales and across disciplines	5	November 2008	2nd International Forum on Water and Food, Ethiopia	D Love, B Ncube, B Gumbo
P70. Management of Olifants Basins floods: application of geospatial stream flow model	2.1 2.8			A Vilanculos
P71. Applying the Gini coefficient to measure the distribution of water use and benefits of water use in South Africa's provinces	3	October 2008	Water for Growth and Development Session Sunday 17 August 2008 Stockholm Water Week	B van Koppen, J Cullis
P72. Upscaling rural livelihood interventions: towards a comprehensive spreadsheet-based water resources model	2.8	November 2009	WaterNet/WARFSA/GWP-SA Annual Symposium, Uganda	D Love, S Uhlenbrook, P Van der Zaag
P73. Understanding hydraulic property rights creation, re-creation and de-creation: A case study of Lorraine and Fumukwe villages, Limpopo basin	3.1	November 2008	2nd International Forum on Water and Food, Ethiopia	P Sithole, B van Koppen
P74. Precision conservation agriculture in Zimbabwe	2.2	September 2008	CGIAR Challenge Program on Water and Food Workshop on Increasing the Productivity and Sustainability of Rainfed Cropping Systems of Poor, Smallholder Farmers, Tamale, Ghana	S Twomlow, L Hove, W Mupangwa, P Masikati, N Mashingaidze
P75. Modelling crop productivity and soil water balance components of field crops in Limpopo	2.2			J Dimes, P du Toit
P76. Early evidence of improved soil quality with conservation farming under smallholder farming conditions in Zimbabwe	2.2	November 2007	ICID Conference, Johannesburg, South Africa	P Belder, S Twomlow, L Hove
P77. Storing and sharing water in sand rivers: a water balance modelling approach	2.1	August 2009	Stockholm Water Symposium, World Water Week, Stockholm, Sweden	D Love, P van der Zaag, S Uhlenbrook
P78. Climate change impact on crop productivity in the semi-arid tropics of Zimbabwe in the 21st century	2.2	September 2008	CGIAR Challenge Program on Water and Food Workshop on Increasing the Productivity and Sustainability of Rainfed Cropping Systems of Poor, Smallholder Farmers, Tamale, Ghana	J Dimes, P Cooper, KPC Rao
P79. Maize yields under supplementary irrigation in the Olifants river basin, South Africa	2.2			MS Magombeyi, T Rasiuba, AE Taigbenu
P80. Water availability deficit in rain fed farming for semi arid Mzingwane Catchment, Zimbabwe	2.1	November 2008	2nd International Forum on Water and Food, Ethiopia	A Mhizha, B Chibulu
P81. In-situ water harvesting technologies in semi-arid southern Zimbabwe: Part I. The role of biophysical factors on performance in Gwanda district	2.2	November 2009	WaterNet/WARFSA/GWP-SA Annual Symposium, Uganda	I Nyagumbo, M Munamati, E Chikwari, D Gumbo
P82. In-situ water harvesting technologies in semi-arid southern Zimbabwe: Part II. The role of socio-economic factors on performance in Gwanda district	3			M Munamati, I Nyagumbo, D Gumbo, E Chikwari
P83. To retain or to drain water in agricultural fields of semi-arid regions using contour	2.2			A Mhizha, J Ndiritu, I Nyagumbo

Title PAPERS	Activity Number	Date	Publisher	Authors
ridges				
P84. Rainwater management for drought mitigation in semi-arid smallholder cropping systems	2.2	August 2009	Stockholm Water Symposium, World Water Week, Stockholm, Sweden	W Mupangwa, S Twomlow, S Walker
P85. Simulation of farming systems in the Olifants river basin, South Africa	2.2			M Magombeyi, A Taigbenu, S Moradet, C Cheron
P86. The Green to Blue Water Continuum: an approach to improve agricultural systems' resilience to water scarcity	Synthesis			A Vidal, B Van Koppen, D Love, B Ncube, D Blake
P87. Problematising and conceptualising local participation in transboundary water resources management: The case of the Limpopo basin, Zimbabwe	3	November 2009	WaterNet/WARFSA/GWP-SA Annual Symposium, Uganda	J Fatch, E Manzungu, C Mabiza
P88. Dead level contour and infiltration pit influence on in-field soil water changes in semi-arid Zimbabwe	2.2			W Mupangwa, S Twomlow, S Walker
P89. Start, end and dry spells of the growing season in semi-arid southern Zimbabwe	2.1			W Mupangwa, S Twomlow, S Walker
P90. The best planting date for Maize (Zea mays L) based on dry days in Chokwe District	2.2			E Magaia, HA Mabilana

Title PhD PROPOSALS	Activity Number	Date	Publisher	Author
PP1. Land/water/livelihood strategies and water resources availability	2.1 2.8	September 2006	UNESCO-IHE	Love, D
PP2. Water and nitrogen management for risk mitigation in semi-arid cropping systems	2.2	2005	University of the Free State	Mupangwa, W
PP3. Nitrogen and salt leaching management on irrigated salt-affected soils in Chókwè irrigation scheme, Mozambique	2.2	March 2007	University of Pretoria	Munguambe, P
PP4. Innovative coupling of Hydrological modelling for IWRM: Linking catchment functioning with socio-economic conditions in the Olifants	2.8	2006	University of the Witwatersrand	Magombeyi, M
PP5. Linkages between the environment, innovations and institutions and their impacts on livelihoods: Cases from the Mzingwane Catchment	3	June 2007	UNESCO-IHE	Mabiza, C
PP6. A comparative study of rural water governance in the Limpopo Basin	3	2007	University of the Western Cape	Sithole, P

Title PhD THESES	Activity Number	Date	Publisher	Author
PhD2. Water and nitrogen management for risk mitigation in semi-arid cropping systems	2.2	2009	University of the Free State	Mupangwa, W

Title MSc DISSERTATIONS	Activity Number	Date	Publisher	Author
D01. 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	2.1	September 2004	University of Zimbabwe, Department of Civil Engineering, M.Sc. Water Resources Engineering and Management	Kileshye Onema, J.-M.
D02. An on-farm evaluation of the effects of low cost drip irrigation on water and crop productivity, compared to conventional surface irrigation system	2.2	September 2004	University of Zimbabwe, Department of Civil Engineering, M.Sc. Water Resources Engineering and Management	Maisiri, N.
D03. Water productivity and yield gap analysis of water harvesting systems in the semi-arid Mzingwane catchment, Zimbabwe	1.6 2.2	September 2004	University of Zimbabwe, Department of Civil Engineering, M.Sc. Water Resources Engineering and Management	Mwenge Kahinda, J.-M.
D04. 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	1.5	June 2005	University of Zimbabwe, Department of Civil Engineering, M.Sc. Integrated Water Resources Management	Murata, R.
D05. Impact And Adaptation Of Climate Variability On Water Supply Reservoir yields	1.3 2.1	August 2005	University of Zimbabwe, Department of Civil	Moyo, B.

Title **MSc DISSERTATIONS**	**Activity Number**	**Date**	**Publisher**	**Author**
For The City Of Bulawayo. (Mzingwane Catchment)			Engineering, M.Sc. Water Resources Engineering and Management	
D06. Impact and sustainability of low cost drip kits, in the semi-arid lower Mzingwane subcatchment, Limpopo Basin, Zimbabwe	2.2	August 2005	University of Zimbabwe, Department of Civil Engineering, M.Sc. Water Resources Engineering and Management	Moyo, R.
D07. Cultivating livelihoods: an assessment of water allocation and management practices in small-scale irrigation schemes -case studies in Mzingwane Catchment	1.6 3.1	August 2005	University of Zimbabwe, Department of Civil Engineering, M.Sc. Integrated Water Resources Management	Munamati, M.
D08. A survey of current on-farm agricultural water management practices in Olifants Catchment – a diagnostic of quaternary catchment B72A	2.2	August 2005	University of Zimbabwe, Department of Civil Engineering, M.Sc. Water Resources Engineering and Management	Ntsheme, O.
D09. Estimating the influence of on-farm Conservation Practices on the Water Balance, Case of the Mzinyathini Catchment in Zimbabwe	2.2	September 2005	Delft University of Technology, Faculty of Civil Engineering, M.Sc.	Woltering, L.
D10. Involvement of stakeholders in the water quality monitoring and surveillance system: the case of Mzingwane Catchment	3	February 2006	University of Zimbabwe, Department of Civil Engineering, MSc dissertation	Nare, L.
D11. The nexus between formal organizations and informal networks from a gender perspective: a case study from South Africa	3	February 2006	University of Guelph Faculty of Graduate Studies, MSc dissertation	Panesah, J.
D12. On farm evaluation of the influence of different conservation agriculture practices on infiltration in rainfed agriculture, compared to conventional farming	2.1 2.2	June 2006	University of Zimbabwe, Department of Civil Engineering, M.Sc. Water Resources Engineering and Management	Dhliwayo, C.
D13. Assessment of the soil water management practices for increased seasonal rain water productivity to mitigate against climatic risks	2.2	June 2006	University of Zimbabwe, Department of Civil Engineering, M.Sc. Water Resources Engineering and Management	Moyo, L.
D14. Effect of soil degradation from grazing pressure on rangeland soil hydrology	2.1	June 2006	University of Zimbabwe, Department of Civil Engineering, M.Sc. Integrated Water Resources Management	Ngwenya, P.T.
D15. Towards improving flood forecasting and early warning systems through integrated technology in the Limpopo basin	1.3 2.8	June 2006	University of Zimbabwe, Department of Civil Engineering, M.Sc. Integrated Water Resources Management	Vilanculos, A.
D16. Environmental impacts of small-scale natural resource exploitation, implications on water resources and rural livelihoods	1.3	May 2007	UNESCO IHE, Department of Environmental Resources	Tunhuma, N.
D17. A seat at the table: which table and at what costs? participation and institutional reform in the water sector in Zimbabwe: case of the Mzingwane Catchment	3	May 2007	UNESCO IHE, Department of Management and Institutions	Svubure, O.
D18. Potential Water Supply of the Mnyabezi Catchment: A case study of a small reservoir and alluvial aquifer system in the semi-arid region of southern Zimbabwe	1.3	July 2007	University of Twente, Department of Water Engineering and Management	De Hamer, W
D19. Evaluating the effect of different water demand scenarios on downstream water availability in Thuli river basin, Zimbabwe	2.8	July 2007	University of Zimbabwe, Department of Civil Engineering, M.Sc. Integrated Water Resources Management	Khosa, S
D20. Effect of rainfall variability on crop yield under semi-arid conditions at sub-catchment level	2.2	July 2007	University of Zimbabwe, Department of Civil Engineering, M.Sc. Integrated Water Resources Management	Chibulu, B
D21. Relationships between gully characteristics and environmental factors in the Zhulube Meso-Catchment: mplications for water resources management	2.2	July 2007	University of Zimbabwe, Department of Civil Engineering, M.Sc. Integrated Water Resources Management	Dondofema, F
D22. The impact of land cover and land use on the hydrologic response of the Olifants	1.3	August 2007	University of the Witwatersrand School of Civil and Environmental Engineering	Ncube, M
D23. Water budget, water use efficiency in	2.1	August	University of the	Rasiuba, T

Title **MSc DISSERTATIONS**	**Activity Number**	**Date**	**Publisher**	**Author**
agriculture in Olifants Catchment		2007	Witwatersrand School of Civil and Environmental Engineering	
D24. Application of the Water Evaluation And Planning (WEAP) model to assess future water demands and resources in the Olifants Catchment, South Africa	1.3	May 2007	Department of Civil Engineering, Colorado State University	Arranz, R
D25. Securing water through land; field findings on water reform and water re-allocation in South Africa: Trichardtsdal, Ofcolaco and Leydsdorp	3.1	May 2007	Wageningen University	Liebrandt, J.
D26. Design of a water quality monitoring network for the Limpopo River Basin in Mozambique	1.3 2.1	April 2007	UNESCO-IHE	Chilundo, M.N.G.
D27. Smallholder participation in water resources management after the land and water sector reforms in Zimbabwe: a case study of the Umzingwane catchment	3.1		University of the Western Cape, Programme on Land and Agrarian Studies	Mandivengerei, S.
D28. Evaluation of the groundwater potential of the Malala alluvial aquifer, lower Mzingwane river, Zimbabwe	2.2	July 2008	University of Zimbabwe, Department of Civil Engineering, M.Sc. Integrated Water Resources Management	Masvopo, T.H.
D29. Estimation of small reservoir storage capacities in Limpopo Basin using geographical information systems (GIS) and remotely sensed surface areas: a case of Mzingwane Catchment.	1.3	August 2005	University of Zimbabwe, Department of Civil Engineering, M.Sc. Integrated Water Resources Management	Saunyama, T.
D30. Modeling the response of small multi-purpose reservoirs to hydrology for improved rural livelihoods in the Mzingwane catchment: Limpopo Basin	2.2	2007	University of Zimbabwe, Department of Civil Engineering, M.Sc. Integrated Water Resources Management	Rukuni, S.
D31. Performance assessment of water distribution in large scale irrigation: Case study of Chokwe Irrigation System in Mozambique	2.1	April 2009	UNESCO-IHE	Julaia, C. De S.
D32. Rainwater harvesting: management strategies in semi-arid areas	2.1	July 2009	University of Pretoria	Ibraimo, N.A.
D33. Low-cost drip irrigation	2.2	July 2005	Luleå University of Technology	Andersson, L.
D34. Local participation in transboundary water resources management: the case of Limpopo Basin, Zimbabwe	3	July 2009	University of Zimbabwe, Department of Civil Engineering, M.Sc. Integrated Water Resources Management	Fatch J.J.

Title **MSc DISSERTATIONS** *(funded through linked CPW&F projects)*	**Activity Number**	**Date**	**Publisher**	**Author**
LD01. An assessment of plankton diversity as a water quality indicator in small man-made reservoirs in the Mzingwane Catchment, Limpopo Basin, Zimbabwe.	1.3	August 2005	University of Zimbabwe, Department of Civil Engineering, M.Sc. Integrated Water Resources Management	Busane Basima, L.
LD02. Analytic Description of Indigenous water resources management practice and its impact on rural livelihoods in the Limpopo Basin in Botswana.	3.1	August 2005	University of Zimbabwe, Department of Civil Engineering, M.Sc. Integrated Water Resources Management	Mpho, T.
LD04. An assessment of traditional water management practices and their implications for improved water governance in the Limpopo Basin: c case of the Sibasa Dam in Mzingwane Catchment, Zimbabwe	3.1	August 2005	University of Zimbabwe, Department of Civil Engineering, M.Sc. Integrated Water Resources Management	Twikirize, D.
LD05. Quantifying total water productivity for multiple-use small reservoirs in Mzingwane Catchment, Zimbabwe	1.6.3	July 2007	University of Zimbabwe, Department of Civil Engineering, M.Sc. Integrated Water Resources Management	Mamba, G
LD06. Institutional framework, water pricing structures and costs of domestic water services in rural poor areas of the Olifants River Basin, South Africa	3.1	October 2005	Agrocampus Rennes	LeFebrve, M.

Title **BSc DISSERTATIONS**	Activity Number	Date	Publisher	Author
B01. Supplementary Irrigation Water Volume Determination for Rainfed Agriculture in the Chókwè Region (summary)	2.2	August 2005	Eduardo Mondlane University, Department of Rural Engineering, BSc Thesis	Mudaca, J.D.
B02. Water management strategies under sufficiency and insufficiency water conditions for tomato and round cabbage production in the Chókwè Irrigation Scheme (summary)	1.6 2.2	August 2005	Eduardo Mondlane University, Department of Rural Engineering, BSc Thesis	Ibraimo, N.A.
B03. Analysis of the soil water storage capacity on maize production in rainfed agriculture in the Chókwè District (summary)	2.2	October 2005	Eduardo Mondlane University, Department of Rural Engineering, BSc Thesis	Almeida, E.
B04. Assessment of the furrow irrigation efficiency in an area of 16 ha in the Distribuidor 9 of the Chókwè Irrigation Scheme (summary)	2.2	August 2006	Eduardo Mondlane University, Department of Rural Engineering, BSc Thesis	Gonçalves, L.
B05. An Inventory of the rainwater harvesting techniques for agricultural production in the Chókwè District (summary)	2.2	August 2006	Eduardo Mondlane University, Department of Rural Engineering, BSc Thesis	Mamade, A.
B06. Assessment of the furrow irrigation efficiency in an area of 16 ha area under tomato production in the Distribuidor 9 of the Chókwè Irrigation Scheme (summary)	2.2	August 2006	Eduardo Mondlane University, Department of Rural Engineering, BSc Thesis	Massolonga, A.
B07. Multiplicative effect of rainwater for maize production in rainfed regime in the Chókwè District (summary)	2.2	August 2006	Eduardo Mondlane University, Department of Rural Engineering, BSc Thesis	Niquice, C.
B08. Assessment of furrow irrigation efficiency in 32 ha of tomato in the Distributor 9 of the Chókwè Irrigation Scheme (summary)	2.2	August 2006	Eduardo Mondlane University, Department of Rural Engineering, BSc Thesis	Pinho, M.
B09. Study of sowing dates to reduce the risk of maize crop failure in rainfed agriculture in the Chókwè District (summary)	2.2	August 2007	Eduardo Mondlane University, Department of Rural Engineering, BSc Thesis	Cambaza, C.
B10. Design of a drip irrigation system for an area of 50 Ha in the Chókwè District (summary)	2.2	August 2007	Eduardo Mondlane University, Department of Rural Engineering, BSc Thesis	Tamele, C.
B11. Quantification of income from groundnut production, Chókwè District	2.2	October 2006	Eduardo Mondlane University, Department of Rural Engineering, BSc Thesis	Jamine, E.H.
B12. Soil water conservation strategies for maize production	2.2	October 2006	Eduardo Mondlane University, Department of Rural Engineering, BSc Thesis	Camba, M.O.M.
B13. Management of Irrigation Water and implications for soil salinisation in Chókwè Irrigation Scheme	2.2	June 2009	Eduardo Mondlane University, Department of Rural Engineering, BSc Thesis	Tomé, W.

Title **PROJECT ACTIVITY REPORTS**	Activity Number	Date	Publisher	Authors
AR01. Report on the project inception Workshop, Bilene, Moçambique, 14-18.03.2004	6.2	September 2004	WaterNet	Love, D.
AR02. Report on the Mzingwane Pilot Stakeholder and Inception Workshop, 6-7.10.2004	6.2	December 2004	ICRISAT	ICRISAT
AR03. Report on the First Stakeholders Workshop for the Challenge Program Water and Food in Sekororo area (B72A), Olifants basin, South Africa, 21-22.10.2004	6.2	December 2004	IWMI	Rollin, D.
AR04. Limpopo Basin (Projects CP17 and CP1): Record of the First Mozambique Meeting Chókwè, 18 - 19 August 2005	6.2	September 2005	Eduardo Mondlane University	Eduardo Mondlane University
AR06. Report on the Mzingwane Catchment Scientific Workshop	6.2	August 2006	ICRISAT	ICRISAT
AR08. Report on the Olifants Catchment Scientific Workshop	6.2	August 2006	IWMI	IWMI
AR09. Record of the First CP17 Scientific Meeting Chókwè	6.2	June 2007	Eduardo Mondlane University	Eduardo Mondlane University
AR12. Report on the Socio-Economic Survey, carried out in the Mzingwane Catchment	1.5	February 2008	CASS	CASS
AR13. Report on the Limpopo Basin Population Database	1.2	April 2008	CASS	CASS
AR14. Socio-economic conditions and agricultural water management practices of	1.5	May 2008	IWMI	E Mapedza, S Moradet, C Cheron, M

Title PROJECT ACTIVITY REPORTS	Activity Number	Date	Publisher	Authors
smallholders in Quaternary Catchment B72A, Olifants River Basin, South Africa				Magombeyi
AR15. Baseline Report: Olifants River Basin in South Africa	1.2	September 2008	IWMI	IWMI
AR17. Report on the 2006 Project Workshop	6.2.5	September 2006	WaterNet	Love, D.
AR18. Report on the 2007 Project Workshop	6.2.5	October 2007	WaterNet	Love, D.
AR19. Report on the 2008 Project Workshop	6.2.5	September 2008	WaterNet	Love, D.
AR20. Relatório final treinamento em técnicas de captação e conservação de água das chuvas rede de extensão de chókwè e guijá Chókwè, 26 a 28 de Maio de 2009 (English summary)	2.5	May 2009	Eduardo Mondlane University	P. Munguambe, M. Chilundo, C. Julaia
AR21. Relatório da 2a Reunião Científica CP17, Chókwè, Moçambique	6.2	June 2009	Eduardo Mondlane University	R Brito, P Munguambe, M Chilundo, F Massingue, E Magaia, C Tamele, C Julaia, N Ibraimo
AR22. Report on the Project Final Workshop	6.2.5	June 2009	WaterNet	D Love et al.
AR23. Mzingwane Catchment, Zimbabwe, Final Stakeholder Meeting Report	6.2	August 2009	ICRISAT	J Dimes
AR24. Baseline Study of the Hydrogeology of the Limpopo Basin: Country studies from Mozambique, South Africa and Zimbabwe [data]	1.3.2	July 2009	Mineral Resources Centre	R Owen, N Madari
AR25. AGRITEX Apprentice Trials Report	2.7	August 2009	ICRISAT	J Dimes
AR26. Institutional Arrangement for Water Management in the Limpopo River Basin: The case of Mozambique	3	September 2009	Universidade Eduardo Mondlane	E Magaia

Title PROJECT INTERIM REPORTS	Activity Number	Date	Publisher	Authors
IR01. Field visit to Mzingwane Catchment, 12-16 December 2004	6.1	December 2004	WaterNet	Love, D.
IR02. Minutes of the Project Executive Committee Meeting, 09.10.2005	6.1	September 2005	WaterNet	WaterNet
IR03. Record of the Zimbabwe Research Progress and Integration Meeting, 20.02.2006	6.1	February 2006	WaterNet	WaterNet
IR04. Record of the South Africa Research Progress and Integration Meeting, 05.12.2005	6.1	December 2005	IWMI	IWMI
IR05. Study of drip irrigation, Sekororo, South Africa	2.2	January 2006	IWMI	L. Benohoud & M. Jolivet
IR06. Agrarian System in Sekororo, Limpopo Province	1.6	August 2005	IWMI	D. Ramay & M. Beullier
IR07. Water chemistry field visits	1.3	April 2006	UZ MRC	D Love, W Moyce, S Ravengai
IR08. Alluvial aquifers in the Mzingwane Catchment: A preliminary report	1.3	August 2006	UNESCO-IHE PhD	D Love
IR09. Field Photographic Report: Small dams in the Mzingwane Catchment	1.3	May 2006	UNESCO-IHE PhD	D Love
IR10. Preliminary report on hydrological gauging stations in the Mzingwane Catchment	1.3	July 2006	UNESCO-IHE PhD	D Love
IR11. Schematisation of the Thuli Basin	2.8	July 2006	UNESCO-IHE PhD	D Love
IR12. Schematisation of the Mwenezi Basin	2.8	August 2006	UNESCO-IHE PhD	D Love
IR13. Metadata & Database Development: Roles and Responsibilities of Scientists	1.6.4	August 2006	ICRISAT	A van Rooyen, X Ncube
IR17. Study of agrarian system and rainwater harvesting tanks to improve small scale farming, Sekororo Area, Limpopo Province - South Africa	2.2	April 2007	IWMI	D Ramay
IR18. Geophysical Investigations of Small Alluvial Aquifers in the Manama Area, northern Limpopo Basin, Zimbabwe	2.1	August 2007	UNESCO-IHE	D Love
IR19. Geophysical Investigations in the Mtetengwe Area, Lower Mzingwane Alluvial Aquifer, northern Limpopo Basin, Zimbabwe	2.1	August 2007	UNESCO-IHE	D Love
IR20. Report on Trials in Chókwè, 2006-7 Season: Evaluation of maize and cowpea's yield when produced on cultivation pits in	2.2	August 2007	Eduardo Mondlane University	C Julaia

Title **PROJECT INTERIM REPORTS**	Activity Number	Date	Publisher	Authors
pure/mixed cultivation				
IR21. Drought characterization at Limpopo Basin, Mozambique	1.3	August 2007	Eduardo Mondlane University	R Brito, C Julaia
IR23. Potential of Agricultural Wetlands	1.6	December 2006	IIAM	M.R. Marques, M. Vilanculos, J. Mafalacusser
IR24. Production Systems in Wetlands	2.2	December 2006	IIAM	M.R. Marques, M. Vilanculos, J. Mafalacusser
IR25. Rainwater harvesting technologies for small scale rainfed agriculture in arid and semi-arid areas	1.6	February 2007	Eduardo Mondlane University	N Ibraimo, P Munguambe
IR26. Soil physics characterization of agricultural wetlands	2.2	December 2006	IIAM	M.R. Marques, M. Vilanculos, J. Mafalacusser
IR27. Review of Water Harvesting Techniques	1.6	October 2006	Eduardo Mondlane University	C Niquice
IR28. DRAFT Institutional arrangements in the promotion of conservational agriculture: a case study of the Mzingwane Catchment Area	3.1	May 2008	UNESCO-IHE	C Mabiza, P van der Zaag, E Manzungu, R Ahlers
IR29. Preliminary Water Resources Assessment for the Limpopo River Basin	1.3	August 2009	UZ DCE	A Mhizha, M Musariri, E Madamombe, Tererai
IR30. A report of the Mzingwane Catchment Council Stakeholder Participation Planning Workshop	3	September 2008	UZ CASS	UZ CASS
IR31. Workshop report on local participation in water resource management in the Limpopo Basin: towards a new institutional model – Ward 14 Guyu, Gwanda	3	March 2009	UZ CASS	E Manzungu, V Dzingirai, R Mashava, J Fatch, B Chakabuda, C Mabiza
IR32. Workshop report on local participation in water resource management in the Limpopo Basin: towards a new institutional model – Ward 6 Hwabayi, Gwanda	3	March 2009	UZ CASS	E Manzungu, V Dzingirai, R Mashava, J Fatch, B Chakabuda, C Mabiza
IR33. Workshop report on local participation in water resource management in the Limpopo Basin: towards a new institutional model – Ward 8 Makwe, Gwanda	3	March 2009	UZ CASS	E Manzungu, V Dzingirai, R Mashava, J Fatch, B Chakabuda, C Mabiza
IR34. Rainfall variability impacts on farmers' management strategies	2.2	July 2009	ICRISAT	EN Masvaya, W Mupangwa, SJ Twomlow
IR35. Water and nitrogen management on salt-affected soils in the Chókwè Irrigation Scheme, Mozambique	2.2	June 2009	Eduardo Mondlane University	Munguambe, P.
IR36. Challenge Program on Water and Food Project No 17 (CPWF PN17) Project Final Workshop, 15 – 18 June 2009, University of the Witwatersrand, Johannesburg	Synthesis	June 2009	WaterNet	Love, D.
IR37. Gender, water and preferred institutional options for water resources management	3	July 2009	UZ CASS	R Mashava, V Dzingirai
IR38. Land Use and Land Cover Assessment in Insiza: Remote Sensing Approach	1.3	August 2009	ICRISAT	Van Rooyen, A., Chirima, A.
IR39. Baseline Study of the water chemistry of the Limpopo Basin: Country studies from Botswana, Mozambique, South Africa and Zimbabwe [data]	1.3.4	June 2009	Mineral Resources Centre	M Meck, D Love, R Owen, S Ravengai, W Moyce
IR41. Possible deviation of hydrological boundaries in the Mzingwane Catchment to follow administrative boundaries	3	June 2009	WaterNet	D Love
IR42. South Africa water reform synopsis	3	July 2009	IWMI	B van Koppen

Title **TRAINING MATERIALS**	Activity Number	Date	Publisher	Authors
TM01. Integrated Groundwater and Surface Water Modelling A hands-on introduction to MIKE SHE	5.3	December 2004	Project partners	Jacobsen, T.
TM02. Micro-dosing manual for extension	5.1	July 2008	ICRISAT	Hove, L et al.
TM03. Supporting Conservation Agriculture Implementation by Smallholder Farmers In Semi-Arid Areas of Zimbabwe: A manual for field officers	5.1	July 2008	ICRISAT	Twomlow, Hove, Maphosa, Mashingaidze, Moyo, Mupangwa
TM04. Conservation Agriculture Toolbox for	5.1	August	ICRISAT	Conservation

Title **TRAINING MATERIALS**	Activity Number	Date	Publisher	Authors
Zimbabwe		2008		Agriculture Task Force for Zimbabwe

Title **SURVEY MATERIALS**	Activity Number	Date	Publisher	Authors
SV01. CPWF Limpopo Basin Baseline Survey: Socio-economic and water management survey instrument	1.2 1.5	July 2005	Project partners	

Title **PROJECT INFORMATION MATERIALS**	Activity Number	Date	Publisher	Authors
Project Progress Reports:				
PR01. 3 monthly report	Synthesis	December 2004	WaterNet	WaterNet
PR02. 6 monthly report	Synthesis	March 2005	WaterNet	WaterNet
PR03. 3 monthly report	Synthesis	June 2005	WaterNet	WaterNet
PR04. Annual report No 1	Synthesis	September 2005	WaterNet	WaterNet
PR05. 3 monthly report	Synthesis	December 2005	WaterNet	WaterNet
PR06. 6 monthly report	Synthesis	March 2006	WaterNet	WaterNet
PR07. 3 monthly report	Synthesis	June 2006	WaterNet	WaterNet
PR08. Annual report No 2	Synthesis	September 2006	WaterNet	WaterNet
PR09. 6 monthly report	Synthesis	March 2007	WaterNet	WaterNet
PR10. Annual report No 3	Synthesis	September 2007	WaterNet	WaterNet
PR11. 6 month report	Synthesis	March 2008	WaterNet	WaterNet
PR12. Annual report No 4	Synthesis	September 2008	WaterNet	WaterNet
PR13. 6 month report	Synthesis	March 2009	WaterNet	WaterNet
Brochures:				
BR01. The challenge of integrated water resource management for improved rural livelihoods in the Limpopo Basin – WaterNet's first network research program	All	September 2004	WaterNet	Love, D. & Jonker, L.
BR02. WaterNet and the Challenge Program on Water and Food	All	July 2008	WaterNet	WaterNet
Powerpoint Presentations are included in the activity reports of workshops				

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Note: the above list excludes Masters Fellows, who are listed in Appendix 4.

F: APPENDICES

Appendix 1 Abstracts of Journal Articles

On farm evaluation of the effect of low cost drip irrigation on water and crop productivity compared to conventional surface irrigation system

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Abstract

This on-farm research study was carried out at Zholube irrigation scheme in a semi-arid agro tropical climate of Zimbabwe to determine how low cost drip irrigation technologies compare with conventional surface irrigation systems in terms of water and crop productivity. A total of nine farmers who were practicing surface irrigation were chosen to participate in the study. The vegetable English giant rape (Brassica napus) was grown under the two irrigation systems with three fertilizer treatments in each system: ordinary granular fertilizer, liquid fertilizer (fertigation) and the last treatment with no fertilizer. These trials were replicated three times in a randomized block design. Biometric parameters of leaf area index (LAI) and fresh weight of the produce, water use efficiency (WUE) were used to compare the performance of the two irrigation systems. A water balance of the inflows and outflows was kept for analysis of WUE. The economic profitability and the operation, maintenance and management requirements of the different systems were also evaluated. There was no significant difference in vegetable yield between the irrigation systems at 8.5 ton/ha for drip compared to 7.8 ton/ha in surface irrigation. There were significant increases in yields due to use of fertilizers. Drip irrigation used about 35% of the water used by the surface irrigation systems thus giving much higher water use efficiencies. The leaf area indices were comparable in both systems with the same fertilizer treatment ranging between 0.05 for surface without fertilizer to 6.8 for low cost drip with fertigation. Low cost drip systems did not reflect any labour saving especially when manually lifting the water into the drum compared to the use of siphons in surface irrigation systems. The gross margin level for surface irrigation was lower than for low cost drip irrigation but the gross margin to total variable cost ratio was higher in surface irrigation systems, which meant that surface irrigation systems gave higher returns per variable costs incurred. It was concluded that low cost drip systems achieved water saving of more than 50% compared to surface irrigation systems and that it was not the type of irrigation system that influenced the yield of vegetables significantly but instead it is the type of fertilizer application method that contribute to the increase in the yield of vegetables. It was recommended that low cost technologies should be used in conjunction with good water and nutrient management if higher water and crop productivity are to be realized than surface irrigation systems.

Keywords: Low cost drip; Water productivity; Brassica napus; Fertigation; Water use efficiency

Impact and sustainability of low-head drip irrigation kits, in the semi-arid Gwanda and Beitbridge Districts, Mzingwane Catchment, Limpopo Basin, Zimbabwe

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Abstract

Resource-poor smallholder farmers in the semi-arid Gwanda and Beitbridge districts face food insecurity on an annual basis due to a combination of poor and erratic rainfall (average 500 mm/a and 345 mm/a, respectively, for the period 1970–2003) and technologies inappropriate to their resource status. This impact on both household livelihoods and food security. In an attempt to improve food security in the catchment a number of drip kit distribution programmes have been initiated since 2003 as part of an on-going global initiative aimed at 2 million poor households per year. A number of recent studies have assessed the technical performance of the drip kits in-lab and in-field.

In early 2005 a study was undertaken to assess the impacts and sustainability of the drip kit programme. Representatives of the NGOs, local government, traditional leadership and agricultural extension officers were interviewed. Focus group discussions with beneficiaries and other villagers were held at village level. A survey of 114 households was then conducted in two districts, using a questionnaire developed from the output of the interviews and focus group discussions.

The results from the study showed that the NGOs did not specifically target the distribution of the drip kits to poor members of the community (defined for the purpose of the study as those not owning cattle). Poor households made up 54% of the beneficiaries. This poor targeting of vulnerable households could have been a result of conditions set by some implementing NGOs that beneficiaries must have an assured water source. On the other hand, only 2% of the beneficiaries had used the kit to produce the expected 5 harvests over the 2 years, owing to problems related to water shortage, access to water and also pests and diseases. 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 production with the drip kit occurred during the wet season. This suggests that most households use the drip kits as supplementary irrigation. Conflicts between beneficiaries and water point committees or other water users developed in some areas especially during the dry season.

The main finding from this study was that 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 the programme should involve a broad range of stakeholders. A first step in any such program, especially in water scarce areas such as Gwanda and Beitbridge, is a detailed analysis of the existing water resources to assess availability and potential conflicts, prior to distribution of drip kits.

Keywords: Access to water; Drip kits; Intervention targeting; Sustainable intervention; Water availability

Alluvial aquifers in the Mzingwane catchment: Their distribution,properties, current usage and potential expansion

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Abstract

The Mzingwane River is a sand filled channel, with extensive alluvial aquifers distributed along its banks and bed in the lower catchment. LandSat TM imagery was used to identify alluvial deposits for potential groundwater resources for irrigation development. On the false colour composite band 3, band 4 and band 5 (FCC 345) the alluvial deposits stand out as white and dense actively growing vegetation stands out as green making it possible to mark out the lateral extent of the saturated alluvial plain deposits using the riverine fringe and vegetation . The alluvial aquifers form ribbon shaped aquifers extending along the channel and reaching over 20 km in length in some localities and are enhanced at lithological boundaries. These alluvial aquifers extend laterally outside the active channel, and individual alluvial aquifers have been measured with area ranging from 45 ha to 723 ha in the channels and 75 ha to 2196 ha on the plains. The alluvial aquifers are more pronounced in the Lower Mzingwane, where the slopes are gentler and allow for more sediment accumulation. Estimated water resources potential ranges between 175,000 m3 and 5,430,000 m3 in the channels and between 80,000 m3 and 6,920,000 m3 in the plains. Such a water resource potential can support irrigation ranging from 18 ha to 543 ha for channels alluvial aquifers and 8 ha to 692 ha for plain alluvial aquifers. Currently, some of these aquifers are being used to provide water for domestic use, livestock watering and dip tanks, commercial irrigation and market gardening. The water quality of the aquifers in general is fairly good due to regular recharge and flushing out of the aquifers by annual river flows and floodwater. Water salinity was found to increase significantly in the end of the dry season, and this effect was more pronounced in water abstracted from wells on the alluvial plains. During drought years, recharge is expected to be less and if the drought is extended water levels in the aquifers may drop substantially, increasing salinity problems.

Keywords: Alluvial aquifer; Irrigated agriculture; Remote sensing; Limpopo basin

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Implementing the millennium development food security goals – Challenges of the southern African context

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Abstract

The Millennium Development Goals' target to halve the proportion of people who suffer from hunger is extremely important in southern Africa, where food security has become increasingly problematic over the last 20 years. One ''quick-win'' proposal is replenishment of soil nutrients for smallholder farmers, through free or subsidised chemical fertilisers. Other proposals include appropriate irrigation technology, improved inputs and interventions targeted at women.

Analysis of over 10 years of agro-hydrological and agro-economic studies from southern African show that a different approach is required to interventions proposed. There are sustainability problems with free chemical fertiliser due to transport costs and ancillary costs. Furthermore, recent studies in Zimbabwe and Mozambique show that significant increases in yield can only be obtained when soil fertility management is combined with good crop husbandry, e.g. timely planting and weeding. Ongoing replenishment of fertility would be dependent on a continued free or subsidised fertiliser supply, and transport system. Increasing access to irrigation will help, but is not the only solution and cannot reach even a majority of farmers. It has been determined that short dryspells are often the major cause of low yields in sub-Saharan Africa. Soil–water conservation approaches, e.g. winter weeding and conservation tillage, can reduce risk and increase yield.

The following specific recommendations are made for urgent interventions to contribute sustainably to food security in southern Africa: (i) To increases access to fertiliser, consider development of strong input markets at end-user level. (ii) Intensification of technology transfer, focusing on capacity building for transfer of existing technologies and much closer collaboration between state and NGO sectors, agronomists and water engineers. (iii) Increasing the uptake of soil–water conservation methods, including conservation tillage and weeding, and supplementary irrigation to minimise adverse effects of dryspells, through investments in farmer training. (iv) Linking crop development strategies to livestock development practices and strategies. (v) Developing non-agro-based livelihood strategies in marginal lands.

Keywords: Food security; Millennium development goals; Soil fertility; Soil–water conservation

Soil–water conservation and rainwater harvesting strategies in the semi-arid Mzingwane Catchment, Limpopo Basin, Zimbabwe

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Abstract

Various soil water management practices have been developed and promoted for the semi arid areas of Zimbabwe. These include a variety of infield crop management practices that range from primary and secondary tillage approaches for crop establishment and weed management through to land forming practices such as tied ridges and land fallowing. Tillage methods evaluated in this study include deep winter ploughing, no till tied ridges, modified tied ridges, clean and mulch ripping, and planting basins. Data collected from the various trials since the 1990s show that mulch ripping and other minimum tillage practices consistently increased soil water content and crop yields compared to traditional spring ploughing. Trial results also showed higher soil loss from conventionally ploughed plots compared to plots under different minimum tillage practices.

Keywords: Dead level contours; Infiltration pits; Planting basins; Soil–water conservation

Involvement of stakeholders in the water quality monitoring and surveillance system: The case of Mzingwane Catchment, Zimbabwe

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Abstract

Stakeholder participation is viewed as critical in the current water sector reforms taking place in the Southern African region. In Zimbabwe, policies and legislation encourage stakeholder participation. A study was undertaken to determine the extent of stakeholder participation in water quality monitoring and surveillance at the operational level, and also to assess indigenous knowledge and practices in water quality monitoring. Two hundred and forty one questionnaires were administered in Mzingwane Catchment, the portion of the Limpopo Basin that falls within Zimbabwe. The focus was on small users in rural communities, whose experiences were captured using a questionnaire and focus group discussions. Extension workers, farmers and NGOs and relevant sector government ministries and departments were also interviewed and a number of workshops held.

Results indicate that there is very limited stakeholder participation despite the presence of adequate supportive structures and organisations. For the Zimbabwe National Water Authority (ZINWA), stakeholders are the paying permit holders to whom feedback is given following analysis of samples. However, the Ministry of Health and Child Welfare generally only releases information to rural communities when it is deemed necessary for their welfare. There are no guidelines on how a dissatisfied member of the public can raise a complaint – although some stakeholders carry such complaints to Catchment Council meetings. With regard to water quality, the study revealed widespread use of indigenous knowledge and practice by communities. Such knowledge is based on smell, taste, colour and odour perceptions. Residents are generally more concerned about the physical parameters than the bacteriological quality of water. They are aware of what causes water pollution and the effects of pollution on human health, crops, animals and aquatic ecology. They have ways of preventing pollution and appropriate interventions to take when a source of water is polluted, such as boiling water for human consumption, laundry and bathing, or abandoning a water source in extreme cases. Stakeholder participation and ownership of resources needs to be encouraged through participatory planning, and integration between the three government departments (water, environment and health). Local knowledge systems could be integrated into the formal water quality monitoring systems, in order to complement the conventional monitoring networks.

Keywords: Catchment management; Participatory management; Stakeholder participation; Water quality monitoring

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Effects of selected dams on river flows of Insiza River, Zimbabwe

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Abstract

This paper examines effects of three dams on flow characteristics of Insiza River on which they are located. The storage capacities of these dams vary from an equivalent of 48–456% of the mean annual runoff. Mean annual runoff and annual maximum flood flows have not been modified by the presence of these dams. The average number of days per year without runoff had decreased downstream of two dams. A comparison was made of flow duration curves at sites upstream and downstream of the selected dams. Significant differences were detected between the flow duration curves of upstream and downstream sites. Exceedance frequencies of low flows had decreased downstream of two dams, while these had increased downstream of the other dam. The study recommends development of operating rules for these dams that will ensure that changes detected in low flows do not adversely affect instream flow requirements.

Keywords: Dams; Flow duration curve; Flow modification; Low flows

Effect of minimum tillage and mulching on maize (Zea mays L.) yield and water content of clayey and sandy soils

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Abstract

Rainfed smallholder agriculture in semi-arid areas of southern Africa is subject to numerous constraints. These include low rainfall with high spatial and temporal variability, and significant loss of soil water through evaporation. An experiment was established at Matopos Research Station, Zimbabwe, to determine the effect of mulching and minimum tillage on maize (Zea mays L.) yield and soil water content. The experiment was run for two years at two sites: clay (Matopos Research Station fields) and sand (Lucydale fields) soils, in a 7 · 3 factorial combination of mulch rates (0, 0.5, 1, 2, 4, 8 and 10 t ha_1) and tillage methods (planting basins, ripper tine and conventional plough). Each treatment was replicated three times at each site in a split plot design. Maize residue was applied as mulch before tillage operations. Two maize varieties, a hybrid (SC 403) and an open pollinated variety (ZM 421), were planted. Maize yield and soil water content (0–30 and 30–60 cm depth) were measured under each treatment. On both soil types, neither mulching nor tillage method had a significant effect on maize grain yield. Tillage methods significantly influenced stover production with planting basins giving the highest stover yield (1.1 t ha_1) on sandy soil and conventional ploughing giving 3.6 t ha_1 on clay soil during the first season. The three tillage methods had no significant effect on seasonal soil water content, although planting basins collected more rainwater during the first half of the cropping period. Mulching improved soil water content in both soil types with maximum benefits observed at 4 t ha_1 of mulch. We conclude that, in the short term, minimum tillage on its own, or in combination with mulching, performs as well as the farmers' traditional practices of overall ploughing.

Keywords: Conservation agriculture; Minimum tillage; Mulching; Planting basin; Semi-arid

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Rainwater harvesting to enhance water productivity of rainfed agriculture in the semi-arid Zimbabwe

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Abstract

Zimbabwe's poor are predominantly located in the semi-arid regions and rely on rainfed agriculture for their subsistence. Decline in productivity, scarcity of arable land, irrigation expansion limitations, erratic rainfall and frequent dry spells, among others cause food scarcity. The challenge faced by small-scale farmers is to enhance water productivity of rainfed agriculture by mitigating intra-seasonal dry spells (ISDS) through the adoption of new technologies such as rainwater harvesting (RWH). The paper analyses the agro-hydrological functions of RWH and assesses its impacts (at field scale) on the crop yield gap as well as the Transpirational Water Productivity (WPT). The survey in six districts of the semi-arid Zimbabwe suggests that three parameters (water source, primary use and storage capacity) can help differentiate storage-type-RWH systems from ‘‘conventional dams’’. The Agricultural Production Simulator Model (APSIM) was used to simulate seven different treatments (Control, RWH, Manure, Manure + RWH, Inorganic Nitrogen and Inorganic Nitrogen + RWH) for 30 years on alfisol deep sand, assuming no fertiliser carry over effect from season to season. The combined use of inorganic fertiliser and RWH is the only treatment that closes the yield gap. Supplemental irrigation alone not only reduces the risks of complete crop failure (from 20% down to 7% on average) for all the treatments but also enhances WPT (from 1.75 kg m_3 up to 2.3 kg m_3 on average) by mitigating ISDS.

Keywords: Rainfed agriculture; Rainwater harvesting system; Water productivity; Yield gap

Potential water supply of a small reservoir and alluvial aquifer system in southern Zimbabwe

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Abstract

Groundwater use by accessing alluvial aquifers of non-perennial rivers can be an important additional water resource in the semi-arid region of southern Zimbabwe. The research objective of the study was to calculate the potential water supply for the upper-Mnyabezi catchment under current conditions and after implementation of two storage capacity measures. These measures are heightening the spillway of the Mnyabezi 27' dam and constructing a sand storage dam in the alluvial aquifer of the nyabezi River. The upper-Mnyabezi catchment covers approximately 22 km2 and is a tributary of the Thuli River in southern Zimbabwe. Three coupled models are used to simulate the hydrological processes in the Mnyabezi catchment. The first is a rainfall-Runoff model, based on the SCS-method. The second is a spreadsheet based model of the water balance of the reservoir. The third is the finite difference groundwater model MODFLOW used to simulate the water balance of the alluvial aquifer. The potential water supply in the Mnyabezi catchment under current conditions ranges from 2107 m3 (5.7 months) in a dry year to 3162 m3 (8.7 months) in a wet year. The maximum eriod of water supply after implementation of the storage capacity measures in a dry year is 2776 m3 (8.4 months) and in a wet year the amount is 3617 m3 (10.8 months). The sand storage dam can only be used as an additional water resource, because the storage capacity of the alluvial aquifer is small. However, when an ephemeral river is underlain by a larger alluvial aquifer, a sand storage dam is a promising way of water supply for smallholder farmers in southern Zimbabwe.

Keywords: Alluvial aquifer, MODFLOW, Rainfall-runoff relation, Potential water supply

The nexus between integrated natural resources management and integrated water resources management in southern Africa

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Abstract

The low productivity of smallholder farming systems and enterprises in the drier areas of the developing world can be attributed mainly to the limited resources of farming households and the application of inappropriate skills and practices that can lead to the degradation of the natural resource base. This lack of development, particularly in southern Africa, is of growing concern from both an agricultural and environmental perspective. To address this lack of progress, two development paradigms that improve land and water productivity have evolved, somewhat independently, from different scientific constituencies. One championed by the International Agricultural Research constituency is Integrated Natural Resource Management (INRM), whilst the second championed predominantly by Environmental and Civil Engineering constituencies is Integrated Water Resources Management (IWRM). As a result of similar objectives of working towards the millennium development goals of improved food security and environmental sustainability, there exists a nexus between the constituencies of the two paradigms, particularly in terms of appreciating the lessons learned. In this paper lessons are drawn from past INRM research that may have particular relevance to IWRM scientists as they re-direct their focus from blue water issues to green water issues, and vice-versa. Case studies are drawn from the management of water quality for irrigation, green water productivity and a convergence of INRM and IWRM in the management of gold panning in southern Zimbabwe. One point that is abundantly clear from both constituencies is that 'one-size-fits-all' or silver bullet solutions that are generally applicable for the enhancement of blue water management/formal irrigation simply do not exist for the smallholder rainfed systems.

Keywords: INRM, IWRM, Green water, Blue water

Design of a water quality monitoring network for the Limpopo River Basin in Mozambique

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Abstract

The measurement of chemical, physical and biological parameters is important for the characterization of streams health. Thus, cost-effective and targeted water quality (WQ) monitoring programmes are required for proper assessment, restoration and protection of such systems. This research proposes a WQ monitoring network for the Limpopo River Basin (LRB) in Mozambique located in Southern Africa, a region prone to severe droughts. In this Basin both anthropogenic and natural driven processes, exacerbated by the increased water demand by the four riparian countries (Botswana, South Africa, Zimbabwe and Mozambique) are responsible for the degradation of surface waters, impairing their downstream use, either for aquatic ecosystem, drinking, industrial or irrigation. Hence, physico-chemical, biological and microbiological characteristics at 23 sites within the basin were studied in November 2006 and January 2007. The physico-chemical and microbiological samples were analyzed according to American Public Health Association (APHA) standard methods, while the biological monitoring working party method (BMWP) was used for biological assessment. The assessment of the final WQ condition at sampled points was done taking into account appropriate indexes, the Mozambican standards for receiving waters and the WHO guidelines for drinking WQ. The assessed data indicated that sites located at proximities to the border with upstream countries were contaminated with heavy metals. The Elephants sub-catchment was found with a relatively better WQ, whereas the Changane sub-catchment together with the effluent point discharges in the basin were found polluted as indicated by the low dissolved oxygen and high total dissolved solids, electric conductivity, total hardness, sodium adsorption ratio and low benthic macroinvertebrates taxa. Significant differences ($p < 0.05$) were found for some parameters when the concentrations recorded in November and January were tested, therefore, indicating possible need for monthly monitoring of WQ. From this study it was concluded that a systematic WQ monitoring network composed of 16 stations would fit the conditions of the LRB. Ambient, earl warning, operational and effluents are the main monitoring types recommended. Additional research at a Basin scale was also recommended to identify the major sources of pollution, their transport and impacts to the downstream ecosystem.

Keywords: Environmental flows, Limpopo, Water quality monitoring

The influence of conservation tillage methods on soil water regimes in semi-arid southern Zimbabwe

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Abstract

Planting basins and ripper tillage practices are major components of the recently introduced conservation agriculture package that is being extensively promoted for smallholder farming in Zimbabwe. Besides preparing land for crop planting, these two technologies also help in collecting and using rainwater more efficiently in semi-arid areas. The basin tillage is being targeted for households with limited or no access to draught animals while ripping is meant for smallholder farmers with some draught animal power. Trials were established at four farms in Gwanda and Insiza in southern Zimbabwe to determine soil water contributions and runoff water losses from plots under four different Tillage treatments. The tillage treatments were hand-dug planting basins, ripping, conventional spring and double ploughing using animal-

Drawn implements. The initial intention was to measure soil water changes and runoff losses from cropped plots under the four tillage practices. However, due to total crop failure, only soil water and runoff were measured from bare plots between December 2006 and April 2007. Runoff losses were highest under conventional ploughing. Planting basins retained most of the rainwater that fell during each rainfall event. The amount of rainfall received at each farm significantly influenced the volume of runoff water measured. Runoff water volume increased with increase in the amount of rainfall received at each farm. Soil water content was consistently higher under basin tillage than the other three tillage treatments. Significant differences in soil water content were observed across the farms according to soil types from sand to loamy sand. The basin tillage method gives a better control of water losses from the farmers' fields. The planting basin tillage method has a greater potential for providing soil water to crops than ripper, double and single conventional ploughing practices.

Keywords: Double ploughing, Planting, basins, Ripping, Soil water

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Building adaptive capacity to cope with increasing vulnerability due to climatic change in Africa – A new approach

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Abstract

The world community faces many risks from climate change, with most scenarios indicating higher temperatures and more erratic rainfall in Africa. Predictions for southern Africa suggest a general decrease in total seasonal rainfall, accompanied by more frequent in-season dry spells that will significantly impact crop and livestock production, and hence economic growth in the region. The hardest hit will be the rural poor in the drier areas, where crop failure due to drought is already common and chronic food emergencies afflict the region in most years. Lessons can be learnt on how the rural poor currently cope with the vagaries of climate and these can be used to help them adapt their current production systems to the future threats of further climate change. But this assumes the institutions that work towards the economic empowerment of the rural poor have the requisite skills to understand their current coping strategies and how adaptation can be facilitated. A new initiative led by Midlands State University and the Zambian Meteorological Office proposes that improving the ability of institutions that train the 'Future Change Agents', who will subsequently support smallholder communities in adapting their agricultural practices to current climate variability, is the first step in building adaptive capacity to cope with future climate change. The capacity of African scientists, regional organizations and decision-makers in dealing with the issues of climate change and adaptation will be enhanced on a continuing basis, and the impacts of their agricultural development programs improved.

Keywords: Climate change, Adaptive capacity, Coping strategies, Drought

Redressing inequities of the past from a historical perspective: The case of the Olifants basin, South Africa

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Abstract

This paper analyses the continuities and changes in water management in the Olifants basin after the first decade of implementation of the National Water Act (1998). By taking a historical perspective of the basin development trajectory, the paper shows how the White minority rulers, who exerted power until 1994, systematically denied historically disadvantaged individuals (HDIs) the right to become significant water users, let alone 'economically viable' water users. In contrast, White water users undertook major water resource development, which, by the 1970s resulted in the emergence of a 'White water economy'. Under the new dispensation (post-1994), the Department of Water Affairs and Forestry (DWAF) took a two-pronged approach in the Olifants basin and elsewhere for redressing the inequities of the past. On the one hand, from the central top down, it opened up the 'White water economy' into a water economy serving especially 'economically viable water users', who rapidly ceased to be White only. As reflected in a range of new measures taken in the Olifants basin, in this new water economy DWAF better targets bulk domestic supplies to HDIs, has more public participation, and is strengthening its regulatory role in terms of cost-recovery, environmental issues, and pollution prevention. On the other hand DWAF seeks to fill the enormous backlog in water services delivery to HDIs, not only for domestic water uses, but increasingly also for productive uses. The major challenge of bottom-up coordinated service delivery for multiple uses through the newly established Provincial and Local Governments and the transforming line agencies is addressed under the recently launched Water for Growth and Development Initiative.

Keywords: water policy, water law, history, basin management, livelihoods, poverty, gender, Olifants basin, South Africa

Crop yield risk analysis and mitigation of smallholder farmers at quaternary catchment level: Case study of B72A in Olifants river basin, South Africa

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Abstract

Currently, Sub-Sahara is experiencing increased frequency of disasters either as floods or droughts which depletes the scarce resources available to sustain increasing populations. Success in preventing food shortages in the African continent can only be achieved by understanding the vulnerability and risk of the majority of smallholder farmers under rainfed and supplementary irrigation coupled with appropriate interventions. Increased frequency of floods, droughts and dry spells pose an increasing threat to the smallholder farmers' food security and water resources availability in B72A quaternary catchment of the Olifants river basin in South Africa. This paper links maize crop yield risk and smallholder farmer vulnerability arising from droughts by applying a set of interdisciplinary indicators (physical and socio-economic) encompassing gender and institutional vulnerabilities. For the study area, the return period of droughts and dry spells was 2 years. The growing season for maize crop was 121 days on average. Soil water deficit during critical growth stages may reduce potential yields by up to 62%, depending on the length and severity of the moisture deficit. To minimize grain yield loss and avoid total crop failures from intra-seasonal dry spells, farmers applied supplementary irrigation either from river water or rainwater harvested into small reservoirs. Institutional vulnerability was evidenced by disjointed water management institutions with lack of comprehension of roles of higher level institutions by lower level ones. Women are most hit by droughts as they derived more than 90% of their family income from agriculture activities. An enhanced understanding of the vulnerability and risk exposure will assist in developing technologies and policies that conform to the current livelihood strategies of smallholder, resource-constrained farmers. Development of such knowledge base for a catchment opens avenues for computational modelling of the impacts of different types of disasters under different scenarios.

Keywords: Drought, Food insecurity, Social vulnerability, Risk

The river basin game as a tool for collective water management at community level in South Africa

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Abstract

Water scarcity in semi-arid catchments presents challenges on achieving equitable sharing of available water resources and avoiding social tensions among small-holder farmers. This paper explores the implementation of a river basin game as a tool to facilitate negotiations and rules of equal access among upstream and downstream irrigation water users in Ga-Sekororo, Olifants river basin in South Africa. The various stages of the game playing methodology are presented in a progressive manner and the outcomes are discussed. Through the application of this game, farmers were able to better relate to their catchment and accepted the board's schematic representation of their reality. They were able to understand top-tail inequities of water supply and to appreciate that solutions lie in the community. The coming together of the small-holder farmers to share knowledge and set agreements on equitable water sharing results in higher benefits such as community harmony, transparency, acceptance of operating rules and improved knowledge to the community as a whole. The collective negotiation exercise produces more acceptable water allocation rules, thereby improving the security of water supply to the irrigation schemes. The paper concludes that local level management of tensions and conflicts through participation as facilitated by the river basin games can be sustainable provided there is proactive support from higher level institutions such as water committees, government and research

Keywords: Conflict resolution, Irrigation, River basin game, Water equity, Downstream user, Upstream user

Micro-dosing as a pathway to Africa's Green Revolution: evidence from broad-scale on-farm trials

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Abstract

Next to drought, poor soil fertility is the single biggest cause of hunger in Africa. ICRISAT Zimbabwe has been working for the past 10 years to encourage small-scale farmers to increase inorganic fertiliser use as the first step towards Africa's own Green Revolution. The program of work is founded on promoting small quantities of inorganic nitrogen (N) fertiliser (micro-dosing) in drought-prone cropping regions. Results from initial on-farm trials showed that smallholder farmers could increase their yields by 30–100% through application of micro doses, as little as 10 kg Nitrogen ha-1. The question remained whether these results could be replicated across much larger numbers of farmers. Wide scale testing of the micro-dosing (17 kg Nitrogen ha-1) concept was initiated in 2003/2004, across multiple locations in southern Zimbabwe through relief and recovery programs. Each year more than 160,000 low resourced households received at least 25 kg of nitrogen fertiliser and a simple flyer in the vernacular explaining how to apply the fertiliser to a cereal crop. This distribution was accompanied by a series of simple paired plot demonstration with or without fertiliser, hosted by farmers selected by the community, where trainings were carried out and detailed labour and crop records were kept. Over a 3 year period more than 2,000 paired-plot trials were established and quality data collected from more than 1,200. In addition, experimentation to derive N response curves of maize (Zea mays L.), sorghum (Sorghum bicolor (L.) Moench) and pearl millet (Pennisetum glaucum (L.) R.Br.) in these environments under farmer management was conducted. The results consistently showed that micro-dosing (17 kg Nitrogen ha-1) with nitrogen fertiliser can increase grain yields by 30–50% across a broad spectrum of soil, farmer management and seasonal climate conditions. In order for a household to make a profit, farmers needed to obtain between 4 and 7 kg of grain for every kg of N applied depending on season. In fact farmers commonly obtained 15–45 kg of grain per kg of N input. The result provides strong evidence that lack of N, rather than lack of rainfall, is the primary constraint to cereal crop yields and that micro-dosing has the potential for broad-scale impact on improving food security in these drought prone regions.

Keywords: Fertiliser, Nitrogen, Semi-Arid, Smallholder, Sorghum, Maize, Pearl Millet, Southern Africa, Zimbabwe

Changing hydroclimatic and discharge patterns in the northern Limpopo Basin, Zimbabwe

D. Love, S. Uhlenbrook, S. Twomlow, P. van der Zaag

Abstract

Changing regional and global trends in climate and discharge, such as global warming related declines in annual rainfall in south-eastern Africa, are likely to have a strong influence on water resource availability, and increase livelihood risk. It is therefore important to characterise such trends. Information can be obtained by examining and comparing the rainfall and runoff records at different locations within a basin. In this study, trends in various parameters of temperature (4 stations), rainfall (10 stations) and discharge (16 stations) from the northern part of the Limpopo Basin, Zimbabwe, were statistically analysed, using the Spearman rank test, the Mann-Kendall test and the Pettitt test. It was determined that rainfall and discharge in the study area have undergone a notable decline since 1980, both in terms of total annual water resources (declines in annual rainfall, annual unit runoff) and in terms of the temporal availability of water (declines in number of rainy days, increases in dry spells, increases in days without flow). Annual rainfall is negatively correlated to an index of the El Niño – Southern Oscillation phenomenon. The main areas of rising risk are an increasing number of dry spells, which is likely to decrease crop yields, and an increasing probability of annual discharge below the long-term average, which could limit blue water availability. As rainfall continues to decline, it is likely that a multiplier effect will be felt on discharge.

Increasing food shortages are a likely consequence of the impact of this declining water resource availability on rain-fed and irrigated agriculture. Declining water resource availability will also further stress urban water supplies, notably those of Zimbabwe's second largest city of Bulawayo, which depends to large extent from these water resources and already experiences chronic water shortages.

Keywords: climate variability, climate change, discharge analysis, Pettitt test, rainfall analysis, water resources, Limpopo Basin, Zimbabwe, Southern Africa

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Rainfall-interception-evaporation-runoff relationships in a semi-arid meso-catchment, northern Limpopo Basin, Zimbabwe

D. Love, S. Uhlenbrook, G. Corzo-Perez, S. Twomlow and P. van der Zaag

Abstract

Characterising the response of a catchment to rainfall, in terms of the production of runoff vs. the interception, transpiration and evaporation of water, is the first important step in understanding water resource availability in a catchment. This is particularly important in small semi-arid catchments, where a few intense rainfall events may generate much of the season's runoff. The 30 km^2 ephemeral Zhulube Catchment in the northern Limpopo Basin was instrumented and modelled in order to elucidate the dominant hydrological processes. Discharge events were disconnected, with short recession curves, probably caused by the shallow soils in the Tshazi subcatchment, which dry out rapidly, and the presence of a dambo in the Gobalidanke subcatchment. Two different flow event types were observed, with the larger floods showing longer recessions being associated with higher (antecedent) precipitation. The differences could be related to: (i) intensity of rainfall or (ii) different soil conditions. Interception is an important process in the water balance of the catchment, accounting for an estimated 32 % of rainfall in the 2007-2008 season but as much as 56 % in the drier 2006-2007 season. An extended version of the HBV model was developed (designated HBVx), introducing an interception storage and with all routines run in semi-distributed mode. After extensive manual calibration, the HBVx simulation satisfactorily showed the disconnected nature of the flows. The generally low Nash-Sutcliffe coefficients can be explained by the model failing to simulate the two different observed flow types differently. The importance of incorporating interception into rainfall-runoff is demonstrated by the substantial improvement in objective function values obtained. This exceeds the gains made by changing from lumped to semi-distributed mode, supported by 1,000,000 Monte Carlo simulations. There was also an important improvement in the daily volume error (dV_d). The best simulation, supported by field observations in the Gobalidanke subcatchment, suggested that discharge was driven mainly by flow from saturation overland flow. Hortonian overland flow, as interpreted from field observations in the Tshazi Subcatchment, was not simulated so well. A limitation of the model is its inability to address temporal variability in soil characteristics and more complexrunoff generation processes. The model suggests episodic groundwater recharge with annual recharge of 100 mm a^{-1}, which is similar to that reported by other studies in Zimbabwe.

Keywords: HBV; Interception; Limpopo Basin; Semi-arid hydrology

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A water balance modelling approach to optimising the use of water resources in ephemeral sand rivers in semi-arid environments

D. Love, P. van der Zaag, S. Uhlenbrook and R. Owen

Abstract

Alluvial aquifers present a possibility for conjunctive use with surface reservoirs for the storage of water in ephemeral sand rivers, such as the Mzingwane River in the Limpopo Basin, Zimbabwe. The Lower Mzingwane valley is a semi-arid region with high water stress, where livelihoods have revolved around the large rivers for thousands of years. However, current water allocation favours the commercial user: Of the 2,600 ha irrigated in the 5,960 km^2 region, only 410 ha are for smallholder farmers. A water balance approach was used to model the surface water resources and groundwater resources to determine the potential for expanding irrigation and to explore water allocation options. Using a combination of field and laboratory investigations, remote sensing and existing data, the Lower Mzingwane valley was modelled successfully using the spreadsheet-based model WAFLEX, with a new module incorporated to compute the water balance of alluvial aquifer blocks. Results showed that the lower Mzingwane alluvial aquifers can store 38×10^6 m^3 of water, most of that storage being beyond the reach of evaporation. Current water usage can be more than tripled: the catchment could supply water for currently-planned irrigation schemes (an additional 1,250 ha), and the further irrigation of two strips of land along each bank of the Mzingwane river (an extra 3,630 ha) – without construction of any new reservoirs. The system of irrigating strips of land along each bank of the Mzingwane river would be decentralised, farmer or family owned and operated and the benefits would have the potential to reach a much larger proportion of the population than is currently served. However, there could be substantial downstream impact, with around nearly one third of inflows not being released to the Limpopo River. The approach developed in this paper can be applied to evaluate the potential of alluvial aquifers, which are widespread in many parts of semi-arid Africa, for providing distributed access to shallow groundwater in an efficient way. This can enhance local livelihoods and regional food security.

Keywords: Alluvial aquifer; arid environments, decentralised system; ephemeral rivers; Limpopo Basin; water balance modelling

Appendix 2 Intervention matrix

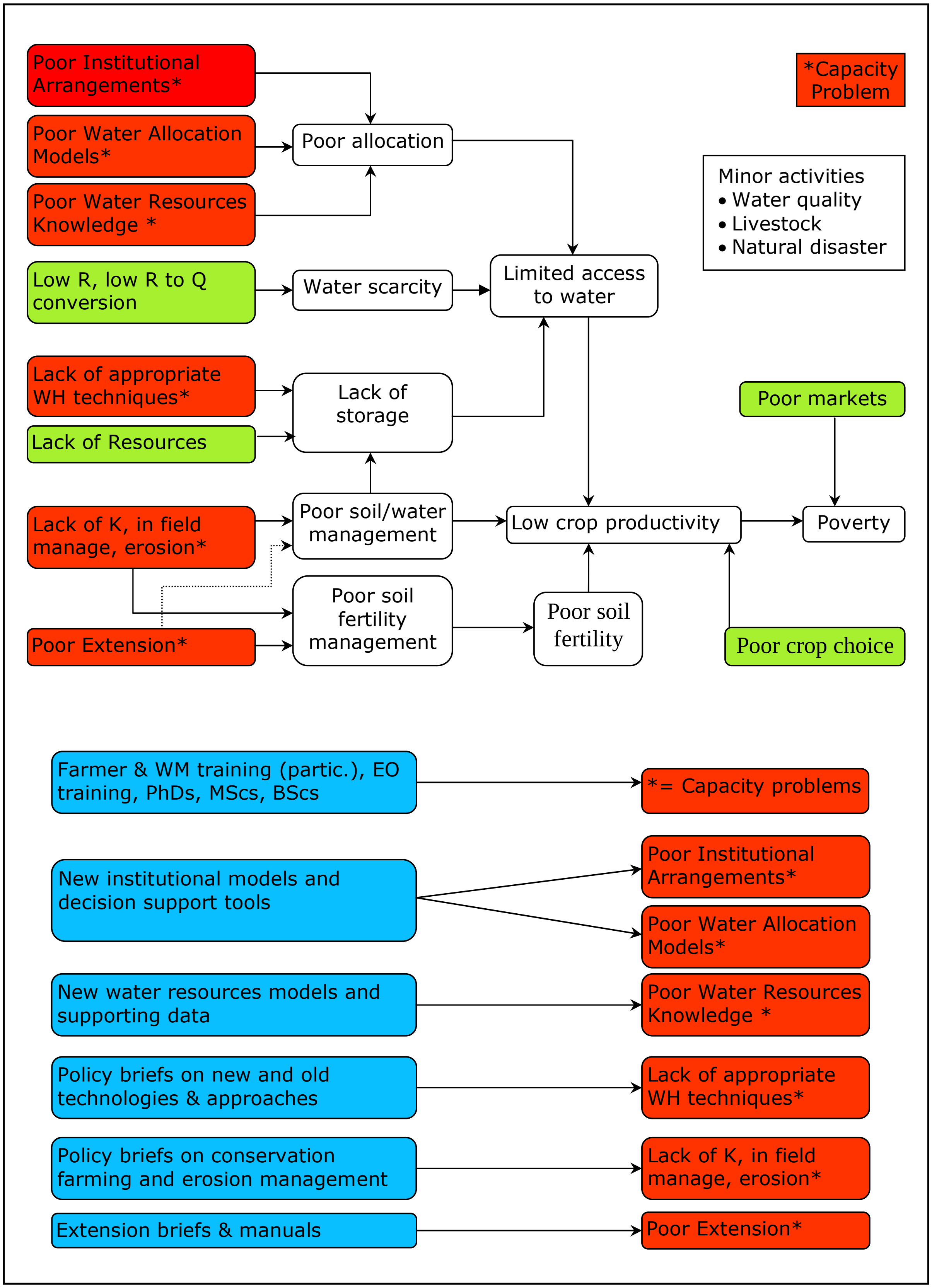
Intervention Package	**Associated Institutions**	**Infrastructure**			**Technology**			**Policies & Institutions**			**New Knowledge**		
(list package or technology)	**Name of institution followed by contact information, links to related web sites or documents**	**Check any of the boxes below that apply**			**Check any of the boxes below that apply**			**Check any of the boxes below that apply**			**Check any of the boxes below that apply**		
		availability	**productivity**	**access**	**availability**	**productivity**	**access**	**availability**	**productivity**	**access**	**availability**	**productivity**	**access**
Mainstreaming capacity building in food and water research	WaterNet bncube@virginmedia.com dlove@waternetonline.org IFWF2 proceedings	x	x	x	x	x	x	x	x	x	x	x	x
Soil water management strategies	ICRISAT s.twomlow@cgiar.org mupangwa@yahoo.com doi:10.1016/j.pce.2006.08.042 doi:/10.1016/j.pce.2006.08.002 doi:10.1016/j.pce.2007.07.030 doi:10.1016/j.pce.2008.06.049		x	x		x	x					x	
Mulching	ICRISAT s.twomlow@cgiar.org mupangwa@yahoo.com doi:10.1016/j.pce.2007.07.030		x	x		x	x					x	
Rainwater harvesting	WaterNet bncube@virginmedia.com IFWF2 Proceedings University of the Witwatersrand akpofure.taigbenu@wits.ac.za doi:10.1016/j.pce.2007.07.011 doi:10.1016/j.pce.2008.06.050 IFWF2 Proceedings CPWF T2 Rainfed proceedings ICRISAT j.dimes@cgiar.org Eduardo Mondlane University kensydoge@yahoo.com draft available					x	x					x	x

Intervention Package	**Associated Institutions**	**Infrastructure**			**Technology**			**Policies & Institutions**			**New Knowledge**		
(list package or technology)	**Name of institution followed by contact information, links to related web sites or documents**	**Check any of the boxes below that apply**			**Check any of the boxes below that apply**			**Check any of the boxes below that apply**			**Check any of the boxes below that apply**		
		availability	**productivity**	**access**	**availability**	**productivity**	**access**	**availability**	**productivity**	**access**	**availability**	**productivity**	**access**
	University of Zimbabwe mhizha@eng.uz.ac.zw IFWF2 Proceedings												
Low head drip kits	ICRISAT s.twomlow@cgiar.org doi:10.1016/j.pce.2006.08.020 doi:/10.1016/j.pce.2005.08.021		x	x		x	x		x	x		x	
Managing salinity in irrigation	Eduardo Mondlane University kensydoge@yahoo.com draft available					x	x					x	x
Alluvial aquifers for smallholder irrigation	UNESCO-IHE dlove@waternetonline.org Mineral Resources Centre, University of Zimbabwe richardo@zol.co.zw Dabane Trust s.w.hussey@dabane.co.zw doi:10.1016/j.pce.2006.08.013 doi:10.1016/j.pce.2008.06.056 draft available www.dabane.co.zw http://en.wikipedia.org/wiki/Maranda,_Zimbabwe#Geography			x			x						x
Stress analysis for groundwater location	Mineral Resources Centre, University of Zimbabwe richardo@zol.co.zw doi:10.1007/s10040-007-0224-7			x			x						x
Improving flood forecasting	AraSul avilankulos@yahoo.com.br WaterNet/WARFSA/GWP-SA				x	x	x	x	x	x			

Intervention Package	**Associated Institutions**	**Infrastructure**			**Technology**			**Policies & Institutions**			**New Knowledge**		
(list package or technology)	**Name of institution followed by contact information, links to related web sites or documents**	**Check any of the boxes below that apply**			**Check any of the boxes below that apply**			**Check any of the boxes below that apply**			**Check any of the boxes below that apply**		
		availability	**productivity**	**access**	**availability**	**productivity**	**access**	**availability**	**productivity**	**access**	**availability**	**productivity**	**access**
	Proceedings												
Modelling upstream-downstream interactions	University of the Witwatersrand akpofure.taigbenu@wits.ac.za UNESCO-IHE dlove@waternetonline.org IFWF2 Proceedings Draft available								x			x	x
Use of the SWAT model in monitoring the effect of land use change on water resources	University of the Witwatersrand akpofure.taigbenu@wits.ac.za draft available								x			x	x
Managing the effects of dams on river flow	UNESCO-IHE dlove@waternetonline.org doi:10.1016/j.pce.2006.08.022 IFWF2 Proceedings		x									x	x
Building institutional sustainability	UNESCO-IHE collin.mabiza@yahoo.com WaterNet/WARFSA/GWP-SA Proceedings IWMI b.vankopen@cgiar.org spinimidzai@yahoo.com draft available							x	x	x	x	x	x
River Basin Game	University of the Witwatersrand akpofure.taigbenu@wits.ac.za manumagomb@yahoo.com							x	x	x			

Intervention Package	**Associated Institutions**	**Infrastructure**			**Technology**			**Policies & Institutions**			**New Knowledge**		
(list package or technology)	**Name of institution followed by contact information, links to related web sites or documents**	**Check any of the boxes below that apply**			**Check any of the boxes below that apply**			**Check any of the boxes below that apply**			**Check any of the boxes below that apply**		
		availability	**productivity**	**access**	**availability**	**productivity**	**access**	**availability**	**productivity**	**access**	**availability**	**productivity**	**access**
	doi:10.1016/j.pce.2008.06.045												
Stakeholder involvement in water quality monitoring	UNESCO-IHE dlove@waternetonline.org doi:10.1016/j.pce.2006.08.037 Eduardo Mondlane University kensydoge@yahoo.com doi:10.1016/j.pce.2008.06.055								x			x	
Irrigation Water Access & Pricing	Power, UNESCO IHE, University of Zimbabwe mhizha@eng.uz.ac.zw muchiemunamati@yahoo.com							x	x				
Integration of germplasm and management	ICRISAT j.dimes@cgiar.org				x						x	x	
Farmer response to rainfall variability	ICRISAT e.masvaya@cgiar.org draft available							x			x		
Water rights and access	IWMI b.vankopen@cgiar.org spinimidzai@yahoo.com draft available							x	x		x		

Appendix 3 Impact Pathway



Appendix 4 Masters Students in PN17

Year	Fellow	Gender, Nationality	Partner, University	Funding	Catchment	Topic	Link to PhD Fellow	Project Status
2003-2004	Kileshye Onema, Jean-Marie	M, DRC	Univ. Zim. Civil Eng.	CP PN17/ WaterNet	Mzingwane	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.	Love	Dissertation accepted
2003-2004	Maisiri, Norman	M, Zimbabwe	Univ. Zim. Civil Eng.	CP PN17	Mzingwane	An on-farm evaluation of the effects of low cost drip irrigation on water and crop productivity, compared to conventional surface irrigation system	Love, Mupangwa	Dissertation accepted
2003-2004	Mwenge Kahinda, Jean-Marc	M, DRC	Univ. Zim. Civil Eng.	CP PN17/ WaterNet	Mzingwane	Water productivity and yield gap analysis of water harvesting systems in the semi-arid Mzingwane catchment, Zimbabwe	Mupangwa, Love	Dissertation accepted
2003-2004	Murata, Rosemary	F, Zimbabwe	Univ. Zim. Civil Eng.	CP PN17/ WaterNet	Mzingwane	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		Dissertation accepted
2004-2005	Moyo, Bekithemba	M, Zimbabwe	Univ. Zim. Civil Eng.	CP PN17/RELMA	Mzingwane	Impact And Adaptation Of Climate Variability On Water Supply Reservoir yields For The City Of Bulawayo. (Mzingwane Catchment)	Love	Dissertation accepted
2004-2005	Moyo, Richard	M, Zimbabwe	Univ. Zim. Civil Eng.	CP PN17/ RELMA	Mzingwane	Impact and sustainability of low cost drip kits, in the semi-arid lower Mzingwane subcatchment,Limpopo Basin,Zimbabwe	Love, Mupangwa	Dissertation accepted

Year	**Fellow**	**Gender,** **Nationality**	**Partner, University**	**Funding**	**Catchment**	**Topic**	**Link to PhD Fellow**	**Project Status**
2004-2005	Munamati, Muchaneta	F, Zimbabwe	Univ. Zim. Civil Eng.	CP PN17/ RELMA	Mzingwane	Cultivating livelihoods: an assessment of water allocation and management practices in small-scale irrigation schemes -case studies in mzingwane catchment	Sithole	Dissertation accepted
2004-2005	Ntsheme, Osten	M, Botswana	Univ. Wits. Civil & Env. Eng.	CP PN17	Olifants	A survey of the current on farm agricultural land and water management practices in the Olifants catchment	Magombeyi	Dissertation accepted
2004-2005	Woltering, Lennart	M, Netherlands	UNESCO-IHE / TU Delft	CP PN17/ RELMA / Lamminga	Mzingwane	Estimating the influence of on-farm Conservation Practices on the Water Balance, Case of the Mzinyathini Catchment in Zimbabwe	Love	Dissertation accepted
2003-2004	Nare, Lerato	M, Zimbabwe	Univ. Zim. Civil Eng.	CP PN17/ WaterNet	Mzingwane	Involvement of stakeholders in the water quality monitoring and surveillance system: the case of Mzingwane Catchment		Dissertation accepted
2005-2006	Panesar, Jespal	F, Canada	IWMI / Univ. Guelph	CP PN17	Olifants	The nexus between formal organizations and informal networks from a gender perspective: a case study from South Africa	Sithole	Dissertation accepted
2005-2006	Dhliwayo, Clever	M, Zimbabwe	Univ. Zim. Civil Eng./ ICRISAT	CP PN17	Mzingwane	On farm evaluation of the influence of different conservation agriculture practices on infiltration in rainfed agriculture, compared to conventional farming	Mupangwa, Love	Dissertation accepted
2005-2006	Moyo, Libertie	M, Zimbabwe	Univ. Zim. Civil Eng./ ICRISAT/ Univ. Zim.	CP PN17	Mzingwane	Assessment of the soil water management practices for increased seasonal rain water productivity to mitigate against climatic risks	Mupangwa	Dissertation accepted

Year	Fellow	Gender, Nationality	Partner, University	Funding	Catchment	Topic	Link to PhD Fellow	Project Status
			Soil Sci. & Agric. Eng.					
2005-2006	Ngwenya, Thobhekile	F, South Africa	Univ. Zim. Civil Eng./ ICRISAT	CP PN17	Mzingwane	Effect of soil degradation from grazing pressure on rangeland soil hydrology	Love	Dissertation accepted
2005-2006	Vilanculos, Agostino	M, Mozambique	Univ. Zim. Civil Eng./ Univ. Eduardo Mondlane FAEF	CP PN17	Chokwe	Towards improving flood forecasting and early warning systems through integrated technology in the Limpopo basin		Dissertation accepted
2006-2007	Tunhuma, Nevin	M, Zimbabwe	WaterNet, UNESCO-IHE	CP PN17 / UNESCO-IHE	Mzingwane	Environmental Impacts of Small-Scale Natural Resource Exploitation, Implications on Water Resources and Rural Livelihoods	Love	Dissertation accepted
2006-2007	Svubure, Oniward	M, Zimbabwe	WaterNet, UNESCO-IHE	CP PN17 / UNESCO-IHE	Mzingwane	A seat at the table: which table and at what costs? Participation and Institutional Reform in the Water Sector in Zimbabwe: Case of the Mzingwane Catchment	Mabiza	Dissertation accepted
2006-2007	De Hamer, Wouter	M, Netherlands	WaterNet, Twente	CP PN17/ U Twente	Mzingwane	Groundwater – surface water relations in an alluvial aquifer, Bengu, Thuli Basin, Zimbabwe	Love	Dissertation accepted

Year	Fellow	Gender, Nationality	Partner, University	Funding	Catchment	Topic	Link to PhD Fellow	Project Status
2006-2007	Khosa, Sangwani	M, Malawi	Univ. Zim. Civil Eng./ ICRISAT	CP PN17	Mzingwane	Evaluating the effect of water demand scenarios on downstream water availability in Thuli river basin, Zimbabwe	Love	Dissertation accepted
2006-2007	Chibulu, Brenda	F, Zambia	Univ. Zim. Civil Eng./ ICRISAT	CP PN17	Mzingwane	Effect of rainfall variability and options for adaptation on household food security under semi-arid conditions at sub-catchment level	Mupangwa, Mhizha	Dissertation accepted
2006-2007	Dondofema, Farai	M, Zimbabwe	Univ. Zim. Civil Eng./ ICRISAT	CP PN17	Mzingwane	Mapping vegetation, soil and gully erosion changes in Insiza sub-catchment using remote sensing and GIS	Mhizha	Dissertation accepted
2004-2006	Ncube, Mtokozhile	M, Zimbabwe	Univ. Wits. Civil & Env. Eng.	CP PN17	Olifants	The impact of land cover and land use on hydrological response in the Olifants Catchment	Magombeyi	Dissertation accepted
2005-2006	Rasiuba, Thabo	M, South Africa	Univ. Wits. Civil & Env. Eng.	CP PN17	Olifants	Water budget allocation, water use efficiency in agriculture in Olifants basin	Magombeyi	Dissertation accepted
2006-2007	Arranz, R	M	IWMI	CP PN17	Olifants	Application of the Water Evaluation And Planning (WEAP) model to assess future water demands and resources in the Olifants Catchment, South Africa		Dissertation accepted

Year	Fellow	Gender, Nationality	Partner, University	Funding	Catchment	Topic	Link to PhD Fellow	Project Status
2006-2007	Liebrand, Jan-Willem	M, Netherlands	IWMI / Wageningen	CP PN17	Olifants	Securing Water through Land; field findings on water reform and water re-allocation in South Africa: Trichardtsdal, Ofcolaco and Leydsdorp	Sithole	Dissertation accepted
2006-2007	Chilundo, Mario	M, Mozambique	UNESCO-IHE/ Univ. Eduardo Mondlane FAEF	CP PN17	Chokwe	Design of a water quality monitoring network for the Limpopo River Basin in Mozambique	Munguambe	Dissertation accepted
2004-2005	Mandivengerei, Stephen	M, Zimbabwe	Univ. Western Cape PLAAS / Univ. Zim. CASS	CP PN17	Mzingwane	Smallholder participation in water resources management after the land and water sector reforms in zimbabwe: a case study of the umzingwane catchment	Sithole	Dissertation accepted
2007-8	Masvopo, Taurai	M, Zimbabwe	Univ. Zim. Civil Eng.	CP PN17	Mzingwane	Characterisation of the Mtetengwe alluvial aquifer, Lower Mzingwane river	Love	Dissertation accepted
2004-2005	Saunyama, Tendai	M, Zimbabwe	Univ. Zim. Soil Sci. & Agric. Eng.	CP PN46 & PN17	Mzingwane	Estimation of small reservoir storage capacities in limpopo basin using gis and remotely sensed surface areas		Dissertation accepted
2005-2006	Rukuni, Sam	M, Zimbabwe	Univ. Zim. Civil Eng./ Univ. Zim. Soil Sci. & Agric. Eng.	CP PN46 & PN17	Mzingwane	Hydrological modelling for the estimation of a cascade of reservoir storages: application of WEAP		Dissertation accepted

Year	**Fellow**	**Gender,** **Nationality**	**Partner, University**	**Funding**	**Catchment**	**Topic**	**Link to PhD Fellow**	**Project Status**
2008-2009	Julaia, Claudio	M, Mozambique	UNESCO-IHE/ Univ. Eduardo Mondlane FAEF	CP PN17	Chokwe	Performance Assessment of the Water Distribution System in the Chókwè Irrigation Scheme, Mozambique	Munguambe	Dissertation accepted
2006-2007	Ibraimo, Nadia	F, Mozambique	Univeristy of Pretoria, Univ. E. Mondlane, FAEF	CP PN17	Chokwe	Rainwater Harvesting: Management Strategies in Semi-arid Areas	Munguambe	Dissertation accepted
2005	Andersson, Lisa	F, Sweden	IWMI / Luleå University of Technology	CP PN17	Olifants	Low-cost drip irrigation		Dissertation accepted
2008-2009	Fatch, Joanna	F, Malawi	Univ. Zim. CASS	CP PN17	Mzingwane	Local participation in transboundary water resources management: the case of Limpopo Basin, Zimbabwe	Mabiza	Dissertation accepted
2008-2009	Chakandida, Bond	F, Zimbabwe	Univ. Zim. CASS	CP PN17	Mzingwane	Stakeholder participation and institutional models	Mabiza	Dissertation accepted
2004-2006	Chinoda, Grecious	M, Zimbabwe	Univ. Zim. MRC	CP PN17	Mzingwane	The Limpopo Mobile Belt: Basin Structure and Potential for Groundwater Occurrence		Student has dropped out
2004-	Moyce, William	M, Zimbabwe	Univ. Zim. MRC	CP PN17 / Res. Council Zim.	Mzingwane	Hydrochemistry of alluvial aquifers, Mzingwane Catchment, Limpopo Basin, Zimbabwe	Love	Student has dropped out

Year	**Fellow**	**Gender, Nationality**	**Partner, University**	**Funding**	**Catchment**	**Topic**	**Link to PhD Fellow**	**Project Status**
2005-2006	Nyalungu, Lucky	F, South Africa	IWMI / Univ. Limpopo	CP PN17	Olifants	Socio-economic conditions and water management as determinants of food security in smallholder irrigation schemes in Limpopo	Sithole	Student has dropped out
2006-2007	Dos Mucudos, Erasmo	M, Mozambique	Univ. Eduardo Mondlane FAEF	CP PN17	Chokwe	Rainfed Agriculture Strategies	Munguambe	Student has changed topic
2005-2006	Malatji, Sylvia	F, South Africa	IWMI / Univ. Limpopo	CP PN17 & PN28	Olifants	Economic instrument to address equity of water allocation and sustainability of small-scale irrigation schemes		Student failed
2004-2005	Busane Basima, Lefranc	M, DRC	Univ. Zim. Soil Sci. & Agric. Eng.	CP PN46	Mzingwane	Biological aspects of small dams		Dissertation accepted
2004-2005	Mpho, Tiego	M, Botswana	Univ. Zim. Soil Sci. & Agric. Eng.	CP PN47	Motloutsi	Indigenous WRM practices in Botswana		Dissertation accepted
2004-2005	Tsvikirize, Doris	F, Kenya	Univ. Zim. Soil Sci. & Agric. Eng.	CP PN47	Mzingwane	An assessment of indigenous water management practices and their implication for effective water governance; a case study of different ethnic groups in the Limpopo Basin, Zimbabwe		Dissertation accepted
2005	Sarron, Corralie	F, France	IWMI / Ecole Nat. Sup. Ag. Rennes	CP PN30	Olifants	Effects of wetland degradation on the hydrological regime of a quaternary catchment. Mohlapitse River, GaMampa valley, Limpopo		Dissertation accepted

Year	**Fellow**	**Gender, Nationality**	**Partner, University**	**Funding**	**Catchment**	**Topic**	**Link to PhD Fellow**	**Project Status**
						Province, South Africa		
2005-2006	Lefebvre, Marie	F, France	IWMI / Ecole Nat. Sup. Ag. Rennes	CP PN28	Olifants	Institutional framework, water pricing structures and costs of domestic water services in rural poor areas		Dissertation accepted