CPWF Project Report

Wetlands-based livelihoods in the Limpopo basin: balancing social welfare and environmental security

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List of Acronyms

CDF	Community Development Forum
CRCE	Center for Rural Community Empowerment, University of Limpopo
DEAT	Department of Environment and Tourism
DWAF	Department of Water Affairs and Forestry
EO	Extension Officer
IWMI-SA	International Water Management Institute, Office for Southern Africa
KNP	Kruger National Park
LPDA	Limpopo Province Department of Agriculture
MWP	Mondi Wetlands Project
NDA	National Department of Agriculture
ORF	Olifants River Forum
RESIS	Revitalization of the Small Scale Irrigation Schemes
UNDP	United Nations Development Program
WC	Wetland Committee
WFW	Working for Wetlands

Acknowledgements

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Executive summary

This report is a synthesis of research implemented for the project on Wetlands-based livelihoods in the Limpopo basin: balancing social welfare and environmental security. The research was motivated by the dependency of many people on wetlands for their livelihoods. It was therefore founded on the basis that the potential of wetlands to contribute to livelihoods is closely related to their ability to maintain ecosytem functions (such as regulating river flows), which is a consequence of their unique hydrological characteristics. The research aimed to contribute to wetland management and ultimately contribute towards ensuring environmental sustainability (MDG7) through the maintenance of vital ecosystem services provided sustainable agricultural practices (in terms of sound hydrological and pollution management) and balanced exploitation of resources are practised.

The project aimed to contribute to enhancing food security and improving the livelihoods of wetland-dependent communities by increasing productivity of water and optimizing and maintaining wetland ecosystem services.

Specifically the project aimed to

- Develop and apply a trade-offs based framework for making decisions about allocations of wetland resources to specific uses, including agriculture.
- Determine the trade-offs among different agricultural uses of wetland water and the trade-offs between each of the agricultural water uses and environmental use; develop guidelines on acceptable levels of wetland water use for agriculture; and encourage this as best practice.
- Identify as part of the trade-off analysis who benefits, e.g., poor women and men farmers, herders, fisher folk; local business people; etc.
- Enhanced capacity of wetland users, researchers, extension officers, natural resource managers, and policy makers.

The most important achievements of the project are the new knowledge and tools captured in the three main outputs of the project – the Framework for inventory, the WETSYS tradeoff model, and the Guidelines for sustainable management - and the partnership and capacity building that resulted from implementation of the project that provide the basis for impact.

The Framework for undertaking wetland inventory, assessment and monitoring in the Limpopo basin, and the tradeoffs model (WETSYS) satisfy the first objective. Objectives two and three were addressed through analysis in case study wetlands as presented in various reports and MSc thesis and summarized here, and in a synthesis that constitutes the third main output of the project: 3) the Guideline for sustainable wetland management and utilization. The forth objective was achieved through engagement of numerous undergraduate and MSc students, direct project engagement with various local extension officers and natural resource managers and through dissemination of new information to higher level decision makers, and feedback workshops to the communities that served the purpose of increasing awareness of wetland value, goods and services.

Key outputs

The framework for undertaking wetland inventory, assessment and monitoring in the Limpopo basin in southern Africa (Finlayson and Pollard, 2009) based on internationally agreed principles and using information and examples from wetlands in the Limpopo River basin provides an outline of approaches and lists key references and source materials along with practical examples and applications. The framework contains information and guidance for making decisions about what inventory, assessment and monitoring is required in response to the main uses and (anticipated) management issues at identified wetlands, whether at the local or basin-scale. It provides information to support managers make decisions about sustainable use of wetlands; it is directed at decision-makers in government agencies. The framework needs to be supported by a capacity development program focusing more specifically on the practicalities of assessing and monitoring wetlands in the Limpopo (and potentially elsewhere) with an emphasis on approaches that can be readily undertaken and provide early warning of possible adverse change. Such a capacity development program could include training and awareness raising components based on user needs related to inventory, assessment and monitoring and how to consider wetland issues at multiple scales from local site to basin-wide.

The integrated tradeoffs model (WETSYS, Morardet, et al, 2010) offers an opportunity for improved understanding of the linkages and feedbacks between different components of the wetland systems and supports the analysis of trade-offs between supply of ecosystem services by the wetland and the wetland's capacity to continue delivering the ecosystem services. The model outcomes assist users and others to understand and discuss more openly the impact of, for example, clearing of reeds for cropping, on the livelihoods of households that are dependent on harvesting natural products. The tradeoffs modeling exercise at the GaMampa wetland showed that tradeoffs are evident at local level, between cropping, natural product harvesting, livestock grazing. The modeling process was instrumental in fostering inter-disciplinary dialogue and identifying knowledge gaps.

The WETSYS model can be used to simulate different management interventions under various global change scenarios. Localized global change scenarios will include changes in climate (rainfall and potential evapotranspiration), population dynamics (changes in natural growth and emigration rate) and economic policies (affecting among others social transfer and level of wage rate). Wetland management options, which will be simulated, include introduction of crops more adapted to wetland environment and reduction of artificial drainage, development of ecotourism with the launch of a recently built tourism facility, and imposing controls on resource use in the wetland. Due to its modularity, WETSYS can easily be adapted to similar small-scale wetlands in Southern Africa.

The guideline for sustainable wetland management and utilization (Chuma et al, 2008). contributes to sustainable utilization and management of wetlands whose ecosystem services are used to support livelihoods.

The main aim of the guidelines is to provide a framework for utilizing and managing wetlands, particularly those wetlands whose ecosystem services are used for livelihood purposes. Its emphasis is to find ways to reconcile the value of ecosystem services that accrue to the livelihoods and the conservation of this important resource in the long term. The guide delivers practical management solutions at three stakeholder levels: farmers and other natural resource users, natural resource management agencies, and governments. It complements government efforts in their quest for effective regulation of wetlands utilization and management.

The guidelines address the needs and interests of three main groups of stakeholders. For users of wetland ecosystem services it provides examples of wetland management based on observations in communities whose livelihoods depend on wetlands goods and services. For policymakers the guide shows the complexity of putting in place functional institutional arrangements that ensure sustainable wetland utilization and hence the importance of considering the linkages and interactions of the different governance arrangements in a wetland. For researchers keen to ensure that utilization and management of wetlands is based on the best available information, the guide provides a framework for research question formulation and framing of research results to ensure relevance to the policy and practical environment.

The partnerships developed through implementation of this project span disciplines, institutions, and countries. The project enabled close collaboration between researchers from multiple disciplines, and strong partnerships were developed with local communities at all three project sites (Intunjambili, GaMampa, and Missavene). Significant capacity building was achieved through joint implementation of research projects with university partners resulting in numerous in-depth analysis of specific issues. Students spent a significant amount of time engaging with stakeholders, understanding stakeholder interests and concerns.

The relationships with the communities of GaMampa and Intunjambili wetlands still continue through other projects (for example the recently initiated WETwin project that focuses on enhancing river basin management through wetland management) developed as a result of the partnership developed and nurtured during implementation of the CPWF funded project[1]. The WETwin project builds on the concept of tradeoffs analysis.

1 WETwin is an EU supported project on "Enhancing the role of wetlands in integrated water resources management for twinned river basins in EU, Africa and South-America in support of EU Water Initiatives". The project objective is to enhance the role of wetlands in basin-scale integrated water resources management (IWRM), with the aim of improving the community service functions while conserving good ecological status.

Finally the involvement of government officials who have the primary responsibility for natural resources management – Department of Environment in South Africa, MICOA in Mozambique, and the Environmental Management Agency in Zimbabwe – ensures that decisions for wetlands and natural resources management in general considers local uses of resources and benefits that accrue locally. This ensures long term awareness and incorporation of local concerns into management programs. There are no guarantees that government officials will continue to be committed to local stakeholders. Yet there seems to be some continued involvement of public officials, for example at GaMampa, more than a year after the project activities on the ground ended. With support of the Landcare Unit of the Limpopo Department of Agriculture, the community sought financial support from the UNDP to assist them in managing the wetland resources.

Implementation

The research was done in three wetlands in the Limpopo River basin, the Intunjambili wetland in Zimbabwe, the GaMampa wetland in the Olifants River catchment, and at Missavene, a floodplain wetland in the lower part of the river basin in Mozambique. Not all the planned activities were implemented in all wetlands, and GaMampa had a higher level of activity due to strength of partners and ease of access. The development of the WETSYS model components took more time than anticipated, and thus it was not possible to test and implement the WETSYS model in all wetlands. Continued use of the model in more wetlands, as is proposed under new projects, will enrich the results and carry forward the work of this project. The greatest constraints to achieving impact relates to the lack of capacity and political and institutional contexts that preclude effective planning and implementation of improved wetland management. These issues are highlighted in the findings and recommendations below.

Key findings and recommendations

Key findings and recommendations from the research are:

- At local level the value derived from wetland farming and the harvesting of other wetland products is significant and has been documented for the study wetlands. This value forms a significant part of households' income and livelihood, and the wetland-dependent proportion of livelihoods is greatest in the poorest households. Thus the poorer segments of the community stand to lose the most if when wetland function is degraded, or when the better off captures resources.

- The WETSYS model provides a way of integrating existing knowledge on small-scale wetlands such as the GaMampa wetland in South Africa and support the analysis of trade-off between supply of ecosystem services by the wetland and its ecological integrity. It is potentially influential fostering inter-disciplinary dialogue and identifying knowledge gaps.

- At the scale of individual wetlands, there is no clear link between land use in the small wetlands and hydrological regime of the catchments in which these wetlands lie. However, the hydrological functioning of the individual wetlands creates conditions that support livelihoods for example through supporting agriculture. Agricultural use of these wetlands impacts water supply at wetland level and the capacity of the wetland to provide water for such use.

- Farmers attempt to create conditions suitable for desired crops rather than finding crops suitable for the wetland condition. The agricultural extension service has a role to play in helping farmers choose crops suitable for the wetland environment.

- Maintenance of a shallow water table in the wetland aquifers is essential for crop production. Water management interventions for agriculture should focus on managing the water table and water distribution across the landscape rather than drainage as a way of minimizing tradeoffs between crop production and water supply.

- Despite the rules and regulations at national level in Mozambique, South Africa, and Zimbabwe, land and water management in wetlands takes place at local level. Different rules, sanctions and penalties are applied and enforced at this level. The local level is therefore the most logical entry point for effective and sustainable management of wetlands.

- Through this project concerted effort was placed on knowledge generation, identification of technologies, and developing capacity of local communities. Continued capacity development for those that engage with local communities to effectively deliver programs to these communities is needed. Capacity development content for this target group should cover facilitation, technical, and management skills.

- The diversity of points of view of wetland stakeholders, including within the local community, and potential tensions between local and external stakeholders requires the participation of all stakeholders at various scales for the sustainable management of such complex systems. However, considering the inequities among stakeholders in terms of wetland technical knowledge, understanding of institutional context, financial means and political power, ensuring the conditions for a real participation is still a challenge and will need government involvement.

- Policy and legislative environment and the penalties for cultivating in wetlands are not sufficiently deterrent. This results in continued wetland use for prohibited uses.

- The design and implementation of relevant policies that are targeted to groups that are dependent on resources and manage these resources should take into account the socio-economic characteristics of households within the community. The socio-economic characteristics of households shape the livelihood strategies that the households engage in.

- Efforts to improve wetland management should integrate awareness, capacity building and programs aimed at supporting alternative livelihood avenues to enable the poor to diversify into non-resource based livelihood activities. This has to be linked with broader rural development programs such as introduction of improved agricultural technologies, investment in irrigation infrastructure, improving access to markets, and specific intervention that promote alternative livelihood strategies.

- There exist opportunities and incentives that can be used as entry points for better and sustainable management of wetlands. These include identifying, together with communities, ways of broadening people's livelihood options. Some apparent opportunities can be seen in promotion of high income wetland use like ecotourism, identifying new markets for off-farm income such as brick-making that takes place around the wetlands, and as well as integrating wetland management into broader rural development programs that are aimed at access to high yielding varieties, improving access to markets, and better extension services. Management options that include strategies to support alternative income generating activities to broaden the livelihood options of the poor will reduce pressure on wetland resources.

- Capacity development for management of natural resources remains an issue in southern Africa. It is recommended that a capacity-building program focusing more specifically on the practicalities of assessing and monitoring wetlands in the Limpopo (and potentially elsewhere) with an emphasis on approaches that can be readily undertaken and provide early warning of possible adverse change. This program could include training and awareness raising components based on user needs related to inventory, assessment and monitoring and how to consider wetland issues at multiple scales from local site to basin-wide (Finlayson and Pollard, 2009).

Further research recommended

- Further research is needed to identify and formalize a set of relevant indicators for institutional functioning of wetland systems in order to include them in the tradeoffs analysis model, and management decision making.

- Tradeoffs analysis was implemented at local level. Extrapolation of research findings, analysis of representativeness of this project's local studies, and up-scaling at catchment level to assess the cumulative impacts of small wetlands use for livelihood purposes at catchment level.

- Our results show that the poorest are most dependent on wetlands, and on a very diverse set of services. Further work could elaborate the diversity of wetland users and the role played by wetlands in their livelihoods strategies, and support these strategies with information about the values of the range of wetland resources and how they might be increased in a sustainable way.

0. Introduction

Wetlands in the Limpopo River Basin (LRB) are important aquatic systems. Their most visible characteristic is the abundance of water in them particularly in the dry season, when compared to the surrounding catchment area. They are an important resource in this basin that is characterised by climatic extremes. The wetlands in the LRB are predominantly *dambos* (seasonally or permanently saturated areas, also referred to as pans), pans, and riverine wetlands. Dambos and pans are associated with some of the upper catchments in the basin, with significant occurrence in the upper Olifants catchment in South Africa; the Mwenezi, Shashe, Tuli, Umzingwane, and Bubi catchments in Zimbabwe; and the tributaries of the Changane catchment in Mozambique. Riverine swamps are confined to the main stem of the Limpopo and Changane tributary and the lower reaches of the Limpopo River in Mozambique. Of the nearly 58,000 hectares of wetlands in the Upper Olifants tributary, 11% are pans (Marneweck and Batchelor, 2002).

In Zimbabwe and Mozambique it is mainly communal populations who live around the dambos and make use of these highly productive resources. In the upper Olifants catchment in South Africa several pans occur on commercial farms, and are used for livestock grazing and cropping. In Zimbabwe and Mozambique, many poor people depending on agriculture for their living utilize wetlands to mitigate problems of low crop yields associated with droughts across the region, and the low rainfall that is characteristic of the basin. The wetlands support livelihoods through agriculture for both food production and income. Dry season crop production and livestock production are some of the uses of dambos and riverine wetlands in Mozambique (Gomes et al., 1998). In drought years wetlands often have sufficient moisture to sustain crop production, mitigating the potential impacts of drought on food availability. Irrigation in the wetlands provides the means to intensify food production, and alleviates constraints resulting from short drought spells or mid-season droughts. If properly managed, wetlands are an asset to the rural communities who depend on them.

In addition to provisioning services through crop and animal production, wetlands support a number of other important environmental functions, including flood control and biodiversity. They are complex and ecologically sensitive environments that are intrinsically linked to the catchments in which they occur. Altering the wetland environment through cultivation, for example, has potential impacts across the wetland and the associated downstrean areas. As such, agricultural production in wetlands has traditionally been considered an antithesis to the conservation of wetlands. The perception is that crop production in wetlands causes degradation of the wetlands, and results in loss of benefits. Yet agriculture has taken place in some of these wetlands for many years, and farmers, regardless of conservation efforts and restrictions through legal instruments, and driven by escalating unemployment, poverty, and increasingly unreliable rainfall, continue practicing varying levels of agriculture in marshes and swamps. Long-lasting efforts towards sustainable management and conservation of wetlands cannot focus on conservation alone; it requires that farmers are taken on board as co-managers of the resource.

There is a large gap in the understanding of the effects of land uses in the wetlands on hydrological processes in the catchments. The agricultural interventions whose costs and benefits are largely unknown make the wetlands, especially the dambos and pans in the upper catchments quite vulnerable. Moreover, the impacts of activities in dambos and pans located in the upper catchments on downstream users (water supply and quality, flood control, flora and fauna, etc.) are still not well understood. While history has shown that wetland ecosystems have the potential to support reasonable livelihoods, continued unplanned conversion of wetlands to cropland will result in environmental degradation and severely compromise the other benefits derived from them. In recent times, perhaps as a result of the realization that restrictions and conservation efforts have not had the expected impact, traditional conservation-oriented thinking has shifted. Globally, 45% of the more than 17,000 major sites devoted to biodiversity conservation have at least 30% of their area utilized for agriculture (Scherr and McNeely, 2002). Solutions to ensure protection of these environments and productivity for people need a multi-pronged approach focusing on conserving the wetlands while maintaining the livelihood benefits to local people.

Over the last decade numerous studies have addressed sustainable utilization of wetland issues but have not addressed the issue of how much wetland area should remain unconverted, and the different levels of intensity of use that do not adversely affect the ecosystem services. In this project trade-off analysis, which can be used to support such decision making processes in agricultural production systems (Antle et al., 2002), was used to study the mix of agricultural water use strategies (crop, livestock production, and fisheries) in *dambos* and riverine swamps and wetlands, and the trade-offs among them, and focused on facilitating sustainable wetland management and development. It developed guidelines and tools that assist in making decisions regarding the use of these wetlands to ensure that livelihoods continue to be supported in a way that does not compromise environmental security. The research was based on the premise that wetlands can be managed in a sustainable manner, and that a balance between protection and agricultural production can be achieved, ensuring optimal use of wetlands.

1. Objectives

The project aimed to contribute to enhancing food security and improving the livelihoods of wetland-dependent communities by increasing productivity of water and optimizing and maintaining wetland ecosystem services. Specifically the project aimed to

- Develop and apply a trade-offs based framework for making decisions about allocations of wetland resources to specific uses, including agriculture.
- Determine the trade-offs among different agricultural uses of wetland water and the trade-offs between each of the agricultural water uses and environmental use; develop guidelines on acceptable levels of wetland water use for agriculture; and encourage this as best practice.

- Identify as part of the trade-off analysis who benefits, e.g., poor women and men farmers, herders, fisher folk; local business people; etc.
- Enhance capacity of wetland users, researchers, extension officers, natural resource managers, and policy makers.

The first objective was fully achieved as evidenced by two of the three main outputs of the project: 1) the Framework for undertaking wetland inventory, assessment and monitoring in the Limpopo basin, and 2) the tradeoffs model (WETSYS) for analyzing tradeoffs made by the different resource use options. Objectives two and three were addressed through analysis in case study wetlands as presented in various reports and MSc thesis and summarized here, and in a synthesis that constitutes the third main output of the project: 3) the Guideline for sustainable wetland management and utilization. The forth objective was achieved through engagement of numerous undergraduate and MSc students, direct project engagement with various local extension officers and natural resource managers and to a lesser extent dissemination of new information to higher level decision makers.

2. Study sites

The project was implemented at three sites in the Limpopo River basin, the Intunjambili wetland in the drier upper part of the basin in south western Zimbabwe, the wetland in the Olifants River catchment in the middle part of the basin, an area with middle range rainfall, and at Missavene, a floodplain wetland in the lower part of the river basin in Mozambique (Figure 1.

2.1 Intunjambili wetland

Intunjambili wetland is located at Intunjambili village in the Matobo communal area in the Matebeleland South province in southwestern Zimbabwe (Figure 2). The Matobo communal area is located about 50 km south west of Bulawayo City. It lies in agro-ecological region 4 (see for definitions of agroecological zones) that is characterized by low rainfall intensity, periodic seasonal droughts. Severe dry spells during the rainy season are common in this zone. The wetland is located in the headwaters of the Tuli River catchment at approximately 20° 27′ S and 28° 41′ E. The wetland has an area of about 30 hectares in a 4.3km^2 catchment. Of the 30 hectares in the wetland, 15 were cultivated at the time of the study.

The geology of the Intunjambili catchment is mainly granite. Soils in the wetland and catchment consist of the fersiallitic group ((Nyamapfene, 1991). They are characterized by moderately leached soils of the kaolinitic order, derived from granite. They have low clay content (10%) in the top soil. The soils can be classified as Ferralic Arenosols (FAO, 1988) or simply Arenosols (World Reference Base, 1998). The large portion of the soils is hydromorphic due to the poor drainage particularly in the valley bottom. The wetland soils have low clay content, high soil organic matter in the central wetland, and sandy soils further away from the center of the wetland. Land cover in the wetland is about 20% natural vegetation (reeds, sedges, and grasses).

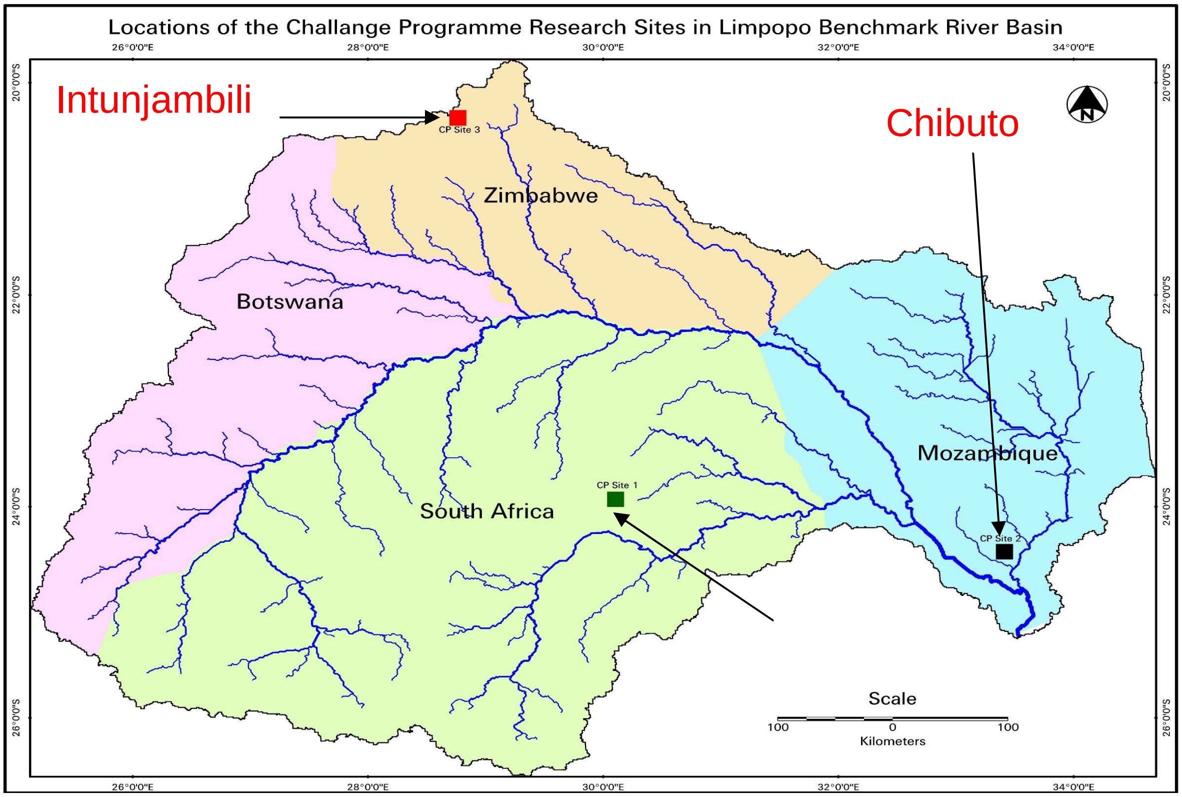

Figure 1. Limpopo basin showing location of the three study sites

Crop production in and around Matobo is risky except in certain very favorable localities where limited drought resistant crops are grown. About 180 households are located the wetland, with a total population of 512 inhabitants who use the wetland for a variety of activities including gardening, provision of domestic water supply and recreational activities. The main livelihood activities in the village are vegetable production in wetland gardens, livestock production, brick making on the edges of the wetland and construction work.

The Matobo area is well known for its many bare rocks, referred to locally as *dwalas.* The area is therefore prone to significant volumes of surface run-off leading to high water levels and sometimes inundation in the wetland in the valleys. Within the study site, there is a big hill, Intunjambili hill, which is the main source of run-off for the valley bottom main catchment area, which drains into Intunjambili River and dam. The area is also characterized by scattered rock outcrops that also contribute to existence of dispersed wetland fields in and around the village. Wetland plots in Intunjambili therefore an be classified into two broad categories: plots that are adjacent to the valley bottom and along the main river catchment area that result from the Intunjambili hill and plots that result from scattered rock outcrops around the area.

Table 1. Rainfall characteristics in the five natural regions of Zimbabwe (Source: Chiputwa (2006), adapted from Rukuni and Eicher, 1994 pp.42)

Agroecological Region	Area (km^2)	% of Total area	Rainfall Characteristics	Type of farming
I	7, 000	2	More than 1, 050 mm rainfall per year with some rain in all months.	Specialized and Diversified Farming Region
II	58, 600	15	700 – 1, 050 mm rainfall per year confined to summer months.	IIA intensive farming region
				IIB intensive farming region
III	72, 900	18	500 - 700 mm rainfall per year. Infrequent heavy rainfall. Subject to seasonal droughts.	Semi-Intensive Farming Region
IV	147, 800	38	450 - 600 mm rainfall per year. Subject to frequent seasonal droughts.	Extensive farming region
V	104, 400	27	Normally less than 500 mm rainfall per year, very erratic and unreliable. Northern Lowveld may have more rain but topography and soils are poorer	Extensive Farming Region

Source: Rukuni and Eicher, 1994 page42

2.2 GaMampa wetland

The GaMampa wetland, covering an area of approximately 1km^2, is situated in a channeled valley bottom close to the centre of the Mohlapetsi catchment, immediately upstream of the confluence of the Mohlapetsi and Olifants rivers (Figure 1) within 24° 05' and 24° 20' S and 30° 00' and 30° 25' E. The Mohlapetsi River originates in the Wolkberg mountains and is one of the tributaries of the Olifants River.

The catchment area above the wetland is approximately 263 km^2 and is predominantly rural, with a low population density. The upper catchment above the confluence of the Olifants with the Steelpoort River comprises relatively natural grassland vegetation, contained within a national reserve (Sarron, 2005). All villages are located, and agricultural activities occur, close to the valley bottom and in the wetland. Wetlands constitute nearly 14% of the Olifants River basin area above the confluence of the Olifants and the Steelpoort rivers.

In the headwaters of the Olifants River they constitute about 10% (Palmer et al., 2002). Based on the distribution of wetland land cover and uses within the wetland is considered to be representative of the upper catchment area of the Sub-basin of Olifants River. The total land extent of the sub-basin is around 3.75 million hectares out of which 0.52 million hectares (14% of the basin area) are wetlands, including both seasonal and perennial forms of wetlands (Kulawardhna et al, 2006). The valley bottom in which the wetland is located has a total land extent of approximately 455 ha, which is less than 0.1% of the total area of the Mohlapetsi catchment. The wetland constitutes about 120 hectares or about 26% of the valley.

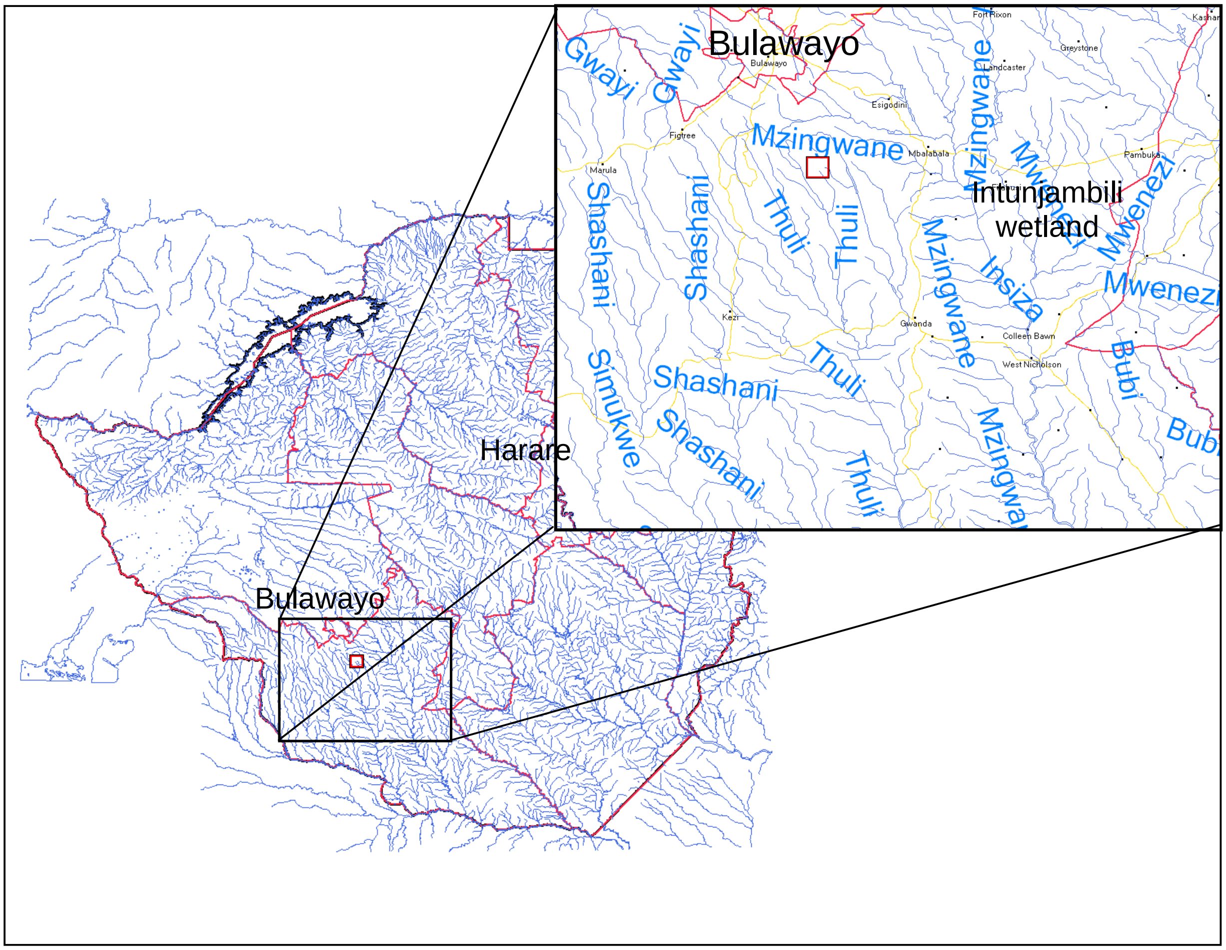

Figure 2. Location of Intunjambili wetland, Matobo communal area, Matabeleland South, Zimbabwe

The wetland is located in the channelled valley bottom section of the river the margins of the wetland extending slightly up the base of the adjacent hill slopes. It extends up to 400 – 500m from the river towards the adjacent hill slopes. The geology underlying the wetland and its catchment is of the Transvaal sequence while much of the catchment upstream of the wetland consists of dolomite, well known for its high groundwater storage capacity. The wetland and its local catchment are underlain by banded ironstone and chert, which are likely to have an intermediate capacity for groundwater storage (Grundling, *Pers. comm.* Working for Wetlands, Pretoria). Within the boundaries of the wetland, the valley floor consists of predominantly fine-textured, poorly-drained areas as well as sandy, reasonably well-drained areas (which are generally located close to the channel and are much less extensive). Most of the organic soil areas appear elevated well above the main channel, and even in major floods much of their area is located above the river's flood line. This also means that they fall outside the main zone of deposition of sediment carried by the river, which is a characteristic feature of wetland areas supporting organic sediments (Kotze, 2005). The main Mohlapetsi River, therefore, contributes little to the overall water supply of the wetland. The wetland appears to be maintained predominantly by lateral inputs (particularly sub-surface) from their local catchments (Kotze, 2005).

2.2.1 Socio-economic setting

The communities around the GaMampa wetland have a total of 394 households, distributed among five villages, namely GaMampa, Manthlane, Mapagane, Mashushu and GaMoila. The villages are located in the valley and in the vicinity of the wetland and in local government ward of Mafefe in the Lepele Nkumpi Municipality, Capricorn District of the Limpopo province. The population of these communities is about 18% of the ward population. The majority of the population is young and household size varies from 1 to 10 people. About 90% of households are classified very poor, poor and vulnerable; households that spent R600 or less a month are seen as very poor, those that spend R601 to R1, 000 as poor, and those that spend R1, 001 to 1, 800 as poor and vulnerable (Statistics South Africa 2000). We assumed that the villages of GaMampa, Manthlane, Mapagane, Mashushu and GaMoila that make up the communities using the wetland have the same characteristics. The GaMampa communities are largely poor; the villages are characterized by limited infrastructure. Most of the households have access to piped water for drinking and sanitation facilities and many have small gardens and kraals in which to keep a limited number of livestock. Other resources identified are the surrounding Wolkberg Mountains included in two nature reserves which provide grazing areas for livestock, wood, and fruits for the population. An important part of this grazing land has been claimed by the local population as their ancestors' land.

Livelihood activities at GaMampa are centered on small-scale agriculture in the wetland and dilapidated irrigation scheme on the wetland perimeter. Mainly old and mature men and women engage in agriculture. Unemployment is high; many men between 25 and 65 years old migrate to the neighboring towns or to the mines in search of employment. Engagement in subsistence farming is not considered as employment. Local job opportunities come mainly from government programs (e.g. the building of schools, road construction, and sanitation projects) but these are limited.

2.2.2 Hydrology of the GaMampa wetland and Mohlapetsi catchment

The Mohlapetsi catchment is made up of the Mohlapetsi River, bushveld in the mountains and the steep sided valley bottom where GaMampa wetland is located. The Mohlapetsi River originates from 1,200m above the sea level in the Wolkberg mountains to 780m in the valley bottom where the wetland is located. The catchment is characterized by seasonal rainfall that largely occurs during the summer months, from October to April. The mean annual rainfall for the catchment is 771 mm, but varies significantly with altitude and aspect. Mean annual rainfall in the higher parts of the catchment (i.e. the north and east) exceeds 1,000 mm (with a maximum of 1,433 mm) whilst in the valley bottom where the wetland is located it is typically 500 – 600 mm. The weather station located closest to the wetland has a mean annual rainfall of 570 mm. Averaged across the catchment the mean annual open water evaporation (i.e. A-pan) and potential evapotranspiration (i.e., Penman-Monteith) are 2,014 mm and 1,428 mm respectively.

The Mohlapetsi River shows both seasonal and inter-annual variation in flow measured at the B7H013 gauge at the bottom of the wetland. The mean annual flow is 37.96 Mm^3, which equates to 144 mm of runoff (McCartney, 2005).

A common perception of stakeholders outside the communities living in the valley was that the GaMampa wetland performed important hydrological functions, most notably the maintenance of dry season flow in the Olifants River (Darradi, 2005). Analysis of historical flow data of the Mohlapetsi River and Olifants River (below the confluence of the Olifants and the Mohlapetsi) confirmed that the Mohlapetsi catchment contributes significantly more to the flow than would be anticipated from a catchment its size (McCartney, 2005).

2.2.3 Ecosystem services

The GaMampa wetland provides several ecosystem services (Table 2). The provisioning services are of importance to the local community. The wetland is used by surrounding communities for a range of livelihood supporting uses including crop production, livestock grazing, and harvesting of natural products.

Table 2. GaMampa wetland ecosystem services

Topic	Information	Information sources
Provisioning services	- Used for (a) crop production, especially during dry periods; (b) grazing (moderate); (c) dietary supplementation through natural edible products and some fish from Mohlapetsi River, (d) provision of domestic water; (e) assumed importance for carbon storage given accumulation of organic matter in wetlands	Kotze 2005
Regulating services	- Flow regulation (retention of water in wetland and release during dry season). - Water storage (for agricultural use)	Kotze 2005 McCartney 2006 Masiyandima et al. 2006
Cultural services	- No information available regarding spiritual or inspirational services - Offers opportunities for formal and informal learning - Potential recreational opportunities and aesthetic services.	Kotze 2005 Finlayson 2005
Supporting services	- Wetland supports extensive organic (peat) soils maintained by permanent saturation	Kotze 2005

Source: Finlayson and Pollard, 2009

2.3 Missavene wetland

The Missavene wetland is located near Chibuto village, in the Gaza Province of Mozambique (Figure 3). It is situated in the lower reaches of the Changane river, the main tributary of the Limpopo in Mozambique (Latitude 24º40′16″ S and Longitude 33º30′25″ E) near the confluence of the Changane River with the Limpopo River. The wetland is wedged between a sand dune to the northeast and the Changane River to the west, and covers approximately 284 hectares, less than 1% of the Changane catchment. Wetlands account for nearly 24% (1,592,600 ha) of the Changane sub-basin and are an important resource for local people.

The Changane River catchment is characterized by two distinct physiographical features; the upper catchment that falls within the Alto Changane Plateau and the low-lying Changane marsh and flood plains characteristic of the lower Limpopo (FEWSNET 2004). As with many wetlands in the lower Limpopo basin the Missavene wetland is fed by direct rainfall and by groundwater from the dune aquifer system that forms the north-eastern boundary of both the wetland and the catchment. The connectivity of the wetland and the dune groundwater system is evident with springs flowing from the base of the dune. The springs maintain the high water levels in the wetland. The wetland is only partially connected to the brackish Changane River system that forms the south-western boundary. According to local wetland users, flooding of the wetland from the river occurs approximately every two years.

Ecosystem services provided by the wetland are listed in Table 3. As the Missavene floodplain is an important and productive agricultural area for local people it appears at first sight to have little remaining value for wetland biological diversity. A rapid appraisal of the biodiversity was undertaken in order to characterize the biological values of the site and enable comparisons with other wetlands. The wetland is important to the local community with the wetland–based livelihood system including a mix of vegetables, bananas, maize, and rice, as well as grazing of cattle and goats, and cutting of grass and reeds. Some of the crop production is done under irrigation with water taken from springs at the base of the sand dune along the edge of the flood plain. Fishing occurs in the Changane River, but is seemingly unimportant in the floodplain or irrigated fields.

Table 3. Missavene wetland ecosystem services

Topic	Information	Information sources
Provisioning services (see App.2)	- Used for (a) crop production, especially during dry periods; (b) grazing; (c) dietary supplementation through natural edible products and fish, (d) provision of domestic water; (e) firewood *Pulchea dioscorides* and (f) building (*P. Mauritius*) & fencing (*Euphorbia tirucalli (milk bush));* (g)	Namburete 2004

Topic	Information	Information sources
	medicinal plants - Permanent lake within wetland important for diversity of fauna/ flora	
Regulating services	- Limited hydrological role but as part of group of wetlands provides marginal contribution to flood delay and attenuation in lower Limpopo through temporary storage in depressions. - Discharge area for a local aquifer system with many springs (tapped for irrigating cropland) - Flow regulation (retention of water in wetland and release during dry season) - Water storage (for agricultural use)	Namburete 2004 Bandeira et al. 2006
Cultural services	- African religion (Mazione) uses wetland area for religious practices; one cemetery (mainly for still-born babies) exists in wetland. - No recreational or aesthetic services but potential exists - Opportunities for formal and informal learning	Finlayson 2005 Bandeira et al. 2006

Source: Finlayson and Pollard, 2009

3. Methods

The multidisciplinary nature of the project required the use of disciplinary methods to address specific disciplinary objectives. A conceptual framework integrating biophysical and socio-economic components was designed, based on Millennium Ecosystem Assessment. Its main characteristic is its dynamic systemic approach: wetlands and communities that benefit from them, and beyond them, and all stakeholders involved in wetland management form a dynamic system composed of several interacting sub-systems that are continually changing as influenced by many external parameters. Two main wetland sub-systems were distinguished - a biophysical and a socio-economic sub-system. The analysis tracks the trade-offs arising from management choices as well as the feedbacks between the systems due to the response of both the ecosystem and wetland users (see Figure 4).

As an example the framework summarizes potential threats and victims taking a more inclusive view of uses and users of wetland services based on the idea that the condition of human well-being directly and indirectly drives changes in wetland ecosystem. These changes may originate from overuse of wetland resources or changes in land use by local population and also from developments initiated by stakeholders outside the wetland and its catchment. These changes bring a wide range of potential threats to wetlands' functioning (Table 4). Beneficiaries and victims of wetland changes can either be the local population itself or downstream users of other wetland services.

This framework is intended for use by managers and decision-makers in government agencies, and would be most valuable used within capacity building and training programs. The framework concepts were operationalized through the development of a dynamic trade off simulation model (WETSYS, Morardet et al., 2010). The methods for data collection for the indicators that were used in the model are summarized in the following sections.

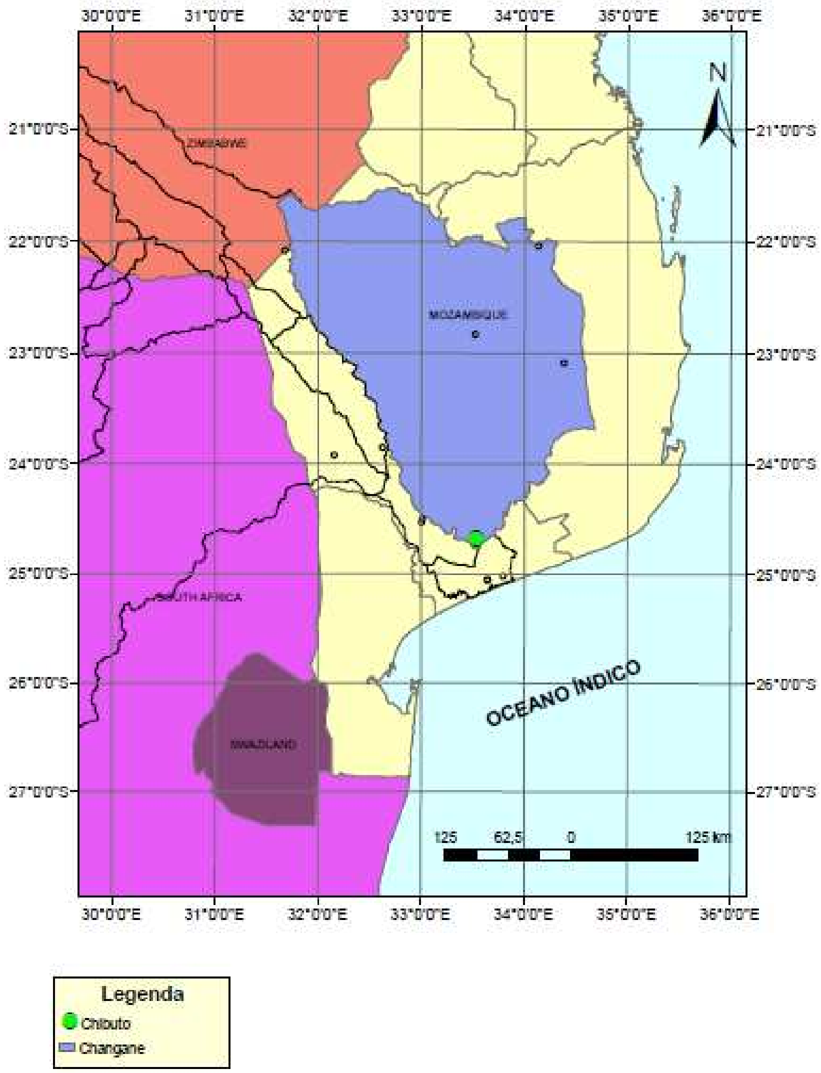

Figure 3. Location of Missavene wetland in Mozambique (Source: Saimone (2009. pp63)

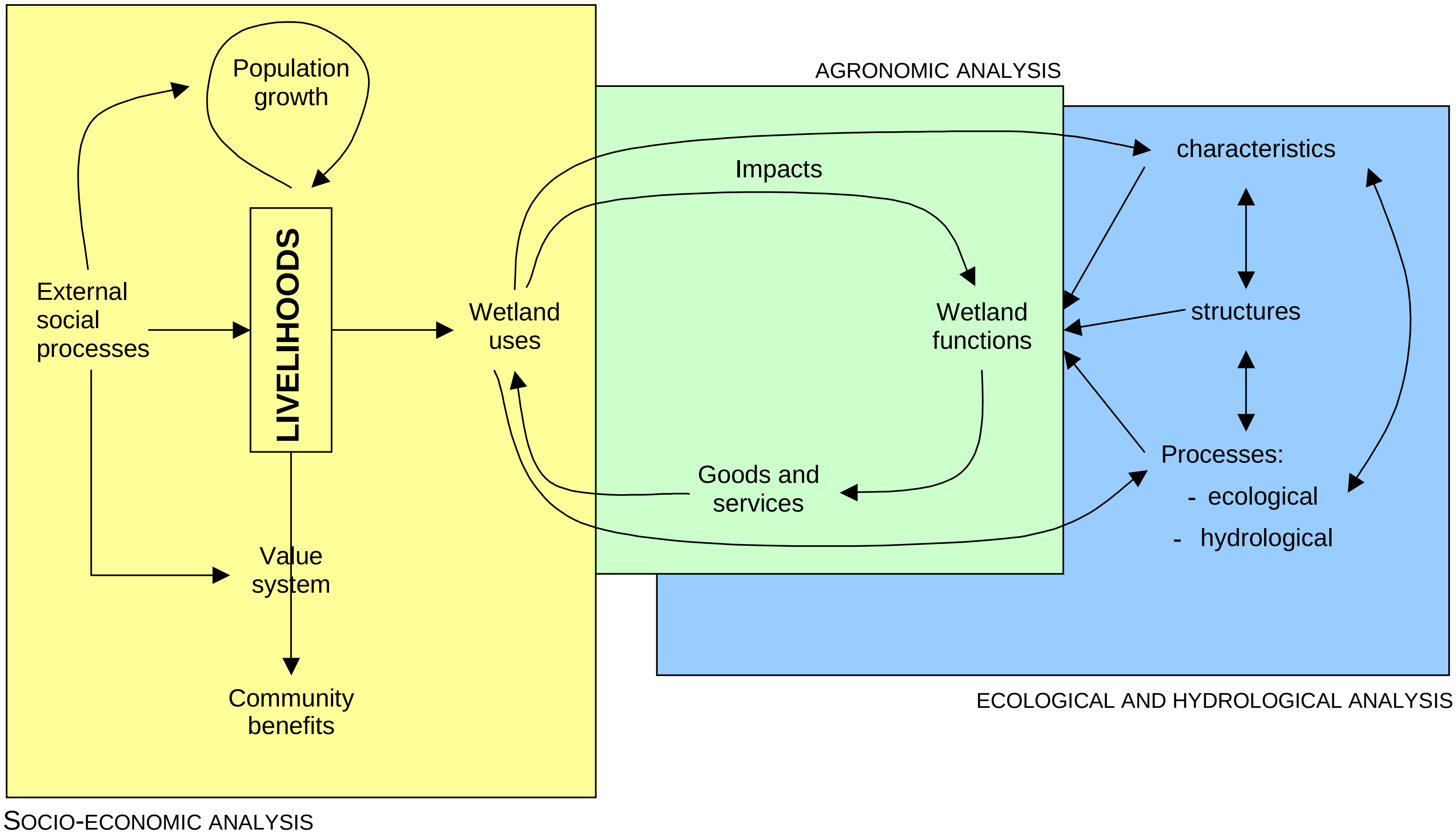

Figure 4. Representation of relationships between wetland socio-economic and biophysical sub-systems and domains of disciplinary analysis

Table 4. Potential threats to wetlands, responsible stakeholders and victims of damages

Potential threats	**Responsible for the damage**	**Victim of damages**
Pollution from agrochemicals	Farmers upstream or within the wetland	Fishermen and fishing industry, onsite and downstream water users, wildlife users
Reduced infiltration/storage due to soil compaction	Farmers within the wetland	Groundwater users, downstream water users,
Reduced flood attenuation	Promoters of land use changes[1]	Downstream population
Increased evaporation from crops	Farmers within the wetland	Onsite and downstream water users, wildlife users
Soil disturbance leading to erosion within the wetland	Promoters of land use changes[1]	Onsite and downstream water users, wildlife users Local farmers and livestock breeders
Downstream pollution arising from reduced efficacy in wastewater treatment	Promoters of land use changes[1]	Downstream water users, wildlife users
Loss of food plant through land use changes	Promoters of land use changes[1]	Local population
Loss of fisheries through pollution/depletion of water	Farmers especially irrigation farmers, other massive water users	Local fishermen
Reduced hunting due to habitat change	Promoters of land use changes[1]	Local population
Loss of construction materials due to land-use changes	Promoters of land use changes[1]	Local population
Loss of medicine plants due to land-use changes	Promoters of land use changes[1]	Local population, health industry
Reduction in cultural value	Various depending on the origin of the loss	Local population
Loss of unique wetland habitat and/or extirpation of species	Various depending on the origin of the loss	Researchers, environmentalists, society as a whole
Loss of tourist/recreational value	Various depending on the origin of the loss	Tourists, tourism industry, local population
Reduced carbon sequestration through disturbance of soil and/or reduction in water logging	Promoters of land use changes[1]	Society as whole

[1] Farmers, livestock breeders and other users within the wetland

3.1 Discipline-specific methodologies for trade-offs component analysis

3.1.1 Biophysical component

Hydrological analysis

The hydrometric analysis carried out was centered on establishing the role of the wetlands to river flow (in the case of the GaMampa and Intunjambili) and, for the Missavene wetland, the role of the wetland in water provision in the wetland. The following sections detail the observations and analysis for GaMampa and Intunjambili wetlands.

Flow

At GaMampa wetland automatic recorded daily water levels were available from the DWAF hydrological database. Flow measurements were made daily at gauging station B7H013, located downstream of the wetland. Data for this station was available for the period 1971 to 2008 with some gaps due to malfunctioning of the gauge or peak flows that were considered inaccurate.

At Intunjambili there were no river flow measurements downstream of the wetland prior to the wetland study. A V-notch weir was installed during the study. A rating relationship was used to estimate the flow generated in the headwaters in which the wetland lies.

Rainfall

Rainfall was measured at each site using manual rain gauges. Rainfall gauges were conveniently installed on farmers' homesteads and selected fields so that the identified farmers would make observations and keep the rainfall records. Rainfall data from national rainfall stations located outside the basin were also obtained.

Evapotranspiration

Daily evapotranspiration data were obtained from measurements made at national meteorological stations. These evapotranspiration data are Penman Monteith evapotranspiration calculated using the approach outlined in FAO56 formula. For the GaMampa wetland the Polokwane station was used while in the case of Intunjambili, the Bulawayo station was used. In all the three cases, the stations were located at least 50km from the site. Mean monthly values were calculated using the time series data that was available.

Within the wetlands open water evaporation also occurs form the open drains that are installed to lower water levels in order to grow crops such as maize and vegetables (Figure 5; Figure 6).

Figure 5. Drain without outlet.

Figure 6. Drain with outlet

Shallow water levels in the wetlands

The shallow water levels in the wetlands were monitored using piezometer wells consisting of 5 cm diameter PVC pipes that ranged mostly from 2 m to 5 m in depth. The piezometers were installed using hand-held augers. At Missavene and Intunjambili some piezometers were more than 5 m deep; these were installed using a drilling rig. The depth of free water was measured using tape with a sounder at the end.

Assessing Mohlapetsi river hydrological change using the GR4J model

The purpose of the Mohlapetsi River study was to quantify the impact of changes in the wetlands (i.e. from natural to cultivated) on the hydrology of the river.

The history of the valley provides three study periods:

- 1970 – 1990 (period 1): the period when the wetland was uncultivated. Crop production took place in the fields bordering the wetland
- 1990/2000 (period 2): transition period, with conversion of parts of the wetland to agricultural land.
- 2000/2005 (period 3): Increased cultivation in the wetlands due to collapse of the irrigation scheme in 2000.

The GR4j (modèle du Génie Rural à 4 paramètres Journaliers) rainfall-runoff model was used to evaluate the change in hydrological functioning between each time period. The GR4j was developed by Nasciemento (1995) and modified by Edijanto and al (1999). It is a rainfall-runoff model with few parameters, developed for data scarce catchments. For detailed model description see Sarron (2005).

The GR4j model was calibrated separately for each period above and then run using the actual rainfall of the two other periods in order to assess the impact of land-use changes.

Assessing catchment and wetland contribution to river flow using the SWAT model

To separate the runoff from the catchment and the wetland flow generated in the upper catchment without the wetland and flow generated in the catchment including the wetland was modeled using the SWAT model for the Intunjambili and GaMampa wetlands.

Observed time series of climatic data (daily rainfall, maximum and minimum air temperature, solar radiation, wind speed, and relative humidity) from Bulawayo and Polokwane were used for Intunjambili and GaMampa respectively.

The stream – shallow aquifer relationship is represented as in Figure 7. The shallow wetland aquifer contributes to stream flows when wetland water level is higher than river stage.

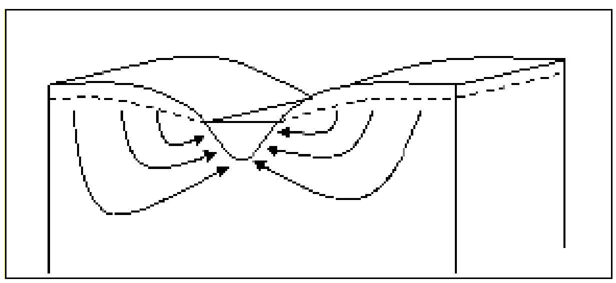

Figure 7. Stream-groundwater relationships gaining stream receiving water from groundwater flow

The shallow aquifer contributes base flow to the river. Water may move from the shallow aquifer into the overlying unsaturated zone. In periods when the material overlying the aquifer is dry, water in the capillary fringe that separates the saturated and unsaturated zones will evaporate and diffuse upward. As water is removed from the capillary fringe by evaporation, it is replaced by water from the underlying aquifer.

Crop production

Area under crop production and the crops produced was established through farmer surveys. From the number of wetland farmers and area per farmer, actual area cropped and resulting total yields from the wetland were estimated. The value of this production was estimated from market prices.

GaMampa wetland land use change analysis and ecological assessment

The purpose of land use analysis was to observe and quantify changes in wetland use. The analysis focused on land use change scenarios that have occurred over time, the impacts of land use change within the wetland on functioning of the wetland, and the change in land use in the wetland as dictated by poor rainfall or lack of access to water.

Landsat 7 ETM satellite images were processed in order to identify six classes of land use based on the visual characteristics of each area. Images from 2 July 1996, 8 July 1998, 10 September 2001, and 24 July 2004 were used in the study. Details of image processing methods are outlined in Sarron (2005). A field survey was undertaken to validate the land use categories of each area. The resultant characterization or zoning was used to generalize about land use in the GaMampa Valley land that includes the wetland.

Ecological assessments were carried out at the study sites with the objectives of

- Establishing the health of the wetland and indicators that can be used to monitor wetland health
- Defining environmental security for the wetland based on local conditions of flora, fauna, wetland processes and processes of linked downstream environments
- Designing a framework for monitoring and analysis of data to assess changes in wetland health due to livelihood-supporting activates over time.

3.1.2 Socioeconomic component methods

The socio-economic component methods included stakeholder and institutional analysis and livelihoods analysis and economic valuation to establish benefits accruing from the wetland. The methods used are summarised in the following sections.

Institutional and stakeholder Analysis

For institutional and stakeholder analysis, data were collected using key informant interviews, focus group discussions, individual wetland users structured interviews, and visual observations of community meetings and activities. Descriptions of the methodologies are in Darradi et al (2006) and Tinguery (2006). The analysis of data focused on the issues at stake for each group of actors and on the relationships between stakeholders (cooperation, conflicts and tensions).

Livelihoods Analysis

At all three case studies data collection for the livelihood and valuation analysis used a mix of participatory tools (key informants interviews, focus group discussion and resource mapping exercise) and a more formal baseline survey of a household sample based on the SL approach. For the GaMampa wetland, a total of 143 households were interviewed in two phases in May and October 2006. The sample was stratified into two clusters of wetland croppers and non croppers. Interviewed households were chosen based on a systematic random sampling. Based on the SL approach, the questionnaire included questions on household demographics, asset endowment (physical domestic and productive, natural), use of wetland resources, crop and livestock production activities and practices, access to services and participation to social networks, sources of income, household budget, sources of food and food security.

Univariate, bivariate and multivariate analysis (multiple correspondence analysis and cluster analysis) was used to categorize households according to their wetland uses. A Multinomial logit analysis was done to examine the factors that influence household choices on using wetland resources. A Tobit model was applied to analyze the factors influencing household dependence on wetland resources.

Detailed descriptions of the individual methodologies are in Chiputwa (2006) and Jogo and Morardet (2008).

Valuation of Ecosystem Services

Valuation was implemented at GaMampa wetland. The valuation of wetland provisioning services was based on the computation of the following value indicators:

- **Total Annual Production or harvest** based on percentage of households involved in the activity estimated from the survey sample and average quantity collected per each of these households ;
- **Gross annual Financial Value**: Total annual production * Price (Maximum, Minimum and Average) ;
- **Annual Cash Income**: Average quantity sold * Average selling price from survey;
- **Net annual Financial Value**: Gross Financial Value – (Fixed + Variable Costs). Cost of implements was calculated using straight *line depreciation*. Cost at time corrected with inflation rate between time of buying and today divided by number of uses.

Detailed descriptions of the individual methodologies are in Adekola (2007).

4. Results

4.1 Hydrological functioning

Groundwater level in the wetland

The changes in the groundwater in the wetland correlate well with periods of rainfall, with groundwater level increases observed immediately after rainfall. In the wetland and further away from the river, high groundwater levels were maintained beyond each rainfall event, an indicator of lateral flow from the hill slope maintaining groundwater levels.

The two distinct groundwater responses observed in the upper and lower parts of the wetland indicate complex processes in the wetland, and different, possibly time-dependent flow generation processes. In the upper part of the wetland the water table rises quickly but does not recede significantly in the dry periods following rainfall. Early in the rainfall season, the water levels continue rising, even between rainfall events (Figure 8), indicating recharge to the wetland area even in dry periods. Adjacent to the river bank (Figure 8) the water level response was consistent with rainfall, showing rapid increases when it rained and rapid decreases immediately after rainfall. This rapid recession observed in the piezometers next to the river bank was indicative of lateral flow from the wetland area adjacent to the river bank.

Groundwater response in the GaMampa wetland in the lower wetland was directly related to rainfall. The lower part of the wetland is characterized by sandy and more permeable soils, allowing for more rapid movement of water, both vertically and laterally. In this part of the wetland, any increase in storage in the wetland due to rainfall is lost shortly after the event through lateral flow to the river, explaining the rapid water table surface elevation changes observed in this part of the wetland (Figure 9). The water table surface showed a gradient in the water table along transects, suggesting groundwater inflow from the slopes into the wetland. This flow was apparent during the wet season, when groundwater levels were high. The groundwater levels did not change much after April, and if flow does continue it would be limited due to smaller head differences between the river and the wetland. The wetland is therefore like a storage reservoir, losing water largely through evapotranspiration (particularly when the groundwater levels are high during the rainfall season) but also through some lateral transfer.

Surface water flow

Dry season flow analysis did not show contribution to flow of the Mohlapetsi by the GaMampa wetland. There are two main reasons why the surface flow observed at B7H013 below the wetland during the dry season cannot be attributed to flow generation by the wetland. First the similarity of surface flow recession in all years including dry years is indicative of the fact that surface flow during the dry season does not originate from the wetland. If it originated from the wetland, there would be no flow measured. Even in a dry year such as 2005/2006, inflows lower than outflow from the wetland area were observed, indicating inflow to the river along the wetland. The absence of water level changes in the wetland in the dry season (between May and December – Masiyandima et al, 2006), also indicates that the flow does not originate from the wetland. It is possible that the wetland simply acted as a conduit and flow comes through the wetland from the surrounding catchment. However B7H013 flows were nearly the same as upstream flows indicating marginal impact of the wetland on flow.

The hydrological analysis indicated that the Mohlapetsi contributes to the dry season base flow of the Olifants River. The analysis did not show the role of the wetland in runoff generation for the river. Despite common perception to the contrary, the wetland appears to make only a very small contribution to dry season flows, certainly in comparison to the amount of water that is evaporated from it. It is more likely that the base flow is generated in the upper catchment and is high, because of the underlying geology and the fact that the catchment is only disturbed very slightly.

Water balance

The dry season water balance showed that less than 2% of water in the shallow wetland aquifer contributes to flow in the Mohlapetsi River. While there is significant groundwater inflow from the surrounding catchment into the wetland, this was almost the same as the calculated potential evapotranspiration from the wetland. This suggests that the wetland loses more water through evaporation.

The dry season water balance showed that groundwater inflow from the surrounding catchment is the largest inflow to the wetland. However, only a small proportion of this flow seems to contribute to lateral flow to the river. Most of the inflow into the wetland is lost through evapotranspiration, either by agricultural crops or natural vegetation. It is not clear how modifying land-use in the wetland will affect dry season flows in the river. Impacts of wetland use are localized and affect ecosystem services that benefit local stakeholder. Provision of wetland ecosystem services is influenced by catchment processes.

Hydrological change in the wetland and the Mohlapetsi catchment

The results of the hydrological change study in the Mohlapetsi catchment (Sarron, 2004) indicate that the catchment generated more runoff after 2000 than before 2000. While this increase in runoff coincides with the period of reduction of the wetland area, it could not be attributed entirely to the increasing cultivation in the wetland. The water balance of the wetland area suggested lower increases in flow from the wetland area in this period after 2000.

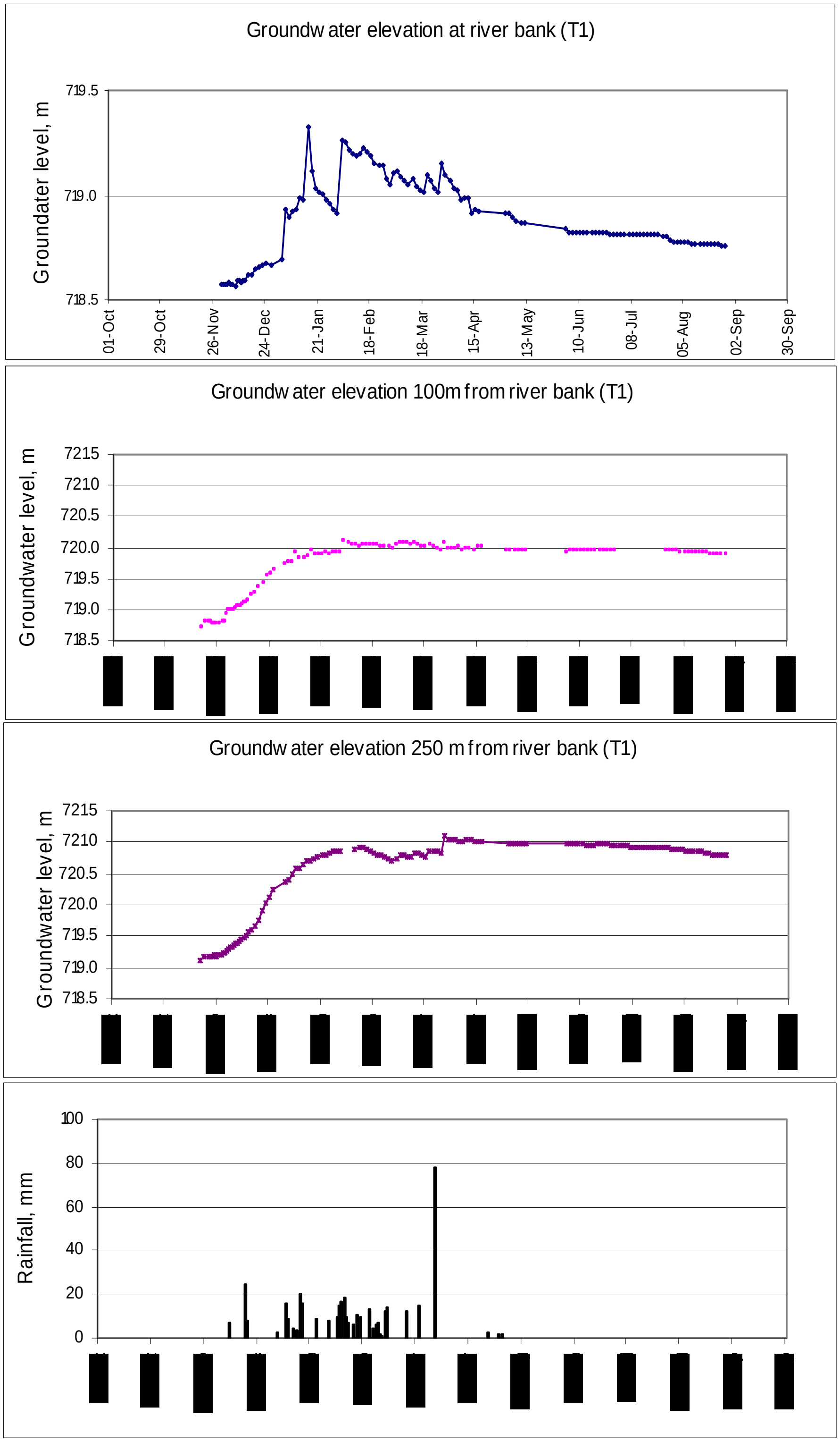

Figure 8. Groundwater elevation along a transect on the upstream part of the GaMampa wetland

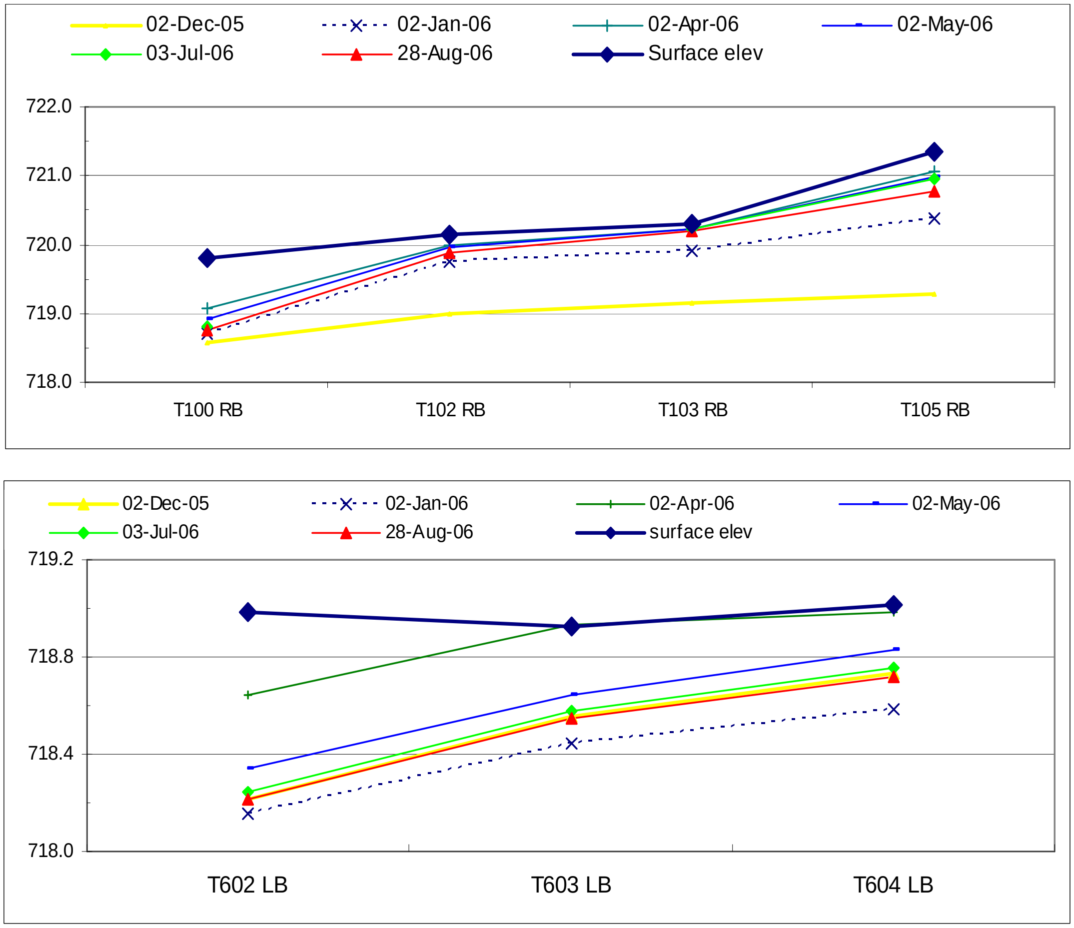

Figure 9. Changes in the elevation of the water table surface along T1 (at upper part of the wetland) and T6 (at downstream end of the wetland)

4.2 Wetland mapping and land use change analysis

4.2.1 Wetland mapping

A significant achievement was the development of methods for mapping wetlands. The study explored automated and semi-automated techniques and highlighted the strengths and limitations of various methods, approaches, and datasets used in mapping wetlands. Detailed information of the areas by land use type in the wetlands was produced and is available in map format. Additional information and maps are available at www.iwmidsp.org. An overview map of the wetlands in the Limpopo basin is in Figure 10. Four wetland classes were defined; their respective areas in the basin are in Table 5). The methodology used is documented in Kulawardana et al., 2006 and Kulawardana et al., 2007.

A map of wetlands showing the extent of wetlands in the Limpopo basin was produced. The basin wetlands were mapped at a scale of 1:250,000. Wetland boundaries in the basin were delineated using Landsat 30-m data for nominal year 2000 and their land use-land cover (LULC) classes were established. The total wetland area in the basin was estimated to be 5.2 million hectares, 12.5 %

of the total basin area (Table 6). The proportion of the wetlands in the 4 basins countries (South Africa, Botswana, Mozambique, and Zimbabwe) was also established. Table 5 shows four broad classes of wetlands mapped and the extent of each of the classes. About 25% of the wetland area in the Limpopo basin is made up of mixed cropland and natural vegetation.

Wetlands of the Changane River sub-basin, Mozambique

The distribution of wetlands in the Missavene wetland and Changane catchment are shown in Table 7. The Changane basin has a mix of seasonal and perennial wetlands in the lower basin flood plains. The vegetation of the Missavene wetland is similar to other wetlands in the lower Limpopo (Kulawardhana *et al.* 2006). A comparison of land use/land cover using very broad classes across the Limpopo basin showed that the proportion of farmland is lower in the Missavene wetland (29%) than across the Changane sub-basin where wetlands that are also farmlands constitute 44% of the basin (Figure 11). The Missavene wetland contained relatively more riparian vegetation and open water areas and less grasslands (see Table 7); however, the coarse categorization used does not differentiate between sedges or rushes and vastly different types of grasses when they have been identified as being common within the wetland (Bandeira, et al. 2006).

The categorization used in this analysis was an imprecise mix of land cover and land use classes that was strongly systematic. Given the coarse categorization used by Kulawardhana *et al.* (2006) further detailed analysis of the land use/cover classes is needed to separate the relative importance of the vegetation types in the wetlands; for example, to separate where possible the different grasses and sedges that support different land uses, but seem to be classified simply as grassland, and whether the natural vegetation classes contained native as well as introduced species such as eucalypt trees.

Table 6 shows the wetland area in the basin in each of the basin countries.

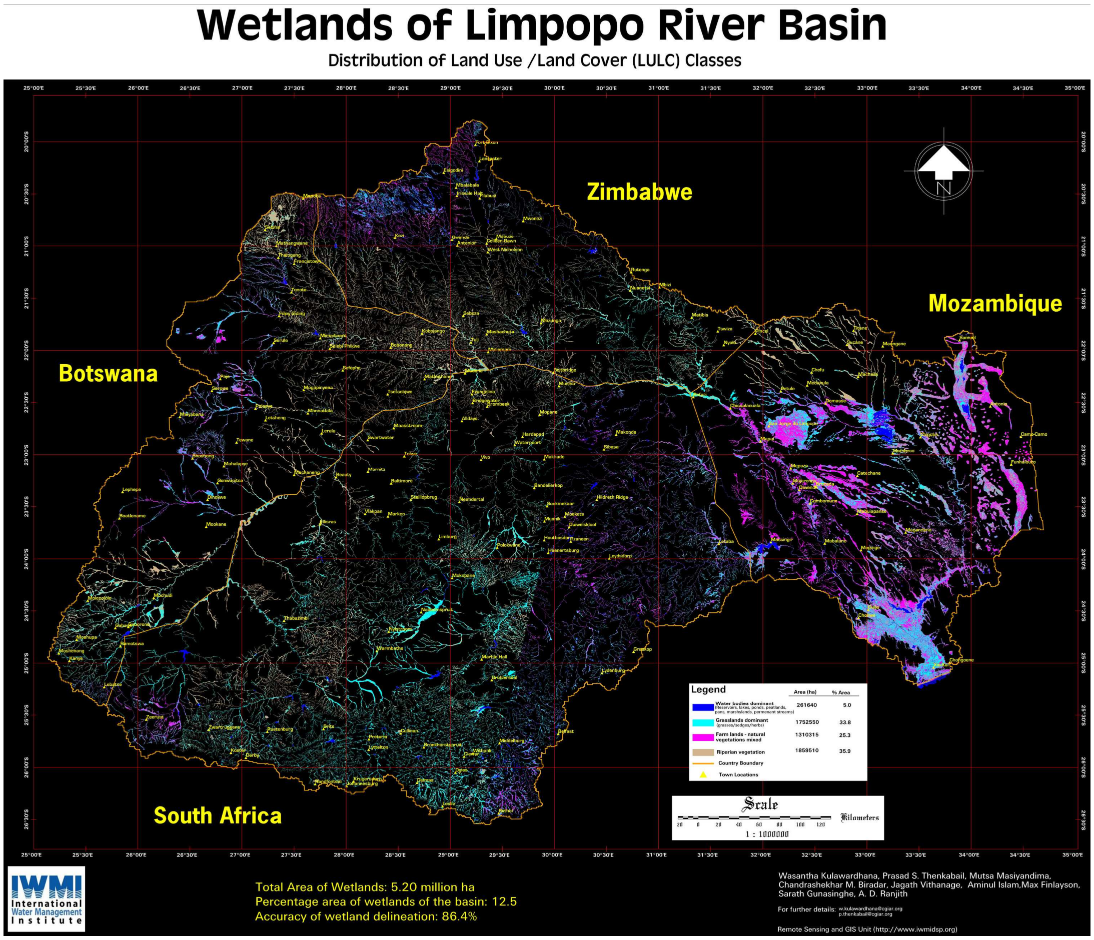

Figure 10. Limpopo River basin wetlands (see **Table 5** for legend) (Kulawardhana et al., 2006)

Table 5. Wetland classes in the Limpopo basin

	Wetland class	Area (ha)
	Water bodies dominant	261,640
	Grasslands dominant wetlands	1,752,550
	Farmlands mixed with natural vegetation	1,310,315
	Riparian vegetation	1,859,510
	Total wetland area	**5,184,015**
	Wetland area as % of basin area	**12.50%**

Table 6. Distribution of land and wetlands in the Limpopo River basin by country

Country	Basin area (Million ha)	% of Limpopo basin area	Area of wetlands (Million ha)
Botswana	8.04	19.3	0.75
Mozambique	8.75	21	2.10
South Africa	18.59	47	1.73
Zimbabwe	6.15	14.9	0.62

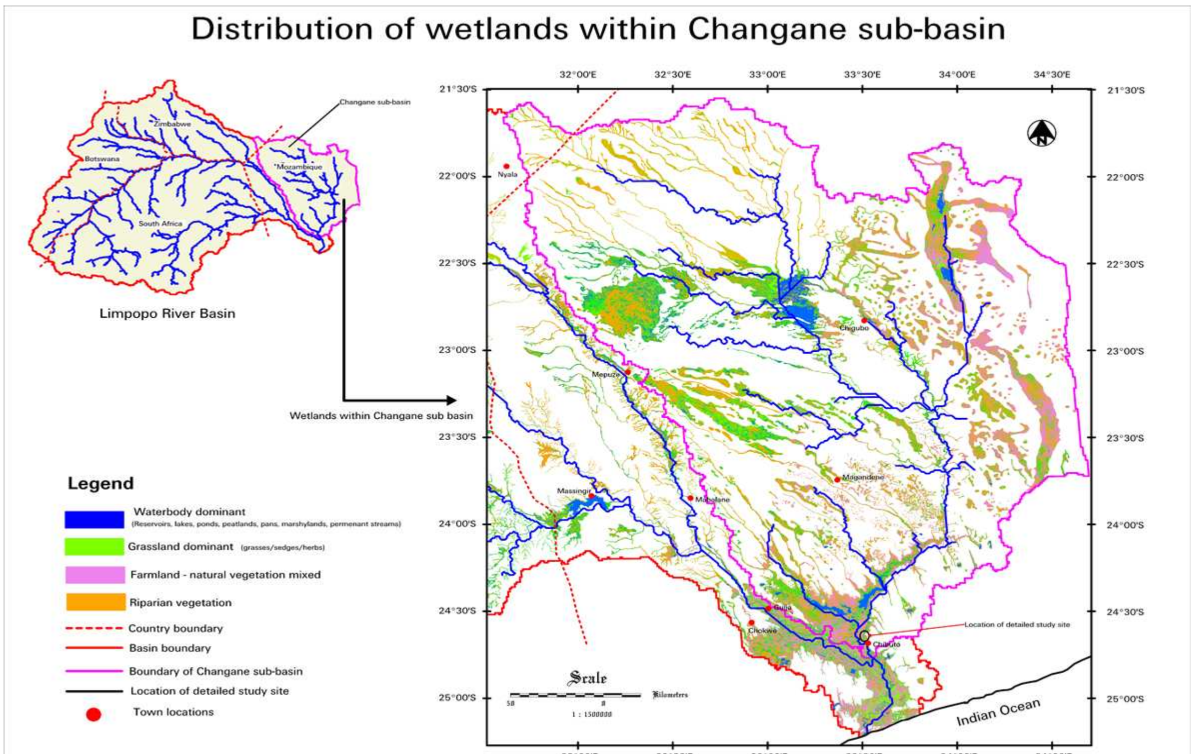

Figure 11. Distribution pattern of broad wetland land use/cover classes within the Changane sub-basin (based on a broad-scale satellite imagery analysis by Kulawardhana *et al.*, 2006).

Table 7. Distribution of broad wetland land use/cover (LULC) classes within the Missavene research site and the Changane sub-basin (based on the coarse categorization provided by Kulawardhana *et al.* 2006).

	Land use\land cover (LULC) classes*	**Changane sub-basin where the research site is located**		**Missavene research site**	
		Land extent		**Land extent**	
		hectares	**% of basin**	**hectares**	**% of wetland area**
1	Water/ perennial – wetlands	74,944	4.7	35.9	12.7
2	Grassland dominant wetlands	431,327	27.1	45.1	15.9
3	Farmland and natural* vegetation mixed wetlands	702,079	44.1	81.5	28.7
4	Riparian natural* vegetation dominant wetlands	384,283	24.1	121	42.7

- These classes are very broad and may be inaccurately labeled; for example it is assumed that grassland also includes sedges and herbs etc, and that natural vegetation refers to non-agricultural plants and may include, for example, introduced eucalypts.

Land use change analysis within wetlands and ecological change

Results of the analysis for GaMampa are presented here. Table 8 reports the changes in land use in the GaMampa valley bottom in South Africa. The following trends were evident:

- Slight enlargement of the urban/bare soil area,
- Reduction of the natural vegetation area (reeds, sedges, etc) in the wetland, as more area was converted to agriculture
- Increase of the land under crop production in the wetland and the dry land
- Progressive decrease of the wetland area under natural vegetation (Figure 12, zones 2 and 3). This zone increasingly became agricultural land.

Table 8. Changes to area of the five main zones in the GaMampa valley

	1996	**1998**	**2001**	**2004**	**Trend**
Wetlands	0.90	0.82	0.66	0.43	↓
Agriculture	1.82	1.87	2.16	2.51	↑
Urban/bare soil	0.95	1.13	1.36	1.36	↑
Woodland/uncultivated	1.43	1.28	0.92	0.80	↓
Total	5.10	5.10	5.10	5.10	

Because of the rapidly changing area under natural vegetation, uncultivated area was used as a proxy for ecological change and change in wetland biodiversity functioning. The evolution of cultivated wetland area (e.g. as shown in Table 8 and Figure 12) was considered a direct indication of ecological change in the wetlands.

The ecological assessments provided a good baseline of the health of the wetlands. The extent of the areas with natural wetland vegetation in each wetland was mapped. Detailed results of the ecological assessments are given in Kotze (2005); Mutambanengwe (2006), and Bandeira et al. (2006).

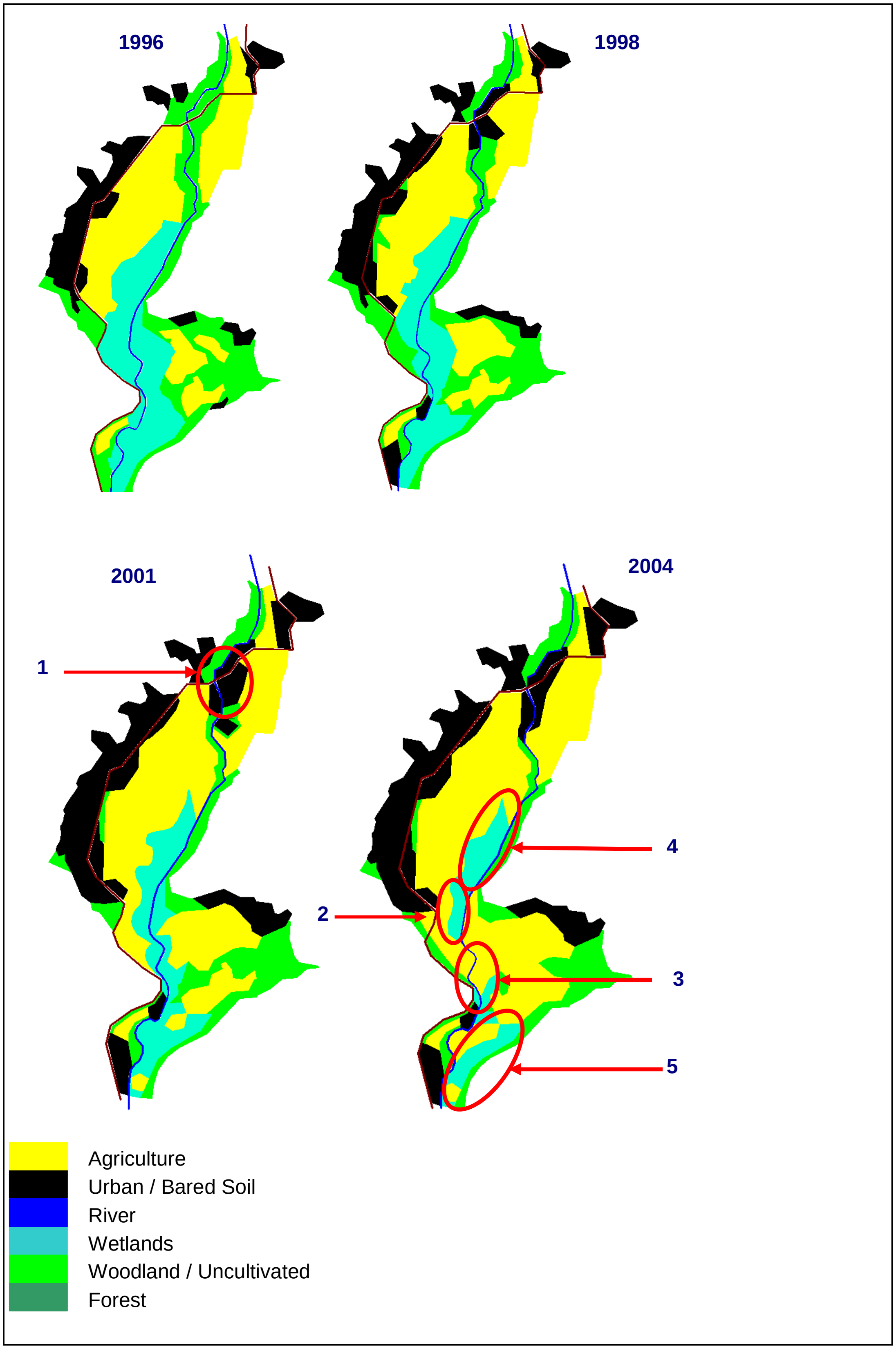

Figure 12. Land use change in the GaMampa valley and wetland between 1996 and 2004 (Sarron, 2005)

4.3 Stakeholder Analyses

The results illustrate the wide range of stakeholders involved in the management of wetlands.

For the GaMampa wetland different groups of stakeholders were identifed: local community organizations such as community development forum and committees (especially the wetland committee, the irrigation committee); traditional authorities (the Paramount chief, Kgoshi[2], and headmen) who give authorizations to cultivate in the wetland and collect reeds and sedges; local municipality represented at local level by the ward councilor; district municipality and provincial governments; national government sector departments such as the Department of Water Affairs and Forestry, Department of Environment, and Department of Agriculture. A local NGO, the Mondi Wetland Program, was seen as an important and influential stakeholder. There were other important external stakeholders including the Kruger National park, located downstream in the Olifants River, and the Olifants River Forum but who were not involved in making decisions that influenced the management of the wetland.

Detailed analysis of the stakeholders is given in Darradi et al (2006). The stakeholders, stakeholder relations, and tensions or possible tensions are shown in Figure 13. Local community members mainly considered the wetland as an agricultural resource for their livelihoods while stakeholders from outside focussed more on its hydrological importance for the Mohlapetsi River and further downstream for the Olifants River. The latter also considered the wetland as an opportunity to develop economically the valley using alternative livelihood activities such as craft industry and tourism. Similarly solutions proposed by the various stakeholders differed according to their perception.

From the stakeholder analysis three main trade-offs were identified: the first one, of which community members are fully aware, was between crop production and natural production of fibres for livestock grazing, crafting and building. The second trade-off was between crop cultivation and hydrological regulation. The local population (as well as downstream water users) is little aware of it, while environmentalist groups and some department staff give it a high priority. The last trade-off was related to the depletion of soil organic matter associated with the artificial drainage of wetland plots and unsustainable agricultural practices. This practice seemed in conflict with future use of the wetland for crop production.

[2] Kgoshi is Chief in Sepedi

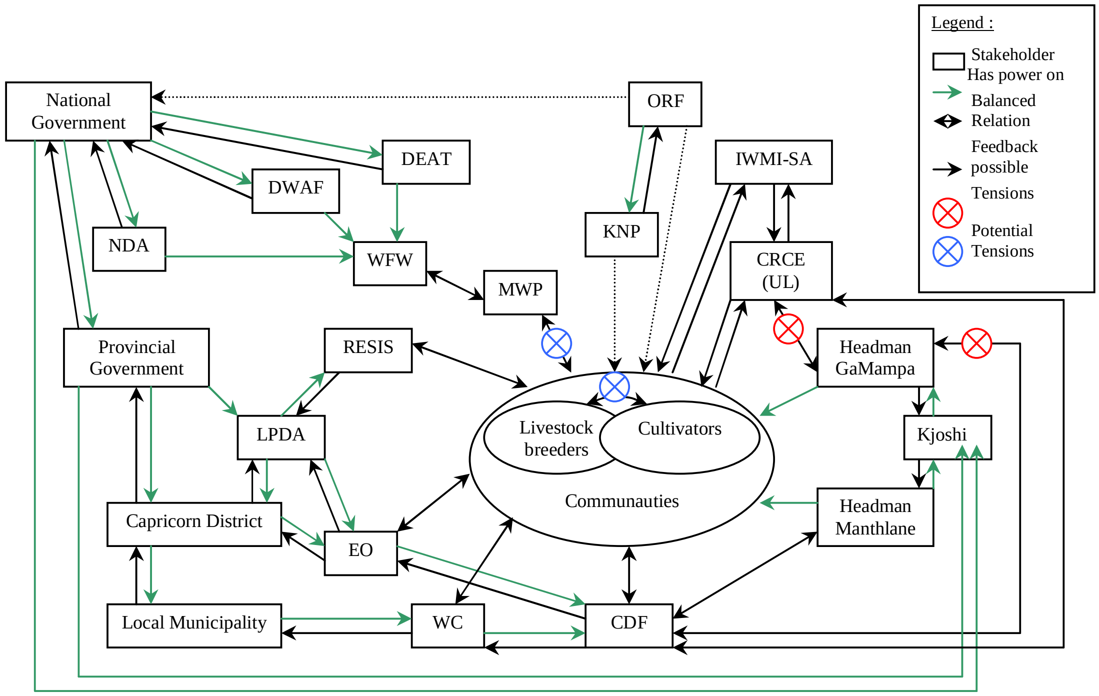

Figure 13. Wetland stakeholders and stakeholder relationships (Darradi, 2006)

4.4 Valuation analysis

The economic valuation results for the GaMampa wetland showed that the contribution of the wetland to the livelihoods of local community, estimated at an annual net financial value of \$211 per household, far exceeded its annual cash income of \$35 per household and was about half of the average monthly cash income from all income sources. Crop production contributed the highest gross and net financial value, whereas sedge collection yielded the highest cash income.

Most of the materials harvested from the wetland were used for household subsistence and were rarely sold. Nevertheless, the survey showed that local households gave more importance to the in-kind contribution of wetland natural resources than to their cash contribution. Generally speaking the GaMampa wetland contributed to the food security (25% of maize needs, 30% of local production), diet diversity (edible plants, vegetables, and fruits), buildings (50% of buildings with thatched roofs), and cash income (from crops and mats that were sold). In addition to their economic and livelihood value, the wetland services were also essential to sustain the social and cultural responsibilities in gift-giving to neighbours and relatives. For some of the products obtained from the wetland (such as sedges and reeds), there was either limited or no alternative location from where these could be obtained.

Benefits derived from the wetland highly varied across households (from \$17 to \$2,625/year) depending on various factors. The study concluded that the local people were highly dependent on the wetland ecosystem services in many ways but that uses exceeded sustainability levels, which jeopardizes their future livelihoods.

In 2006 when the crop production covered more than 60 % of the wetland, the net financial value realized from the wetland was $160,000. The net financial value from crop production alone was about $32,000 or about 20% of the total value from the wetland (Figure 14). Cropping use dominated while the rest of the services generated more value. Cropping generated more cash income than the other services yet it benefited only about 25% of the community.

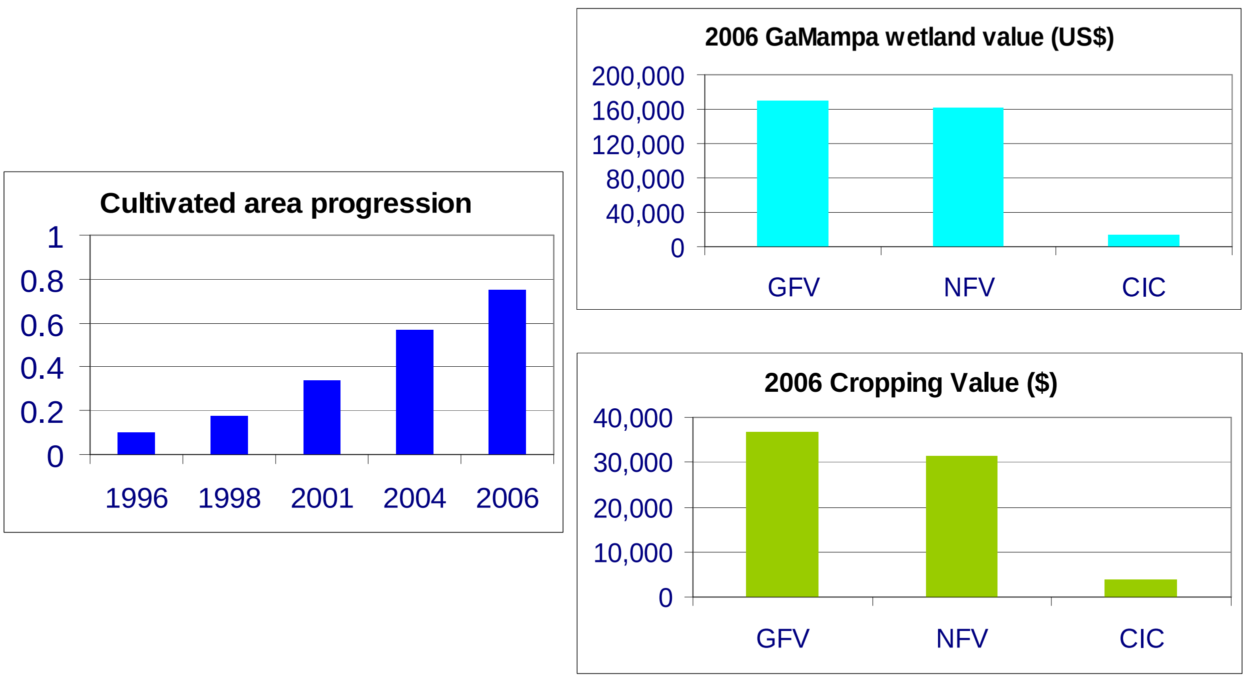

Figure 14. Changing land use in GaMampa wetland between 1996 and 2006; wetland value and cropping value in 2006 (Adekola, 2007). GFV is gross financial value; NFV is net financial value, and CIC is cash income realized by the community.

4.5 Livelihood analysis

The livelihood analysis results highlighted the diversity of wetland uses, their relationships with other assets endowment and their contribution to livelihoods. Almost all households at GaMampa engaged in one or more wetland activity (Figure 15). The nature of household use of wetlands, strongly differentiated across households, appeared to be highly influenced by socio-economic factors. Households with large family size and female-headed households were more likely to engage in both wetland cropping and collection of wetland natural products (reeds, sedges and edible plants). Education of household head also displayed the expected negative sign with respect to collection of natural wetland products. As expected, access to income from off-farm activities, land holding size per capita (used as a proxy of food security) and wealth (represented by an index based on asset endowment) were negatively and significantly related to use of wetland for cropping and collection of natural products. Finally the results showed that households with access to irrigation plot were less likely to engage in collection of natural products as expected, but more likely to engage in wetland cropping.

The results of the Tobit model used indicated that gender of household head, education, access to off-farm income and wealth status are key variables influencing dependence on wetland resources (measured as an index which expresses the total value of products collected from the wetland as a fraction of annual household income). Education and access to off-farm income significantly reduced household dependence on wetland resources. Poor households were more dependent on wetland products than the non-poor.

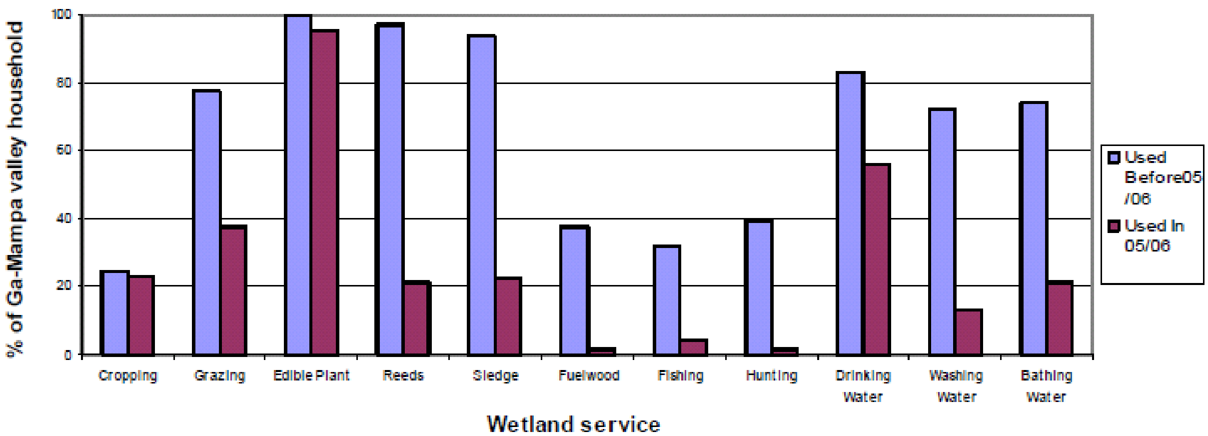

Figure 15. Proportion of households using the wetland before and during 2005/2006 season for each wetland service (Adekola, 2007)

4.6 Determinants of wetland uses

The livelihood analyses at GaMampa and Intunjambili wetland were used to derive wetland user typologies. These typologies presented one common feature of the two wetlands: some households benefit more than the others from wetland (or at least have multiple uses of wetlands) although some others limit their use to the most common ones.

Cropping in the wetland is always associated with other uses

At Intunjambili there were five household types as follows:

- Household type A - engaging in a small number of wetland uses, among the most common within the community (cropping, fuel-wood and water collection). Their wetland plot was frequently located outside the system.
- Households type B used the wetland for a high number of activities including the least common such as fishing, collection of craft materials and medicinal plants, and cultural use
- Households in type C also engaged in a large number of wetland uses. They differed from class B by the fact that they did not collect craft materials. Their wetland plot was more often located outside the system.
- Households in type D had no plot in the wetland but used it for livestock grazing, collection of fuel-wood, building materials, edible fruits, and water.
- Households in types E and F used the wetland mainly for cropping. They were characterized by the absence or low frequency of the other most common uses (grazing, fuel-wood and building materials collection). Class F households differed from class E by their use of wetland water. Class E households more frequently owned a wetland plot within the system than the average.

At GaMampa there were six household types as follows:

- Households from Type 1 (19 households) used wetland for cropping and half of them also for livestock grazing.
- Households from Type 2 (20 households) used wetlands for cropping, collecting edible plants and water, some of them also harvested building materials.
- Households from Type 3 (27 households) used mostly the wetland for harvesting natural resources (edible plants, building and craft materials) and livestock grazing; only 26% had a wetland plot.
- Households from Type 4 (35 households) used wetland mainly for edible plant collection. 11 households among them did not have any use of wetland.
- Households from Type 5 (27 households) used wetlands mainly for livestock grazing; some of them also collected edible plants.
- Households from Type 6 (15 households) had the highest number of wetland uses: cropping, grazing and edible plant collection, but also building and craft materials collection and water.

Despite slight differences between the two sites, wetland user typologies presented common features. Some households benefited more than the others from the wetland (or at least had multiple uses of wetlands) although some others limited their use to the most common ones. Cropping in the wetland was always associated with other uses.

At GaMampa asset-poor households were more likely to engage in wetland cropping and collection of natural products than asset-rich households. A possible explanation is that poor households have less livelihood opportunities outside agriculture and are therefore more vulnerable to climate risks such as droughts. Due to their permanent soil moisture and rich soils wetlands offer a safety net for the poor. In contrast, asset-rich households are less likely to engage in wetland cropping and collection of natural products because they possess assets which buffer them against negative income and food shocks and are generally less dependent on agriculture and natural products for their livelihood. This result can also be explained in terms of substitution effect: rich households can afford substitutes for wetland products (such as iron sheets for roofing and foam mats) and natural products might be considered inferior goods. This result is consistent with other studies which have found that asset poor households are more dependent on natural resources (Narain et al., 2008; Fisher, 2004; Coomes et al., 2004).

At Intunjambili asset-rich households were more likely to engage in wetland cropping and natural product collection. This result may be due to the fact that rich households were larger and therefore have higher demand for resources as well as more labour available to harness them in a context where there are few other livelihood opportunities. Another possible explanation of this result might be that rich households are socially well-connected, influential and are able to use their influence to obtain access to wetland resources.

4.7 Tradeoffs analysis model

A dynamic simulation model (WETSYS) was developed for the GaMampa wetland using the STELLA® platform. The model brings links the biophysical and economic components. It simulates the impacts of alternative wetland management strategies and external pressures on wetland ecosystem functioning and community well-being.

The model is divided into five interactive sectors namely: hydrology, crop production, natural resources, land use and community well-being (Figure 16) and a sixth sector controls annual and seasonal cycles of activities. Hydrological processes in the wetland impact on the provisioning services (crop production and natural resources), mainly through supply of water. Provisioning services generate food and income and ultimately determine the level of community well-being together with external sources of income. Human use and management of the wetland for provisioning services impact on the processes that provide the benefits. The model runs on monthly time step. The model sectors, their linkages, and feedback loops are described in detail in the following sections.

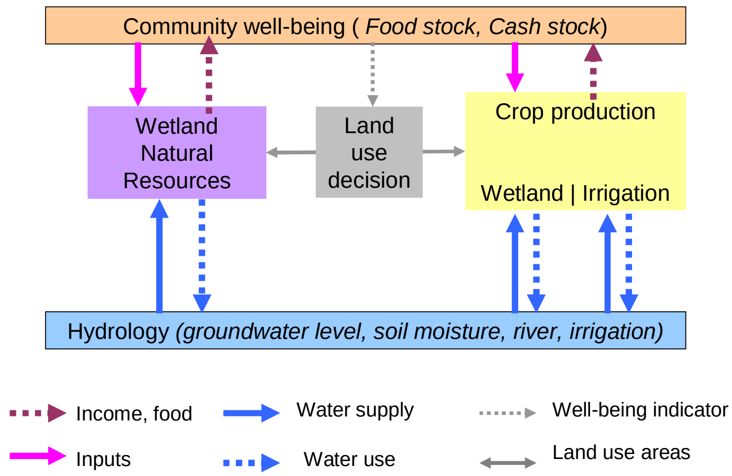

Figure 16. Model sectors and their linkages

4.7.1 Hydrology sector

This sector (represented in Figure 17) describes the hydrology of the wetland. The objective of the sector is to model the impact of loss of water from the wetland through crop water use on water retention in the wetland and wetland contribution to river flow. The GaMampa wetland system comprises six hydrological units inter-linked by water transfers between them - the upper Mohlapetsi River catchment, the hill slopes, the irrigated scheme on the perimeter of the wetland, the root zone in the cultivated and natural wetland, the shallow aquifer below the wetland, and the river (Figure 18).

The flow of the Mohlapetsi River upstream of the wetland is mostly generated from the upstream part of the Mohlapetsi catchment that is predominantly under natural vegetation. As most of the area in the upper catchment is classified as a Nature Reserve, no land use change impacts are considered for the upper catchment. River inflow to the wetland area is considered to depend only on rainfall in the upper catchment.

Water storage in the wetland is influenced by:

- Rainfall and runoff in the valley bottom and the upper catchment.
- Soil moisture fluxes in the wetland and recharge to the shallow groundwater.
- Natural and artificial drainage of the wetland: because the shallow groundwater level in the wetland is close to the surface for most of the year and particularly in the rainfall season when most agricultural production is carried out, farmers dig open drainage canals to lower the water levels so that the root zone is aerated. Many of these channels do not have an outlet; they act as open water areas.

- Groundwater inflow from the surrounding catchment (GWi): Much of the upper catchment consists of dolomite and a significant groundwater recharge to the regional aquifer takes place in the upper catchment. This regional groundwater flows into the shallow aquifer of the GaMampa wetland as evidenced by the many springs observed at the foot of the hills.
- Irrigation diversion for the irrigation scheme above the wetland: Immediately upstream of the wetland is a water diversion for the irrigation scheme on the perimeter of the wetland. The main and primary irrigation canals are lined but are broken in many places, resulting in loss of water due to leakage. Irrigation water is channeled to the plots via secondary earthen canals that also leak severely. It is assumed that some water seepage from the irrigation scheme into the wetland groundwater storage occurs, recharging the wetland.
- Surface overflow between the wetland and the river (OF) during extreme events.

The soil water content in the root zone, in the cultivated wetland was computed as:

$$MC_{t+1}^{w} = MC_{t}^{w} + P_{eff} + CR^{w} - ET_{a}^{w} - E_{bs}^{w} - R^{w}$$

where MC is soil water content, P_{eff} is effective rainfall, CR is capillary rise from the shallow groundwater, R is recharge from root zone to groundwater, ET_a is crop actual evapotranspiration, and E_{bs} is evaporation from bare soil. W subscripts stand for wetland cultivated area. In the natural wetland area, the water dynamics is similar except for E_{bs} as the soil is always covered by natural vegetation. In the irrigation scheme, diverted irrigation water constitutes an additional inflow into the soil moisture and there is no capillarity rise from groundwater.

Crop and natural vegetation evapotranspiration are by far the largest water losses from the GaMampa wetland. FAO guidelines are used in the model for computing crop and natural vegetation evapotranspiration. Recharge to the shallow groundwater occurs only when moisture in the root zone exceeds water holding capacity.

Following the above, the water balance of the GaMampa wetland and shallow aquifer can therefore be presented as follows:

$$\Delta S_{w} = R + GW_{i} - LF + IL - CR$$

where ΔSw is change in storage in the wetland, GWi is groundwater inflow from the hill slopes, LF is lateral flow or groundwater outflow from the wetland to the river, IL is losses from irrigation scheme, and CR is capillarity rise. Considering that surface water inflow from the hills to the wetland (SWi) and overland flow (OF) between the wetland and the river are negligible, they were omitted in the model. The main groundwater outflow from the wetland is subsurface flow (LF) or seepage at the edge of the wetland to the river. This flow occurs along the entire length of the wetland.

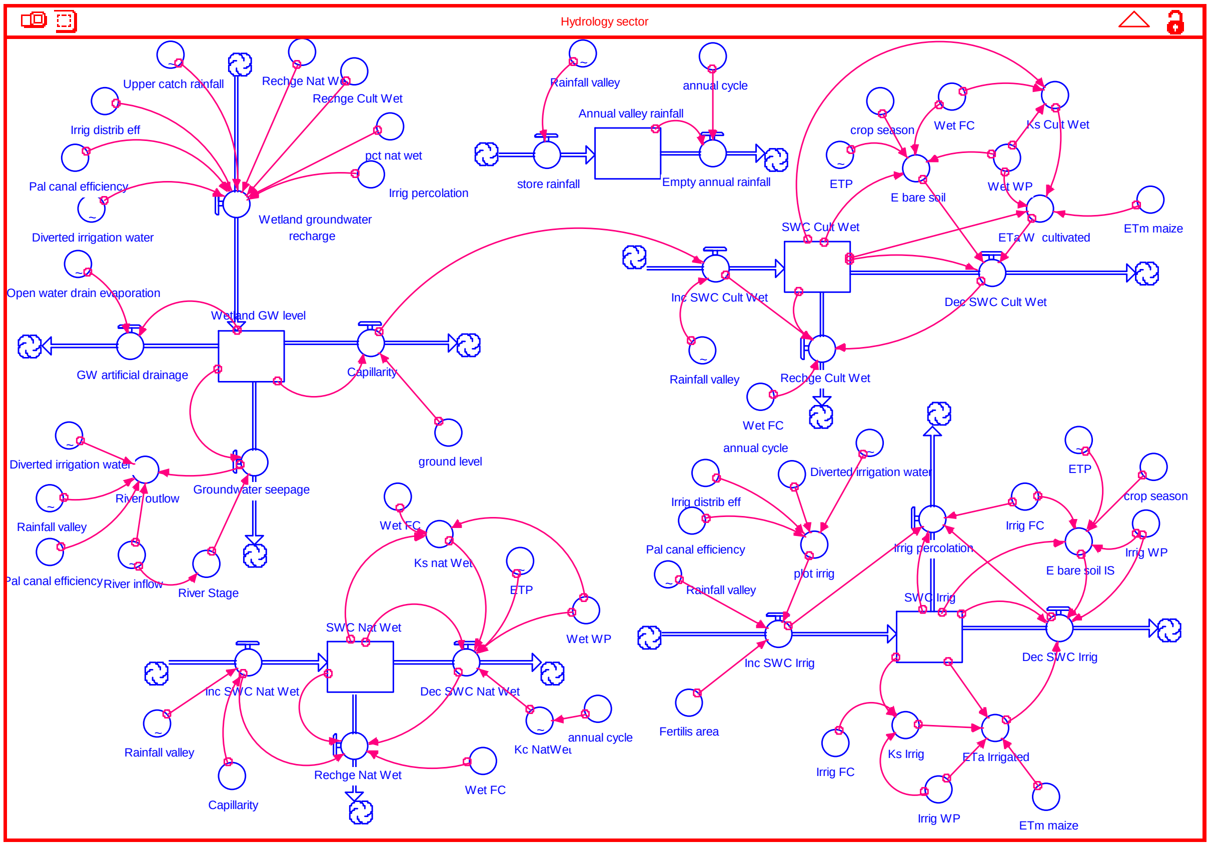

Figure 17. Hydrology sector

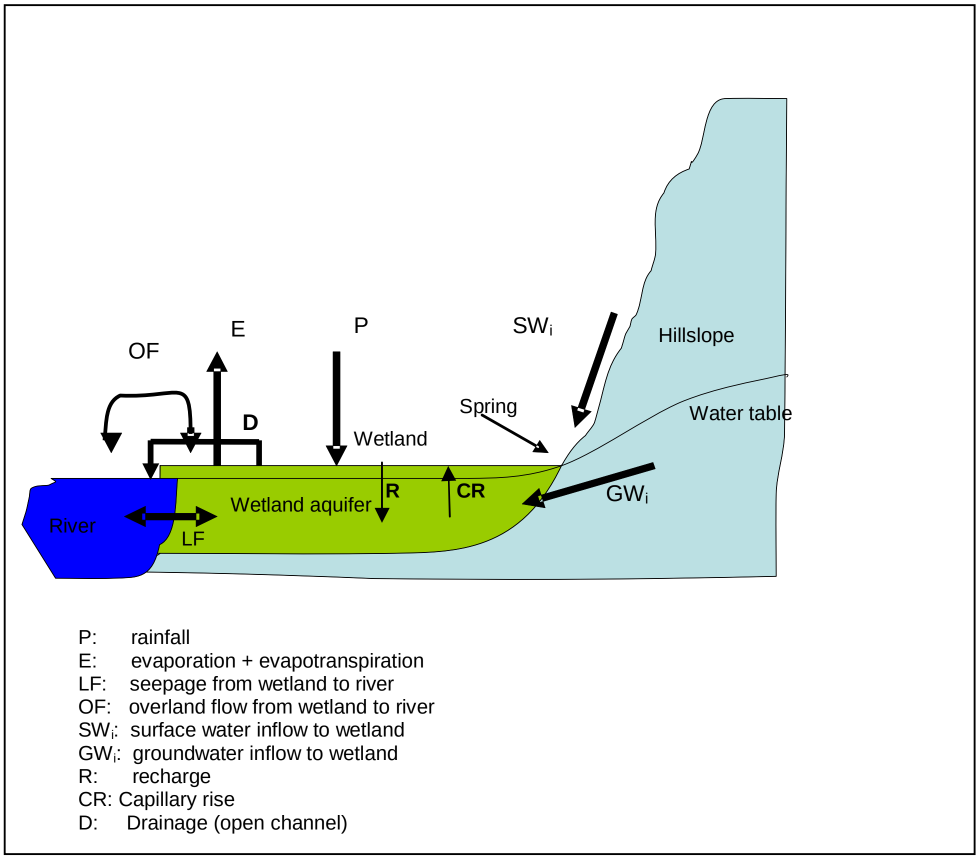

Figure 18. The GaMampa wetland flow generation conceptual model (Modified from McCartney, 2005)

4.7.2 Crop production sector

The crop production sector distinguishes the wetland cultivated area and the irrigated area, the dynamics of which is very similar except for the linkages with the wetland biophysical system. Wetland cultivated area is the difference between the total wetland area (fixed) and natural wetland area. However, the wetland cultivated area changes annually due to conversion of the natural wetland area and abandonment of cultivated area to natural vegetation. Maize is the only crop considered in the model and crop production only occurs once a year. Crop yields are modeled as a function of evapotranspiration using the crop yield response to water function described by Doorenbos and Kassam, 1986.

$$Y_a^i = Y_m^i \left[1 - k_y * \left(1 - ET_a / ET_m\right)\right]$$

where i, represents wetland or irrigation scheme, Y_a is actual yield (ton/ha), Y_m is maximum yield (ton/ha), ET_a is actual crop evapotranspiration over the cropping season (mm), ET_m is maximum crop evapotranspiration over the cropping season (mm), and k_y is crop yield response to water stress factor.

Maximal evapotranspiration, ET_m, is computed on a monthly basis, from potential evapotranspiration ETP using crop coefficients k_c ($ET_m = k_c$*ETP), and then summed over the cropping season. Actual evapotranspiration is computed from ET_m: $Et_a = k_s * ET_m$, where k_s depends on soil water content. Et_a is also computed on a monthly basis and summed over the cropping season. In the irrigation scheme ET_a is impacted by rainfall and irrigation water, and in the wetland by rainfall and groundwater level.

Values for k_c, k_y and k_s are derived from the literature. Y_m values are derived from household surveys (Adekola, 2007; Jogo *et al.*, 2008) and cross-checked with previous findings (Chiron, 2005). From farm surveys and field observations maize production provides higher yields in the wetland than in the irrigation scheme while requiring less labour and inputs (Chiron, 2005).

Total crop production depends on crop yields, the cultivated wetland area, and cultivated area in the irrigation scheme. Maize producer prices were derived from national series (Statistics South Africa, 2009).

The crop production sector of the model is shown in Figure 19.

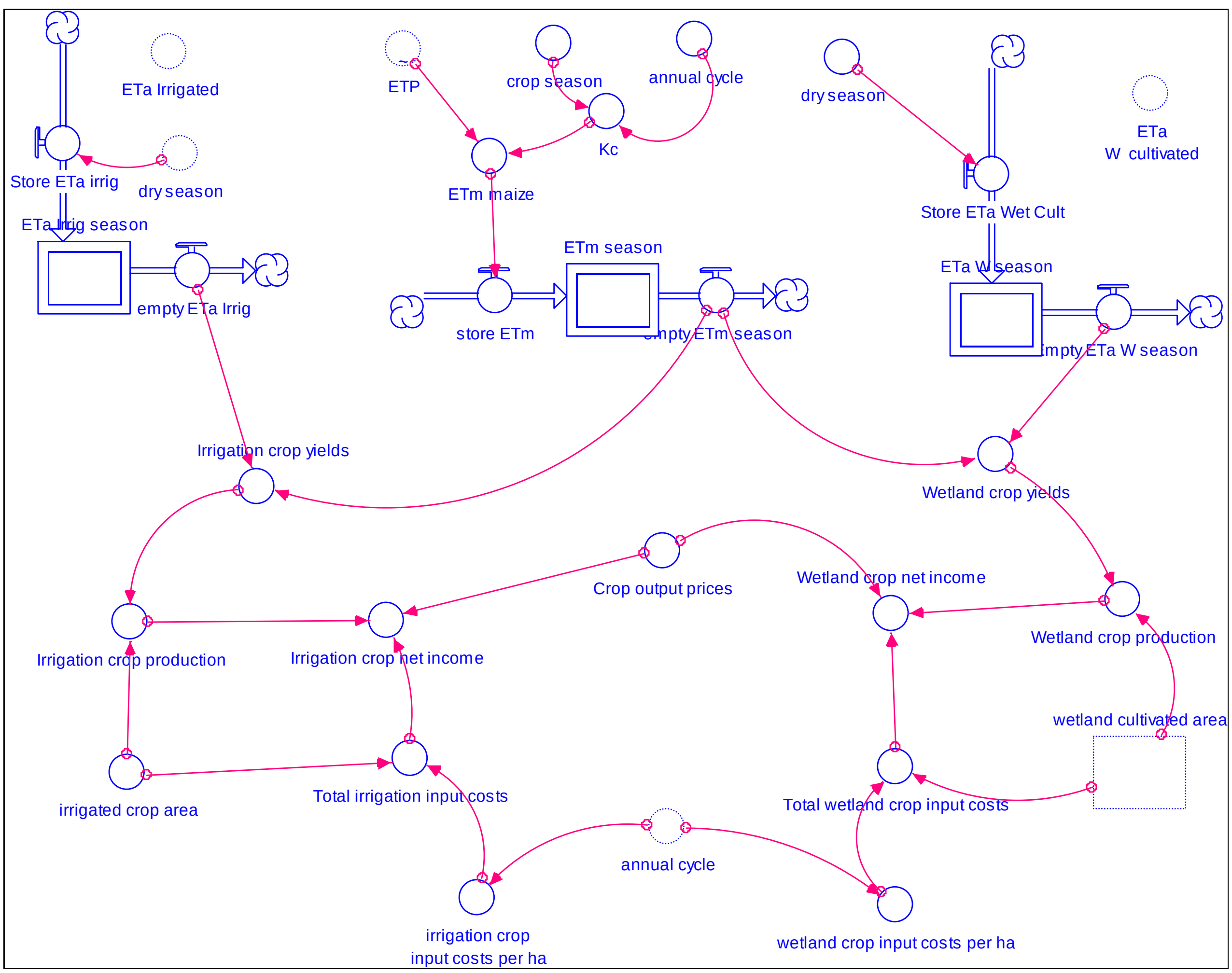

Figure 19. Crop production sector

4.7.3 Land use sector

This sector describes the processes that lead to conversion of the wetland to cropland. Two land use classes are considered in the wetland: the wetland cultivated area and the natural wetland area. The GaMampa wetland natural area is covered by natural vegetation, including sedges, reeds, and other natural products that are used by the local community (see natural resources sector). In a given period, the natural wetland area is the difference between the total wetland area (fixed at 120 hectares according to Kotze, 2005) and wetland cultivated area. Information from focus group discussions shows that wetland conversion to agriculture is primarily driven by poor production in the irrigation scheme due to water shortages related to degradation of irrigation infrastructure and droughts. Therefore, we linked wetland conversion to variability in annual rainfall and the need to seek for extra food to meet population grain requirement.

In the model it is assumed that the decision to clear natural wetland for cropping occurs in September, so that farmers have time to clear the land before it is time to sow (in December). Three possible situations for conversion of the wetland to cultivation exist. When rainfall of the previous cropping season is below a given threshold new wetland farmers are attracted in the wetland by the higher yields in the wetland compared to the irrigation such that they convert part of the natural wetland to agricultural land. The number of new farmers is in relation with the annual food security index - the ratio of annual food consumption over annual food needs (see community well-being sector) and the current number of wetland farmers. Based on household survey, we assumed a fixed area converted per new wetland farmer, set at 0.7ha, which is the average wetland plot size per wetland farming household.

Wetland cultivated area can be abandoned when the rainfall is very high and saturated soils in the wetland cause crop losses. This situation was never observed in GaMampa wetland in the recent past, therefore we could not calibrate the equation of wetland abandonment on observed data. We assumed that wetland abandonment occurs when rainfall is above a second threshold and that the area abandoned is proportional to the current wetland cultivated area. In any situation where rainfall is comprised between the two thresholds, wetland cultivated area and number of wetland farmers remain stable.

The land use sector of the model is shown in Figure 20.

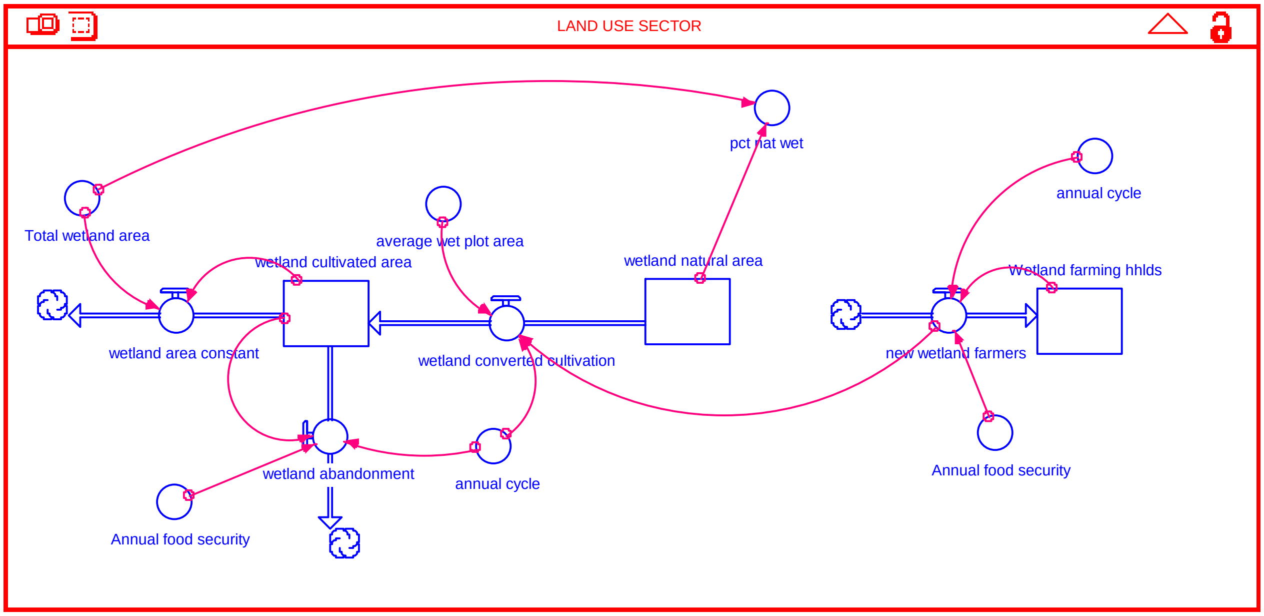

Figure 20. Land use sector

4.7.4 Natural resources sector

This sector models the dynamics of wetland natural biomass. Due to limited data on the study site, its formulation relied mainly on literature review. Reeds (Phragmites australis and Phragmites mauritanus) and sedges (Cyperus latifolis and Cyperus sexangularis) are the main species used by the local community.in the wetland. They cover respectively 20% and 2.5% of the natural wetland area (Kotze, 2005). Following Woodwell, 1998 and Hellden, 2008, we assumed that wetland biomass growth follows a logistic growth function, where the actual growth rate varies negatively with the ratio of actual biomass to carrying capacity of the wetland (i.e., the maximum quantity of biomass per unit area).The carrying capacity was set to a maximum of 70tons per hectare per annum. This corresponds to the maximum annual productivity of reeds (Finlayson and Moser, 1991 cited in Turpie et al.1999), considering that in the case of reeds, maximum annual productivity is equal to carrying capacity. The initial value of total biomass was computed by multiplying the biomass productivity by the wetland natural area.

Thenya (2006) reported growth rate of phragmites species up to be 300% just after harvest in Yala swamp, Kenya. We used an intrinsic growth rate of wetland biomass of 0.3 as a first and very conservative approximation. Reeds are deemed to be resistant to drought and variation of water levels, and little is known on the effects of water regime on its production level (Roberts and Marston, 2000), therefore we assumed that intrinsic growth rate is independent of groundwater level. The intrinsic growth rate is multiplied by a density dependent factor (1 - Xt / kx), which captures the changes in actual growth rate as biomass stock changes.

Harvest of natural wetland plants occur once a year in July. Harvest per hectare is the product of number of harvesters times quantity harvested per harvester over the natural wetland area. The number of harvesters evolved over time on a yearly basis according to available biomass per head and previous harvest per household. Each year in July biomass available per head is assessed by the community. It is computed from natural wetland area, biomass per hectare and the present number of harvesters. The number of new harvesters is proportional to actual number of harvesters. It is assumed that the new harvester rate is proportional to the relative difference between available biomass per head and the maximum harvest per head (set at 0.6T/ha according to household survey, Adekola, 2007). Similarly, harvester drop out rate depends on the harvest per head: if harvest per head is close to the maximum harvest per head then drop out rate is close to 0, and if harvest per head is close to 0 then drop out rate is close to 1.The fraction of harvested biomass which is sold on the market is valued at market prices (obtained from household survey) and feeds into the cash stock (community well-being sector).

The natural resources sector of the model is shown in Figure 21.

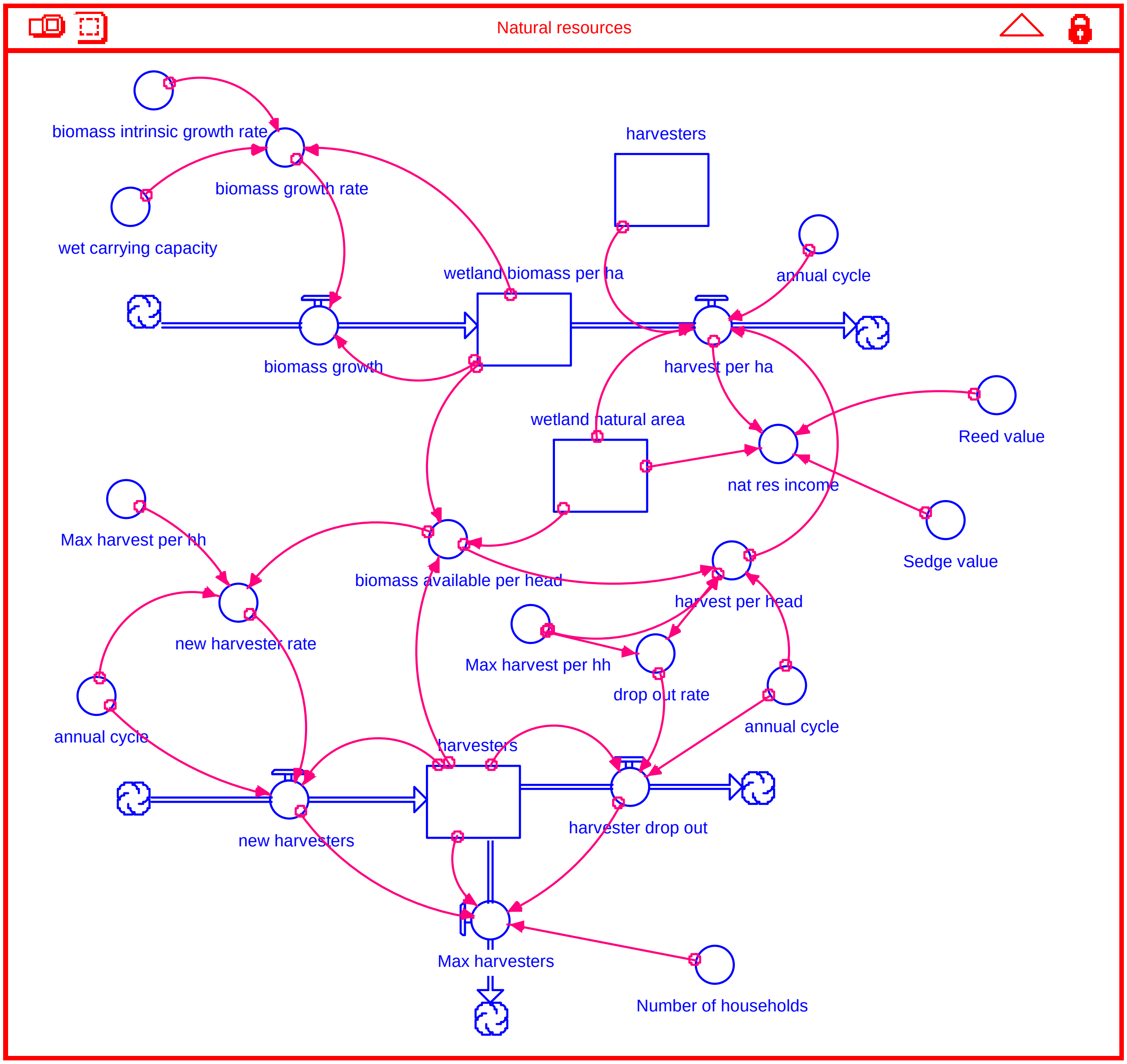

Figure 21. Natural resources sector

4.7.5 Community well-being sector

Population dynamics

The dynamics of human population in the study area influences the demand for wetland and other resources through the food and cash stocks dynamics. An exponential population growth function is used following other studies (Woodwell, 1998; Hellden, 2008). Population growth depends on natural growth rate (birth and death rate) and migration rates. Population natural growth rate and emigration rate are held constant over the simulation, respectively at the district average estimated at 1.7% per year and at 1% per year (Limpopo

Provincial Government, 2004). From focus group discussions conducted in the study area, we assumed that there is no immigration in the area.

Cash stock dynamics

Cash stock component is used to model income index, a component of community well-being.

Initial cash stock is set at one month of non farm income. Cash inflow is composed of: net income of wetland harvested natural biomass, which is computed in the natural resource sector; off-farm wage income and social transfers from the government. Off-farm wage income is assumed to be a function of the proportion of households engaged in wage work and of the average income earned from wage work. Similarly, exogenous income from social grants is a function of the proportion of the population entitled to receiving social grants (children under the age of 14 and adults aged 64 and over). Proportions of the population in each category were derived from household survey and assumed to be constant over time, to avoid complexity of the model. Both off-farm wage income and social transfers occur at monthly time step, whereas income from harvested wetland natural products only occurs once a year at time of harvest.

Cash outflow is the sum of non-food expenditure and food purchase. Non food expenditure is the sum of domestic expenditure, and crop inputs expenditures (see crop production sector). The level of cash stock at each time period determines the maximum quantity of food that the community can buy. At any point in time, cash available for food purchase is equal to cash stock less minimum basic non-food expenditures and crop input costs. An income index is computed from cash stock:

$$\text{Income index} = (\text{Cash} / \text{Population\_Number} - \text{poverty\_line})/\text{poverty\_line}$$

with the poverty line set at R150 per month (StatsSA 2007) to cover the non food basic expenditures.

Food stock dynamics

At the beginning of the simulation, the food stock is assumed to be at a mid level with the harvest from the last cropping season partly consumed by the needs of the total population over the dry season. It is assumed that maize is not sold on the market and only used for households' consumption; therefore there is no food sale. The population uses this stock to cover its monthly food needs (estimated at 95kg/household/month, according to Adekola 2007). When the food stock is empty, the community starts to buy maize to meet their food needs if the cash stock allows it (food purchase). Buying price of maize is assumed to be 15% higher than farm gate price.

Food stock increases once a year in April with maize production from wetland and irrigation scheme. It decreases every month with food consumption, which ideally depends on food needs per person and total population, but is limited to food stock at any point in time. So it may happen that food consumption is less than food needs.

Food security index is defined at any point in time as the ratio of food consumption over food need. Similarly, an annual food security index is computed once a year in September from annual food consumption and annual food needs to make decision over natural wetland conversion to agricultural land (see land use sector).

Well-being of the community is assessed each month based on three dimensions: the satisfaction of food requirements (measured through the food security index), the capacity of meeting basic non food expenditures (assessed via the income index) and the status of the natural wetland (measured by wetland index, equal to the ratio of actual natural wetland area over the maximum wetland natural area). The community well-being index is an output of the model on the basis of which scenarios are evaluated.

The community sector of the model is shown in Figure 22.

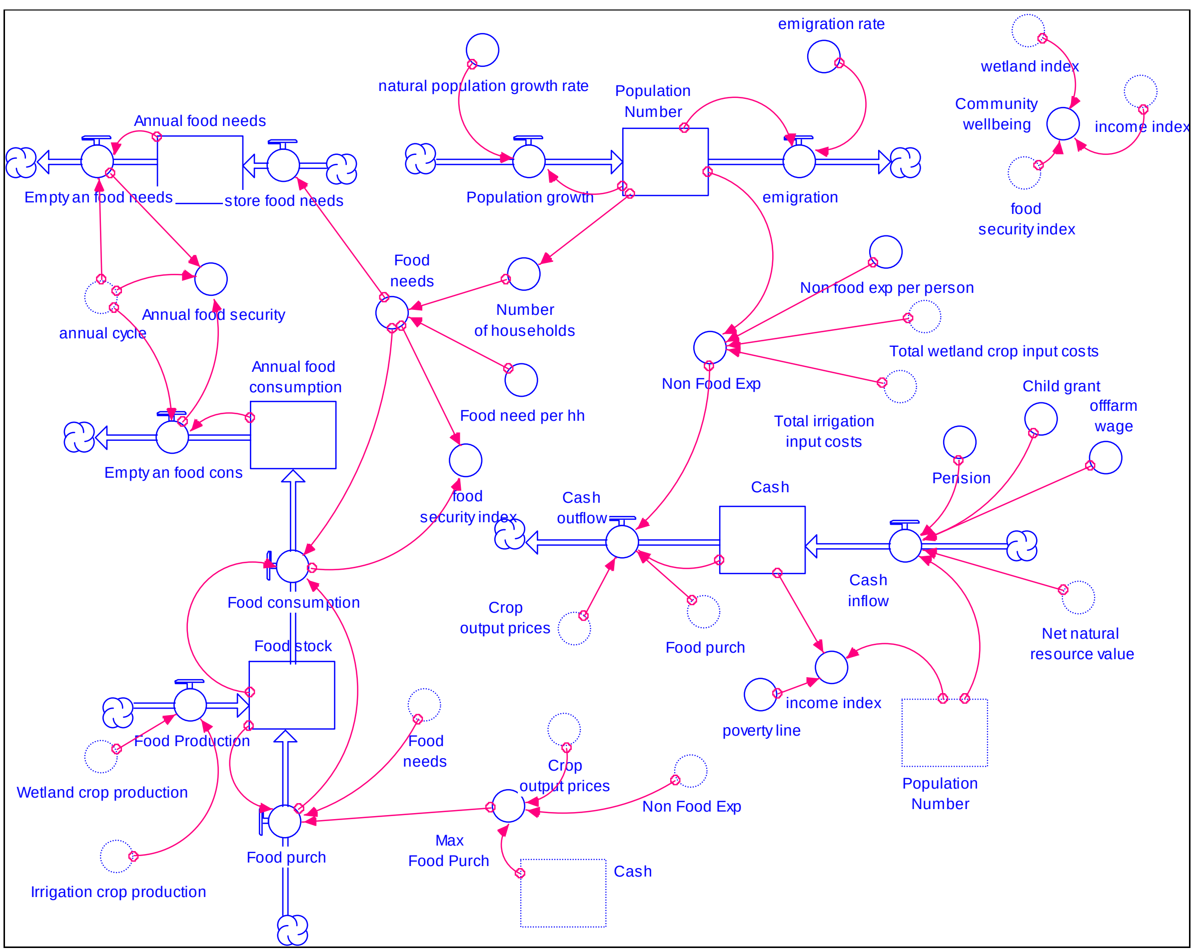

Figure 22. Community well-being sector

4.7.6 Model calibration

The model was calibrated such as it reproduces past observed evolution of land use from 1990 to 2006. The challenge with the GaMampa case study was the limited availability of data for calibration, particularly with socio-economic information.

4.7.7 Conclusions

The WETSYS model integrates existing knowledge on small-scale wetlands such as the GaMampa wetland in South Africa and support the analysis of trade-off between supply of ecosystem services by the wetland and its ecological integrity. The modeling process was instrumental in fostering inter-disciplinary dialogue and identifying knowledge gaps.

The WETSYS model can be used to simulate different management interventions under various global change scenarios. Localized global change scenarios will include changes in climate (rainfall and potential evapotranspiration), population dynamics (changes in natural growth and emigration rate) and economic policies (affecting among others social transfer and level of wage rate). Wetland management options, which will be simulated, include introduction of crops more adapted to wetland environment and reduction of artificial drainage, development of ecotourism with the launch of a recently built tourism facility, and imposing controls on resource use in the wetland.

Due to its modularity, WETSYS can easily be adapted to similar small-scale wetlands in Southern Africa.

Main challenges in the development of the model were the limitation in available time series data to calibrate it, especially regarding the socio-economic information, and the difficulty to translate narratives about past land use changes into quantitative decision rules. Possible improvements and developments of WETSYS include: improved land use decision rules, through the incorporation of stakeholders' knowledge, feedback from well-being to population dynamics through emigration rate, linking biomass production to wetland groundwater level, adding a sector on organic matter dynamics in the wetland soil.

5 Project performance

5.1 Project objectives and outputs

The project was designed with four objectives as follows:

- Develop and apply a trade-offs based framework for making decisions about allocations of wetland resources to specific uses, including agriculture.
- Determine the trade-offs among different agricultural uses of wetland water and the trade-offs between each of the agricultural water uses and

environmental use; develop guidelines on acceptable levels of wetland water use for agriculture; and encourage this as best practice.
- Identify as part of the trade-off analysis who benefits, e.g., poor women and men farmers, herders, fisher folk; local business people; etc.
- Enhance capacity of wetland users, researchers, extension officers, natural resource managers, and policy makers.

At the onset of the project the following outputs were envisaged

1. An inventory of the different methods of wetland water management for agriculture to support livelihoods and a framework for a gender-disaggregated social welfare index based on food security and income goals of farmers.
2. Empirical knowledge of the natural resource base's potential to produce agricultural products and ecological goods and services.
3. Framework for analyzing trade-offs between food production/security and environmental security developed and applied; and comparative analysis of social welfare benefits accruing from various options for wetland water use for agriculture and the trade-offs among them, including trade-offs among different intensities of each use.
4. Knowledge of technical management inputs to attain different levels of crop production in wetlands and the associated trade-offs.
5. Recommendations and guidelines for allocating uses to *dambos* and riverine swamps for extension agents, traditional decisionmakers, and wetland users; and policy recommendations on agricultural wetland use regulation.
6. Enhanced capacity of wetland users, decision makers (both government officials and traditional decision makers), researchers, and other stakeholders.

The project outputs were revised in January 2007 at a project progress review meeting attended by all project partners and the Limpopo Basin Coordinator. Three outputs that would be of key importance to stakeholders in the Limpopo basin were identified. These were agreed on as the final outputs of the project. This decision was communicated to the CPWF as well as stated in request for an extension for project implementation. The revised project outputs are:

- Baseline for wetland monitoring in the Limpopo
- Methodology for tailored management options
- Trade-off model and scenarios

5.2 Project performance by objective

The extent of achievement of objectives by the project is outlined in **Table 9**

Table 9. Extent of achievement of project objectives

Objective	**Sub-objective**	**Status at project completion**	**Key outputs**
Develop and apply a trade-offs based framework for making decisions about allocations of wetland resources to specific uses, including agriculture.	Develop a trade-offs based framework for making decisions about allocations of wetland resources to specific uses, including agriculture.	Complete	Assessing trade-offs in wetland utilization in the Limpopo River basin: a research framework
	Apply trade-offs analysis framework	Model application was initiated for GaMampa. Validation of the model could not be completed within the scope of the project.	1. Empirical model and results from analysis of the impacts of alternative management regimes on wetland functioning and economic well-being* 2. Integrated modeling for assessing the trade-offs at Ga-Mampa wetland: Balancing human well-being and ecological integrity** 3. Trade-offs between livelihoods and wetland ecosystem services: an integrated dynamic model of Ga-Mampa wetland, South Africa. Proceedings of LANDMOD2010. Montpellier. February 3-5, 2010. www.symposcience.org***
Determine the trade-offs among different agricultural uses of wetland water and the trade-offs between each of the agricultural water uses and environmental use; develop	Determine wetland stakeholders	Complete	1. GaMampa: Darradi et al: Analysing stakeholders for sustainable wetland management in the Limpopo River basin: The case of GaMampa wetland, South Africa, Proceedings of the 7th WATERNET/WARFSA/GWP-SA Symposium "Mainstreaming IWRM in the Development Process", Lilongwe, Malawi, 1-3 November 2006, 25 p 2. Chiputwa et al., 2006. Diversity of wetland-based livelihoods in Limpopo river basin 3. Lopes, Avelino and Nícia Givá. 2006. Stakeholder analysis: wetland uses and perceptions: The case of Mussavene wetland

Objective	Sub-objective	Status at project completion	Key outputs
guidelines on acceptable levels of wetland water use for agriculture; and encourage this as best practice.	Determine extent of use of wetland goods and services by stakeholder / stakeholder group	Complete	1. Wellington Jogo. 2009. Ecological-economic modelling of inland wetland systems in the Limpopo basin: balancing human well-being and ecological security. PhD Thesis submitted to the Department of Agricultural Economics, Extension and Rural Development, Faculty of Natural and Agricultural Sciences, University of Pretoria 2. Adekola, O. 2007. Economic valuation and livelihood analysis of the Provisioning services provided by Ga-Mampa wetland, South Africa. MSc. Thesis. Wageningen University 3. Chiputwa, B. 2006.Socio-economic analysis of wetland utilization and livelihood implications on poor farmers: A case study of Intunjambili community. MSc Thesis, Department of Agricultural Economics, University of Zimbabwe. 4. Chiputwa, B., S. Morardet and R. Mano, 2006. Diversity of wetland-based livelihoods in Limpopo River basin. Proceedings of the 7th WaterNet / WARFSA/GWP-SA Symposium, 1-3 November 2006. Lilongwe, Malawi. 5. Givá , Nícia. 2006. Análise sócio-económica da contribuição dos wetlands nos meios de sustento das comunidades adjacentes. CPWF Project Report.
	Develop guidelines	Complete	1. Chuma et al., 2008. Guideline for sustainable wetland management and utilization: key cornerstones. Project Report 2. Finlayson, C. M. and S Pollard, 2009. A Framework for Undertaking Wetland Inventory, Assessment and Monitoring in the Limpopo Basin, Southern Africa. CPWF Project Report.
Identify as part of the trade-off analysis who benefits, e.g., poor women and men farmers, herders,		Complete	1. Stakeholder analysis reports 2. Economic valuation methodology and report 3. Application of tradeoffs model

Objective	Sub-objective	Status at project completion	Key outputs
fisher folk; local business people; etc			
Enhance capacity of wetland users, researchers, extension officers, natural resource managers, and policy makers.		Complete	1. BSc reports 2. MSc theses 3. PhD thesis 4. Awareness raising in wetland communities 5. Research capacity enhanced through joint implementation. Transfer of ecological analysis tools (Kotze, 2005) to partners working at Intunjambili and Chibuto wetlands

*Chapter 6 of PhD thesis -
**Paper not published at the end of the project but under revision by authors (Morardet et al) for publication in 2010) –

5.3 Project performance by output

Table 10. Extent of Achievement of Project outputs specified in project document

Output Narrative Summary	Measurable Indicators	Means Of Verification	Status
1. An inventory of the different methods of wetland water management for agriculture to support livelihoods and a framework for a gender disaggregated social welfare index based on food security and income goals of farmers.	Inventories carried out at three wetland sites; social welfare index developed.	Research reports and journal article.	Reports: 1. Water Management interventions in wetlands in the Limpopo basin: examples from GaMampa, Intunjambili, and Chibuto wetlands - this report was incomplete at t the end of the project. It will be submitted to the CPWF 2. Water management interventions at Chibuto 3. Water Management interventions at Intunjambili 4. The reports cited above contain the inventories of water management interventions at the three case studies 5. A well being index is a parameter developed and used in the WETSYS model (see Morardet et al, 2010)

Output Narrative Summary	Measurable Indicators	Means Of Verification	Status
2. Empirical knowledge of the natural resource base's potential to produce agricultural products and ecological goods and services.	Potential of wetlands to produce agricultural products and ecological goods and services established and disseminated by 2007.	Journal articles; research technical reports.	Unpublished Reports and theses: 1. Charlie, A. S. 2006. Investigation of gardening, cultivation and grazing on the Intunjambili wetland. A thesis submitted in partial fulfillment of the requirements for BSc Honours Degree in Agriculture. University of Zimbabwe. 2. Mamane, Sipho. 2005. Effects of wetland utilization on the water table for Intunjambili wetland, Matopo. An Undergraduate Research Project Submitted in Partial Fulfillment of the Requirements of the Degree of BSc Honours in Agricultural Engineering 3. Sibanda, T. 2005. An undergraduate Research Project Submitted in Partial Fulfillment of the Requirements of the Degree of BSc Honours in Agricultural Engineering. University of Zimbabwe. 4. Saimone, Francisco and Paiva Munguambe. 2006. Land use maps, cropping pattern and water management in Chibuto Wetland. 5. Adekola, O. 2007. Economic valuation and livelihood analysis of the provisioning services provided by GaMampa wetland, South Africa. MSc thesis, Wageningen University

Output Narrative Summary	Measurable Indicators	Means Of Verification	Status
3. Analytical framework for analyzing trade-offs between food production/security and environmental security developed and applied; and comparative analysis of social welfare benefits accruing from various options for wetland water use for agriculture, and the trade-offs among them, including trade-offs among different intensities of each use.	Tradeoff analysis framework developed by month 18; and tested by month 24.	Published journal articles and peer-reviewed research reports.	Framework for analyzing tradeoffs developed. The framework is outlined in the report "Assessing trade-offs in wetland utilization in the Limpopo River basin: a research framework" Application of tradeoffs model was implemented for GaMampa wetland. The completed application at the end of the project is documented in the report "Trade-offs between livelihoods and wetland ecosystem services: an integrated dynamic model of Ga-Mampa wetland, South Africa"
4. Knowledge of technical management inputs to attain different levels of crop production in wetlands and the associated radeoffs.	Management inputs for selected crop production targets and the associated tradeoffs disseminated by 2008.	Published journal articles and peer-reviewed research reports.	Output of the tradeoffs model.
5. Recommendations and guidelines, based on tradeoff analysis, for allocating uses to *dambos* and riverine swamps for extension agents, traditional decisionmakers, and wetland users; and policy recommendations on agricultural wetland use regulation.	Guidelines and recommenda tions published and disseminated in 2008.	Research reports and workshop reports.	Guideline document produced - Guideline for sustainable wetland management and utilization: key cornerstones.
6. Enhanced capacity of wetland users, decision makers (both government officials and traditional decision makers), researchers, and other stakeholders.			

<table>
<tr><th>Output Narrative Summary</th><th>Measurable Indicators</th><th>Means Of Verification</th><th colspan="2">Status</th></tr>
<tr><td>6.1. Capacity to implement research built.</td><td>Four MSc and two PhD students involved in field research, and complete their programs by 2008</td><td>MSc and PhD theses</td><td colspan="2">- 1 PhD research completed
- 6 MSc completed
- Several BSC research projects completed
- 1 month GIS and Remote sensing internship by Mozambique researcher, Francisco Saimone completed at IWMI in 2007.</td></tr>
<tr><td rowspan="3">6.2. Training of wetland users in new or improved water management methods; farmers' capacity to manage and utilize wetland resources improved</td><td rowspan="3">Training carried out at all sites by end of 2005.</td><td rowspan="3">Reports of training sessions, and monitoring and evaluation feedback from wetland users.</td><td>September 2004
Facilitator: E. Chuma and Mozambique team</td><td>Soil and water management demonstration to the Intunjambili community*</td></tr>
<tr><td>July 2005. Facilitator: E. Chuma and Mozambique team</td><td>Soil and water management demonstration to the Chibuto community*</td></tr>
<tr><td>January 2006. Facilitator: E. Chuma and Mozambique team</td><td>Farmer group meeting – Demonstration of the use of participatory rural appraisal tools of resource mapping and seasonal and cropping calendar development*</td></tr>
<tr><td>6.3. Wetland users workshop to disseminate knowledge on the possible options for wetland resource use and the associated tradeoffs.</td><td>Workshop carried out by end of second quarter in 2008.</td><td>Workshop report*</td><td colspan="2">Several dissemination workshops were held by way of feedback of results. Example workshops are:
- GaMampa Institutional analysis feedback workshop
- GaMampa Stakeholder analysis feedback workshop
- GaMampa ecological valuation workshop</td></tr>
<tr><td>6.4. Workshops to disseminate knowledge to extenstion, research, and natural resource management staff</td><td>Workshop carried out by end of second quarter in 2008.</td><td>Workshop report</td><td colspan="2">Final dissemination workshops were held at Intunjambili and GaMampa.
Due to time and budgetary constraints such a workshop was not held at Chibuto.</td></tr>
</table>

Output Narrative Summary	Measurable Indicators	Means Of Verification	Status
6.5. Policy workshop	Policy workshop carried out during second half of 2008.	Workshop report	Policy workshop was not held due to the changes to implementation plan (see section 5.4) as well as time and budgetary constraints

5.4 Summary of project perfomance

The project outputs were delivered to the CPWF after the following changes to the implementation plan.

Changes made to implementation plan:

In January 2007 the project team and basin coordinator realigned the project outputs. The basin coordinator (Mr. Shaker) indicated that stakeholders/decision makers in the Limpopo basin would be more interested in and benefit more from practical outputs from the projects such as guidelines for using wetlands to sustain their livelihoods without damaging the environment. The guidelines could be at different levels (micro or macro) and sensitivity analysis could be done to inform the guidelines.

Based on ongoing work and outputs at this stage, the project team agreed that the project would deliver the following three outputs:

- Baseline for wetland monitoring in the Limpopo
- Methodology for tailored management options for wetlands
- Trade-off model and scenarios

Changes to planned activities

Two significant changes to field activities were made in January 2007.

- Development of the model was to be limited to GaMampa and Chibuto wetlands. Hydrological monitoring for the CPWF project at Intunjambili would be stopped.
- Socio-economic monitoring would be stopped in first quarter of 2007 and would only be carried out when required for the three products above. When required such monitoring would be targeted at select variables and for smaller samples.

These changes are outlined in the project meeting report (document "Project Meeting report 22-25 Jan 2007.pdf – submitted with this synthesis report)

Extension of project duration:

A no-cost extension was requested to finalize project outputs in by the third quarter of 2008.

During 2007 and 2008 there were changes to the project team with project scientists moving to new responsibilities. As a result, there were delays in finalization, including editing of several of the project reports. Publishing some of the reports is still being pursued by the individual researchers. As reports get published, the CPWF will be informed.

6 International Public Goods

6.1 New insights – tools and methodology

6.1.1 Framework for inventory, assessment, and monitoring of wetlands

One of the outputs delivered to the CPWF is a framework for undertaking wetland inventory, assessment and monitoring in the Limpopo basin in southern Africa (Finlayson and Pollard, 2009). The framework is based on internationally agreed principles and uses information and examples from wetlands in South Africa, Mozambique and Zimbabwe. The framework provides an outline of approaches and lists key references and source materials along with practical examples and applications. It is not a technical manual; as a lot of technical material already exists this is referenced not reproduced.

6.1.2 Tradeoffs analysis approach

WETSYS, the tradeoffs model developed as part of this project provides an innovative approach for assessing the costs and benefits of wetland agriculture. The model provides an alternative for assessing the value of wetland agricultural system while considering the costs to other ecosystem services essential for human well-being. The modeling process proved to be instrumental in fostering inter-disciplinary dialogue and identifying knowledge gaps.

Traditional disciplinary modeling approaches do not capture the linkages between the socio-economic and biophysical factors in a wetland ecosystem. The modular nature of the WETSYS model can easily be adapted to similar small-scale wetlands in Southern Africa. Also, other components can easily be added to existing models

Wetland management options that can be simulated using WETSYS include (1) rehabilitation of the irrigation scheme, (2) introduction of crops more adapted to wetland environment and reduction of artificial drainage; (3) development of ecotourism with the launch of a recently built tourism facility; and (4) imposing controls on resource use in the wetland. The choice of management options is informed by discussions with the community as well as field surveys that took place between 2004 and 2008. This process conducted with the involvement of local and external stakeholders can support the development of wetland management plans.

6.1.3 Applications of spatial analysis to wetland change and variability of wetland goods and services available in the wetland

With increasingly available high resolution monitoring and mapping of changes within wetland ecosystem provides a powerful insight to changes in wetlands. Mapping the extent of encroachment of agriculture into natural wetland on a regular basis provides data on the rate of loss of the wetland and associated services, the benefits accruing from crop production, and wetland water use fro crop production. Such mapping as documented in Kulawadarna et al (2007) is useful to change detection.

Time series spatial analysis of the encroachment of crop production into wetlands allows assessing the spatial and temporal variation of the cropped land within the wetland as well as seasonal availability of goods and services accruing from the wetland. The analysis also enables the assessment of the extent and variation of wetland goods and services that accrue to other stakeholders outside the wetland boundaries, for example beneficiaries of water flowing downstream (the irrigators at Intunjambili) or other water users in general (Olifants river stakeholders downstream of the GaMampa community) as they are affected by the encroachment of cropland.

The availability of high resolution satellite imagery makes it possible to have fairly accurate assessments of the changes in land uses in wetlands and also the total value accruing from the wetlands

6.1.4 Contribution to guidelines for wetland ecosystem management

Continued expansion of agriculture presents real benefits for wetland users. The expansion also has costs in terms of other opportunities lost. Also, there are challenges associated with managing the wetlands under the existing institutional and legal frameworks and without monitoring and evaluation. Generic guidelines provide practical solutions for wetland agricultural environments that ensure that livelihood benefits are not derived at the cost of ecosystem services.

In the report "Guideline for sustainable wetland management and utilization: key cornerstones", Chuma et al (2008) outlined the key elements to sustainable management of wetlands. The guide's main objective is to provide a framework for utilizing and managing wetlands, particularly those wetlands whose ecosystem services are used for livelihood purposes. It provides practical management solutions at three stakeholder levels: farmers and other natural resource users, natural resource management agencies, and governments. It complements government efforts in their quest for effective regulation of wetlands utilization and management. To this end it should be seen as support for and not a replacement for existing efforts at sustainable wetland management.

The eight cornerstones outlined in the guide highlight many options for entry points for wetland management activities in any community. These are

1. Sound understanding of the wetland ecology and socio-economic situation by communities and outsiders
2. A community-based monitoring and evaluation system which enables to learn and adapt from successes
3. Management interventions which balance ecosystem functions and human needs
4. Incentives which encourage the maintenance of ecosystem services
5. Legal frameworks of different actors which are coherent and encourage sustainable use of wetlands
6. Negotiated local rules and by-laws which discourage unsustainable use of wetlands
7. Agreed-upon and functional institutional arrangements which facilitate and regulate sustainable wetland utilization and conservation

8. Facilitation of land users / communities which ensures an inclusive, consensus-based planning and management process

No single cornerstone is more relevant than the other, and the implementation in practice can follow any particular order.

6.2 Outcomes and impacts

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
Communities	Communities are more aware of the need to maintain ecosystem functioning of the wetlands. They understand better the linkages between the benefits they derive from wetlands and the functioning of the wetlands	Sharing of research findings such as: ▪ value of wetland goods and services ▪ Showing how management of wetland was leading to disappearance of the wetland and ecosystem services	▪ Engaging stakeholders through workshops where results were given back to the community (for example after each specific study feedback sessions with the community were organized). ▪ Research results were shared directly with communities	In a meeting with the GaMampa community farmers were openly contributing to the discussions on setting objectives for a management plan of the wetland. This is a discussion that was unlikely to happen at the beginning of the CPWF project 30.
Communities	Continued discussions of wetland management. With the help of the Limpopo Department of Agriculture, the community used some of the project findings to motivate support for management of the wetland from UNDP.	Information was made available to the community through stakeholder feedback workshops. This information relates to: ▪ increasing agriculture and decreasing reeds and sedges ▪ wetland value ▪ Hydrological functioning	Results feedback workshops that were held regularly in the community. At some of these meetings, external stakeholders (for example Limpopo Department of Agriculture, Limpopo Department of Environment, Working for Wetlands, were invited and were represented)	▪ By the end of the project the community at GaMampa was more open to discussing wetland management issues with external stakeholders. A request for GaMampa to be included on the priority list for Working for Wetlands interventions was made to the Limpopo Working for Wetlands officer. ▪ The GaMampa community seeking assistance from LDA to write a grant

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
				proposal to seek resources for managing the wetland is a significant step towards sustainable management of the wetland
Government agents (agricultural extension officers and environmental officers)	Government agencies engage wetland users	Ecosystem value of wetlands to local stakeholders (local wetland users)	Stakeholder identification at the beginning of the project as well as effective stakeholder engagement at all levels	Government officials are increasingly engaging communities. In a follow up project at GaMampa government officials at local, provincial, and municipal levels actively participate in stakeholder discussions on management of the wetland.
Government agents (environment, local municipality) that work with the community at	They are considering drawing up and implementing a wetland management plan.	Awareness on the local uses of wetland resources	Results of analysis (stakeholder spectrum, livelihoods, land use and land use impacts, economic valuation)	There was commitment from government officers at the final stakeholder workshop

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?

Wetland management planning has the greatest potential of being adopted and having impact. The communities realize the challenges that are associated with managing the wetland sustainably under the current land use practices. They thus continue to seek assistance and information to manage the wetlands to support livelihoods.

Wetland management planning will have impact on two levels. First, the communities will have an action plan for managing the wetlands. Second, monitoring and evaluation plan that will be included in the management plan will require continuous assessment of the ecosystem by communities and responsible government departments. Information necessary for management of the wetlands will therefore be provided to the relevant stakeholders.

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.

Continued awareness-raising among the communities by government extension officers and environmental officers will ensure local institutional memory of the relevance of maintaining ecosystem services for livelihoods.

Access to alternative resources that support livelihoods, particularly land and water remains a challenge in areas like GaMampa, Intunjambili, and Chibuto. Engagement of stakeholders external to the wetlands, especially at GaMampa and Intunjambili where there are obvious beneficiaries downstream who will be impacted by agricultural development in the wetlands ensures that all view points are considered when decisions for land uses in the wetland are made.

One of the project partners, IWMI, will continue to implement activities at GaMampa wetland until 2011. It will implement the WETwin project that builds on CPWF Project 30. The objective of the WETwin project is to enhance the role of wetlands in basin-scale integrated water resources management (IWRM), with the aim of improving the community service functions (agriculture, food provisioning services, provision of drinking water) while conserving good ecological status of the wetland. This project, with its focus on decision support tools, builds on the tradeoffs analysis initiated by the CPWF PN30. Further, the WETwin project pays special attention to stakeholder engagement.

On the more global scale results and knowledge from this project are integrated into IWMI's institution wide wetland program that has direct engagement with Ramsar convention and other stakeholders. Recently as part of IWMI's corporate communications strategy, a special topic webpage and brief for wetlands and agriculture was launched by IWMI to celebrate World Wetlands Day (http://www.iwmi.cgiar.org/Topics/Wetlands/index.aspx).

At GaMampa and Intunjambili IWMI's Sustainable Management of Inland wetlands project provided an opportunity to implement detailed land cover mapping of the wetlands. At Intunjambili the same project facilitated the activity for determining hydrological functioning of the wetland. Under this project a Soil Water Assessment Tool (SWAT) model was set up run for the wetland.

7 Partnership achievements

The partnerships developed through implementation of this project span disciplines, institutions, and countries. The multidisciplinary nature of the project required close collaboration between researchers. Also, because the project required an understanding of local management of resources, strong partnerships were developed with local communities at all three project sites (Intunjambili, GaMampa, and Missavene).

The integrated model and its components is an outcome of the combined understanding of the functioning of wetland ecosystems. The analytical exercise resulted in enhanced understanding of the linkages and feedbacks between the functioning and services provided by the ecosystem. Model scenarios show the different levels of benefits derived as well as the resulting level of services that the wetlands can provide.

Joint implementation of research projects with university partners resulted in numerous in-depth analysis of specific issues. An example is the local valuation of wetland resources at GaMampa that was implemented as masters' thesis research. The student was able to spend considerable amounts of time in the field, having in depth discussions with local stakeholders. Similarly students spent a significant amount of time engaging with stakeholders, understanding stakeholder interests and concerns.

The relationships with the communities of GaMampa and Intunjambili wetlands still continue through other projects (for example the recently initiated WETwin project that focuses on enhancing river basin management through wetland management) developed as a result of the partnership developed and natured during implementation of the CPWF funded project[3]. The WETwin project builds on the concept of tradeoffs analysis.

Finally the involvement of government officials who have the primary responsibility for natural resources management – Department of Environment in South Africa, MICOA in Mozambique, and the Environmental Management Agency in Zimbabwe – ensures that decisions for wetlands and natural resources management in general considers local uses of resources and benefits that accrue locally. This ensures long term awareness and incorporation of local concerns into management programs. There are no guarantees that government officials will continue to be committed to local stakeholders. Yet there seems to be some continued involvement of public officials, for example at GaMampa, more than a year after the project activities on the ground ended. With support of the Landcare Unit of the Limpopo Department of Agriculture, the community sought financial support from the UNDP to assist them in managing the wetland resources.

8 Summary findings and recommendations

8.1 Findings

The research findings are summarized in the following paragraphs.

- There is an increasing trend among resource poor households without access to water infrastructure to utilize water in the wetlands for food

3 WETwin is an EU supported project on "Enhancing the role of wetlands in integrated water resources management for twinned river basins in EU, Africa and South-America in support of EU Water Initiatives". The project objective is to enhance the role of wetlands in basin-scale integrated water resources management (IWRM), with the aim of improving the community service functions while conserving good ecological status.

production and domestic water in some cases (e.g. for Mozambique and Zimbabwe).

- At local level the value derived from wetland farming and the harvesting of other wetland products is significant. This value forms a significant part of households income or livelihood.

- The typology of wetland users shows that it is difficult if not impossible to characterize the typical wetland user and generalize across the basin or region. At GaMampa asset-poor households were more likely to engage in wetland cropping and collection of natural products than asset-rich households. This was explained by the limited livelihood opportunities outside agriculture available for asset poor families. They are more vulnerable to climate risks such as droughts. At Intunjambili asset-rich households were more likely to engage in wetland cropping and natural product collection. These households were socially well-connected, influential and were perhaps able to use their influence to obtain access to wetland resources. They also had access to resources, enabling them to invest in wetland crop production.

- At the scale of individual wetlands, there is no clear link between land use in the small wetlands and hydrological regime of the catchments in which these wetlands lie. However, the hydrological functioning of the individual wetlands creates conditions that support livelihoods for example through supporting agriculture. Agricultural use of these wetlands impacts water supply at wetland level.

- The WETSYS model provides a way of integrating existing knowledge on small-scale wetlands such as the GaMampa wetland in South Africa and support the analysis of trade-off between supply of ecosystem services by the wetland and its ecological integrity. It is potentially influential fostering inter-disciplinary dialogue and identifying knowledge gaps. However, there are several challenges relating to the tradeoffs modeling approach. The first concerns elaboration and implementation of complex models in a context of data scarcity such as the Limpopo River basin where this project was implemented. Second the format of the research outputs need to be adapted to the targeted stakeholders. Finally, engagement of stakeholders in the analysis could be improved to ensure that findings are used in the decision making process.

- The challenges faced by wetland users are many; a multi-faceted approach incorporating both social and technical issues is considered more appropriate. Most approaches are disciplinary, focusing on hydrology or institutional aspects or ecology in isolation. Optimal management solutions require integration of the different disciplines and consideration of the linkages and feedbacks.

- Water management interventions are implemented in wetlands in order that certain desirable crops can be grown. These include drainage for crops like maize, irrigation in drier areas of the wetlands, and the use of residual moisture. These interventions result in different outcomes that are desirable at different times of the year.

- With the current water management practices in the wetlands there is a potential for altering the structure and function of the wetlands, and their capacity to sustain livelihoods and provide other ecosystem services in the future. For example, the "excess" of water during the rainy season was identified as one of the major constraint leading most of the time to land abandonment and therefore, limiting crop production. This excess water is drained, reducing residence time of water in the wetlands, directly affecting the provisioning service of agricultural production supported by the wetland.

- Maintenance of a shallow water table in the wetland aquifers is essential for crop production. Water management interventions for agriculture should focus on managing the water table and water distribution across the landscape rather than drainage as a way of minimizing tradeoffs between crop production and water supply.

- Despite the rules and regulations at national level in Mozambique, South Africa, and Zimbabwe, land and water management in wetlands takes place at local level. Different rules, sanctions and penalties are applied and enforced at this level. The local level is therefore the most logical entry point for effective and sustainable management of wetlands.

- There exist opportunities and incentives that can be used as entry points for better and sustainable management of wetlands. These include identifying, together with communities, ways of broadening people's livelihood options. Some apparent opportunities can be seen in promotion of high income wetland use like ecotourism, identifying new markets for off-farm income such as brick-making that takes place around the wetlands, and as well as integrating wetland management into broader rural development programs that are aimed at access to high yielding varieties, improving access to markets, and better extension services.

- Policy and legislative environment and the penalties for cultivating in wetlands are not sufficiently deterrent. This results in continued wetland use for prohibited uses. Land disturbances, including water abstraction from the wetlands as well as drainage seemed to be standard practice at the case studies. The agricultural extension service does not have the capacity to support such use through providing technical advice.

- There has been concerted effort on knowledge generation, identification of technologies, and developing capacity of local communities. Similar effort needs to go into capacity development for those that engage with local communities to effectively deliver programs to these communities. Capacity development content for this target group should cover facilitation, technical, and management skills.

- Understanding ecosystem services provided by the wetland, to whom they accrue and their value is important for managing the wetlands. Scientists can identify the ecosystem services and quantify extent and temporal and spatial distribution as well as identify the beneficiaries (who, where and temporal variations). The communities need to understand the information generated by scientists and how it helps them to manage the resources and maintain the goods and services provided. Community based monitoring of change in the wetland promises to be one of the best approaches for communities to understand the change in functioning of the wetland.

8.2 Recommendations

The tradeoffs analysis implemented pays little attention to the role of institutions and incentives, which is fundamental to ensure that an acceptable wetland management strategy is implemented. As such, the research is likely to have more impact as decision support tool for resource allocation and therefore resource management at local level than on policy at a higher level. Further research is needed to formalize relevant indicators for institutional functioning of wetland systems and include them in the tradeoffs analysis model.

Tradeoffs analysis was implemented at local level. The issues of extrapolation of research findings outside the research sites and up-scaling at catchment level were not addressed in the project. Other disciplinary modeling tools would be needed to determine the representativeness of the studied sites in the Limpopo basin as well as to assess the cumulative impacts of small wetlands use for livelihood purposes at catchment level.

The design and implementation of relevant policies that are targeted to groups that are dependent on resources and manage these resources should take into account the socio-economic characteristics of households within the community. The socio-economic characteristics of households shape the livelihood strategies that the households engage in (Chiputwa, 2006; Jogo et al., 2008).

The diversity of points of view on GaMampa wetland, including within the local community, and potential tensions between local and external stakeholders impose the participation of all stakeholders at various scales for the sustainable management of such complex systems. However, considering the inequities among stakeholders in terms of wetland technical knowledge, understanding of institutional context, financial means and political power, ensuring the conditions for a real participation is still a challenge and will need government involvement.

Farmers try to create conditions suitable for different crops rather than find crops suitable for the wetland condition. The agricultural extension service needs to influence farmers' crop choice so that crops suitable for the wetland environment are produced.

A key policy implication of the livelihood analysis is that any program that seeks to mitigate the impacts of agricultural use of wetlands on the provision of other ecosystem services should take into account the diversity of wetland users and the role played by wetlands in their livelihoods strategies. This needs to be supported by information about the values of wetland resources and how they might be increased in a sustainable way. When the true economic value and the various non-use ecological functions wetland provide are explicit to all stakeholders, then the opportunity costs associated with the unwise and uncontrolled use of wetland services will be explicit.

Wetland management policies should include strategies to support alternative income generating activities to broaden the livelihood options of the poor to reduce pressure on wetland resources. Alongside programs that propose alternative livelihood options, efforts should be maintained to simultaneously develop sustainable management strategies for small wetlands such as GaMampa, Intunjambili and Missavene.

Capacity development for management of natural resources remains an issue in southern Africa. It is recommended that a capacity-building program focusing more specifically on the practicalities of assessing and monitoring wetlands in the Limpopo (and potentially elsewhere) with an emphasis on approaches that can be readily undertaken and provide early warning of possible adverse change. This program could include training and awareness raising components based on user needs related to inventory, assessment and monitoring and how to consider wetland issues at multiple scales from local site to basin-wide (Finlayson and Pollard, 2009).

Finally, better access to education for the rural poor is critical for enhancing the potential to earn non-resource based income in the formal sector and reduces pressure on wetland resources. Therefore, efforts to improve wetland management should integrate awareness, capacity building and programs aimed at supporting alternative livelihood avenues to enable the poor to diversify into non-resource based livelihood activities. This has to be linked with broader rural development programs such as introduction of improved agricultural technologies, investment in irrigation infrastructure, improving access to markets, and specific intervention that promote alternative livelihood strategies.

9 Publications

There are a number of reports from the project, including journal papers, papers in conference proceedings, student theses, and unpublished project documents. The publications span four subject areas: institutional analysis, livelihood analysis, stakeholder analyses, trade-off analysis, wetland ecological assessments, and wetland land use and hydrology.

Institutional Analysis

Tinguery N., 2006. The interface between local community based wetland resources management and the formal wetland policies, laws and institutions in South Africa and Zambia, MSc thesis, The Heller School of social policy, Brandeis University

Livelihood Analysis

Adekola, O. 2007. Economic valuation and livelihood analysis of the provisioning services provided by GaMampa wetland, South Africa. MSc thesis, Wageningen University.

Adekola, O., S. Morardet, et al. (2008). The economic and livelihood value of provisioning services of the Ga-Mampa wetland, South Africa. 13th IWRA World Water Congress, Montpellier, France. http://www.worldwatercongress2008.org/resource/authors/abs291_article.pdf

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Givá , Nícia. 2006. Análise sócio-económica da contribuição dos wetlands nos meios de sustento das comunidades adjacentes. CPWF Project Report.

Masclet S.2007. Diversity of wetland uses and livelihood strategies in GaMampa valley. Limpopo province. Internship report. CPWF Project Report

Stakeholder Analysis

Lopes A and Giva N. 2006. Stakeholder analyses, wetland uses and perceptions: the case of Missavene wetland, Chibuto, Mozambique. CPWF Project report.

Darradi, Y. 2005. Analyse de la perception des porteurs d'enjeux. Le cas de la zone humide du bassin versant de la Mohlapitse River, Province du Limpopo, Afrique du Sud. Mémoire de fin d'études pour l'obtention du titre d'Ingénieur des

Travaux Agricoles, Ecole Nationale d'Ingénieurs des Travaux Agricoles de Bordeaux (MSc Thesis)

Darradi, Y., Grelot, F. and Morardet, S. 2006. Analysing stakeholders for sustainable wetland management in the Limpopo River basin: The case of GaMampa wetland, South Africa, Proceedings of the 7th WATERNET/WARFSA/GWP-SA Symposium "Mainstreaming IWRM in the Development Process", Lilongwe, Malawi, 1-3 November 2006, 25 p.

Trade-offs Analysis

Morardet, Sylvie, Mutsa Masiyandima, Wellington Jogo, and Dinis Juizo. 2010. Trade-offs between livelihoods and wetland ecosystem services: an integrated dynamic model of Ga-Mampa wetland, South Africa. Proceedings of LANDMOD2010. Montpellier. February 3-5, 2010. www.symposcience.org

Jogo, W., S. Morardet, M. Masiyandima, and D. Juizo 2008. Integrated modeling for assessing the trade-offs at GaMampa wetland: Balancing human well-being and ecological integrity. CPWF Project Report.

Koukou-Tchamba Ate, 2004. Assessing trade-offs between agricultural production and wetlands preservation in Limpopo River basin: a participatory framework. Internship report (CPWF project document)

Masiyandima, M., S. Morardet, D. Rollin, L. Nyagwambo, G. Jayasinghe, and P. Thenkabail (forthcoming). Assessing trade-offs in wetland utilization in Limpopo River basin: a research framework. CPWF Project Report.

Wetland ecological assessment and ecosystem valuation

Adekola, O. 2007. Economic valuation and livelihood analysis of the Provisioning services provided by Ga-Mampa wetland, South Africa. MSc. Thesis. Wageningen University

Bandeira, Salomão, Alice Massingue Manjate and Osvaldo Filipe. 2006. An ecological assessment of the health of the Chibuto wetland in the dry season, Mozambique -emphasis on resources assessment, utilization and sustainability analysis. CPWF Project report

Finlayson, C. M. and S Pollard, 2009. A Framework for Undertaking Wetland Inventory, Assessment and Monitoring in the Limpopo Basin, Southern Africa. CPWF Project Report.

Kotze, D. C., 2005. An ecological assessment of the health of the Mohlapetsi wetland, Limpopo Province. South Africa: Centre for Environment, Agriculture and Development, University of KwaZulu-Natal. CPWF Project Report

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Masiyandima, M. and Wellington Jogo. 2008. Wetland Water Management Interventions for Agriculture in three rainfall zones in the Limpopo basin. CPWF Project Report.

Munguambe, P., M. Chilundo, D. Juízo, S. Moniz, A. Ndeve & F. Saimone. 2008. Farmers' water management practices in Chibuto wetlands, Mozambique. CPWF Project report

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Guidelines

Chuma, E., M. Masiyandima, M. Finlayson, M. McCartney, and W. Jogo. 2008. Guideline for sustainable wetland management and utilization: key cornerstones. CPWF Project Report

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