Integrated water resource management (IWRM) research for mitigating drought and improving livelihoods within the Limpopo Basin

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Abstract

The Challenge Program on Water and Food Project Number 17 has been running within the Limpopo Basin for three years. The main goal of the project is to contribute to improved rural livelihoods of poor smallholder farmers 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 in the Limpopo Basin. The project also has a strong bias towards human capacity building which is fully integrated into all research activities. The research is 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 is characterized; and Institutional Research which aims to develop appropriate institutional models for water governance and strengthen institutions and policies for water productivity and risk mitigation. The outputs of the research will be used to develop guidelines for catchment management across political boundaries. The research has so far generated results that are showing that there is potential to manage water resources and improve productivity within the dry Limpopo Basin using IWRM principles. Under FFBAR conservation farming has shown that crop water management and the use of nitrogen fertilizer can improve crop yields by margins of more than 200 kg/ha. Water resources research has helped in the characterization of rainfall-runoff relationships and a better understanding of the potential yield and use of alluvial aquifers within the basin. Under institutional research responses to water scarcity have been characterized and further studies are underway to understand differences and try to create linkages across institutions within the Limpopo basin. The IWRM approach is promising to be a beneficial research approach for improving livelihoods within the Limpopo Basin.

Key words: Crop productivity, institutional models, IWRM, rainfall runoff partitioning

1. Introduction

The Limpopo Basin is one of the benchmark basins for the Challenge Program on Water and Food (CPWF). One of the projects that the program is implementing in the basin is Project 17 (PN17) with the title 'The Challenge of Integrated Water Resources Management for Improved Rural Livelihoods: Managing Risk, Mitigating Drought and Improving Water Productivity in the Water Scarce Limpopo Basin'. The project started in 2004, and it was recently extended for one more year to run for a total of five years.

The Challenge Program on Water and Food is addressing a number of problems that are related to water, agriculture and institutional arrangements for water management within the Limpopo basin. The basin covers mostly semi-arid regions with a mean annual rainfall of 530 mm (range 200 -1200 mm) (Harrington et al, 2004). The rainfall is unreliable making rain-fed farming a risky business, and droughts are common during the growing season (Butterworth *et al.*, 1999; Twomlow and Bruneau, 2000; Unganai and Mason, 2002). The water that is available within the basin is becoming a competition commodity among countries and communities, with a precarious balance between available water resources and water demand (e.g. Basson and Rossouw, 2003; Mazvimavi, 2004; Mugabe *et al.*, 2007; Nyabeze, 2004; Vörösmarty *et al.*, 2000). The major issues being addressed within the basin include improving crop productivity without increasing water use by introducing drought resistant varieties and suitable land management practices, introducing appropriate water policies and governance, and adopting a basin approach to water management (Harrington et al, 2004). The PN17 project addresses some of these issues.

The major goal of PN17 is to contribute to improved rural livelihoods of poor smallholder farmers through the development of an Integrated Water Resources Management (IWRM) framework for increased productive use of green and blue water flows and risk management for drought and dry-spell mitigation at all scales in the Limpopo basin. The project is being implemented by 14 partners who are made up of two consultative group of international agricultural research (CGIAR) centres, 10 national research centres (NARES), one agricultural research institute (ARI) and 1 non-governmental organization (NGO). The project covers Mozambique, South Africa and Zimbabwe. The project is unique among all other projects in that it is led by WaterNet, a network organization that is outside the CGIAR system.

The main objectives of the project are:

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 is to build evidence that improving water management through the IWRM paradigm improves rural livelihoods from the basin (trans-boundary) scale down to the field scale (farmers). Three research areas are covered: farmer field based action research (agriculture), Water resources research, and institutional research.

2. Characterization of the Limpopo Basin

Baseline Studies

Baseline data was collected for various components of the Limpopo Basin before the start of the Challenge Program Projects. The biophysical data collection included the assessment of general climatic characteristics and the occurrence of droughts within the basin (Brito et al., 2007). More detailed climate studies are on-going. Soils and geology baselines have also been produced. A preliminary water resources assessment was carried out mainly through the assessment and modeling of runoff generated in the Olifants and Mzingwane Catchments. The assessment of alluvial and other aquifer resources was carried mainly in the Mzingwane Catchment. Surface storage and water quality have also been studied within the whole basin (Love *et al*., 2006a, Chilundo *et al*., 2007). Figure 1 shows the PN17 study sites where detailed studies are carried out within the Limpopo Basin.

Socio-economic data collection included population surveys and other surveys to assess the socio-economic conditions in smallholder farming systems within the basin (CASS 2007, Brito *et al*., 2006a, 2006b). Land and water management practices were also studied (Love *et al*., 2006b; Mupangwa *et al*., 2006).

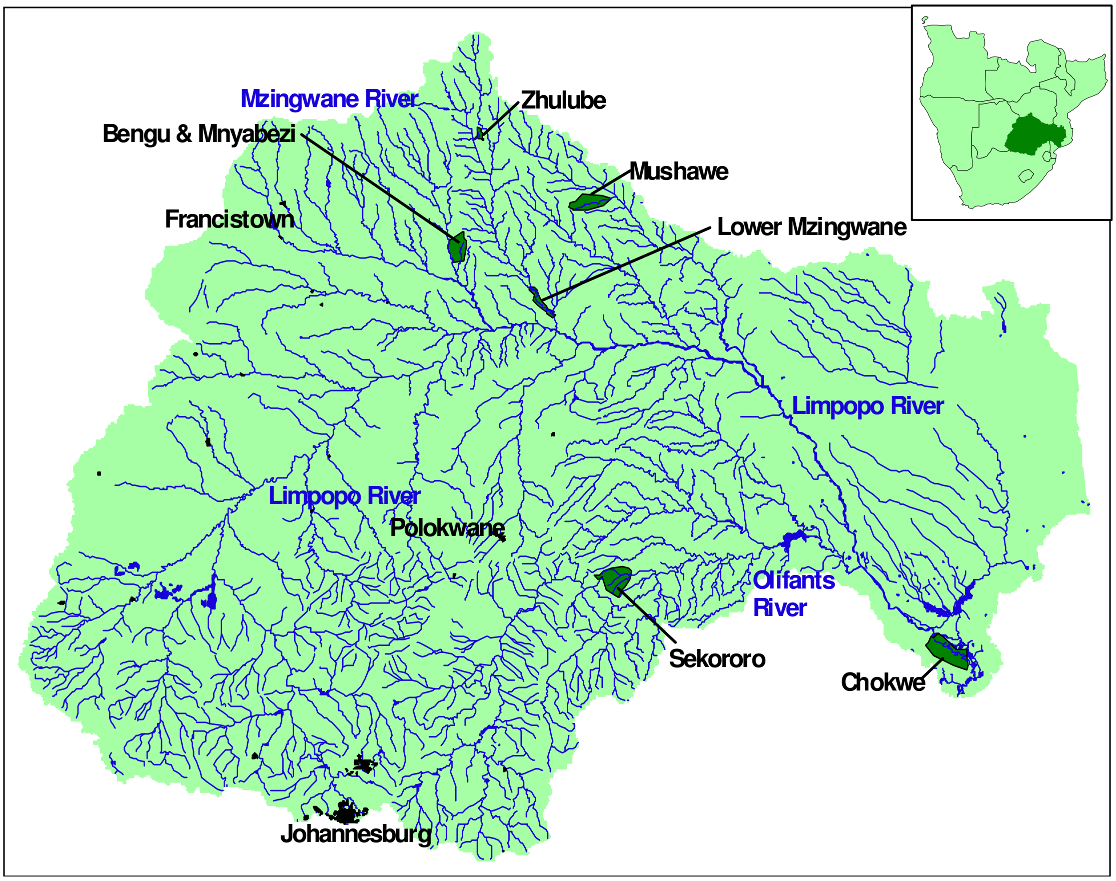

Figure 1 PN17 study sites in the Limpopo Basin

3. Improved Understanding of Water Resources

The main objective of water resources research is to develop 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. Research in water resources includes the preliminary evaluation of water resources, water flow partitioning and upscaling to tributary river basins. Other components of the studies include hydrogeological and water chemistry studies.

Preliminary Water Resource Base

The development of the preliminary water resource base estimation for the Limpopo Basin is in progress. Analysis of water use in the Olifants Catchment (Nyabeze *et al.*, 2006) shows agriculture as the major water user (45 %) followed by power generation, mining and industry (25 %) and domestic use (12 %). The developing conflict between these users, as a consequence of South Africa's industrialisation and development has previously been discussed (Taigbenu *et al.*, 2005). The overall water balance for the Olifants Catchment on 1:50 year assurance shows a deficit of about 160 million m^3/annum and the catchment is in the process of closing (Nyabeze *et al.*, 2006). A similar process of catchment closure appears to have started in the Upper Mzingwane Subcatchment (Love *et al.*, 2006c), a process which is compounded by dam management practice where low flows are retained by the major dams (Kileshye Onema *et al.*, 2006)

Rainfall and Runoff Variability

One of the principal sources of risk to smallholder communities is variability in rainfall, with its consequent impact on green water flows. In the Limpopo Basin, this is strongly correlated with the (ENSO) (Figure 2). Blue water flows are impacted by this and by variability in runoff.

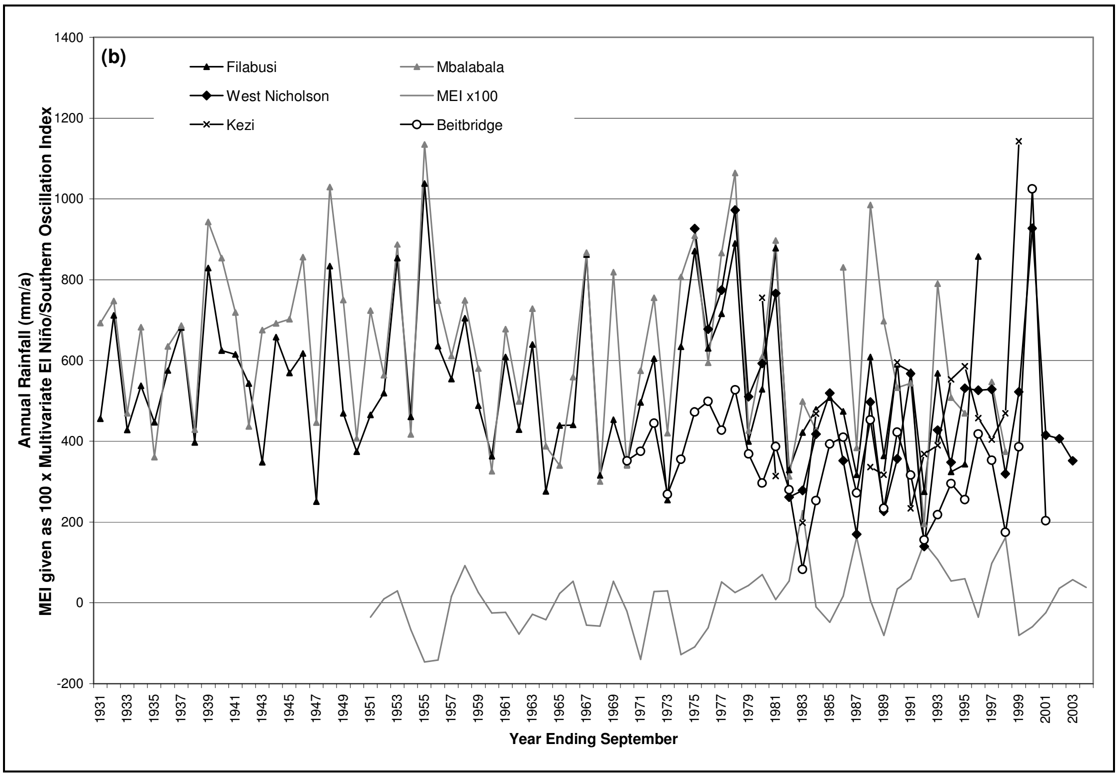

Figure 2 Annual rainfall of selected climate stations in the northern Limpopo Basin (Love *et al.*, 2008), contrasted with the Multivariate ENSO Index (MEI, data: annual averages derived from Wolter, 2007), 1931/32 to 2003/04.

Rainfall variability in the northern Limpopo Basin was characterised using a desktop study and a field study. In the desktop study, historic trends in a series of rainfall variability parameters, including total annual rainfall, number of wet days, length of growing season, number of dry spells and number of days of heavy rainfall were analysed using INSTAT, SPSS and Spell Stat. Results showed that between 1921 and 2000 there has been an insignificant change in the overall trend in total annual rainfall and number of wet days per-year (Mupangwa *et al.*, in press). However, use of the Pettitt test identified change to a drier rainfall regime around 1980 at several of the rainfall stations, confirmed as significant by t-tests. The number of dry spells showed a significant trend of continuous increase at two stations and a significant change to more dry spells around 1980 at five stations (Love *et al.*, 2008). Surprisingly, despite accepted wisdom in the region in changes in the start and end of the growing season, our analyses indicates not major changes over the period reviewed in this study. There are better prospects of receiving rainfall during the January to March period than October to December in semi-arid southern Zimbabwe. The field study, undertaken across 40 households in a selected meso-catchment, showed that daily rainfall amounts varied considerably across the catchment (Masvaya *et al.*, in press).

This study shows that there is substantial spatial and temporal variability in rainfall and that there signs of change to a drier regime. The variability itself imposes significant risk on smallholder farmers, who have to deal with great uncertainty in rainfall availability and intensity. However, the field study showed that in a good rainfall yea, household resource status, particularly their access to draft animal power, followed by access to seed and fertilizer played dominant roles to when a crop was planted and these relative to the rainfall received within the season, affected the overall crop yields

Runoff Generation

The impact of human-environment interactions on runoff generation is being studied in the project through the application of the SWAT model (Soil and Water Assessment Tool; Arnold *et al.*, 1993; Arnold and Foster, 2005). To date, this has been applied succesfully to the B72A, E, F, G & H quaternary catchments in the Olifants Water Management Area of South Africa (Ncube and Taigbenu, 2007.), with a strong correlation between measured and observed runoff data (Figure 3). Results showed a strong correlation between land cover and the hydrologic response: range grass reduced runoff the most, followed by forestry but arid land gave the highest increase in runoff. The SWAT model is now being applied in the Mzingwane river basin (Love *et al.*, in press b).

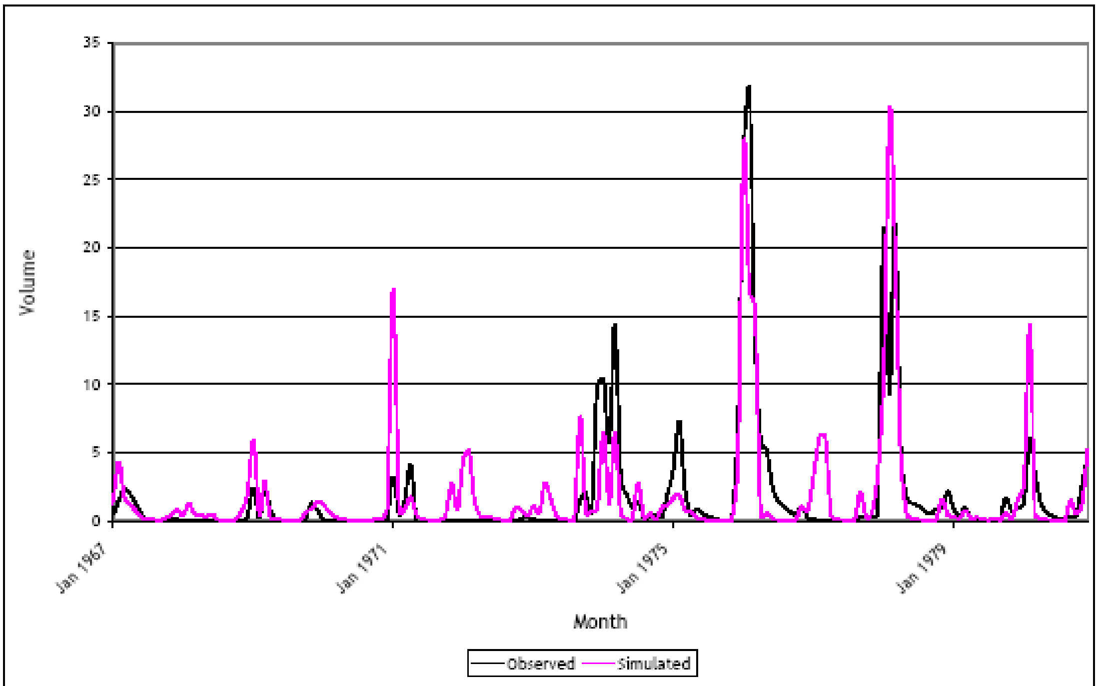

Figure 3 Observed and simulated runoff, B72E – H catchment, Olifants Catchment.

The Soil Conservation Services (SCS) method was used to measure rainfall-runoff relationships for the Mnyabezi and Bengu Catchments of the Mzingwane River using changes in volume of the small dams at the downstream end of each catchment as a discharge gauge (De Hamer, 2007b). The collected daily water level data from the period March - May 2007 were used to calibrate the rainfall-runoff model. The calibration process of the rainfall-runoff model resulted in an initial abstraction of 7.6

% of the actual retention. It was concluded that the SCS method is a useful tool to simulate the rainfall-runoff relation of small ungauged catchments.

Hydrogeological studies
Studies on the distribution, properties, usage and potential expansion of alluvial aquifers were carried out within the Mzingwane Catchment, showing that these offer a low cost and under-utilised source of irrigation water. The Lower Mzingwane alluvial aquifer is one of the largest, with an estimated storage of over 1.5×10^7 m^3 (Moyce *et al.*, 2006). Five commercial agro-businesses use alluvial groundwater for citrus, wheat, maize and vegetable production. The water is abstracted from boreholes and well-points in the river and on the banks. These large users are resupplied by release of water from Zhovhe Dam, which recharges the aquifer. Zhovhe Dam also releases water for Beitbridge town, which abstracts the water from the Limpopo River, into which the Mzingwane flows (Love *et al.*, 2007b). Downstream of agro-businesses are poor smallholder farming communities with no access to irrigation water. Studies show that sufficient alluvial groundwater is stored in this river reach to offer a good potential for smallholder irrigation (Masvopo *et al.*, in press). However, a disadvantage of the system is that the current scheme of managed releases from Zhovhe Dam has caused a change in the river morphology and the aquifer structure close to the dam. In the long run, this has implications for the sustainability of the aquifer (Love *et al.*, in press a).

The scale of equipment required to access water from the alluvial aquifer of a large river such as the lower Mzingwane is quite substantial: well points and electric pumps. However, the possibility exists that the use of sand dams and simpler abstraction technology may readily be used in smaller rivers (Mansell and Hussey, 2005) and these would be more affordable for poor communities to obtain and maintain. The limitations of scale and other factors were studied in the alluvial aquifers of three meso-catchments of the Upper Bengu, Mnyabezi 27 and Mushawe in the Mzingwane Catchment (Love *et al.*, 2007a). Results showed that for small aquifers such as these drying out occurred within a short period. The Upper Bengu aquifer dried out within 24 hrs and the Mnyabezi 27 aquifer within 17 days of a flow event. However, the Mushawe aquifer was determined to be perennial (Figure 4).

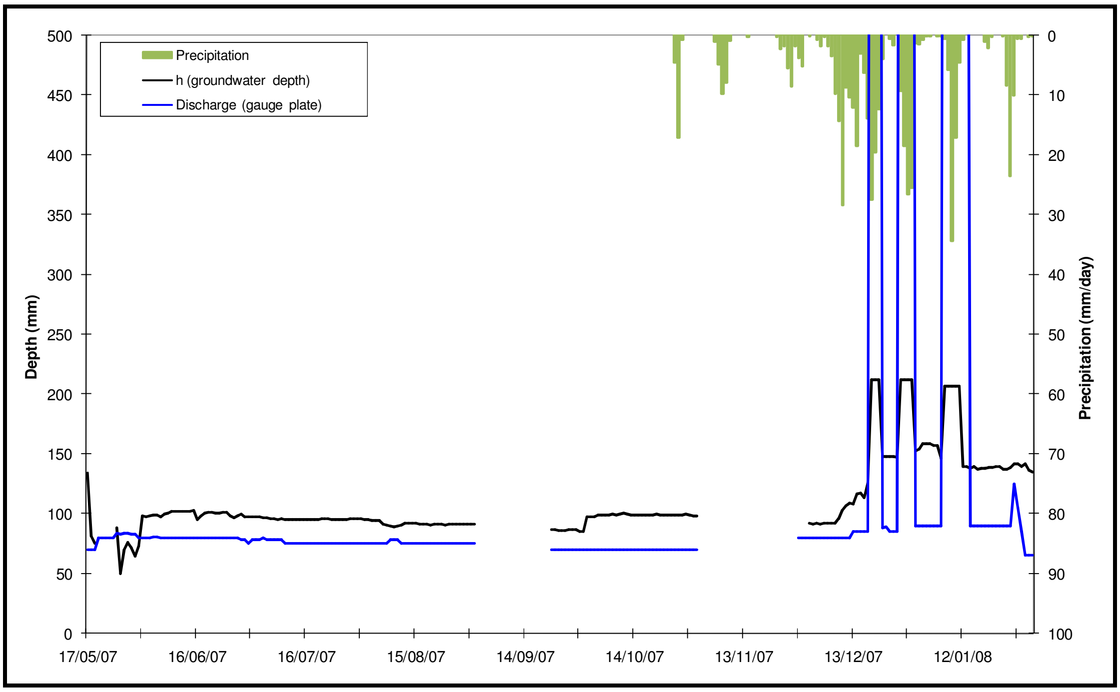

Figure 4 Variation of groundwater levels with river discharge and precipitation, Mushawe. The results show the availability of groundwater, even during the dry season. Dry season discharge is a result of outflow of groundwater from the top of bridge foundations which function as a sand dam.

The two main losses from an alluvial aquifer, evaporation and seepage, constrain the viability of any sand river to host alluvial groundwater. Evaporation is controlled by scale (mainly depth), while seepage is controlled by the underlying geology. It was determined that seepage is the main loss for aquifers with a depth of more than 1 m, and thus the main reason for the Mushawe aquifer being perennial is the favourable underlying geology – unweathered granites as compared to the highly weathered granitic gneisses at Bengu and Mnyabezi 27. This suggests that geological surveys (much of which are readily available) can provide a rapid method to indicate whether or not a small alluvial aquifer can hold water for extended periods of time.

Modelling the results using MODFLOW showed that the potential water supply in the Mnyabezi catchment under current conditions ranges from 2,107 m^3 (5.7 months) in a dry year to 3,162 m^3 (8.7 months) in a wet year (De Hamer *et al.*, 2007b). The maximum period of water supply after increasing the height of the dam spillway and building a sand dam was 2,776 m^3 (8.4 months) in a dry year and in a 3,617 m^3 (10.8 months) wet year. The sand storage dam can only be used as an additional water resource because the storage capacity of the alluvial aquifer is small, and compromised by seepage through the underlying weathered granite.

On-going studies include mapping groundwater in flows in fractured aquifers in underground workings (Figure 5).

Figure 5 Measuring fracture orientation for stress analysis, Vubachikwe Mine, Mzingwane Catchment.

Water Quality Management

Water quality studies have been carried out in Zimbabwe and Mozambique. Physico-chemical, biological and microbiological characteristics of 23 sites within the Limpopo River Basin in Mozambique were studied in November (2006) and January (2007) (Chilundo *et al.*, 2007). The obtained data indicated that sites located at proximities to the border with upstream countries were highly contaminated with transition metals. This suggests pollution from industrial or mining sources, mainly in South Africa but also in Zimbabwe. In contrast, further downstream, the ions concentration, faecal coliforms and elevated organic loads derived from discharge of untreated wastewater were responsible for the deterioration of water quality at sampled sites. The differences of some parameters were statistically significant ($p<0.05$) when the concentrations found in November and in January were tested, suggesting a possible influence of flow increase for the change of concentrations.

A systematic water quality monitoring network composed of 16 stations was proposed within the basin. Ambient, operational, effluent and early warnings were the main monitoring types recommended. Furthermore, the study recommends additional research at a basin scale to identify the sources and fates of pollutants, its transport along the main subcatchments and impacts for the downstream ecosystems.

Analyses of water quality in the Zhulube catchment, a key study area in the Mzingwane Catchment, Zimbabwe showed elevated levels of mercury and sulphates in the Tshazi River, which have been attributed to the processing of gold ore along the river (gold panning), and high levels of iron, nickel and arsenic which may be due to the local geology (Tunhuma *et al.*, 2007b). Mercury levels were highest along the

Tshazi river where gold panning is widespread. Sediment levels in the Tshazi River are nearly twice as high as those of the Zhulube River (Tunhuma *et al.*, 2007a). The results have prompted further studies under the new dimension of Payment of Environmental Services (PES) a collaborative project with another CPWF project. The results will show the extent of the problem but more importantly how the communities view the issue and how they think the problems can be solved.

4. Farmer Field Based Action Research (FFBAR)

Farmer field based action research has been conducted within the three pilot catchments within the Limpopo Basin. The main objective of the work is to develop 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. Research has so far covered interventions such as conservation farming (Zimbabwe), rainwater harvesting (South Africa, Mozambique and Zimbabwe), irrigation and salinity (Mozambique), wetland cultivation (Mozambique) and drip irrigation (Zimbabwe). Work on drip irrigation has been completed and presented to a wider audience and a policy brief has also been produced (Moyo *et al*., 2006). Wetland cultivation is the focus of another Challenge program project hence this section will discuss conservation farming, rainwater harvesting, supplemental irrigation and salinity studies only.

Conservation Farming

On-farm and on-station experiments were established in the Mzingwane catchment 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 intention was to measure soil water changes and runoff losses from maize plots under the four tillage practices (Mupangwa *et al*., 2007a, 2007b). Runoff losses were found to be highest under conventional ploughing. Planting basins retain most of the rainwater that falls 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, and was generally highest under conventional ploughing and lowest under basin tillage. Soil water content was consistently higher under basin tillage than the other three tillage treatments (Figure 6).

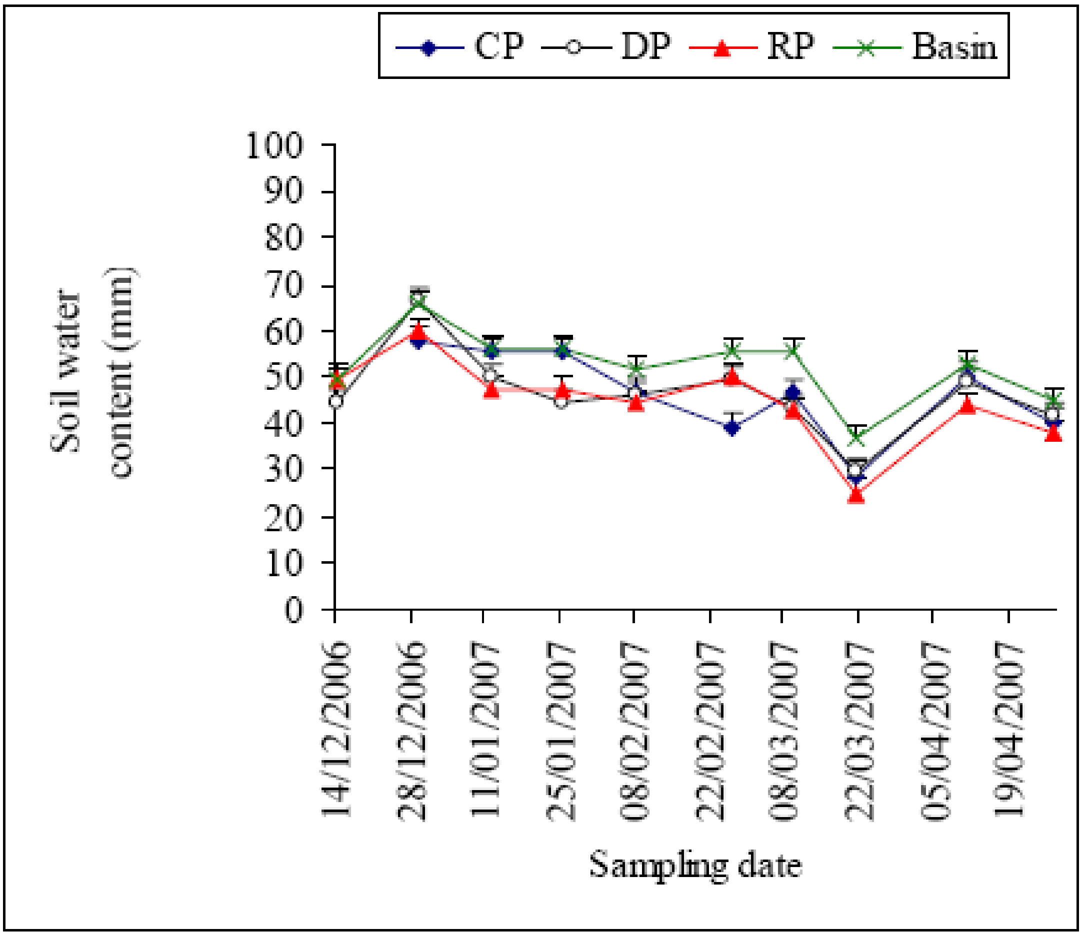

Figure 6 Soil water content for different tillage practices; CP = conventional ploughing, DP = deep ploughing, RP = ripper.

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 practice. Maize yield results have shown that when nitrogen fertilizer is applied in addition to water management crops yields can increase by margins of up to 200kg/ha, improving the household food security of smallholder farmers. Similar results have also been obtained for on-station studies of cowpea under the same range of treatments as the maize in Zimbabwe (Mupangwa *et al.*, in press b) and cowpea and maize in Mozambique (Julaia, 2007): at a significance level of 10 %, one site showed significant maize yield differences between the water treatments, reaching larger yields when produced on basin tillage with mulching than under conventional tillage.

Rainwater Harvesting

In Mozambique four studies examined rainwater harvesting (Mamade, 2006) and an inventory of rainwater harvesting techniques was prepared. The main rainwater harvesting techniques identified were: pits, flood recession agriculture, small dams and use of road runoff water. Within these techniques, the pits appeared to be the most adopted by the local families (approximately 21 %). The study shows also that some techniques are used simultaneously like the flood recession agriculture, most of the times combined with sowing pits or furrows.

Another study in Mozambique looked at the potential of rainwater harvesting through its “multiplicative” effect to improve the maize production in rainfed regime in the Chókwè District (Niquice, 2006). The results showed that yields in rainfed crop production are variable and affected by the rainfall distribution, with water deficits occurring in flowering and grain filling stages. The safety to obtain yields ($Ya/Yp \geq$ 0.5, 0.65 e 0.8) increased with the level of the expected yield. Using harvesting factors, the safety to obtain yields ($Ya/Yp \geq$ 0.5, 0.65 e 0.8) was reduced. The harvesting factor of 5 is the most suitable to obtain safety yields.

In Zimbabwe, using field survey results, the Agricultural Production Simulator Model (APSIM) was used to simulate seven different treatments (Control, Rain Water Harvesting (RWH), Manure, Manure + RWH, Inorganic Nitrogen and Inorganic Nitrogen + RWH) for 30 years on deep aAlfisol 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 transpirational water productivity (from 1.75 kg m^{-3} up to 2.3 kg m^{-3} on average) by mitigating in-season dry spells (Mwenge Kahinda, 2007).

In Sekororo South Africa, a study was undertaken to evaluate the rainwater harvesting tanks established under the CPW&F small grants programme (Ramay, 2007). The study showed that many farmers do not use the tanks, even when inflows of water had occurred. The water requires lifting from the tanks, which the farmers have to do with buckets and they are reluctant to do this. Furthermore the small storage capacity of the tanks means they cannot irrigate for very long, at best for one or two months on a very small garden (< 500 m^2). The tanks can only supply irrigation water to the larger plot size of 5,000 m^2 for a few days. Given the labour costs of installation, the livelihood benefit of the rainwater harvesting tanks was found to be negligible.

Supplemental Irrigation

Crop yield risk and vulnerability studies have been conducted in Sofaya, Subcatchment B72A of the Olifants Catchment. Fieldwork and modelling are in progress in a study linked to agricultural water productivity. Crop yield risk and vulnerability to drought was studied from an interdisciplinary perspective by applying a set of indicators (physical, socio-economic and environmental) in order to define drought risk management and sites requiring urgent intervention (Magombeyi and Taigbenu, 2007)

Results indicate that the long-term frequency of droughts and dry spells occurred at intervals of 2 years and 2 times in one season respectively, indicating high frequency of exposure to drought and dry spell hazards. The maize crop yield can be significantly reduced by intra-seasonal dry spells at critical growth stages even if total seasonal rainfall is above average. The impact of dry spells in the 2006-2007 is demonstrated by comparing the variation in soil moisture content between the rainfed site and the site where supplemental irrigation was applied (Figure 7) with yield.

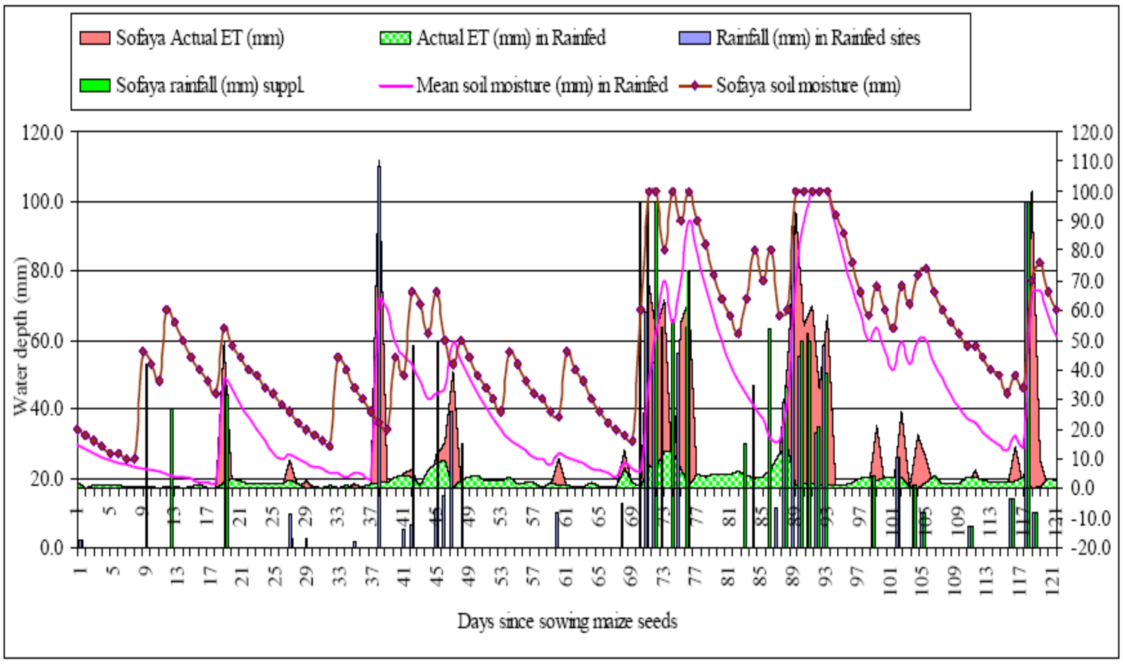

Figure 7 Climatic data monitored in pilot plots, Subcatchment B72A: Sofaya supplementary irrigation site vs. rainfed site.

The moisture deficit occurred from the 55th day to 70th day which are the vegetative and flowering stages of the maize crop. Sofaya site, which applied supplementary irrigation (120 mm), managed to keep the moisture content above 18 – 20 % at the flowing stage and above 30 % for the rest of the growth stages to yield formation and ripening. However, under rainfed moisture soil moisture content went below 6 %. The yield realized from the Sofaya site was 2.0 t/ha (ET_{actual} = 430 mm) while for the rainfed site it was 0.6 t/ha (ET_{actual} = 320 mm).

Salinity studies

The Chókwè Irrigation Scheme (CIS) in Mozambique is experiencing variable and declining crop yields mainly due to soil salinisation and other agronomic practices that include poor water management. This is aggravated by the semi-arid climatic conditions and climate change phenomena which affects the availability of water and increases the occurrence of floods and droughts in the region. Work within the scheme includes assessing the supply-demand issues in relation to irrigation water as well as the management strategies under different soil salinity conditions in the CIS (Munguambe, 2007).

Trials have been established according to treatments outlined in Table 1 at three sites within the CIS. The sites are characterised by different degrees of salinity (Table 2). Hydrological parameters were characterised using 17 piezometers, 8 permeability tests and 12 infiltration tests.

Table 1 Trials in the Chókwè Irrigation Scheme

Water Treatment	Nitrogen Treatment
Irrigation water is applied once a week according to a scheduling/calendar	Farmers practice: 100 kg/ha for a target yield of 5-6 ton/ha
Irrigation water is applied once a week according to soil water deficit (adaptive management: salinity threshold)	Increased nitrogen: 200 kg/ha for a target yield of > 10 ton/ha

Table 2. Salinity characterisation of study sites, Chókwè Irrigation Scheme

[redacted]

Preliminary results indicated that the final grain yield of the none-saline plots (~10 ton/ha) was twice the yield under saline conditions (~4.8 ton/ha) in both seasons. The impact of nitrogen application rates and the water treatments on the final yield was not significant. Both nitrate and salt contents tend to decrease along the growing season as a result of the leaching process. Therefore, the use of an integrated and adaptive approach for both salt and nutrient management was found to be relevant in mitigating the nutrient leaching under salinity conditions (Munguambe, in press).

5. Institutional Models

The main objective of institutional research is to develop institutional models for water governance that aim at strengthening policies for water productivity and risk mitigation at catchment and basin scale. Work in this area has been carried out mainly in Zimbabwe and South Africa. Work has so far covered institutional mapping, historical analyses of water management and allocation, and stakeholder participation. Studies in the last year of research will include using the Institutional Analysis and Development (IAD) Framework to isolate and analyse institutional arrangements and governance outcomes in water management, and rural crop and livestock production. The framework will be used to locate and analyse a number of aspects of institutions and how they influence governance outcomes. So far Institutional research has produced some interesting results.

Institutional Mapping

Work in Zimbabwe included an analysis of water resources management at the local level. Institutions at the local level were identified; and linkages between institutions mapped; and the strengths and weaknesses of local institutions identified. Water Point Committees have the responsibility of allocating water, deciding on issues such as turns, ensuring that there are no conflicts, and resolving them should they arise. However, these committees tend to only operate properly where there is a manageable infrastructure, such as valves or pumps. This can be seen by the difference between a dam managed for irrigation water and livestock dams in the same communal area.

Boreholes in a village tend to be well managed, but boreholes near business centers are usually neglected, and they almost literary belong to no one (Mabiza *et al.*, 2006).

Historical Analysis of Water Management and Allocation

The trajectory of the Olifants Basin was studied from an historic perspective (Van Koppen, 2007). The colonial state, which lasted till 1994 in South Africa, systematically prevented historically disadvantaged individuals (HDIs) from becoming significant water users, let alone 'economically viable' water users. In contrast, white water users undertook major water resources development, which, by the 1970s resulted in the emergence of a 'white water economy'. In this era, water governance concepts were introduced such as water as an economic good, planning according to basin boundaries, involvement of the private sector with the state's role shifting to regulator, and the recognition of 'the environment' as a water user in its own right. Water management under the new dispensation, as enshrined in the National Water Act (1998) brought continuity and change. The 'white water economy' continued as a formal water economy serving 'economically viable water users', also in the Olifants WMA. However, in implementing already planned infrastructure, there was more emphasis on water as a social good, bulk domestic water supplies, public participation and Environmental Impact Assessments. Two institutional innovations in the Act, Catchment Management Agencies (CMAs) and participatory water resource strategy formulation, are aimed at democratizing water resources management in the institutional void of South Africa's transition from territorial and institutional segregation to a unitary state. After dismantling the apartheid governance structures and replacing those by brand-new Provincial and Local Government and still transforming line agencies, the major challenge is building from scratch water delivery support structures and ensuring coordination. Efforts are increasingly aligned under the umbrella of 'Water for Growth and Development', which is developmental, better targets HDIs, and calls for integrating domestic water services and water resources management.

Re-allocation of water rights under water reforms have been found to be just as important to smallholders as land reform, and just as hotly contested. Re-allocation of water does not mean that the struggle for water stops, on the contrary, the struggle for water rights continues (Liebrand, 2007).

Stakeholder Participation in Water Management

The participation of rural community members in smallholder formal and informal irrigation activities in their locale, and their representation in the new water councils was studied in Zimbabwe (Svubure, 2007). A framework of analysis, informed by notions on participation and institutional arrangements for collective action was constructed to help understand what shapes the participation of community members in smallholder formal and informal irrigation water use associations in Zhulube, Mzingwane Catchment. It was determined that the availability of family labour, age, wealth, gender, and farming experience were some of the human factors that contributed to the attainment of membership in the water use associations (WUAs). WUAs have elaborate decision-making structures under which in practice, the general meeting of all members is used for decision-making through a laborious consensus decision-making process. It was also observed that the WUAs network with other institutional arrangements around them and that the subcatchment and catchment councils are virtually unknown to the water users on the ground.

In the Olifants Catchment a study was carried out to find out whether there are locally defined categories within Sekororo that are used to include or exclude others from accessing, using and benefiting from water resources. In cases where increasing scarcity of socio-economic resources, competition over rights of access and use to available resources tends to increase and processes of exclusion become more explicit and potentially violent. The research was primarily based on exploratory qualitative research work where interviews, group discussions, transact walks and document review were the main methods for data collection. Preliminary results show that ethnicity, gender and religion are the more important categories for group formation and exclusion. These groups become overlapping and contested categories that define identities of the various actors involved.

IWRM Systems Development

Work in this area is still being developed in all countries. However, some concepts have been investigated in Zimbabwe. The concepts of 'catchment planning', 'stakeholder participation' and the political nature of water resources management were investigated, particularly how they are understood and implemented in catchment planning processes (Mabiza *et al.*, 2007; in press). The study also assessed how different actors envisage the output of the process (and the catchment plan itself). The national guidelines on catchment planning as contained in the Water Act (1998) were used to get the national overview on catchment planning. Document review and key-informant interviews were used to investigate how catchment planning is understood by different actors, how the process was planned for, and how stakeholders were involved in it. Data shows there are different conceptualisations of 'catchment planning' between and among the drafters of the law, policy-makers, policy-implementers and the water users. Institutional actors spearheading catchment planning processes also do not have the capacity to engage different stakeholders. It is suggested that catchment planning and stakeholder participation have to be understood in the context of the strategic interests of the different actors which determine how they view the whole process.

6. Training and Capacity Building

The main reasons for incorporating training and capacity building in the project were to build human capacity among farmers, extension officers, water managers and researchers at local universities in the Limpopo Basin and in Southern Africa. Strategies to implement this objective have been varied. Key research in PN17 is undertaken by seven Ph.D. fellows, registered at WaterNet member institutions. The fellows are supervised by scientists from member universities and participating CGIAR centres. Each Ph.D. fellow is linked to masters (MSc) students who undertake their dissertation projects within PN17. The unique benefit of this arrangement is the involvement of scientists in the supervision of research and capacity building projects at different scales, starting from farmer fields to river basin results in the development of core capacity, with an appreciation of the challenges and linkages at the different scales within the basin.

A total 30 masters dissertations have been completed and accepted: 20 at the University of Zimbabwe, 2 at the University of the Witwatersrand, South Africa, 1 at Guelph University, Canada, 1 at Colorado State University, USA, 3 at UNESCO-

IHE,Netherlands, 1 at Wagenigen University, Netherlands ,1 at Twente University of Technology, Netherlands and 1 at the Delft University of Technology, Netherlands. Of these dissertations, 26 were funded directly through Challenge Program PN17 funds or matching funds, and 4 were funded through linked Challenge Program projects, 2 at the University of Zimbabwe, 1 at Eduardo Mondlane University, Mozambique, 1 at Limpopo University, South Africa, 1 at the University of the Western Cape, South Africa, 1 at University of Pretoria, South Africa.

The project also involves capacity building at community, extension officer and water manager level:

1. Participatory on-farm pilot studies involving farmers and extension officers provides indirect training.
2. Participatory development of institutional and water resources models involving water managers also provides indirect training.
3. Direct training and extension shall also be provided in key areas.

7. Conclusions

A lot of knowledge and data has been generated through the Project PN17. The objective of capacity building has been fulfilled to a large extent. Water resources research, farmer field based action research and institutional research approaches have also generated a large wealth of scientific knowledge and in some cases interventions that have shown immediate benefits to the smallholder farmers. The next challenge is to inform policy and to make sure that the developed interventions benefit the Limpopo basin population through upscaling and outscaling the results. It has been recognized that upscaling and outscaling will not be possible within the time frame of the project. Therefore, the project is now establishing linkages with the CPWF basin focal project (BFP) through FANRPAN. One of the major objectives of the BFP project is to validate and test agricultural water management "intervention packages" that have been developed within the basin. This provides a niche for disseminating the results of the PN17 project.

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