Knowledge compendium

Dialogue on bridging water, food security and sustainable agribusiness development in Africa

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H.P. Ritzema, J. Harmsen, W. Wolters, J. Boonstra and J. Froebrich

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Abstract

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In this knowledge compendium a series of contributions illustrates how Wageningen UR cooperates with African organizations in finding innovations to combat water scarcity and to deliver the scientific knowledge necessary for future actions. In most of these activities, the integration of the formal knowledge of WUR with the tacit knowledge of the local stakeholders plays an important role. The Dutch Ministry of Economic Affairs, Agriculture and Innovation (EL&I) has stimulated the preparation of this compendium to disseminate the knowledge on these innovations among stakeholders throughout the African continent. This knowledge compendium presents a selection of recently finished research projects or on-going projects on water challenges in African food security. They are clustered under four themes: (i) challenges; (ii) advances in research; (iii) adaptation and implementation, and; (iv) knowledge transfer. The contributions aim to stimulate further research and cooperation as a basis for the development of further management measures.

Key words: water scarcity, capacity building, Africa, food security, sustainable development, agribusiness

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Summary

Water scarcity is considered to be one of the largest threats for many of the agriculture-based countries in Africa. Using agriculture as the basis for economic growth in these countries required a productivity revolution in smallholder farming. Save Water - Save Harvest - Save Live are the main objectives when it comes to the achievement of sustainable development through water. Efforts can be made to reduce the total consumption of water and to protect the water quality (Safe Water), to increase the harvest security by carrying out irrigation and drainage at the right place and at the right time (Save Harvest), and addressing water as a threat to humans, through floods and water borne diseases and the spread of hazardous substances with the flow of water (Save Life). Needless to say, these three objectives are never given the same priority. Moreover, the absence of special effort to exploit common synergies increases the likelihood of conflicting activities. In Africa, Wageningen UR cooperates with numerous organizations in finding innovations to combat water scarcity and to deliver the scientific knowledge necessary for future actions. In most of these activities, the integration of the formal knowledge of WUR with the tacit knowledge of the local stakeholders plays an important role. The Dutch Ministry of Economic Affairs, Agriculture and Innovation (EL&I) has stimulated the preparation of this compendium to disseminate the knowledge gained among stakeholders throughout the African continent. A complete overview of the water-related research activities of Wageningen UR in Africa is too ambitious. Therefore, this knowledge compendium on water challenges in African food security presents a selection of recently finished research projects or on-going projects. They are clustered under four themes: (i) challenges; (ii) advances in research; (iii) adaptation and implementation, and; (iv) knowledge transfer.

The theme “Challenges” start with an example how water options can be used to improve ecosystems, harvest security and hydropower in the Zambezi basin and is followed by a more general contribution how the concept of “Save water - safe harvest - safe life” can be used to increase water productivity under water stress. Under the theme “Advances in research”, examples from Ethiopia, Mozambique, South Africa and countries in the North Africa region are presented on land use planning using water productivity indicators and with the focus on rainfall, on nutrient balances to increase food production, on risk reductions for pesticides and on drainage to reduce the risk of salinization in irrigated agriculture. The theme “Adaptation and improvement” presents examples of an integrated approach for land and water use in the Nile Basin, an assessment of the water harvesting potential in this region and on the reduction of soil contaminations in West Africa. The theme “Knowledge transfer” presents examples of innovating agricultural water management through science and technology, knowledge brokerage, long-term partnerships and the role of science in multi-stakeholder processes. The contributions aim to stimulate further research and cooperation as a basis for the development of further management measures.

Challenges

1 Introduction

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1.1 Global issues

Without doubt, water scarcity, together with energy scarcity, food security and environmental safety, is one of main challenges faced in the world. This is because of the simple reason that the world population is growing while pollution and deterioration of usable freshwater resources are on the rise. Under water scarce conditions reducing the consumption of water and preventing pollution of accessible water resources is required. In the year 2000, world leaders set far-sighted goals to free a major portion of humanity from the shackles of extreme poverty, hunger, illiteracy and disease. They defined eight millennium goals for achieving gender equality and the empowerment of women, environmental sustainability and a global partnership for development. Water obviously plays an important role in food production (goal 1), environmental sustainability (goal 7), but it is also critical in health issues (goals 4, 5 and 6) and in creating conditions that support the education and empowerment of women (goals 2 and 3). On the level of Governments and United Nations, the Commission on Sustainable Development (CSD) shares visions on topics related to the development needs of Africa. Agriculture adapted to climate change plays an important role in sustainable development. In May 2009, water in relation to agriculture was one of the cross-cutting themes during the CSD 17 meeting in New York. Worldwide agriculture consumes 70% of all fresh water withdrawals. In response to the many competing claims on water and the decreasing availability of water in many regions, there is a need for better water management. CSD stresses that it is important to manage sustainably for these competing uses of water and land resources. This includes support the implementation of sustainable and efficient water resources development and management schemes, including integrated water resources management within each country, and, where appropriate, through international cooperation, improve irrigation efficiencies, ground water and on-farm soil, and water management practices, including for drinking water to overcome water shortages, improve water quality and enhance food security.

Strengthening the knowledge base and information-sharing on drought, water stress and drought risk are a prerequisite for sustainable development. The equitable and sustainable use has to be assured, as well as integrated management and development, of national and shared water resources in Africa, in accordance with existing international agreements and national priorities. Recognizing that the earth's ecosystems provide services that are crucial for human well-being, including the provision of clean and reliable water supplies, they addressed the central question 'How can the preservation of natural ecosystems become a principle objective of water management?'. For appropriate water management it is necessary to make a plan for allocation of water based on adequate data and information. This should not be limited to a specific region (e.g. deltas), but should include both upstream and downstream parts of the river basin. If available data is insufficient it has to be made available or collected in well-designed monitoring programs. It has to be realized that such basins often includes multiple administrative areas. This is obvious if it is a trans-boundary river, but even within countries different provinces may have different ideas on development. Awareness at the level of (i) local farmers and other local stakeholders; (ii) water using industries (small and large scale) and; (iii) administration at different levels has to be supported by the activities in the basin.

Lakes and wetlands contain a very large part of the surface freshwater. They have a role as a buffer, but also in improving the water quality due to self-purifying properties and sedimentation of (contaminated) suspended particles. Wetlands provide ecosystem services and should be well managed. The same applies for terrestrial ecosystem functions in the water cycle. More generally, there is a strong link between poverty and water management water and there is an urgent need to improve water governance. It is recognized that incorporating new scientific knowledge and data are important, but that it has to be complemented with community-based traditional knowledge.

1.2 Challenges for Africa

Water scarcity is considered to be one of the largest threats for many of the agriculture-based countries in Africa. Using agriculture as the basis for economic growth in these countries required a productivity revolution in smallholder farming. Save Water - Save Harvest - Save Live are the main objectives when it comes to the achievement of sustainable development through water. Efforts can be made to reduce the total consumption of water and to protect the water quality (Save Water), to increase the harvest security by carrying out irrigation and drainage at the right place and at the right time (Save Harvest), and addressing water as a threat to humans, through floods and water borne diseases. In addition, the spread of hazardous substances with the flow of water (Save Life) needs to be considered too. Needless to say, these three objectives are never given the same priority. Moreover, the absence of special effort to exploit common synergies increases the likelihood of conflicting activities.

1.3 Save Water

Africa faces huge water and food challenges in view of increasing pressures by population growth, the global climate change and socio-economic developments (urbanization, changes in diets and lifestyle, etc.). This requires a fundamental rethinking of the conceptual framework of land and water management. In dealing with water issues, the general focus has been on supply and demand management of surface water and groundwater resources (referred to as 'blue water' resources). This approach does not sufficiently acknowledge the role of rainfall ('green water') as the ultimate water resource. Green water is a continuous source of new and clean water. The fate of rainfall is principally determined by land use. It should thus be recognized that the availability and quality of surface water and groundwater resources, and their spatial-temporal variability, primarily depends on land use and land management. Spatial planning and land management are, therefore, crucial for water management, especially in arid and semi-arid zones, where the (exploitable) groundwater and surface water generally represent a small percentage of the rainfall. Green water has to be stored in the system and made available during the growing season. Spatial planning and land management should primarily focus on (commercial) forestry, agriculture and town planning, as these land uses are largely manageable. Agriculture and forestry can be regarded as the world’s principal 'rainfall processing industries'.

1.4 Save Harvest

Besides water, agriculture needs nutrients. For most African farmers nutrients are very expensive, especially if these have to be imported. It is therefore important to use nutrients that are already in the system. This is a normal procedure if life stock is involved. Manure is considered as a valuable source. Nutrients are also present in waste and waste water. Waste can be used as a source for soil improvers like compost and waste water can be used for irrigation. Preconditions are that persistent contaminants are absent and also that pathogens do not survive. It is not easy to do this in a correct way, but it can be considered as a challenge. If organic and industrial waste can be kept separated, less energy is necessary for cleaning and waste becomes reusable.

1.5 Save Life

It should be realized that water scarcity is not only meaning too less water, but also too dirty water. In the 60's of last century it was recognized in the northern countries that all developments had increased water pollution and that water quality in several of the large catchment areas had become too bad to use this water directly. As a reaction, huge investments were made in sewage treatment plants to purify waste water. This approach was successful and it is possible again to talk about ecological potential of surface water (EU-Water Framework Directive). Although sanitation is a hot issue, it is not to be expected that sewage treatment plants will be soon present all over most African countries on the short term. In making future plans, it will be necessary to take into account present and future sources that may contaminate the water. Management of waste is a challenge to improve reuse and to reduce the wasting of energy and resources.

1.6 Wageningen UR and Africa

'To explore the potential of nature to improve the quality of life' is the mission of Wageningen University and Research centre (Wageningen UR). Within the domain of 'healthy food and living environment', we work around Africa doing research for government agencies and the private sector. The huge water and food challenges require a fundamental rethinking of the conceptual framework of land and water management. Wageningen UR had developed various approaches to address production ecology, approaches to quantify sustainable production thresholds, and multidisciplinary approaches to co-create innovative solutions and to develop agribusiness. Bridging such approaches and to communicate advances at an extended stakeholder level will not only help to provide approaches for sustainable agri-business development but also to facilitate a dialogue between Dutch Governmental and Non-Governmental stakeholders. Innovation through science and technology are critical for the agriculture-for-development agenda to succeed on four fronts. First, at a global level, science will become even more important to meet growing demand in the face of rising resource constraints and energy costs. Second, in all countries, science and innovation are central for maintaining market competitiveness, both domestic and global. Third, the potential of science to address poverty in both favoured and less-favoured regions has yet to be fully tapped. Tailoring technologies to growing heterogeneity among farmers and to differentiated needs of men and women farmers remains a scientific and institutional challenge. And fourth, science will be critical in adapting to and mitigating climate change and tackling environmental problems more generally. This is especially true for Africa as 33 out of the 50 least developed countries are in this continent.

1.7 Knowledge Compendium

In Africa, Wageningen UR cooperates with numerous organizations in finding innovations to combat water scarcity and to deliver the scientific knowledge necessary for future actions. In most of these activities, the integration of the formal knowledge of Wageningen UR with the tacit knowledge of the local stakeholders plays an important role. The Dutch Ministry of Economic Affairs, Agriculture and Innovation (EL&I) is an important supporter of these projects. As several of the EL&I priority regions are situated in Africa, the Ministry has stimulated the preparation of this Knowledge Compendium to disseminate the knowledge gained among stakeholders throughout the African continent. A complete overview of the water-related research activities of Wageningen UR in Africa is too ambitious. Therefore, this knowledge compendium on water challenges in African food security presents a selection of recently finished research projects or on-going projects. They are clustered under four themes: (i) challenges; (ii) advances in research; (iii) adaptation and implementation, and; (iv) knowledge transfer. The contributions aim to stimulate further research and cooperation as a basis for the development of further management measures. At the same time the knowledge compendium may serve as basis for the debate how to strengthen business development and private sector development as pivotal part of the new Netherlands policy. Understanding the boundary conditions and possibilities for maintaining an increased agricultural production under water stress conditions will help to set up sustainable growth in the times to come.

2 Water options to improve ecosystems, harvest security and hydropower in the Zambezi

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Abstract

Water distribution in a country that generates a large amount of water 105 km^3/ year and has an estimated annual renewable groundwater potential of 49.6 km^3/year is a challenge. The current twelve dams in the Zambezi river generate 4900 MW of hydropower, while the potential of the river is 13,500 MW. The water of the Zambezi is essential for Ramsar sites (1,550,000 ha in Zambezi floodplains and Kafue flats). To adapt to climate change there is a need to strongly improve harvest security. The way to realize that is using more irrigated agriculture. It has been concluded that economical development of some 270,000 ha for irrigated agriculture is possible to increase food security. Four sets of policy measures are in place and are further developed to ensure that irrigated agriculture contributes to both poverty alleviation and economic growth, while at the same time the requirements of the ecosystems are considered.

2.1 Introduction

Zambia has a pervasive dependence on rains for its farming. It has therefore, from time to time, suffered severe droughts, resulting in reduced crop yields and losses in livestock. Both agricultural production and productivity have shown high vulnerability to adverse weather patterns with cyclical trends in national harvest and a trend of alternating surpluses and food deficits. The overall macro-economic growth and welfare indicators are sensitive to the availability or absence of food surpluses and deficits. There is thus an urgent need to break this pattern especially that Zambia possesses tremendous land and water resources.

2.2 Potentials in Zambia

2.2.1 Availability of water

Zambia receives on average approximately 105 km^3/year rainfall and has a renewable groundwater potential of 49.6 km^3/year . The distribution over the years (and within years) is however not uniform and wet years receive twice as much rains as dry years on a national scale. Within the country differences can be even more. Zambia receives about 40% of the surface water resources in the SADC region. Zambia lays within the Zambezi (75%) and the Congo basin (25%), the Zambezi being the main basin therefore. Within the Zambezi basin, Zambia is the most important country (Figure 2.1). Average annual rainfall in Zambia can vary between less than 800 mm in region I to over 1200 mm in region III (Figure 2.2).

With these amounts of water Zambia can be considered as s water rich country and there is a large potential for agriculture development if this water can be made available on the proper time and proper place. This in contradiction with a country like Egypt, where further development is already limited by the availability of water.

2.2.2 Agricultural development

Zambia's irrigation potential is 2.75 million ha based on water availability and land irrigability Out of this potential, it is believed that 523,000 ha can be economically developed, but other sources, such as the World Bank, report a higher value, 672,000 ha (2008). Currently 156,000 ha of land are irrigated in Zambia, which is about 30 percent of the economical irrigation potential and three percent of cultivated area.

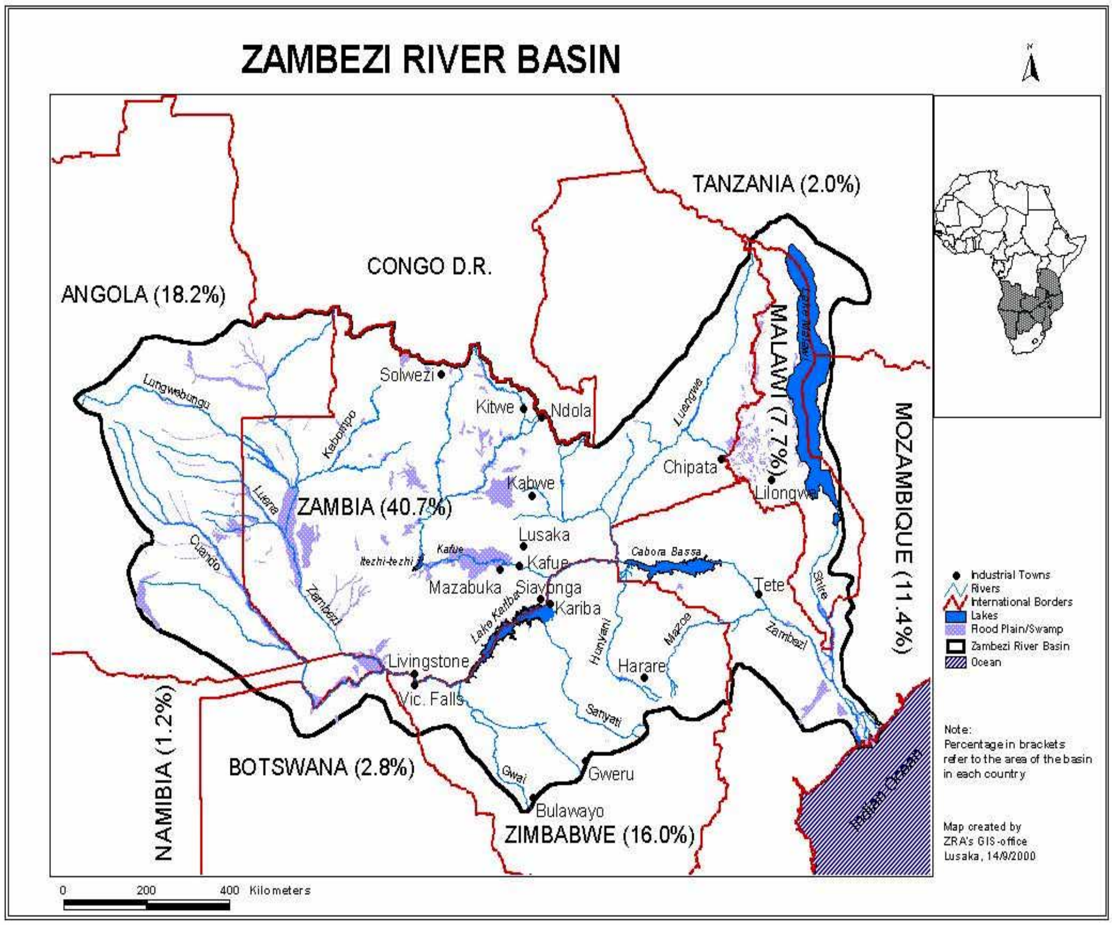

Figure 2.1
Zambezi River Basin.

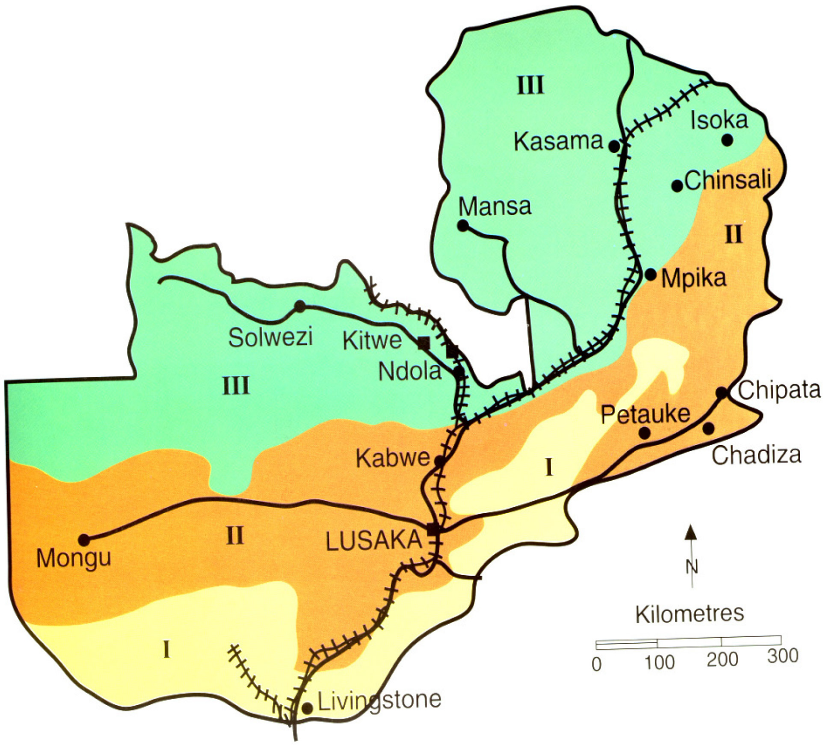

Figure 2.2
Agro ecological zones in Zambia.

2.2.3 Hydropower

Water is also essential for the production of energy, a vital input to the socio-economic development of the country. Hydroelectric power is the main driver of the country's industrial development. Zambia's current installed electric power capacity is 1,800 MW with 94% being from hydropower. Total useable hydropower potential of Zambia is approximately 6,000 MW which is far higher than the present available capacity. National demand for power in 2015 is expected to total 2,380 MW requiring 1,200 m^3/s of water.

Zambia has not fully exploited its hydropower potential and as a result electricity coverage for domestic lighting and heating, mining, industrial, agriculture and manufacturing is low resulting in the overexploitation of wood fuel, which increases deforestation. There is a need to develop the remaining hydropower potential. For this to be realized there is a need to encourage private and public investment in the energy sector.

2.2.4 Wetlands

Zambia is also home to several wetlands. These wetlands are ecosystems, harbouring various rare and endemic species, such as the Kafue Lechwe and Wattled Crane.These wetlands have international importance. Eight wetlands have Ramsar status. These include the Zambezi Floodplains (900,000 ha of which 760,000 ha are swamps) and the Kafue Flats (650,000 ha of which 260,000 ha are swamps). Furthermore the rivers in Zambia are also key for National Parks with large mammals that provide the natural resources essential for building tourism. Adequate availability of water is key for the survival of these wetlands.

Various issues have negatively affected the performance of the management and development of water resources to meet the demands of competing groups of users. Water resources have generally not been well managed resulting in issues such as inadequate supplies to meet various needs, pollution, inadequate information for decision making, inefficient use of the resource, inadequate financing and limited stakeholder awareness and participation.

2.3 Developments

2.3.1 Water resources

The development of the Zambian water resources for agriculture is fundamental to meet the objectives of accelerating growth and better sharing the benefits among the population. Access of subsistence, emerging and commercial farmers to water and irrigation is a major determinant of land productivity, the stability of yields, and the increase in rural competitiveness. Water resources management is also crucial in reducing vulnerability to droughts and floods, and the potential impacts of climate change. Achievement of the desired and planned socio-economic development of the country is not possible without further development of water resources infrastructure as a platform for economic growth and poverty reduction.

In Zambia there is an increasing need for water conservation / harvesting. The present rainfall and water resources are highly erratic. The **erraticness** of water resources will still increase as a result of the global climate change. Extreme events, both droughts and floods, will occur more frequently, while the land will be more susceptible to land degradation and erosion, all having detrimental effects on agriculture and ecosystems. As the **adaptive capacity** in rural areas is generally limited, these areas are generally **vulnerable** to climate variability and climate change.

To solve or mitigate land and water problems in Zambia not only **water harvesting** measures should be considered, but also **water retention** measures. Water harvesting measures are principally aimed at reducing the outflow of water from a certain area, thus at **utilizing a larger portion of the (rain)water**. Water retention measures are principally aimed at **attenuating the water outflow**, resulting in more available water in times of scarcity, smaller risks of floods and droughts, and less land erosion.

The concept of **rainwater harvesting** has nowadays been substituted by **water harvesting**, as many alternative water harvesting techniques have been developed in the past decades. There are no standard solutions for land and water problems and no standard water harvesting and water retention measures. Each situation requires an area-specific intervention, which considers the present situation, future trends and **uncertainties** herein, the physical environment and the human factor/capacity. Alterra is specialized in integrated land and water solutions. As any intervention in the land system will have repercussions on the water resources and vice-versa, land management and spatial planning are important tools that can actively be used in water conservation and water retention, in addition to specific infrastructures.

2.3.2 National policies

In 2001, the Government of Zambia initiated the Water Resources Action Programme (WRAP), to complement the reforms initiated in 1993 and to reform the water resources management sector. WRAP had the objective to reform the water resources management sector adopting a broad and holistic perspective of the water sector - an approach that espouses the principles of Integrated Water Resources Management (IWRM). It was WRAP's aim to support the National Water Policy in the establishment of a comprehensive framework for the use, development and management of water resources in a sustainable manner with strong stakeholder participation. Dambo's comprise 12.5% of the area of Zambia. Dambo's are a class of complex shallow wetlands in central, southern and eastern Africa, particularly in Zambia and Zimbabwe. They are generally found in higher rainfall flat plateau areas, and have river-like branching forms which may be nowhere very large, but common enough to add up to a large area. For Zambia it is therefore important to include dambo's in the plans.

To complement and build on the work of WRAP, the government initiated the Water Sector Programme Support (WSPS) in 2006. The integrated water resources component of this initiative is supporting the IWRM activities in the Ministry of Energy and Water Development (MEWD), strengthening the water rights systems administered by the Water Board, groundwater monitoring in pilot areas, IWRM capacity building; piloting of decentralized water resources management structures and rehabilitation and construction of small dams and weirs in the Ministry of Agriculture and Cooperatives.

The IWRM process in Zambia has been carried out with the private sector and in collaboration with all relevant stakeholders. External partners like Wageningen UR are involved to facilitate the implementation process. The Government added Water Efficiency to Integrated Water Resources and Management (IWRM/WE) (2006-2030) for sustainable management of the country's water resources.

The broad objectives of the IWRM/WE programme will be pursued through:

The broad objectives of the IWRM/WE programme will be pursued through:
- **Water Resource Monitoring**: To monitor water resources with regard to quantity, distribution and quality, including variability in time and space and their interaction with all water use processes in order to provide a firm basis for the optimal development of Zambia's water resources.
- **Water Resource Planning**: To produce catchment outline plans for all catchments in Zambia that addresses inter- sectoral linkages in the management of water resources aimed at supporting cross-sectoral development needs and maximise the economic benefits accruing thereto.
- **Water Resources Infrastructure Development**: To achieve sustainable water resources development with a view to facilitate an equitable provision of adequate, quantity and quality of water for all competing groups of users at reasonable costs and ensuring security of supply under varying conditions.
- **International Waters**: To strengthen capacity of regional cooperation on shared water courses in support of regional development.
- **Research and Development:** To develop innovative and appropriate approaches and technologies for the effective development of the national water resources:
- **Adaptation to Climate Change in water resources management and development:** To strengthen capacity for mitigation and adaptation to effects of Climate Change in Water Resources Management and Development.

2.3.3 Planned activities

The Government of Zambia has been building their development plans on the IWRM/WE programme proposal. To ensure adequate implementation of the development plan a detailed projects portfolio has been produced. Precise investment needs based on the comprehensive project surveying are being assessed and accurate project sheets are being produced. Type of interventions planned to increase productivity are given in Table 2.1.

Table 2.1
Interventions directed to increase productivity at the various categories of farmers in Zambia.

TYPE OF FARMER	POVERTY ALLEVIATION	FOOD SECURITY	ECONOMIC GROWTH
TRADITIONAL FARMERS	Improved equity through a more enabling environment	Improved equity through a more enabling environment	Participatory rehabilitation and upgrading of existing infrastructure
	Water harvesting	Water harvesting	Irrigation management transfer
	Dambo development	Dambo developmentParticipatory rehabilitation and upgrading of existing infrastructure	
	Participatory rehabilitation and upgrading of existing infrastructure	Participatory development of demand driven irrigation	
EMERGING FARMERS	Increasing employment opportunities on small farms through a more enabling environment	Increasing employment opportunities on small farms through a more enabling environment	A more enabling environment Improved and expanded support infrastructure Improved and expanded supply side infrastructure Expanded value added opportunities
COMMERCIAL FARMERS	Increasing employment opportunities on commercial farms through a more enabling environment	Increasing employment opportunities on commercial through a more enabling environment Better incentives for production of food staples	A more enabling environment Improved and expanded support infrastructure Improved and expanded supply side infrastructure Expanded value added opportunities

2.4 Conclusions

In the 21st century, agriculture and water are crucial for poverty alleviation, economic growth and sustainable development in Zambia. Water is crucial in assuring food supply and harvest security. Hydrological extremes already create direct threats to human life. Agriculture is a major user of water withdrawals. Integrated land and water resource management is needed in Zambia and the Zambezi basin at large.

Specific elements that need to be addressed are:
Water Resource Monitoring. Monitoring water resources with regard to quantity, distribution and quality, including variability in time and space and their interaction with all water use processes in order to provide a

firm basis for the optimal development of Zambia's water resources. This includes the effects of economic activities including mining and the increased use of fertilizers and pesticides on water quality

Water Resource Planning. Production of catchment outline plans for all catchments in Zambia that address intersectoral linkages in the management of water resources aimed at supporting cross-sectoral development needs and maximising the economic benefits accruing thereto is essential.

Water Resources Infrastructure Development. Achievement of sustainable water resources development with a view to facilitate an equitable provision of adequate, quantity and quality of water for all competing groups of users at reasonable costs and ensuring security of supply under varying conditions is an area requiring major efforts.

International Waters. To strengthen capacity of regional cooperation on shared water courses in support of regional development is essential for peaceful and sustainable exploitation of regionally available resources.

Research and Development. To develop innovative and appropriate approaches and technologies for the effective development of the national water resources is needed for rapid economic development.

Adaptation to Climate Change in water resources management and development. To strengthen capacity for mitigation and adaptation to effects of Climate Change in Water Resources Management and Development is essential to ensure harvest security in Zambia.

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3 Save water, safe harvest, safe life – a need to increase water productivity under water stress

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Abstract

Time has come to rethink the consequences of the global food crises and of climate change. For a more sustainable development more robust and stable systems are needed. Creating buffers can overcome the impact of higher variability in rainfall. To that end a number of recommendations have been made with regard to water management as a prime input to save water, and ensure safe harvest and safe life. An increase in water productivity in agriculture is needed. This increase must be realized in combination with multiple uses systems of water management. Institutional strengthening is essential to reach these objectives. An agenda is suggested to increase sustainability in agricultural water management.

3.1 Introduction

Access to water in sufficient quantity and quality is the basis of sustainable development. Water is intrinsically tight to health, food security, poverty eradication and environmental protection. Especially in its link to sustainable development, water is a central component in all eight Millennium Development goals. Global demand for water and food will double by 2050, driven by population growth and, increasingly, by changing diets due to increase in wealth.[1] The ecological footprint and impact on the environment is already huge today and the number of species threatened with extinction is rising rapidly with almost half of the world's population facing a scarcity of water.[1] Focal points and emerging issues of sustainable development are always affected by the fact that the water view cannot be restricted on a single aspect. Water is an essential public good and input for food harvests, biodiversity, human health and energy. Water for food production can therefore not only be seen as an economic good, but, as this water use has also influence on the environment, it is also a public good. Food producers are part and parcel of their environment and region. In fact it helps to differentiate three major views, how ones may look on water in the context of sustainable development.

Save water – Water as an endangered resource base
The required increase in production and future population growth will lead to increased water stress. In contrast to water scarcity, water stress, as defined by the EEA, considers the deterioration of usable water resources, both by pollution and overconsumption. Therefore, safeguarding of water resources in terms of quantity and quality has an upmost relevance for any future development.

Safe harvest – Water as a critical factor in assuring food supply
The critical issue for improving food security under limited water resources is to assure that the crop can be harvested and the maximum amount of product per consumed unit of water is realized. Crop losses and hence

losses of resources invested have to be minimized. This calls for improved flexible concepts to innovate irrigation practices and techniques for supplementary irrigation (minimal water use), and improved nutrient, pest and weed management, supported by improved seasonal forecasting capabilities to anticipate extreme weather conditions and climate variability.

Safe life – Water as a direct threat to people and nature
The impact of hazards caused by hydrological extremes (flood and droughts) and resulting pressure in human life requires an increased attention within integrated land and water management. This relates to direct impacts such as environmental refugees, loss of human life and livestock, and the loss of soils and crops. The indirect impacts include the resulting spread of hazardous substances and bacterial contaminations e.g. from flooded or destroyed sewage systems. The direct and indirect impacts put the battles to reduce malaria, diarrhea, HIV/AIDS and undernourishment all under pressure. To minimize such risks, water stress must therefore be minimized.

3.2 Increase water productivity of agriculture

With the increased demand for commodities efficiency in use of natural resources should be increased as much as possible. "We will need to double global food production by 2050," FAO Secretary General Diouf said earlier this year. Boosting smallholder farmer food production is therefore action B of the Ban Ki Moon's High Level Task Force 'Global Food Security Crisis'.[7]

Water is a key factor in food production. Priorities for improvement of water productivity include[1]:
- Areas where poverty is high and water productivity is low and where the poor could benefit (much of Sub Saharan Africa).
- Areas of water scarcity (Nile) by gains in economic water productivity.
- Areas with little water resource development, such as Sub-Saharan Africa.
- Areas with falling groundwater tables and drying rivers. According to the International Association of Hydrologists, 'Today a global withdrawal of 600-700 km^3/a makes groundwater the world's most extracted raw material.'

It is now realized that the distribution of precipitation and hence water availability is affected by climate change. In several parts of the world, notably in Southern, Western and Northern Africa rains may become more erratic and average annual precipitation may diminish. Parts of Eastern Africa may face more flooding and in most regions wider variability in precipitation is expected. As this will be associated with an increase in average temperature, shifts in ecosystems with its food production systems will take place. At international level this creates the need to face the consequences of this migration of agricultural production systems. Long term adaptation strategies on where production areas of crops are best placed are needed. At the global level, specialisation of agricultural production in optimal localities, and in specific rain fed areas, is the most effective single water saving measure in food production with a projected saving in global agricultural water consumption of thirty percent.[1,6]. It therefore has tremendous potential to contribute to safe harvests. National analyses of robust and climate-proof planning of land use for food production systems can be made and translated into more detailed adaptation strategies for all stakeholders..

Progress in seasonal forecasting is underway. When the seasonal rainfall predictions become more reliable, food producers may take advantage of this information by selecting planting dates, varieties and crops that best fit the expected rainfall pattern. Nations can facilitate free and early access to seasonal forecasting information by the food producers within the country.

Higher variability in rainfall will increase the vulnerability of rain fed agriculture. Creation of additional water storage to overcome temporary shortages of water must be stimulated to boost water buffer capacity. Such storage is most efficient when stored underground in aquifers. Also storage of water in the field can play an important role in increasing water holding capacity. Additional buffers can be created by storage in ecosystems or surface storage. Floods will provide an opportunity to feed the buffers with extra water and make them an important input for additional food production. Further research and development is needed in how to expand water holding capacities is needed to plan these buffers in such a way that maximum benefits and a minimum of negative externalities will be realized. Upon implementation of these water buffers adverse effects of a more erratic rainfall distribution on harvest security can then be overcome by applying more supplementary irrigation during dry spells. Where full-fletched irrigation schemes have been developed to a considerable extend, more innovation in rain fed systems with supplementary irrigation is so far underdeveloped and can play an important role in boosting food production. Such systems can also play a more prominent role in providing ecosystem services than to many full-fletched irrigation systems.

Enhancing agricultural productivity is achieved best by improving the availability of the various production factors simultaneously. Increasing water supply only for instance, may give limited gains when nutrient availability is constraining productivity more fiercely. This can actually be the case in many rain fed agricultural systems in e.g. Ethiopia. Hence supply of nutrients could increase the water use efficiency. Rainwater should however be effectively managed and recycling of nutrients should be optimized as much as possible.

In irrigated agriculture, yields are generally higher, but efficiencies in the use of both water and nutrients could be significantly enhanced. Hence the same or slightly higher yields could be obtained with fewer inputs. Better (supplementary) irrigation and drainage management practices geared towards the local situation are essential to achieve these gains with higher investments in dams and irrigation. Gains can be achieved also by solving tail-end problems in irrigation schemes. Enhanced water use efficiency may reduce leaching losses and, in case the savings are not used to expand the area under cultivation, may increase the potential for re-use of water downstream. This is however no loss, as any water saved in upstream irrigation simply runs downstream through its natural (river) flow. Saved water could also be used upstream to expand the cultivation acreage.

Good formal arrangements in irrigation schemes on differentiation in priority and price of water allocation can be an effective way in boosting water and food production efficiency. Without good governance the risk of priority in water allocation to powerful farmers but without the associated differentiation in costs could result in water allocation to such farmers (at subsidized costs) at the expense of potentially more efficient uses of water.

Risk management measures to support food security capacity need to include:

- *Secure the access* of the rural poor to water for agriculture and ensure equitable water distribution mechanisms.
- *Invest* in raising and sustaining the productivity of (sub) basins as a whole, through multiple small developments in the constituent sub-production systems that explicitly account and exploit the up- and downstream interactions between the sub-systems along the 'water chain'.
- *Enable and support* the development and implementation of innovative multifunctional production systems that also provide public goods/services (either locally/nationally or globally) and that ensure effective exploitation of high capital investments complementary to other uses of water.
- *Stem and regulate* the pressure for rapid, short term and opportunistic gains in expansion of commercial crop production enterprises that can contribute to economic development in a way that also supports the livelihoods base of other users of natural resources.

Photo 3.1
Innovation in irrigated agriculture is required to define best combination of new irrigation technologies and alternative high value crops.

3.3 Enhancing the productivity and value of multiple use systems

Water is shared among multiple uses and users with quantity and quality impacts passed along the 'water chain' from rain to sea. Focuses on single product/service maximization – while achieving marked increases in global food and industrial production – can often result in passing on of water impacts. The environment and the poor are often at the receiving downstream end of degraded or negated water resources.[1] We are confronted with the need to double global food production by 2050, rising demands for bio-based fuels, fibres, climate change mitigation (i.e. carbon sequestration) and adaptation (i.e. flood and drought protection[2]), clean and safe water and sustainable environment. We must move away from segmented, and competition thrive, water use production systems to integrated multiple use systems that provide multiple services also from their synergetic interactions[1]. There is a need to apply an ecosystems approach to agriculture, and a productive services approach to ecosystems[2]. Additional mechanisms like Green Water Credits can be further introduced. For public goods such as forests a need for new approaches is also discussed. Also for water the question is what policy measures can be taken to facilitate and support transformation from segmented water use systems to integrated multiple use systems?

Non-provisioning services

Food, energy, water supply and industries are traditional strong sectors that place large demands and claims on water use, driven by their single focus on production of selected provisioning services.[1,3] However, (agro) ecosystems have a much wider spectrum of services to offer and to sustain. Ecosystems provide benefits to human well being and society at large - the so called non-provisioning services as: (a) regulating services which include water retention, purification and flood protection; (b) cultural services, such as recreation and spiritual well being; (c) supporting services as carbon sequestration and nutrient cycles; and (d) biodiversity.[3] In contrast to provisioning services these non-provisioning services have the character of public goods or externalities (as opposed to private goods) that provide services and benefits to larger segments of society than the process owners alone.[4] Achieving sustainable water and natural resources patterns of use must value and sustain this wider spectrum of ecosystem services by both the public and the private sector.[1]

In water stressed situation the private sector and its value chains have generally limited interest for public goods derived from water, as they usually cannot capitalize on these through their marketing of private goods. To entice the private sector into systems with multiple use of the limited water, there is a need for stronger regulation and guidance on limiting the negative externalities of agricultural commodities, energy and industry on the provision of local and global public goods.

To achieve the valuing of public goods by the private sector the following must be integrated in regulatory, fiscal policies and market mechanisms[4]:
- *Assess the benefits* of public goods provided by regulatory services of (agro) ecosystems, such as water purification and flood control, on their economic value.
- *Establish which segment of society is the primary beneficiary* of the public goods/services, and thereby it's primary customer.
- *Determine the scale* on which the public goods/services operate. Are public goods/services primarily provided at the local scale - e.g. water purification, flood control, water retention, recreation, biodiversity – or primarily on the global scale - e.g. carbon sequestration, biodiversity, climate change mitigation and adaptation?

In water stressed conditions local arrangements to achieve multiple uses in agricultural water use and management and ecosystem conservation are more effective than (supra)national initiatives, as local initiatives can better adapt to the wide diversity, dynamics and specificity of natural resources use, agriculture production systems, ecosystems and stakeholders.
(Supra)National policy measures and initiatives should therefore refrain from being prescriptive in their measures and financial arrangements, and instead be targeted at providing:
(i) A general policy framework for multiple use and the provision of public goods from ecosystem services, targeted at the drivers of agricultural water use and ecosystems preservation[15];
(ii) The general means and/or measures for the design of financial arrangements;
(iii) Equip local (public) authorities with the mandate to plan, regulate and financially arrange multiple (water) use systems that are based on the exploitation of private and public services.

Capacity of local authorities[1] must be strengthened to plan, regulate, implement and monitor financial/fiscal policies in the fostering of multiple use systems. Their main role is to *foster private demand* for multiple uses and public goods targeted at:
(i) providing an economic rationale and incentive to exploit and deliver public goods;
(ii) setting regulatory boundaries to the exploitation level of resources - in particular with regard to water resources quantity and quality;
(iii) promoting and providing incentives for diversification and innovation in the delivery of provisioning services (private goods) - in particular when providing public goods (as flood protection) are the primary function, but where innovative production of food or other private goods as secondary function can still be achieved.

Strategies in inter- and intra-sector diversification
To overcome competing claims concrete advances to the goal of sustainability (both social and environmental), there is an urgent need for a concrete bottom-up approach that explicitly focuses on enhancing the efficient and sustainable use of water within and across sectors.

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1 Local authorities are synonymous here to all sub-national authorities. Depending on the scale at on which public goods and services may be derived from non-provisioning ecosystem services, these may range from councils/districts, sub-catchment or river basin authorities to provinces or states.

From a hydrological perspective multiple water uses among sectors and users are the norm rather than the exception, where water is shared and passed on along the 'water chain'.
The water chain ranges from rainfall, fresh water replenishment and depletion, drainage and evapotranspiration (agriculture and ecosystems), hydropower, industry, fisheries, rangeland,
floodplains, municipalities, etc.

This multiple use or 'water chain' approach must focus on:
(i) The (sub) sectoral water use and management techniques currently deployed/practiced.
(ii) The water quantity and quality interactions of a given (sub) sector with sectors up- and downstream – with a particular focus on the interdependencies of water in- and outflows.
(iii) The identification and promotion of innovative water use and management techniques *within* sectors that enhance the efficacy and water productivity of the sector as well as improve the water (quantity and quality) interactions of the sector with other sectors by accounting for the other sectors' water needs and criteria, and explicitly facilitates the multiple use of water resources through the enhancement of inter-sectoral water use synergies and improve the sectors' water use externalities

Key areas for policy measures to focus on in establishing this 'water chain' approach are:
- *Device policies and plans that foster diversification* of water use and production systems within and across sectors - e.g. (irrigated) agriculture, fish/aquaculture, aquatic ecosystems (biodiversity, pollination and harbouring pest predators); flood plains, recreation etc.).[1]
- *Invest in innovative water use and management practices* with targeted R&D on: (i) enhanced productivity and sustainability production/service systems that reduce negative impacts on waters and exploit this for productive purposes (e.g. multi-culture aquaculture systems with regenerated mangrove water filters, rice-fish systems, waste water based irrigated agriculture); (ii) 'closed' cycle systems that minimise impacts along the 'water chain'.
- *Inform and define* opportunities for multiple use water chain approach and develop a R&D agenda from local opportunities and constraints.
- *Foster cross-sectoral collaboration* at the locality - e.g. forge cross-sectoral analysis of the 'water chain' and identification of the opportunities and constraints.[2]

Safeguarding poverty reduction:
Reduction of poverty remains an urgent and daunting task and challenge; in particular in poor rural settings. Can sustainable development and eradication of hunger and poverty be combined?
The attainment of food security through securing and increasing the agricultural output of provisioning services forms for the rural poor, rightly and by default, the utmost priority of livelihood strategies. Societal demand for the attainment and securing of public goods and services is correlated to economic wealth[4]. Drivers and pressures on natural resources may drive further expansion and intensification of agricultural production and water use, often at the expense of ecosystem sustainability.[15]

Multiples use systems consist of diversified (sub) production systems in crop, livestock, fish and other products and that are intertwined with aquatic and terrestrial ecosystems. They have a significant capacity in reducing poverty and sustaining food and nutritional security of a multitude of livelihoods and multiple livelihood strategies. This capacity to provide a diversified and multitude source of food and protein is often the backbone of subsistence strategies within and across rural families. To raise this productivity requires multiple small investment and developments in agricultural production that explicitly acknowledge the (water) interactions across the sub-systems.

Strategic spatial distribution of services
Highly intensive agricultural production systems that provide little or no role in ecosystems can still be considered as providers of public goods as cheap and affordable food to society at large (both at national as

well as global scale) is such a public good. Delimitation and concentration of environmental externalities (in particular in terms of land, water and nutrient resources) is another example. Agricultural intensification can also serve to stem and deflect further drivers and pressures for increased land use by agriculture in other (agro) ecosystems. Such public benefits of agricultural intensification is best realized when food benefits can be shared around the nation and the globe without hindrance of trade and policy barriers[4].

Policies must be in place and enforced that where non-provisioning services and public goods within the landscape or river basin are subdued to that of agricultural food production and security at some localities, these services and goods are secured at other more suitable localities.

3.4 Institutional strenghening

Time is not on our side. Over the last decades the manpower in public institutions has been thinly spread, but needs to grow[1,3]. Where the public sector was reducing its role the required institutional strengthening has hardly been taken over by private partners. The public sector needs to recapture its responsibility for public institutions in quantitative terms.

Obviously the active involvement and *participation of stakeholders* is imperative to search for consensus on priorities, to benefit from tacit knowledge, and to create genuine commitment on policies that have large social impacts. In this process the different levels of decision making at which stakeholders operate must be well acknowledged. More local governance with direct involvement of stakeholders helps. The knowledge and experience of stakeholders can and must be linked to higher level governance structures. Higher levels structures are being or have already been established. Higher level institutions can and must take up their roles in monitoring and regulation. However it takes time for such organizations to provide the required policies in reaching the desired harvest security and sustainability and robustness of ecosystems, minimizing health risks and contributions to energy needs[2]. At the same time action and implementation must be taken up at more local levels, where development really can take off. By working parallel no valuable time is lost. The CSD Water Action and Networking Database (CSD WAND) can speed up the linking up process to other initiatives as it serves as a platform for exchanging information and best practices, lessons learned and relevant international agreements and policy recommendations.

Stakeholders that have not settled on a permanent base are groups that are too often underrepresented in governance structures. Pastoralists and livestock farming play a major role in several areas in the whole system of land use, but are often not taken in full consideration. As a result of this overall planning and implementation of water management plans do not cater for the needs of pastoralists. Pastoralists are in a disadvantaged position because their land and water rights, may be present in informal systems, but their needs are not catered for in formal systems.[8] Pastoralists in systems with increased pressures on the use of natural resources, in this case grass and water, are under heavy pressure to change their way of life and develop less nomadic ways of subsistence. Without governance structures that actively involve the pastoralists, the speed of adaptation in land and water governance is hampered by interventions by pastoralists that also reduce the speed of adaptation for the other stakeholders involved. Positive initiatives and experiences can serve elsewhere as an example how to progress by involving pastoralists.

While institutional strengthening is seriously quantitative strengthening, in the Maputo declaration African leaders concluded that 10% of GNP must be invested in agriculture from a level below 5%, qualitative changes are also essential to result in sustainable development.
Interaction with the various sectors and stakeholders in all processes starting from the initiation phase throughout the implementation and maintenance phase at the local level must therefore be part and parcel of institutional strengthening.

3.5 Increasing sustainability by reducing vulnarabilities

The prospect of increasing pressures on water combined with higher variability in rainfall and climate change may lead to harvest insecurity. This calls for better managed and more robust systems for water management. In order to be sustainable, policies, interventions and future investments have to be aimed at ***reducing the vulnerability of livelihoods and ecosystems***. Especially in Sub Saharan Africa both floods and droughts have major impacts. Interventions in key-sectors have to be implemented through trans-disciplinary activities of poverty reduction.

The challenge is to prioritize and optimize interventions and investments in agricultural water management, so that they result in the ***maximum overall reduction in vulnerability***, considering the various sectors. The prioritization policy needs to combine the quantification of vulnerability as a mean to identify priority hotspots with the identification and assessment of intervention and investment strategies related to water and other sectors. The debate has moved to the concept where vulnerability is now recognized as the central focus in the understanding of poverty.

Intervention and investment strategies have hydrological, agronomical, ecological and socio-economical impacts that are intertwined and enjoy varying priorities by stakeholders. In addition, tough decisions on prioritization are sometimes needed, which may imply social restructuring, thus entailing serious risks of social tension and conflicts in an area or community. The prioritization process is, therefore, often cumbersome and not transparent.

An ***integrated multi criteria analysis*** is often applied for ranking strategies. In order to be effective, an integrated multi-criteria analysis requires reliable, quantitative and qualitative assessments of the various intervention and investment strategies, according to clear, objective ***indicators*** that are accepted by the stakeholders. Further research and development is necessary.

To guide development investments and practical adaptation measures it is also needed to consider that vulnerability can be reduced by safeguarding the water resource base. In particular reducing the desertification and overexploitation of ground water is needed. Implementing concrete services in mitigation and adaptation can also be included.

Future measures also have to take into account that vulnerability is also to be reduced in the whole chain of using water resources. This needs to include the factors such as the market volatility of food and energy and may require a higher diversity and elasticity of production systems.

Improved methods of seasonal forecasting of rainfall can be used as planning information in adapting food production systems to the upcoming rainfall. The information resulting from these improved methods must be made freely available to all farmers by appropriate means. Better use of this information contributes to increased food production. To cope with higher variability in rainfall due to climate change, increasing the buffer capacities of water is advised, be it in aquifers, surface water or water stored in ecosystems and soils. Measures to restore more stable food prices would ease further investments in the water and agricultural sector.

Future work would strongly benefit from insight on the quantification of transdisciplinary measures and their impact on vulnerability reduction, such as the impact and role of biodiversity on the drought resilience of agro-based rural economies. In this context the role of multiple use systems will appear in a new dimension and while higher diversity will often go along with higher resilience.

3.6 Agenda

Time has come to rethink agricultural water management and its role in solving the global food crises and climate change. For a more sustainable development more robust and stable systems are needed. Creating water buffer capacity can overcome the impact of higher variability in rainfall. To that end a number of recommendations have been made with regard to water management as a prime input to save water and contribute to safe harvest and safe life.

1. Nations are called upon to have identified by next year their potential to strengthen their buffer capacity for water. The potential buffer capacity to minimize the impacts of floods and droughts can be combined with expected impact of climate change on precipitation. A national investment and implementation plan can be the next steps in enhancing robustness.
2. The international community is called upon to start a process to rethink the most robust global food production systems based on the sustainable use of water for food production and non-food production services. Early national adaptation strategies where the public sector, apart from creating an enabling environment for the private sector, also must provide adequate capacity to design, implement and monitor land and water management policies, are urgently needed to meet the challenge to feed the world in the years ahead.
3. While water for food production is vital, it must be embedded in ecosystems where public and private valuing of water for multiple uses and public goods is part and parcel of such systems. Both the national buffer improvement plans and the global food production systems must value the ecosystems.

Productivity agenda

4. Boosting smallholder farmer food production shall be promoted by targeted innovations and improvements in agricultural water management practices in rain-fed and irrigated agriculture.
5. Local and regional production stakeholders are called upon to serve with their investments in increased water productivity as engines for growth in production, while securing sustainability by valuing all uses of the systems.

Public goods agenda

6. Nations will assess the benefits of water as public goods, establish the primary beneficiary and determine the scale on which water as public goods operate. Nations will ensure the development of mechanisms, together with stakeholders to create public and private demand.
7. Nations invest in innovative water use and management practices that foster diversification of water use.
8. Nations will secure access of the rural poor to water.

Governance agenda

9. Multiple water governance entities at local levels are essential; where local levels must interact with more centralized structures (this would start development at local level parallel with developing monitoring and regulation at higher levels). Public support will be arranged.
10. Cross-sectoral collaboration can foster innovative management practices based on interaction between sectors and uses (rather than centrally planned allocation and distribution principle of water and other scarce resources):
11. Nations urgently need to strengthen the institutional capacity to manage water for local engines for development to kick-off. The first main component of this strengthening is to be the increase in multidisciplinary. The second component is to be a quantitative capacity strengthening.

Sustainability agenda

12. The research community is called upon to evaluate methodologies and set priorities in investments in water management on their reduction of vulnerability and effects on poverty eradication.

To realize th ese ambitions, in fact we have no choice if we want to feed the world, the call on the public sector in food production to implement these recommendations on improving agricultural water management immediately and strengthen their institutional capacity. Then and only then will we be able to feed our children and grandchildren, a responsibility we have to take up now.

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Advances in research

4 Nutrient stocks, flows and balances for increased crop production

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Abstract

For natural reasons, African soils are low in organic carbon and nutrients. On top of that soil nutrient depletion rates are high because removed nutrients with harvests are not adequately replenished by fertilizers and/or organic inputs. In this paper an overview is presented of the consequences this poor soil quality status has on a multitude of issues, including water availability and water quality. Directions for solutions are indicated and involve, amongst others, detailed understanding of causes and consequences of nutrient management. Monitoring of farm management strategies plays a crucial role in this.

4.1 Integrated soil management to initiate sustainable development

There is no way in which different natural resources can be ranked in order of importance for agricultural production as they are all needed and ignorance of one factor will affect others as well. Yet, it is possible to indicate initiators of environmental degradation, and most authors agree that a decreasing soil quality (e.g. by a negative balance of organic inputs and outputs) may be the starting point of a cascade of environmental degradation with severe results for crop production (e.g. Lal, 2009; Diamond, 2005). Nevertheless, soil is generally regarded as a 'fait acomplis' by spatial planners and policy makers, not being aware that soil contains the highest number of living biomass per unit of volume and hence should rather be regarded as a living organism with abilities to adapt to a changing environment; for better and for worse. In this paper a brief overview is provided of the role of soil in complex tropical farming systems in relation to other production factors like water and climate and how the performance of smallholder farms in the tropics can be assessed.

4.1.1 Water

When farmers complain about decreased rainfall, it is often not the rainfall itself that has decreased, but rather the water holding capacity of the soil and hence the availability of water over time for agricultural production. The water holding capacity is largely determined by soil depth, soil texture and organic matter content of the soil, where organic matter can be considered as a sponge that can absorb and release water over time and soil depth as the size of the sponge. Soils with smaller particles (silt and clay) have a larger surface area, which allows such soils to hold more water. In a sustainable system, soil organic matter contents are preserved by applying crop residues, manure and compost to the soil. However, there is an increasing challenge in improving soil organic matter due to alternative uses of organic materials for fuel (Figure 4.1), biogas production, building materials, etc. The decrease in application of organic materials to the soil eventually results in decreased water holding capacity and hence decreased water availability.

Also water quality is strongly related to soil functioning. When water passes through soil it is filtered and e.g. pathogens are removed from passing water. Moreover, the buffer capacity of soil implies that soils can retain and release nutrients over time. Like the water holding capacity also the buffer capacity for nutrients is strongly influenced by soil organic matter and clay contents. A limited buffer capacity increases leaching of nutrient and causes water quality deterioration and decreased nutrient recovery in harvestable products.

4.1.2 Nutrients and organic matter

Low soil nutrient stocks and soil nutrient depletion are regarded as fundamental biophysical root causes of low food production and consequently hunger and poverty (Sanchez, 2002). This is because crop and grass yields and their dietary value are a reflection of the nutrient status of the soil. In many parts of the world, but specifically in Africa, soils can have low zinc levels resulting in zinc deficiency symptoms of, especially, women and children. In general, decomposition of organic matter results in the release of nutrients, and contributes to the soil fertility status of the soil. At the same time, preservation of the organic matter (i.e. non decomposition) results in improved soil quality. This contrast between short term (nutrient release) and long term (soil quality improvement) has become known as the 'organic carbon dilemma' (Janzen, 2006) as it can not be achieved simultaneously for a unit of organic matter.

4.1.3 Climate Change

Since the release of the 4th assessment report of the IPPC, in which is stated that for Africa carbon sequestration and improved soil management are the most promising climate mitigation strategies, there is an increased attention on (developing) interventions that can both increase yields and at the same time sequester C in soil. However, with recent projections of agricultural growth especially the non-CO_2 greenhouse gases are expected to increase and more structural options may be found in reduction of these gases (Van Beek et al., 2010). For the coming decades (2010-2050) the share of greenhouse gas emissions originating from agriculture is expected to increase drastically (circa 150% until 2050, Van Beek et al., 2010), unless these emissions are decoupled from agricultural growth, e.g. in an integrated approach in which greenhouse gas emissions are minimized and the sequestration of CO_2 is maximized. This can be done through the following among others:

- Nutrient management: increase nutrient use efficiency to increase food productivity whilst limiting nutrient losses (including N_2O).
- Livestock management: increase efficiency of manure (to reduce N_2O emissions and increase productivity) and housing (efficient manure collection and reduction of CH_4 emissions).
- Improve soil management and reduce soil degradation through incorporation of organic matter in soil (C sequestration), improve tillage methods and prevent soil erosion (e.g. by stone bands, grass strips, contour ploughing, terracing, cover crops, etc).

4.1.4 Call for quantitative data on farm management

All what is written above is likely to sound plausible based on common rationale. However, at the same time the impacts of changes of farm management and changing environments are extremely difficult to quantify. In a recent paper in Nature Sachs et al. (2010) makes a plea for a more consistent global monitoring of farm practices. In this paper we present a monitoring method that is being used for over 20 years and is at present the most used monitoring toolbox in tropical Africa. Moreover, the concepts of nutrient balances, stocks and flows are considered to highlight the importance of monitoring nutrient flows at farm level to i) understand current practices, ii) indicate nutrient 'leaks' in farm management, and iii) indicate best fit solutions for improved farm performance.

Figure 4.1
Alternative use of organic matter: dung being dried for fuel in Ethiopia.

4.2 Monitoring farm performance

Monitoring is best distinguished from 'other' research that it lacks a predefined experimental set up with a certain intervention and a control group. Monitoring can be defined as the systematic registration of a variable, in this case farm management. Since 1990 Wageningen UR has developed a comprehensive toolbox that at present captures systematic monitoring of nutrients, pesticides, labour and economic indicators at field, livestock and farm level. The implementation of monitoring water and organic matter management are foreseen.

4.2.1 The MonQI toolbox for monitoring farm performance

At present the most widely used tool for monitoring farm performance in the tropics is the MonQI toolbox (Schlecht and Hinaux, 2004), which is the successor of the NUTMON toolbox. The history of the MonQI toolbox is extensively described in Smaling et al. (2011) and methodological procedures are described in Vlaming et al. (2001). The MonQI toolbox is a farm monitoring tool that facilitates structured interviews with farmers concerning their daily management of crop and livestock, data entry, data storage and data checking, data processing and presentation. Nowadays, MonQI is used by a blend of users going from state-of-the-art science towards agencies for certification for niche markets.

The MonQI toolbox is multi-scale and consists of the internal compartments crops, livestock, household, redistribution, stock and one or more external compartments (e.g. markets). Through the farm partitioning it is possible to analyze and visualize internal flow of nutrients and/or capital from one compartment to the other. By using internal farm compartments, different farming strategies can be evaluated and best practices identified. Such best practices can be labeled Integrated Nutrient Management (INM), and offer concrete options for action.

INM technologies often combine one or more of the following categories:

- adding nutrients to the system (increasing IN flows), such as the application of mineral fertilizers and amendments, concentrates for livestock, organic inputs from outside the farm, and N-fixation in wetland rice and by leguminous species
- saving nutrients from being lost from the system (decreasing OUT flows), such as erosion control, keeping crop residues inside the farming system, and planting deep-rooting species to reduce leaching losses
- recycling the volume of nutrients within the system so as to maximise nutrient use efficiency and system productivity (improving routing of internal flows).

Figure 4.2
Structured farm interviews using the MonQI toolbox in Ethiopia.

4.3 Stocks, flows and balances

Estimates of the global mean soil organic carbon stocks in the top one meter of soil layer are approximately 110 ton C ha^{-1}, but the mean stock in Africa is only 57-60 ton C ha^{-1} and in West Africa even less, i.e., 42-45 ton C ha^{-1} (Batjes, 2001). Generally European agricultural soils have an average SOC content that is twice the level of those in sub-Saharan Africa (SSA). This is not the result of land use history, but largely of differences in soil age and climatic conditions. With the exception of soils of 'recent' volcanic origin, most African agricultural soils are derived from two billion year old granites, whereas most European agricultural soils are developed in peri-glacial and Holocene sediments, as are many soils of the fertile deltas of Asia.

Where there are stocks, there are flows. All soils gain and lose nutrients over time. Hence, soil nutrient stocks change due to incoming and outgoing flows. This is true at each spatial scale going from individual agricultural plots up to global scale through trade in agricultural commodities. Calculating or estimating nutrient flows allows the drafting of a nutrient balance. For sub-Saharan Africa net flows were negative, i.e., 22 kg N, 2.5 kg P and 15 kg K are lost annually per hectare over the 1982-1984 period (Stoorvogel and Smaling, 1990). This study triggered substantial debate on soil fertility management in SSA, and the role of fertilizers, culminating in involvement of many donor agencies, as well as political commitments on fertilizer use at the Africa Fertilizer Summit in Abuja in 2006. Furthermore, a plethora of nutrient balance studies at different spatial scales emanated, inside and out of Africa (Smaling et al., 2011). These studies revealed options for improved nutrient management at farm level and stressed the importance of including in-farm nutrient management and in farm performance assessments, i.e. the recycling or re-use of nutrient on-farm which can be achieved by intensive in-farm nutrient management.

Figure 4.3
Discussion of MonQI farm reports in Kenya.

4.3.1 The concept of re-use

To represent the level of recycling of nutrients within the farm, the concept of re-use (RU) is presented as a possible indicator for (sustainable) soil management for small-scale farming systems. Notably, through sound farm management practices, nutrients may be re-used several times, e.g. from herbage to manure to crop uptake to fodder, etc. By re-using nutrients the effectiveness of imported nutrients may multiply and nutrient re-use may be a valuable indicator of farm nutrient efficiency and may help to identify best practices. The longer nutrients are captured within the farming system, the higher the possibility of plant-uptake and/or consumption by livestock. Therefore, high re-use of nutrients may result in increased productivity of the farm and consequently in increased farm incomes and decreased environmental losses. In-farm RU of nutrients can be analyzed using standardized data assessments (nutrient monitoring). However, high in-farm turn-over rates of nutrients do not necessarily indicate high re-use of nutrients. High in-farm turn-over rates may also point to soil depletion when these nutrients are extracted from soil in stead of being imported from off-farm compartments (i.e. market). Also, during every nutrient translocation losses occur. Hence, a proper indicator refers to high quantitative nutrient turn-over with a minimum of translocations. Consequently, RU was defined as the amount (kg) of in-farm nutrient turn-over divided by the number of in-farm nutrient translocations. A study in Kenya described by Van Beek et al. (2009) shows that RU of N can differ considerably between farms and that the RU is positively related to net farm income. Hence, the more nutrients are recycled within the farm, the higher the net farm income. Moreover RU appeared to be related to the number of livestock and hence to the availability of manure. In an intensive farming system in Kenya livestock appeared to be the nutrient pump, thus resulting in relatively high RUs (Van Beek et al., 2009).

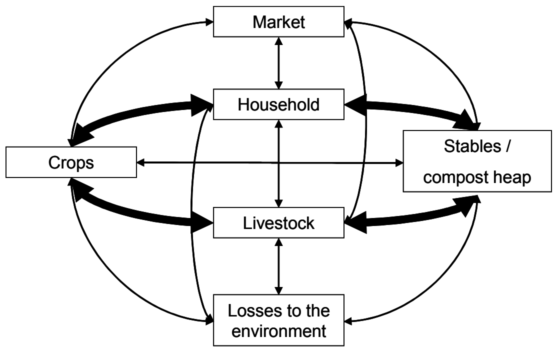

Figure 4.4
Schematized farm nutrient management strategies in Kenya for Kiambu (left) and Mbeere (right). The thickness of the arrows indicates the intensity of nutrient flows. The differences in farm nutrient management strategies were mostly caused by differences in livestock management (see text).

4.4 Outlook

Soil carbon and nutrient stocks in Africa are at an alarming low level compared to the global average and continue to decline. Numerous projects have been implemented to restore soil fertility or at least slow down the depletion rate, but results appeared difficult to prove within the typical project span of less than five years. Soil is a slow responding system.

Monitoring farm management practices may help to quantitatively assess the impact of interventions. One such system is the MonQI toolbox. Through farm monitoring nutrient leaks in the farm system can be identified and targeted interventions can be developed, like zaï, use of compost pits, biomass transfers, contour planting, and improving the efficiency of crop-livestock systems. While Many Integrated Nutrient Management (INM) technologies are potentially successful and have been adopted, others have not been fully adopted in some parts of sub Saharan Africa due to challenges of farmers socio-economic circumstances and prevailing policy environment. This paper postulates that the priority focus should be on spreading successful INM technologies while learning from emerging constraints in the technology-adoption pathway.

Going by recent analyses of 'success stories' in African agriculture and natural resource management, some authors have argued that more been achieved on improved varieties (maize, rice), eradication of diseases (cassava viruses, rinderpest), and improved market opportunities (horticulture, floriculture) than through INM technologies (Gabre-Madhin and Haggblade, 2004). However, successes in micro-dosing of fertilizer and improved land management are notable (Reij and Smaling, 2008), but there is no major leap ahead yet in fertilizer and manure use, and INM in general. As peri-urban systems show positive nutrient balances, even in SSA, it may be worthwhile to improve agricultural areas that are not too distant from major cities in such a way that they benefit from fertilizers, city waste, crop rotations that include leguminous species, conservation tillage and maintenance of SOC, and erosion control in relatively large-scale management units.

Smallholder farmers play a key role in rural development and various public-private interventions have been initiated to assist smallholders in optimizing farm management (increase productivity and income), in sustainable use of natural resources (water, pest and soil fertility management), in improving market linkages, diversifying sources of income and reducing risks. The need for actual farm management information and monitoring change and impacts, as well as for generating information to assist learning and innovation processes in smallholder enterprises will remain high and so is the demand for further development of the MONQI toolbox, e.g. with modules on water management and energy.

Finally, although awareness of nutrient balances has increased among agricultural scientists the subject still features marginally in most debates about sustainable agricultural development. As a result, the great missing link between nutrient balance assessments and agricultural policy remains unaddressed. Few countries, particularly in SSA, have developed comprehensive policies, including subsidies, credit and marketing, to promote increased fertilizer use and INM. This remains a serious concern in view of even the most optimistic projections of nutrient needs to feed the world population in 2050. Banking on fertilizers alone is, however, not the way ahead for resource-poor farmers. Not only can the price be prohibitive, but also the way it is offered on the market (in 50 kg bags), substandard product quality, and the risk of late availability during the growing season make resource-poor farmers look for broader INM options. Nonetheless, a concerted effort is required to raise the visibility of soil nutrients as an essential ingredient in sustainable agriculture. Little political action has been taken so far, apart from pledging support during the 2006 Africa Fertilizer Summit, where it was agreed to raise fertilizer use in SSA to 50 kg ha^{-1} (against the current <10 kg ha^{-1}). Under NEPAD, African governments also promised to spend 10% of GDP on agriculture. These promises are yet to be fully implemented.

More than twenty years of work on nutrient balances in Africa demonstrate clearly the importance of managing the entire nutrient balance, i.e., all the inputs and outputs and not just the partial management of single nutrients or partial nutrient losses such as erosion or additions such as fertilizer. Nutrient management may not be rocket science, but is knowledge intensive and sound management could benefit the African people in an immediate way.

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5 Risk assessment of pesticides in aquatic ecosystems in South Africa

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5.1 Introduction

South Africa is the highest produce-producing and therefore the highest pesticide consumer on the African continent. Although greatly beneficial to the industry, indiscriminate and over usage of agrochemicals pose a risk to the aquatic ecosystems through non-point source pollution (Naidoo and Buckley, 2003). Data on these risks are limited in the developing countries such as Africa since limited environmental monitoring of pesticides is undertaken. This is due to technical, logistical and economical constraints in determining the links between exposure and effect on non-target organisms (London et al., 2000). Methods that are able to screen for and monitor pesticides that could pose a risk according to site-specific scenarios are therefore necessary. Economical and easy-to-use predictive models incorporated into Preliminary Risk Assessments (PRA's) are useful in this regard and have been developed and applied globally to assist in estimating the probability of risks of pesticides associated with aquatic ecosystems. Currently no such risk assessment model is applied in South Africa for this purpose.

The main aim of this study was to present and assess the suitability of selected PRA models as screening tools for estimating potential pesticide exposure and associated effects within aquatic ecosystems. To achieve this, the primary objectives were to apply and validate these models for assessing predicted risks and to relate these to actual ecological hazards by monitoring the exposure and effects of selected pesticides that were identified as potentially posing a risk. It was hypothesised that the data determined by these models would elucidate the association between potential risks of pesticides and actual environmental impacts and could therefore be applied and validated for South African conditions. A framework was thus developed using multidisciplinary approaches to predict the risks of agricultural pesticides to non-target aquatic organisms and to validate these risks in an area known to have a high pesticide usage, namely the Crocodile (west) Marico catchment. This area is representative of a typical farming community in the subtropical central area of South Africa. The catchment exhibits high urban and agricultural usage, which has compromised the overall ecological integrity of the aquatic system.

Figure 5.1
Use of pesticides in intensive agriculture in South Africa.

Figure 5.2
Monitoring, sampling of fish.

5.2 Risk assessment approach

This study was based on integrating multidisciplinary techniques following the implementation of a tiered approach for assessing the ecological risks of selected pesticides used within the study area. Tier 1 starts with the PRA assuming a relatively worst-case scenario by identifying pesticides most commonly used (through public surveys) and estimating exposures posing a potential risk to the aquatic environment using the PRIMET (Pesticide Risks In the tropics to Man, Environment and Trade; Van den Brink et al., 2005) model. The second tier can establish a more realistic characterisation of risk for the pesticide application scenarios of interest by using models such as PERPEST (Predicting the Ecological Risks of PESTicides, Van den Brink et al., 2002), PEARL (Pesticide Emission Assessment of Regional and Local Scales, Tiktak et al., 2000), TOXSWA (TOXic substances in Surface Waters, Beltman and Adriaanse, 1999), or SSDs (Species Sensitivity Distributions, Posthuma et al., 2002). Higher tiers then include comparing the results from the PRA model predictions to the actual hazards of pesticides and can determine if these risk models are valid under South Africa conditions. This can be achieved using a combination of laboratory- and field-based monitoring assessments in the form of a triad approach (using chemical, toxicological and ecological assessments) to construct several lines-of-evidence (LoE) (Chapman, 2000). The risk assessment process ends with a summary and integration of the data based on the multiple LoEs gathered during monitoring using a weight-of-evidence (WoE) approach.

5.3 Methods and results

The proposed framework used in this study was divided into five phases following the above mentioned Tiers (Figure 5.1), incorporating multiple assessments.

5.3.1 Phase 1: Situation analysis

The *First Phase* started with a problem formulation step and consisted of an initial data review and situation analysis, to ascertain the current situation regarding patterns of pesticides used by farmers in the irrigated areas along the Crocodile and Magalies rivers. This was accomplished using surveys (questionnaires and interviews) to generate information relevant to the PRA. It was determined that pesticides were extensively used within the study area, with 17 of the 94 most frequently-encountered pesticides being targeted and used for further assessment.

5.3.2 Phase 2: Preliminary risk assessment

The *Second Phase* involved the implementation of a PRA, which aimed to gather further information on the environmental characteristics of the pesticides and study area. This was done in order to estimate potential risks to the aquatic ecosystem through pesticide exposures. The PRA was conducted on seventien pesticides identified during the first phase of the study. The PRIMET model requires a minimum of input data, including pesticide characteristics and information from local landowners on pesticide usage and application, as well as a description of the physical scenario of the system. The PRA was expressed as an exposure toxicity ratio (ETR) determined by dividing the predicted environmental concentration (PEC) by a no observed effect concentration (NEC) based on laboratory toxicity data using algae, Daphnia and fish. The results for a particular pesticide based on worst-case assumptions indicate either that: the risk is acceptable (ETR < 1), a risk may be present ($1 > \text{ETR} < 100$) or a risk is certain (ETR > 100).

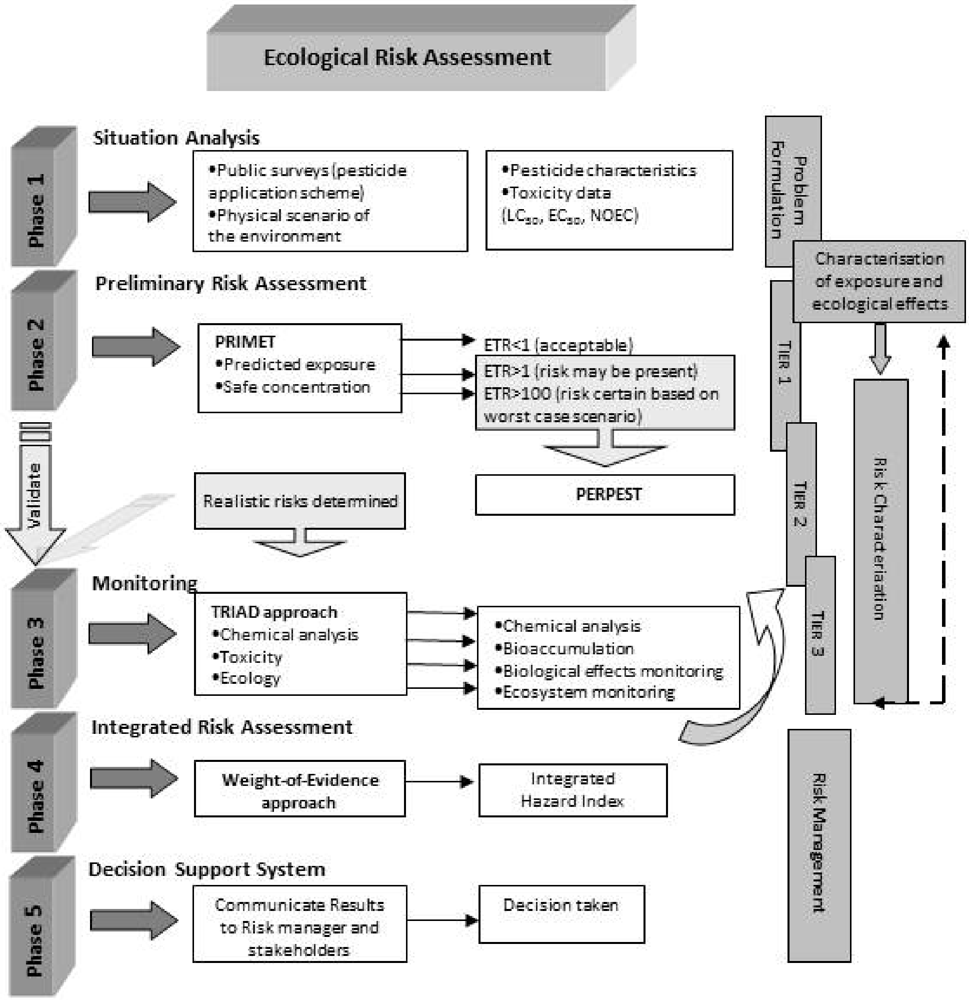

Figure 5.1
Pesticide risk assessment framework for the Crocodile (west) Marico catchment, South Africa.

From the list of pesticides that are commonly used, deltamethrin, cypermethrin, parathion, dichlorvos, carbaryl, bromoxynil, linuron, methomyl and aldicarb were identified as having possible risks to the aquatic environment. Deltamethrin (ETR = 75) and cypermethrin (ETR = 55) indicated the highest probability of risks. Pesticides posing no risk included fenamiphos, abamectin, pendimethalin, captan, endosulfan, alachlor, bentazone and cyromazine. Those pesticides that were identified as a possible or definite risk using the PRIMET model were used in the PERPEST model to determine the probability of classes of effects (i.e. no, slight or clear effects) of a particular concentration of a pesticide on eight grouped endpoints. This model is based on a case-based reasoning approach and is a technique that solves new problems by using past experience. It is based on empirical data extracted from published literature describing the results from mesocosm and microcosm experiments for freshwater model ecosystem studies involving pesticides. Deltamethrin and cypermethrin were again noted as posing the greatest risk and clear effects determined by PERPEST were predicted for aquatic insects and macrocrustaceans, followed by microcrustaceans and rotifers. High percentages of clear effects on insects were also predicted for carbaryl (PEC = 3.7 µg/ℓ), parathion (PEC = 0.58 µg/ℓ) and dichlorvos (PEC = 0.63 µg/ℓ). Linuron (PEC = 1.1 µg/ℓ) was predicted to have minimal clear effects on community metabolism, macrophytes and phytoplankton classes, while less clear effects of bromoxynil are likely to occur within periphyton communities. Application of both the lower-tier

PRIMET and higher-tier PERPEST models showed similar trends in that they both ranked the top five pesticides in the same order of risk.

Standard laboratory toxicity tests are used to establish no effect concentrations (NEC) that could be deemed 'safe' for aquatic ecosystems (Cooney, 1995). As insecticides are intended to evoke a rapid response in target populations and are generally degraded rapidly, short-term effects such as acute lethality toxicity assessments using fish and invertebrates are therefore important 'tools' in evaluating the hazards to aquatic ecosystems (Moore et al., 1998). South Africa follows international protocols using standard test species in the absence of local representatives. It is, however, argued whether international data from standard species that are traditionally based on temperate species (*Daphnia pulex* and *Danio rerio*) can be used to adequately determine risks to tropical or subtropical ecosystems (Kwok et al., 2007). Therefore tests on selected indigenous species (the freshwater shrimp - *Caridina nilotica,* and fish species - *Barbus trimaculatus* and *Oreochromis mossambicus*) found within the study area were conducted using three selected pesticides (deltamethrin, dichlorvos and endosulfan). The LC_{50} values determined for 48 h *C. nilotica* and *D. pulex* and 96 h *B. trimaculatus, O. mossambicus* and *D. rerio* were 0.003, 0.016, 0.07, 0.099 and 0.042 µg/ℓ, respectively for deltamethrin, 0.076, 0.265, 2342, 296 and 631 µg/ℓ, respectively for dichlorvos and 3.74, 3.78, 4.44, 4.09 and 5.34 µg/ℓ, respectively for endosulfan. Deltamethrin had the overall highest toxicity to all selected aquatic organisms and in particular to *C. nilotica*. The high sensitivity of indigenous organisms to the three pesticides makes them promising test organisms for biomonitoring and ecotoxicological investigations.

5.3.3 Phase 3: Monitoring

The *Third Phase,* subsequent to the PRA, was a validation study to relate the actual hazard of selected pesticides to their potential risk. The hazard assessment phase was completed using a triad ecotoxicological approach. Monitoring assessments used to assess hazards of pesticides and to classify the environmental quality of the ecosystem included: chemical analyses of sediments and water; bioaccumulation in fish liver tissue; biological effects monitoring using biomarkers and a direct toxicity assessment of receiving water incorporating a selection of organisms; and ecosystem monitoring assessing biotic communities (vegetation, diatoms, macroinvertebrates and fish) and other physico-chemical driver assessments. Physico-chemical parameters (temperature, pH, dissolved oxygen, total dissolved solids and electrical conductivity), nutrients (ammonium, ammonia, nitrate, nitrite, orthophosphate, total phosphate, calcium, soluble chloride and sulphate) and other system variables (turbidity, chemical oxygen demand, mass concentration of suspended solids and mass fraction organic and inorganic matter in suspended solids) were measured at all the sites during the time of sampling. Monitoring activities were carried out between 2006 and 2007 at sites found adjacent to intensive agricultural activities, sites surrounded by predominately urban activities and a comparatively unimpacted upstream reference site. The sampling was undertaken during high (summer) and low (winter) flow conditions.

Water, sediment and biota (fish liver tissue) were analysed to determine if selected pesticides were present at a site. Analysis was limited to selected pesticides based on data obtained in *Phase 1* of the study and included: cypermethrin, deltamethrin, dichlorvos, endosulfan (α, β and sulphate) and parathion. Levels of pesticides measured in all water and sediment samples were below detection limits (<0.01 µg/ℓ and mg/kg). Residue analyses of fish tissue indicated the presence of low concentrations of cypermethrin (0.01 mg/kg), endosulfan α (0.01 - 0.03 mg/kg), β (0.01 mg/kg) and sulphate (0.02 mg/kg) at the agricultural sites, with none found at the urban and unimpacted sites found upstream of all agricultural activities. Although not all pesticides were assessed due to the high cost of analyses, the presence of other pesticides occurring within the system cannot be disregarded. The evidence of bioaccumulation of some of these pesticides indicated that some form of exposure had occurred at the agricultural sites relative to other land use sites, despite the low recorded concentrations.

A suite of secondary biomarker data, which formed part of a collaborative study (Visser, 2009) was used to establish sublethal responses of bioindicator organisms from the different land use sites. This technique involved the transplantation of fish from a known uncontaminated site to potentially impacted sites and exposing the organisms *in situ* for four weeks. Following the exposure, organisms were removed and assessed for biomarker responses [acetylcholinesterase (AChE), malondialdehyde (MDA), catalase activity (CAT), protein carbonyls (PC), cellular energy allocation (CEA) and condition factor (CF)]. Reponses of the biomarker assessment indicated that fish were not adversely affected by pesticides but suffered from oxidative stress to a greater extent. Furthermore, it was found that, seasonal variation played an important role in biomarker responses with the highest degree of responses occurring during low flow conditions for most biomarkers tested. A decrease in AChE response occurred from high flow to low flow conditions for both agricultural sites. Although no significant site differences were recorded for MDA levels, the highest overall levels were recorded at one of the agricultural sites. The urban site exhibited the highest CAT activity, while high PC levels were recorded at an agricultural site. With regards to CF, fish were in an overall good condition at all sites, while no significant differences were determined for CEA responses. A depletion of carbohydrates and lipid reserves were observed from low flow to high flow at the agricultural sites.
The potentially hazardous effects of receiving water from selected sites were evaluated using the Direct Estimation of Ecological Effect Potential (DEEEP) method incorporating a suite of bioassays (Slabbert, 2004) namely the *Danio rerio* and *Daphnia pulex* lethality, *Selenastrum capricornutum* growth inhibition and the Ames mutagenicity plate incorporation assays. Hazard assessment categories (based on the South African resource management Ecoclassification system) were proposed to standardise the output of the different toxicity assessments. The results indicated that receiving water from intensive agricultural sites showed the highest effects to all tested biota. Noteworthy were algal inhibition (-23%), high lethality to fish and Daphnid (>30%) and mutagenicity (mutagenic ration ≥ 2) of either the TA98 (frameshift mutagen) or TA100 (base-pair substitution mutagen) bacteria, evident for agricultural sites. The highest cumulative hazard score was calculated for an agricultural site. Receiving water at urban sites, which were associated with increased nutrients and lowest pesticide usage showed few adverse effects to organisms, while the relatively unimpacted site indicated no hazard to any organisms, and only a slight stimulation to algal growth. Weighted hazard scores indicated that the water from the unimpacted site was least hazardous, urban sites moderately hazardous, and the agricultural sites had the highest potential impact to aquatic organisms. The use of the direct toxicity assessment approach in assessing site-specific potential toxicity hazards of receiving water impacted by agricultural activities was effectively demonstrated and provided a means of assessing the ecological integrity of aquatic ecosystems.

Pesticides have the potential to cause adverse impacts to a variety of non-target aquatic communities and can affect the structure of aquatic ecosystems (Liess et al., 2005). By implementing various ecological monitoring techniques it was determined if and how local aquatic communities inhabiting these ecosystems and associated drivers were affected by pesticides. Ecosystem monitoring was carried out by using standard protocols that are currently being used in the South African River Health Programme (RHP). The RHP primarily makes use of both biophysical and rule-based biological indices (e.g. fish, invertebrates, in-stream and riparian habitat) to determine the response of the aquatic environment to quantify the ecological integrity of the aquatic ecosystem. Biotic response indices implemented were for invertebrates [South African Scoring System, version 5 (SASS5) and Macroinvertebrate Response Assessment Index (MIRAI)]; fish [Fish Response Assessment Index Fish (FRAI)], diatoms [Generic Diatom Index (GDI), Eutrophication/Pollution Index (EPI), Biological Diatom Index (BDI), Specific Pollution sensitivity (SPI) and Percentage Pollution Tolerant Valves (%PTV)], riparian vegetation [Vegetation Response Assessment Index (VEGRAI)] and habitat [Integrated Habitat Assessment Systems (IHAS)]. In addition an ecological driver component involving physico-chemical water quality [Physico-chemical Driver Assessment Index, PAI)] was included. The MIRAI, diatom, IHAS and VEGRAI indices form part of a secondary dataset generated by Walsh (2008) in a concomitant study. Changes in macroinvertebrate and fish community assemblages across sites and flow regimes were also investigated and assessed using univariate (i.e. diversity, evenness, richness) and multivariate statistical analysis (i.e.

redundancy analysis). These techniques are commonly used in ecological community studies to elucidate differences in community structure due to changes in land use patterns (Berenzen et al., 2005).

Macroinvertebrates and fish community data generally responded in a consistent way in that the dominant trend from statistical analysis in both assessments was the spatial variation and separation of the unimpacted site from the urban and agricultural impacted sites. The unimpacted site typically had a high diversity and abundance of macroinvertebrates and supported a number of sensitive and unique macroinvertebrate (Amphipoda, Heptageniidae, Helodidae, Pyralidae, Chlorocyphidae, Philopotamidae, Psephenidae and Dixidae) as well as fish (*Amphilius uranoscopus, Barbus motebensis* and *Labeobarbus polylepis*) taxa. The unimpacted site had the highest overall index scores indicating macro-invertebrate, fish and instream-habitat communities to be in a better ecological state than the impacted sites. Walsh (2008) indicated that the unimpacted site was oligotrophic and diatom communities indicated uncontaminated water with continually high dissolved oxygen levels and was placed in an overall good quality category class. The PAI index classified this site as having good physico-chemical water quality. Overall, the unimpacted site therefore retained ecosystem functionality and scored higher than all other sites for all metric and indices.

The urban and agricultural sites were generally similar with regards to impairment indicated by ecosystem monitoring metrics and indices. The distinction between the agricultural and urban sites was ambiguous due to the similarity of shared abundance and dominance of tolerant macro-invertebrate taxa (Oligochaeta, Simuliidae and Chironomidae) but to a lesser extent, fish taxa (*Labeobarbus marequensis* and *Pseudocrenilabrus philander*). In general, this study found that the fish and macro-invertebrate communities at both the urban and agriculturally sites were impaired with regards to the metrics and indices used. Diatom response indices indicated the agricultural impacted sites to be in an overall slightly more modified state than impacted urban sites. The PAI index was also less discernable between sites and indicated a consistent moderate change from reference conditions for agricultural sites. Urban and agricultural impacted sites were, however, distinguishable based on the relationship between communities and water quality data using multivariate statistical analysis. In particular, electrical conductivity for the macro-invertebrate assessment and sulphate, chloride and total dissolved solids for the fish assessment, contributed significantly to changes observed in community structures. Historically, high values of these physico-chemical parameters have been associated with agriculturally impacted sites (related to the use of pesticides and fertilisers) and were also found to be correlated, within this study (Collins and Jenkins, 1996).

Agricultural impacted sites were also evidently grouped when additional environmental variables (bioaccumulation analyses, bioassays and biomarkers) were included in the multivariate analysis. The macroinvertebrates and fish community structures at the agricultural sites were correlated with toxicity endpoints (*D. rerio*, *D. pulex* and algal inhibition) and high conductivity, sulphate, nitrite and chloride concentrations. Macroinvertebrates were characterised by a decreased abundance, community diversity, richness and evenness and an absence of sensitive taxa. Fish communities at the agricultural sites were also correlated with the low concentrations of insecticides as well as some biomarker responses. Even though it is probable that other unmeasured variables could have influenced the macro-invertebrate and fish assemblages, the separations of the urban sites from the agricultural sites indicated that an isolated impact was occurring at the agricultural sites. Since none of the selected pesticides were detected at the urban site this could indicate that the impact occurring at the agricultural sites are most likely related to intensive agricultural activities linked to pesticide and fertiliser inputs occurring in the vicinity of these sites.

5.3.4 Phase 4: Integrated Risk Assessment

In the *Fourth Phase* the results from the multiple LoEs were integrated into an integrated risk assessment framework using a WoE approach. The purpose of this phase was to determine the sensitivity of chemical, toxicological and ecological assessment techniques to agricultural impacts. The data were further used to develop an integrated rating system that assigned numeric values to characterise the relative degree of environmental impacts occurring at each site. The endpoint categories were assigned a rating and were subsequently consolidated into an overall integrated hazard index by a weighted means approach. The final outcome of the integrated hazard index using the WoE approach, provided three possible outcomes based on the various LoE: no/negligible, low/moderate and high hazards and were then used to validate congruence with the risks predicted in the PRA. The proposed framework allowed for the determination whether the pesticides that were identified to have a probability of risk were posing a hazard to the system, and to what degree the system was impacted.

The WoE approach followed proved to be useful in discriminating between relatively unimpacted reference, urban and agricultural impacted sites and assigning a hazard category representing no or negligible, low and moderate hazards for each group of sites, respectively. Downstream agricultural impacted study sites were expectedly the most impaired and although not definitive, pesticides were found to be an important stressor component to the system separating these sites from urban impacted sites. While ecological parameters and other physico-chemical drivers also contributed to impairment, this LoE seemed to be less important in discerning agricultural from urban impacted sites. Despite the similarity of most of the ecosystem monitoring metrics and indices to urban impacted sites, the agricultural impacted sites indicated a higher hazard due to the direct toxicity of surface water. These responses were positively correlated with the bioaccumulation of selected organochlorine (endosulfan) and pyrethroid (cypermethrin) pesticides. Biomarkers provided an additional LoE for agricultural and urban impacts. It was demonstrated that, while ecosystem metrics were able to distinguish impacted from unimpacted sites, bioaccumulation and toxicity data were able to indicate a potential for adverse effects at the agricultural impacted sites. It was found that high pesticide usage within an agricultural area poses a moderate hazard to the aquatic system, especially on diatoms and macro-invertebrate communities, with urban impacts and poor catchment management further upstream compounding these impacts. From the results of the PRA, it was found that estimated pesticides used in the agricultural impacted sites posed a possible risk to the aquatic ecosystem and were expected to have a large impact on the insects and crustaceans and a lesser impact on fish communities. The WoE approach using multiple assessments, for the agricultural impacted study sites strongly corroborates the predicted areas of greatest risk and for this reason can be seen as a promising approach to follow.

5.3.5 Phase 5: Decision Support System

The final and *Fifth Phase* proposed and recommended a DSS (Decision Support System) that can be used for informed decision making by relevant governmental authorities and environmental risk managers as well as a dissemination tool towards responsible pesticide usage by the agricultural sector.

5.4 Conclusions

The PRIMET and PERPEST models provide compelling preliminary estimates of risk for pesticides and could be used effectively in South Africa. The PRIMET model provides a useful model for quantifying and comparing risks of pesticides applied within an agricultural area. The model was effectively used in this study to predict the risks in the aquatic scenario and was found to be user friendly due to easily accessible and available data. The results of the tiered risk assessment approach indicated that several pesticides have the potential to impact non-target species within the aquatic ecosystem. Overall, deltamethrin was identified to pose the highest probability of risk to aquatic macro-invertebrates. Laboratory tests confirmed the highly toxic nature of the pesticide to organisms occupying the study area. It was established that confidence of the models can be increased if local species were incorporated into the model databases. This study also demonstrated the usefulness of combining the series of tests using the DEEEP approach and the role this approach could play in assessing the toxicity hazards in river water samples that receive agricultural inputs and how this approach can be incorporated into national monitoring programmes. The integration of results from multiple assessment endpoints can be integrated into a tiered WoE approach to determine environmental impacts within a study site. This study assessed a number of multidisciplinary approaches and successfully demonstrated the overall hazardous impacts (both urban and agricultural). The use of this integrated approach provides a convenient and useful tool of assessment, since it integrates and summarises a suite of exposure and/or effects assessments, facilitating the definition of risk categorisation. The approach followed allows management and decision-makers to assess the quality of the aquatic environment based on the prevalence of evidence given in the WoE approach.

This approach appears to be promising in the field of ecological risk assessment of pesticides, especially in developing countries such as South Africa that lack resources and expertise to monitor pesticides using chemical analysis alone. It further has the potential to be formalised and incorporated into future management and monitoring protocols within developing countries. The PRA models will be able to assist farmers in reducing the environmental risks of pesticide usage in a user-friendly and cost-effective manner by providing an indication of which pesticides, at what dosages and applications would pose the lowest risk potential in their particular scenarios. This will allow for a more responsible environmental choice of pesticide usage. This approach thus offers a significant improvement over the use of expensive and time-consuming analytical testing for the presence of pesticides and simulation models or the use of safety factors.

This study represents a first attempt at combining different sources of information to discriminate agricultural impacted sites and in assigning impacted sites using an integrated hazard index score. It is recognised that additional studies summarising more data will result in higher confidence in reassessing and adjusting weighting and the protocols followed. Therefore the approach outlined here should not be viewed as a definitive product, but rather as a first step in the continuing effort to integrate multiple measurement methods in environmental risk assessment and to establish a framework for interpreting results. The field of science is progressive and the approach used within this study also has room to advance.

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6 An approach for Pesticide Risk Reduction in Ethiopia

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Abstract

Ethiopia is in the process of intensifying and diversifying its agriculture to meet national demands for food, but also to increase agricultural exports (e.g. of coffee, flowers and vegetables). Both intensification and diversification may lead to increased use of agrochemicals such as pesticides. However, pesticides, when used inappropriately, can affect agricultural productivity, thus reducing the sustainability of agricultural intensification and diversification, and can result in adverse effects on human health, the environment and water quality. Therefore, sustainable growth of the agriculture sector, and protection of human health and the environment in Ethiopia require effective regulation and management of pesticides.

In 2010 the Government of Ethiopia, with aid from the Netherlands, has initiated a Pesticides Risk Reduction Project (PRRP). The overall goal of the programme is to contribute to a sustainable pesticide management system in Ethiopia in order to regulate pesticide use by farmers, taking into account the whole pesticide life cycle from registration and procurement, import/local manufacture of pesticides, to distribution, use and monitoring, including quality control and waste management, and to improve the environment, health of growers and the surrounding community, and to stimulate the economic performance of the Ethiopian agricultural sector. It is acknowledged by all stakeholders, including representatives of relevant ministries and the African Union, that the present programme on pesticide risk reduction is important and may serve as a pilot project for other African countries or regions

6.1 Introduction

Most of African countries lack adequate pesticide management capacities and this situation has resulted in the generation of large stocks of obsolete pesticides, empty pesticide containers, contaminated equipment, materials and heavily contaminated soil at certain sites and water bodies with a daily impact on human health and on natural enemies of pest species.

Inadequate use of pesticides may have a large impact on quality of surface and ground water, Presence of residual pesticides in water reduces the usefulness for drinking water and will reduce the ecological quality of surface water systems.

Residue problems have been reported on some export crops at different occasions. For example, the export of coffee and sesame from Ethiopia to Japan is hardly possible because Japan has set the strictest possible residue limits for any agricultural produce to be imported to its country. Also the fast growing horticulture export sector of Ethiopia faces a lot of problems. Some pesticides with high human and mammalian toxicity and pesticides that have been restricted in developed countries are still circulating in the country due to poor regulation no compliance with Global Good Agricultural Practice (Global GAP). These conditions reflect a mismanagement of pesticides at different stages of the life cycle of pesticides in the country. One of the basic problems in the management of pesticides is the lack of a proper registration system in Ethiopia. Pesticide registration is still at the development stage and there is little expertise in the field of implementing internationally agreed pesticide registration procedures and guidelines and not enough capacity for conducting the required lab analysis which may lead to a situation of registering pesticides that are harmful for public health and the environment in general. Moreover the awareness on safe and judicious use of agricultural and public health pesticides is very limited. This has resulted, especially among smallholder horticulture farmers, in widespread misuse and abuse of pesticides, including unsafe storage.

In addition, over the last ten years the Ethiopian government has been concerned about safe disposal of obsolete stocks (see also Chapter 7). In collaboration with the government of Ethiopia, the Food and Agricultural Organization of the United Nations (FAO) secured funds from international donors and insured disposal of 2273.43 tones during obsolete pesticide projects. Currently about 415 tones are also safeguarded awaiting finalization funding arrangement from Croplife International. However, the country is not still free from obsolete pesticides. The existing inventory data confirms an estimated additional stock of over 400 tones new obsolete pesticides and large quantities of contaminated containers and pesticide application equipment remain scattered over the country. A number of sites have also been identified which are believed to show significant levels of soil contamination and which may be affected by burial old pesticides.

At the same time, Ethiopia is in the process of intensifying its agriculture to meet national demands for food and to increase agricultural exports like coffee, flowers (Figure 6.1) and vegetables. This implies that for sustainable growth of the agriculture sector there is an immediate need for proper regulation and management of pesticides.

Pesticide management therefore receives much attention from the government in order to attain high quality agricultural produce for local consumption and export, protect public health and natural resources. In view of this, the Government of Ethiopia has initiated a national programme to improve pesticide management along the pesticide life cycle: from the registration and import of pesticides, to use and monitoring, and including quality control and waste management.

6.2 Towards a better use of pesticides

In 2006, the Animal and Plant Health Regulatory Department (APHRD) of the Ministry of Agriculture and Rural Development (MoARD) initiated a strategy for pesticide use reduction and introduced Integrated Pest Management (IPM) on cotton and awareness building on misuse of pesticides in close collaboration with FAO and local NGO. This scheme resulted in behavioral change among cotton growers in the southern region by following eco-friendly cotton production methods. The same scheme also served as a spring board for introduction of organic cotton farming by a Dutch NGO involving over 700 Cotton IPM Farmer Field School (FFS) graduate farmers (although the investor pulled out as the result of the global financial crisis). In the meantime APHRD requested assistance by FAO to review the pesticide proclamation and draft associated regulations and to assess the analytical capacities of all pesticide laboratories with regard to the quality control of pesticide formulations and pesticide residue analysis. It also invited Alterra, part of Wageningen UR, in the Netherlands to support the development of local technical capacity for the registration of pesticides and biopesticides.

Up to now there have been several piecemeal support projects with limited results. During a workshop in Addis Ababa in September 2008 it was decided to develop a comprehensive programme for pesticide registration and management in order to cover the various above-mentioned gaps. APHRD, Alterra and FAO started a joint collaboration on pesticide risk reduction in Ethiopia. During the workshop local partners were invited and representatives of the Federal Environmental Protection Agency, the Ethiopian Institute of Agricultural Research, the Ethiopian Horticultural Producers and Exports Association, and the Drug Administration and Control Authority were represented for properly embedding of the activities in local institutional setting.

In September 2009 a Pesticede Risk Reduction Project (PRRP Ethiopia) was presented and discussed on a well attended stakeholder meeting, including representatives of relevant Ministries and the African Union. The plan was enriched and endorsed. It was now acknowledged by all stakeholders that the proposed programme is comprehensive and concrete and is seen as an important pilot for other African countries or regions. The implementation of the planned activities started in February 2010 and will finish by the end of 2013.

Figure 6.1
Ethiopia is an important flowers exporting country. Pesticides are used in growing of flowers.

The programme is based on all identified needs in terms of human and institutional resources for the implementation of pesticides and biopesticides registration and the needs for the enforcement of post registration activities. It covers both agricultural pesticides as well as public health pesticides.

6.3 Goal and objectives of the programme

6.3.1 Goal

The overall goal of the programme:

To contribute to a sustainable pesticide management system in Ethiopia in order to regulate pesticide use by farmers, taking into account the whole pesticide life cycle: from registration and procurement, import/local manufacture of pesticides, to distribution and use and monitoring, including quality control and waste management. To improve the environment, health of growers and the surrounding community, and stimulate the economic performance of the Ethiopian agricultural sector.

This programme will function as a pilot for other African countries and regions and it will contribute to the national programme on food security and agricultural development focusing on sustainable intensified crop production in Ethiopia. It also contributes to the Comprehensive Africa Agriculture Development Programme (CAADP), a programme of the New Partnership for Africa's Development (NEPAD). This project links with all four pillars of CAADP, namely pillar 1, land and water management, pillar 2, market access, pillar 3, food supply and hunger and pillar 4, improvement of agricultural research. Finally it will also contribute to the Millennium Development Goal (MDG) 1, aimed at reducing poverty and to MDG7, sustainable environment and livelihood. In this project pesticide management is listed as priority in government policy and Ethiopia is currently showing several initiatives to implement the International code of conduct on distribution and use of pesticides.

Within the programme a frame work for registration and post registration will be developed. The main objectives of the PRRP programme are:
1. To develop a legal framework for the registration and post registration of pesticides (regulation, directives and guidelines).
2. To develop a proper pesticide registration system for Ethiopia and capacity building on dossier evaluation.
3. To develop a well functioning post registration system (including development of reference laboratory with analytical capacities for quality control[2], monitoring, procurement guideline, inspection, storage of pesticides, capacity building and training).
4. To develop a formal consultation platform that will support APHRD with advice on (post)registration issues.
5. To execute an impact assessment of the new (post) registration system.

[2] Japan will be funding a national laboratory for pesticide residue analysis and USAID is interested in training and operational aspects of the future lab for residue analysis.

6.4 Registration Tools

The coming years the following issues will be addressed in Ethiopia.

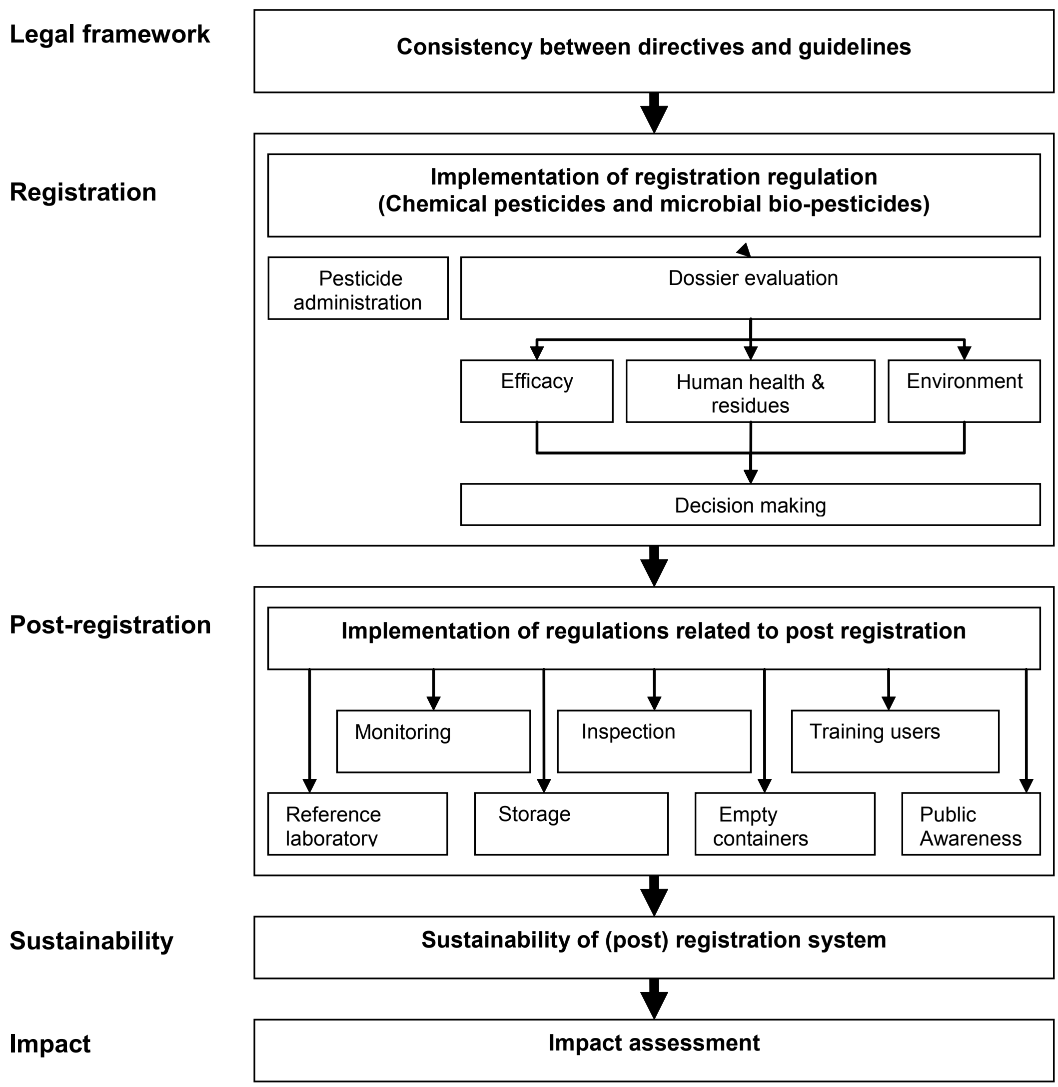

Figure 6.2
Overview of the framework of the PRRP programme.

Legal framework
Within the programme a proper legal framework will be combined with registration and post-registration tools as shown in the framework in Figure 6.3.

The legal framework in the PRRP programme will ensure the consistency between the law (Proclamation on the Registration and Control of Pesticides and the accompanying regulations) and the methodologies, guidelines etc. that will be developed during the project. The legal framework was written during the start of this programme and adaptation of the current regulations and guidelines could be a result of the development of the new registration and post registration system (Figure 6.3).

Figure 6.3
APHRD staff preparing group presentation on status of pesticide registration and post registration in Ethiopia. Ms. Ambra Gobena, legal expert of FAO, discussing the draft regulation with Mr. Fikre Markos, Deputy Head of APHRD.

Registration system for pesticides
Development of technical and scientific capacity will ensure sound pesticide management in Ethiopia at the pesticide registration stage. It is necessary to:
1. Strengthen the administrative registration management unit through capacity building.
2. Develop a scientific evaluation system for registration of agricultural pesticides (chemical and microbial biopesticides) and public health pesticides. The scientific system will focus on biological efficacy, human health aspects, pesticide residues and environmental issues.

Post-registration system for pesticides
Development of a sustainable post-registration system will focus on the following issues:
1. Development of reference laboratory with analytical capacities for the quality control of pesticide products used in agriculture and public health sectors.
2. Monitoring systems related to pesticide quality control, user's health and pesticide residues in agricultural products developed and linked to the Pesticide Stock Management System (PSMS).
3. Inspection system of pesticide containers, labeling system and quality of pesticide control.
4. Appropriate storage of pesticides and stock management of pesticides in plant protection, the control of migratory pests and vectors in public health.
5. Development of a management system for empty containers and small quantities of obsolete pesticides
6. Training of pesticide distributors, retailers and applicators in agriculture and public health sectors; and
7. Public awareness and capacity building of professionals.

The approach will focus on the development of sustainable systems through guidelines, standards and protocols. In addition, much attention will be given to capacity building through workshops and training.

Sustainability of the developed systems
All developed systems and various elements will need to be sustainable, also after the end of the programme. Therefore, approaches and mechanisms will be developed to ensure sustainability of an effective Ethiopian pesticide management system in the long term.

Sustainability will be ensured by focusing on various aspects of the development of a sustainable pesticide management system:
1. A financial and institutional feasibility study will be available which assesses options for sustainable funding of pesticide management in Ethiopia, including such activities as registration, inspection, pesticide quality control, post-registration monitoring, etc.
2. Technical and scientific sustainability: development options to ensure the long term technical and scientific quality of the pesticide management system in Ethiopia.
3. Legal and institutional sustainability in order to ensure that all elements of the pesticide management system which are being developed have a sufficient legal basis (as far as required) and are integrated, as much as possible, within the appropriate Ethiopian government institutions and non governmental stakeholders, i.e., mainstreaming of pesticide management.

Impact assessment
Impact assessment will be done to evaluate the impact of the newly developed systems related to (post-) registration of pesticides. At the start of the project (2011) a study on the reference situation will be done focusing on:
1. Pesticide use by farmers.
2. Environmental impact of pesticide use.
3. Impact on human health of pesticides use.
4. Existing capacity of professionals.
5. Knowledge of pesticide users.

After 5 - 10 years the study will be repeated and the impact of the activities within project will be evaluated.

6.5 Conclusion

The joint PRRP programme covers all aspects of pesticide legislation in the agriculture and public health sectors: setting up a sustainable system and capacity building for pesticide registration in agriculture and public health sectors and a concrete and holistic plan for post registration aspects (monitoring, inspection, quality control, storage, capacity building).

The following benefits are expected as outcome of the programme in terms of:
- Economy - contributing to enhancement of food security and better livelihood among smallholder farmers and exporting high quality agricultural products (satisfying the requirements of importing country).
- Public health - preventing hazards associated with pesticides.
- Clean environment - water and soil with no/minimum pesticide contamination.

Results of the pilot in Ethiopia will be an example for development of a registration system in other African countries.

Acknowledgement

The PRRP programme receives financial support from the Government of the Netherlands, represented by the Minister of Foreign Affairs/Development Cooperation and from the Food and Agriculture Organization of the UN (FAO). The Ministry of Agriculture and Rural Development (MoARD) of Ethiopia contributes to this programme by making available sufficient qualified personnel to execute the activities underlying the Programme. MoARD will also provide office space, secretarial services, communication facilities and transport as deemed necessary for the efficient execution of the project. All parties agreed to strive to mobilize additional financial resources to allow the execution of activities of the project plan which are as yet not funded. The authors are thankful to the whole project team that is working on the programme!

Figure 6.4
Scenery of the countryside, approximately 45 km north of Addis Ababa.

7 Drainage to sustain irrigated agriculture in North-Africa

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7.1 Introduction

The population in Africa is projected to grow from 965 million people today to more than 2000 million in 2050. At present, 80% of the Africa's poor people live in rural areas and are directly or indirectly dependent on agriculture. The majority of the farmers are smallholders, owning less than one hectare of cultivable land (Photo 7.1). Increased productivity, profitability and sustainability of small-scale agriculture are essential to reduce poverty in rural areas and thus important for achieving the Millennium Development Goals. To be able to feed the growing population and to banish hunger, food and feed production will need to be doubled in the coming 25 to 50 years (Molden, 2007). The majority of this increase has to come from investments in improved irrigation and drainage practices in existing agricultural areas as there is not much scope for horizontal expansion. There is scope for improvement as currently only 29% of the agricultural lands in North Africa are irrigated and only 16% are drained (Table 7.1). At the same time, however, land degradation is occurring in irrigated areas through waterlogging and salinization. No exact data are available for North Africa, but worldwide, salinity and related waterlogging affects about 10-16% of the irrigated lands. In this paper, the role of drainage in irrigated agriculture in the arid and semi-arid regions of North Africa is analysed and recommendations for improving agricultural water management practices are formulated. The recommendations follow three lines: (i) balancing top-down against bottom-up; (ii) from standardization to flexibility, and; (iii) focus on capacity building. Furthermore, irrigation and drainage are not treated as separate issues, but as part of Integrated Water Resources Management (IWRM). To enhance the role of drainage in IWRM, tools are presented for improving water efficiency and creating an enabling environment, highlighting the changing institutional roles and functions and the required management instruments.

 

Photo 7.1
The majority of the farmers in Africa are smallholders, owning less than one hectare of cultivable land. Example from the Nile Delta, Egypt: harvest of maize (left) and Egyptian clover (right).

Table 7.1
Irrigated and drained area in North Africa (source www.icid.com).

Country	Cropped area (CA)	Irrigated area		Drained area		Population	Productivity for cereals
	(Mha)	(Mha)	(% of CA)	(Mha)	(% of CA)	(Million)	(T/ha)
Algeria	8.22	0.57	7	0.06	1	34.7	1.4
Egypt	3.42	3.42	100	3.00	88	75.0	7.5
Libya	2.15	0.47	22	NA	NA	6.3	0.6
Morocco	9.38	1.45	15	0.12	1	31.2	0.6
Tunisia	4.93	0.39	8	0.08	2	10.3	1.5
Total	**19.88**	**5.73**	**29**	**3.20**	**16**	**122.7**	**3.9**

7.2 The role of drainage in irrigated agriculture in North-Africa

In North-Africa, which its (semi-)arid climate, irrigation is a tool that allows farmers to cope with inadequate and unreliable rainfall. Drainage is a strategy for enabling farmers to cope with irregular rainfall and to safeguard investments in irrigation by removing excess water and salts brought in by the irrigation water (Ritzema, 2009). In irrigated agriculture, integration of irrigation and drainage is needed for three seasons (Snellen, 1997). First of all, integration is needed to manage the water balance in order to reduce water requirements for irrigated agriculture. Secondly, to manage the salt balance, because even with improved irrigation practices the leaching requirements have to be met. And thirdly, to manage the financial balance in order to reduce the public costs of operating irrigation and drainage schemes. Irrigation in fact brings water twice, firstly to meet crop water requirements and secondly to provide leaching of the salts brought in with the same irrigation water. Drainage enhances the soil capacity to act as a storage room, especially when there are options for operational control to maintain the water table at a higher level. Water balance studies done in Egypt show that controlled drainage can also improve irrigation efficiencies. Improving irrigation efficiency means that drainage discharges and total salt load will decrease, but the quality will deteriorate as a result of the increasing concentrations of salts. Nevertheless, reuse of drainage water can supplement irrigation water deficiencies and can be a viable option for minimizing disposal needs. Reuse can be practised at farm, system and regional level. At farm level, drainage water can be reused when it is of good quality. Farmers can pump water for irrigation directly from the open drains or use shallow wells to pump groundwater. At project and regional level, drainage water can be pumped back into the irrigation system, where it is mixed with better quality irrigation water. The quantity and quality of both the irrigation and drainage water determine how much drainage water can be reused. Drainage water, however, can never be completely reused because the salts that are imported with the irrigation water have to be exported out of the area. Another complicating factor is the increasing use of waste water for irrigation. The impacts of reusing drainage and waste water on catchment hydrology, including the transport of salt loads, are still insufficiently understood. Subsurface drainage can also be considered as irrigation modernization in the sense that it saves on water use. In the off-season, the lower water table reduces the soil evaporation and thus the salinization of the root zone, making subsurface drainage an important tool for maintaining the soil quality.

The countries in North Africa have invested heavily in irrigation (Photo 7.2 and 7.3) and, to protect these investments and to increase the sustainability of their agricultural lands, in drainage. Drainage development is mainly driven by the level of agricultural development and the related technical merits and (farm) economic viability as an instrument for more profitable land use and further agricultural development.

Photo 7.2
Egyptian farmer in front of the Nile Barrage. The Nile Barrage is used to supply irrigation water to the farmers in the Nile Delta.

Photo 7.3
In the countries in North-Africa, irrigation is a tool that allows farmers to cope with inadequate and unreliable rainfall: example from Projet d'irrigation d'Abda-Doukkala, Morocco.

The governments are the driving force behind the installation of drainage systems (Photo 7.4). The organizational setup is purely top-down. Although most farmers are poor and do not have the means to invest in drainage, they clearly see the benefits and are willing to contribute. Despite their willingness, farmers' involvement only starts after the drainage system has been installed; only then they are asked to become involved in operation and maintenance. This top-down approach does generally not encourage farmers to take up their responsibilities. A more service-oriented approach has been promoted since the 1990s, but has not yet gained much of a foothold in practice. It can be concluded that, although the installed systems are technically sound and cost-effective, drainage development lags behind irrigation development and consequently a substantial part of the irrigated areas suffer from waterlogging and salinity. An exception is Egypt, where the Government took full responsibility for the implementation of subsurface drainage systems. But even in Egypt, handing over operation and maintenance to the farmers is problematic. This is mainly because the drainage systems are designed and implemented by governments, with the users, the small farmers, having little responsibility and making little input: a top-down approach in which location-specific conditions and farmers preferences are hardly taken into consideration. Furthermore, similar to irrigation, the emphasis has been more on the technical aspects (the physical infrastructure), while the organizational aspects (institutional infrastructure) have been insufficiently taken into account (Kuper et al., 2009). It should be remembered, however, that most farmers are poor and do not have the means to invest in drainage. A farmer who was asked *When would you consider yourself to be a rich farmer*? answered *When I can give my family three meals a day*.

Photo 7.4
The Egyptian Government is implementing an ambitious programme to provide all agricultural land in Egypt with subsurface drainage by 2012.

7.3 The need for drainage in irrgated agriculture

An analysis of the subsurface drainage practices in irrigated agriculture shows that the installed systems are technically and economically sound (Ritzema, 2009). They effectively prevent waterlogging and root zone salinity and consequently increase crop yields and rural income. The analysis supports the prevailing view that deep drains are unnecessary for salinity control and that improved operational management can further reduce drain depths and design discharges. Water and salt balance studies conducted in Egypt show that rice cultivation plays an important role in the leaching of salts from the soil profile, reducing the drainage intensity during the cultivation of other crops. Controlled drainage can save irrigation water supply up to 30% and at the same time reduce drainage outflows up to 25%. The introduction of new types of installation equipment and materials and the corresponding implementation practices has made large-scale implementation feasible. The economic analysis shows that these subsurface drainage systems are a very cost-effective measure for combating waterlogging and salinity in irrigated agriculture. For example, in Egypt, the introduction of subsurfade drainage resulted in an increase in the Gross Production Values with € 500 - 550 per hectare and the annual net farm income of the traditional farm increased by € 375 per hectare in non-saline areas and by € 200 per hectare in saline areas. The payback period was no more than three to four years. The impact of drainage on national agricultural production is also significant; drainage accounted for about 8% of production in the agricultural sector. The contribution to the gross domestic product is estimated at about € 0.9 billion per year. The government prefinances the total cost of the installation of subsurface drainage. Farmers pay-back these costs over 20 years with a grace period of three to four years without interest, which effectively amounts to roughly a 50% subsidy. The recent rise in the major food commodity prices will increase the economic returns even further.

Despite these positive signs, the role of drainage in irrigated agriculture has been quite insignificant in the last decades. In many 'vision' and policy documents, irrigation is seen as the key developmental intervention, while drainage is only mentioned as a necessary preventive/remedial supplementary measure to irrigation, but not as a development instrument in its own right (Molden, 2007). There are several other reasons why drainage needs to receive special attention:

- In small-scale irrigation, drainage is always a joint effort. Water infrastructure in arid and semi-arid conditions is traditionally based on the water supply situation. Disposal of excess water requires a complementary infrastructure that invariably serves a multitude of users. Drainage therefore requires the cooperation of stakeholders, which makes it more difficult to organize. Research conducted in Egypt, Tunesia and Morocco show that farmers are willing to cooperate, but that an appropriate organizational setting is often lacking.
- The boundaries of drainage units generally do not coincide with the boundaries of irrigation units. Research conducted in Egypt shows that, by matching irrigation and drainage units, considerable savings, especially in water, can be made.
- The institutional set-up is complex and enforcement of rules and regulations is difficult. In contrast to irrigation, where direct benefits to stakeholders are involved, rules and regulations for drainage are much more difficult to enforce. Drainage fees need to be collected and, unlike the irrigation supply system, it is difficult to disconnect unwilling customers. The existing institutional setup, often based on irrigation system layout, needs to be modified or adapted as to improve drainage efficiency.
- Drainage is at the end of the pipeline. Drainage systems not only discharge excess water and pollutants resulting from irrigation and agricultural practices, but also waste water from rural industries and rural villages. As such, drainage may pose serious threats to downstream water users. Often, combinations of treatment, local reuse and accepting the export of pollutants will be a solution that all stakeholders need to agree upon.
- Disposal of drainage water creates off-site externalities. Drainage water discharged back into the river from which it was originally obtained as irrigation water has a higher salt content and is also often polluted with residues of fertilizer, pesticides and waste water from villages, cities and industries. Upstream users benefit from disposal, downstream users, or society as a whole, bear the cost. This calls for state regulation.
- Reuse of drainage water. Although drainage water from irrigated lands has a higher salt concentration than the irrigation water from which it originates, its quality may still be good enough for reuse in downstream areas. Drainage water can supplement freshwater resources, sometimes only after mixing. In the end, however, the salts have to be removed from the area. Increased irrigation efficiency and pollution of drainage water, however, put additional constraints on this reuse.
- Initial investment costs versus long-term benefits. Investment costs in drainage are only a fraction of the investment costs in the irrigation infrastructure (usually between 10 and 30% of the investment cost for irrigation). Nevertheless, investment costs are high and full benefits often accrue only after a few years. Salinity build-up is a slow process and subsistence farmers normally do not have the resources to invest for the benefit of the next generation.

The Comprehensive Assessment of Water Management in Agriculture, a critical evaluation of the developments in the water sector over the last 50 years by a broad partnership of practitioners, researchers and policymakers, calls for 'a change in the way we think about water and agriculture' (Molden, 2007). It makes a strong pledge 'to abandon the obsolete divide between irrigated and rainfed agriculture, to consider agriculture as an ecosystem and to recognize the importance of preserving the natural resource base on which agricultural productivity rests'. Four reasons to invest in irrigation are presented: (i) to reduce poverty in rural areas, (ii) to keep up with global demand for food, (iii) to adapt to urbanization, and (iv) to respond to climate change. Although the report recognizes the role of drainage, it is surprising that, besides the remark that 'investments in drainage are likely to continue at fairly modest levels', the role of drainage in irrigated agriculture is not addressed. This is an omission, because there is a fifth reason to invest in water and agriculture: drainage to protect investments in irrigated agriculture.

7.4 Improving drainage practices: the way forward

The Drainage and Integrated Analytical Framework (DRAINFRAME) approach developed by the World Bank's Agriculture and Rural Development Department is a recent and promising attempt to look at agricultural drainage from an integrated natural resources management perspective (Abdel-Dayem et al., 2004). The DRAINFRAME approach recognizes three main settings: (i) the biophysical environment, (ii) human society, and (iii) the institutional setting. The application of the DRAINFRAME approach in Egypt has shown that it offers a useful approach and methodology for analysing water management situations in an integrated manner and can offer useful contributions to the project planning cycle. It was also concluded, however, that the approach needs a more systematic elaboration of the stakeholders and a mature methodology for evaluating the institutional setting of water management situations. Based on the messages of DRAINFRAME and an analysis of the current practices, the following challenges for enhancing the role of drainage have been formulated (Ritzema, 2009):

- **Balancing top-down and bottom-up**. Participation by farmers needs to be increased in all phases of the implementation process. More attention needs to be paid to the identification of the stakeholders and their needs, preferences and willingness to contribute. A participatory learning and action approach is an effective and efficient method to assess the need for drainage, to create a mutual understanding of the problems and to develop an integrated approach to development. Participatory modelling is a useful tool for creating a better understanding among the stakeholders of the complexity of the problems and the effectiveness of solutions. Through these participatory tools, the link between technical aspects (requiring physical solutions) and organizational aspects (requiring institutional changes) can be enhanced.

- **From standardization to flexibility**. Instead of standardized design and implementation practices, a much more flexible approach based on location-specific conditions and stakeholders' preferences is recommended. Integration between the irrigation and drainage network needs to be improved. The challenge is to find a balance between the individual need for irrigation and drainage, which varies from field to field, and the fact that drainage at farm level is a collective activity. This requires better operational control. Controlled drainage will allow the farmers to optimize their on-farm water management, based on the specific conditions and their own preferences. Furthermore, it enables the farmers to respond to changes in land use and/or the effects of climate change.

- **Due attention for capacity development**. More stakeholder participation and more flexibility can only be achieved if the tacit or local-specific knowledge of these stakeholders is linked to the explicit knowledge of researchers, planners and designers. A four steps of the knowledge-creating process has been developed to design a capacity-building strategy. In this knowledge-creating process, the explicit knowledge of the researchers can be disseminated through education and training (internalization) and then, through research, be linked to the tacit knowledge of the stakeholders by sharing experiences (socialization). Bringing the tacit and explicit knowledge together yields new knowledge (externalization). In turn, this can again be combined with explicit knowledge from elsewhere (synthesis) and used in guidelines and by advisory services.

The above recommendations will facilitate the further introduction of drainage in arid and semi-arid irrigated areas throughout the world and contribute to a better, more sustainable use of the precious land and water resources in these areas. This requires policy and institutional changes for which governments would have to take the lead. In consultation with the stakeholders, governments need to develop a drainage policy that emphasizes the need to treat the reclamation of waterlogged and salt-affected areas in irrigation projects and the creation of fresh irrigation potential or its utilization with equal importance. This policy would have to include a time-bound action plan to safeguard these irrigated lands against these problems. Farmers would have to be willing to participate and pay part of the cost, but as the benefits often go beyond the direct interest of the farmers concerned, governments need to finance or prefinance part of the costs. The stakeholders, including the farmers, need to contribute, either in cash or in kind (labour).

Further research and development is needed to meet the specific needs of the North-African countries, which each have their own specific climatic, physical and social conditions, and to cope with climate change, land use changes and requirements related to the quantity and quality of drainage water. These changes will require modifications in drainage practices: from planning and design to implementation and operation and maintenance. It is the farmer who has to adapt his farming system to these changing needs. The challenge for the research and education community is to support farmers in managing their fields in a more sustainable way and to enable them to cope with these changes. Only if these challenges are met will investments in irrigated agriculture in arid and semi-arid areas be protected, increasing its sustainability and its contribution to feeding the growing population.

7.5 Acknowledgement

The knowledge and experience presented in this paper is the result of cooperation in a number of projects in North Africa. In these projects, the author worked together with many scientists, professionals and other stakeholders. Without the assistance of all these colleagues, it would not have been possible to write this paper.

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8 Managing water by managing land: interactive land use planning using water productivity indicators

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Abstract

Many river basins in the world experience unprecedented pressures on -and increasing competition for- water resources. The availability and quality of water resources are, however, principally determined by land use and land management. In the absence of specific land planning institutions at catchment level, river basin organizations should take up the responsibility to liaise with spatial planners and land users aimed at the better incorporation of land use planning and management in water management.

Land and water development and management strategies may serve multiple policy objectives, which can also vary from place to place. Examples of development targets are food security, income security, social security (employment), equitable water allocation and ecological integrity.

To facilitate stakeholders' discussions, policy dialogues and negotiations on land use planning and management Alterra, LEI and WaterWatch have developed an interactive open-source web-based discussion support tool, which can instantaneously generate spatially distributed information on tangible indicators on water consumption, (economic) water productivity, water-related employment and water availability. The tool can assist stakeholders to evaluate trade-offs between alternative land development scenarios and courses of (social) actions that may impact on water resources and water use. As the tool uses consistent, transparent, impartial and verifiable information, it stimulates open discussions among stakeholders and contributes to confidence building. The tool has been applied in stakeholders' meetings in the Inkomati basin in Southern Africa.

8.1 Introduction

8.1.1 Global water stress

Many river basins in the world experience unprecedented pressures on land and water resources. Main drivers are the population growth, socio-economical developments (such as the liberalization of the world food markets), socio-cultural developments (such as changes in lifestyles and diets) and the global climate change. These developments result in a rapid worldwide growing demand for fresh water. At the same time are water resources subject to increased variability in availability and quality, causing increasing imbalances between supply and demand.

The increased competition for water, which has social, agronomic, economic and environmental implications, is globally recognized as one of the most serious problems of this millennium. In many river basins water resources are over-exploited, which causes tension or conflicts between water users and the degradation of important ecosystems.

8.1.2 Stakeholders and water management

To effectively deal with competing claims on water resources good communication between stakeholders within the river basin is crucial. Their active and genuine participation is imperative in the search for consensus on water management and for raising commitment to support and comply with decisions taken. This entails a legal and institutional setting which properly reconciles the interests of all stakeholders in the river basin. It also requires transparent and impartial information, particularly in the case of large river basins with stakeholders from various sectors, regions and countries.

8.1.3 Scope and objectives of research

In many water-stressed river basins tough decisions on water allocation, reallocation and/or prioritization are inevitable, as the scope for water supply management (e.g. transport and/or storage of water) and water demand management through increasing end-use efficiencies (e.g. water saving measures, water reuse) has often been fully exploited already. These decisions are generally the domain of water managers. This situation does however not sufficiently acknowledge the role of rainfall as the ultimate water resource, as will be shown in this article. As the fate of rainfall and the availability and quality of surface water and groundwater resources, including their spatial-temporal variability, primarily depends on land use and land management, spatial planning and land management are crucial for water management.

In this article the role of land use planning in water management will be elaborated and a tool will be presented that can support stakeholders in a river basin to identify and discuss feasible land development scenarios that can serve various policy priorities. The tool has been applied in the Inkomati river basin, within the framework of stakeholder discussions on trans-boundary water management issues.

8.2 Rationale: Managing water by managing land

Water management organizations, including River Basin Authorities, are usually -and to various degrees- responsible for the development, distribution and protection of surface water and groundwater resources. These water resources however cover only a small portion of the hydrological cycle and the overall water resources in a river basin. The surface water and groundwater can be referred to as 'blue water' (Figure 8.1). Blue water is the traditional domain of water engineers and licensing authorities, as this water can be transported and manipulated through water infrastructures.

The soil moisture is referred to as the 'green water' resource (Figure 8.1). Any manipulation of green water is principally done through land management practices (by the land user). The use of the soil water by the various possible land uses (e.g. agriculture, forestry, nature) causes a green water flow to the atmosphere. Soil water can be replenished naturally by precipitation, or artificially through irrigation (blue water). The green water flow may, therefore, (partially) originate from rainfall and from blue water resources.

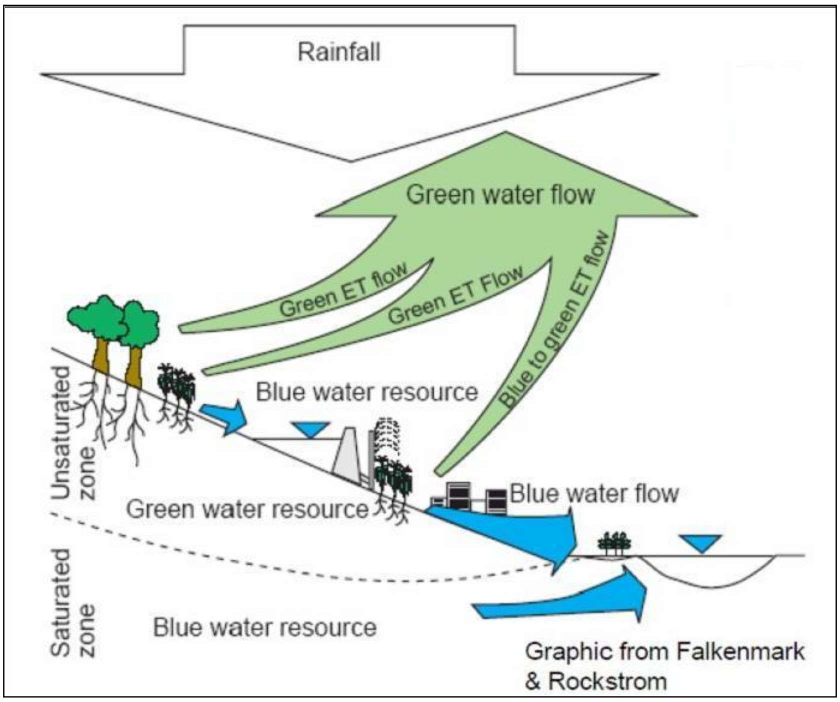

Figure 8.1
Blue and green water (after Falkenmark and Rockström).

On a global scale blue water constitutes only one third of the rainfall (Falkenmark and Rockström, 2006). In water-scarce river basins the blue water resources often represent an even lower percentage of the rainfall. It would, therefore, make sense to pay more attention to the management of the green water in relation to rainfall, as the manipulation of the green water flows can have huge impacts on the hydrology and water resources of a river basin. The planning and management of green water flows is principally the domain of spatial planners and land users, such as farmers.

8.3 Coping with competing claims on water resources

8.3.1 Green water flow management

Discussions on water allocation often highlight the stake of irrigated agriculture, which can be regarded as the portion of agriculture that uses blue water resources. In many river basins in semi-arid areas irrigated agriculture may indeed utilize most of the allocated blue water resources. It is, however, often ignored that the total consumptive water use in a basin by rain-dependent agriculture, forestry and ecosystems generally largely exceeds the water consumption by irrigated agriculture.

In this research the focus has, therefore, been on the investigation of options to manipulate the green water flows through spatial planning rather than manipulating blue water resources (e.g. by water saving or reallocation). An important implication of green water flow management is that the traditional distinction between rain-fed and irrigated agriculture becomes superseded, as irrigated agriculture can just be regarded as one of the many water uses that generates green water flow.

8.3.2 Challenges in spatial planning

A major constraint in green water flow management is that land use is generally not planned and managed at the level of river basins, despite of the huge impact of land use on the hydrology and water resources. As a result sub-optimal conditions have often emerged. Good economical or ecological prospects of downstream areas are often being infringed by water scarcity or pollution, while less favorable areas, located in the upstream portions, are using the water resources sub-economically or sub-ecologically. This is especially valid for trans-boundary river basins, where upstream countries tend to focus on their own interest rather than on the entire river basin.

In the absence of specific land planning institutions at catchment level river basin organizations should be encouraged to start dialogues and discussions with spatial planners and to incorporate - where possible - land use planning and management issues in their mandate. To be effective there should be a good understanding of the interaction between land and water, particularly in the consumptive water use of the various land uses.

8.3.3 Need for transparency

A frequently occurring problem in land and water management issues is that data and models are not transparent and objective, which obstructs their acceptance by stakeholders. The acceptance by stakeholders is often more critical than the accuracy of information. In this research the focus has, therefore, been on relatively simple, verifiable methods that generate consistent information throughout the river basin.

8.4 Policy objectives and prioritization

Any land and water development and management strategy should obviously follow policy objectives and priorities, which can serve single or multiple development goals. Policy objectives in land and water management can target:
- Food security
- Income security
- Social security (employment)
- Equitable water allocation
- Ecological integrity

Indicators can help to assess the current situation and to identify and evaluate proposed land and water development scenarios which best serve the policy objectives and priorities. For this purpose a set of indicators is used (Table 8.1).

Table 8.1
Indicators (see also Hellegers et al., submitted).

Policy objective	Indicator	Description
Food security	Crop water productivity	Beneficial biomass per unit of water consumed
Income security	Economic water productivity	Net private benefits per unit of water consumed
Social security	Job water productivity	Employment per unit of water consumed
Equitable water allocation	Water availability for downstream uses	Volume of water to downstream uses
Ecological integrity	Ecological returns on water	Various indicators for biodiversity possible

The policy objective to promote food security is aimed at maximizing the *crop water productivity*, which is the beneficial biomass (yield) per unit of consumed water. If income security should have the highest priority then land and water management scenarios should target maximum *monetary returns on water*. For agriculture this implies that the monetary value of the produced beneficial biomass (yield) per unit of consumed water should be maximized. The economic water productivity can be calculated if the prices of commercial (agricultural and forestry) inputs and outputs are known. The economic water productivity is also referred to as the *value of water* or *net return to water*.

The policy objective to promote social security is here defined as maximizing the employment per unit of consumed water. The policy objective to promote equitable water allocation is aimed at ensuring that sufficient water is available to downstream uses. The water availability to downstream uses is an important indicator for the ecological reserve (environmental flow requirements) and water assurance commitments (water rights), including international agreements. Disaster management such as floods and droughts can also be regarded as aspects of water equity, however to adequately assess these phenomena additional, more specific indicators are required. The policy objective to prioritize on ecological integrity should focus on land and water management options that maximize the ecological benefits per unit of consumed water, for example through the creation of valuable nature areas.

8.5 Discussion support for policy development

8.5.1 Concept

Alterra, LEI and WaterWatch have jointly developed an interactive, web-based and GIS-based tool to assist land and water managers in identifying and assessing scenarios that best serve the policy objectives and priorities (the tool supports strategic management). As policy priorities may vary across the river basin while also multiple objectives may need to be addressed the tool does not optimize on land and water management, but rather support discussions. Stakeholders can interactively identify and evaluate land development scenarios and quickly assess whether or not envisaged policy priorities will be achieved. As ecological objectives and tangible biodiversity indicators can be very diverse across a catchment the tool does not incorporate information on the ecological returns on water. However, stakeholders can define environmental flow requirements through the water availability indicators.

The tool is based on a number of relatively simple concepts and assumptions, giving priority to objectivity, transparency and rapid assessments. These qualifications make the tool suitable to be applied in multi-stakeholder meetings, in workshops and by individuals to analyze (and jointly discuss) the current situation and identify alternative land development strategies. Promising alternatives may then be investigated by more detailed studies (Figure 8.2).

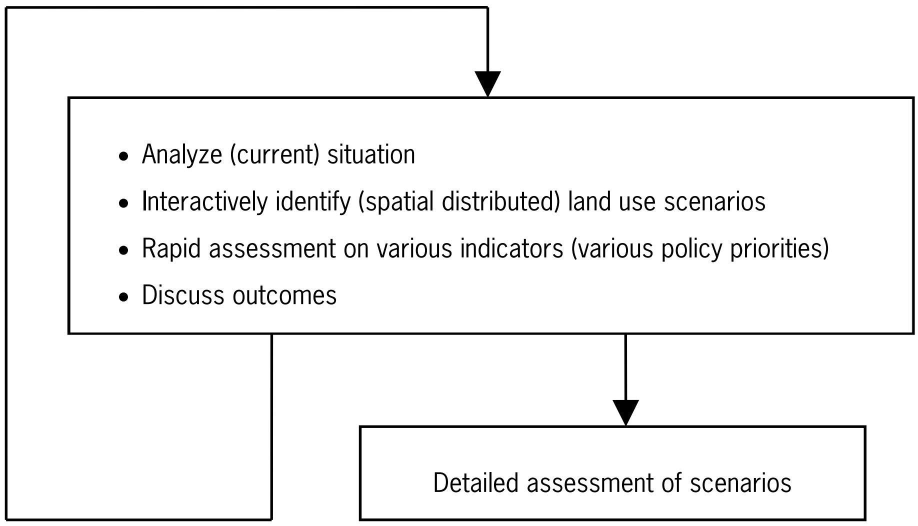

Figure 8.2
Scenario development.

8.5.2 Data

To quantify the land and water indicators, land use data, climatic data, crop growth data and socio-economical data are required. Table 8.2 present a summary of the required data and data sources:

Table 8.2
Summary of data and sources.

Indicator	Data required	Data source
Crop water productivity	Land use [1])	Land use maps
	Actual evapotranspiration [3])	Satellite images & remote sensing
	Beneficial biomass or yield [3,4])	Satellite images & remote sensing
Economic water productivity	See under Crop Water Productivity Market price [3])	Surveys, statistical bureaus, farmers' organizations
	Variable financial production cost [3])	
	Fixed financial production cost [3])	
Job water productivity	Land use [1])	Land use maps
	Number of jobs required to manage the land	Surveys, statistical offices
	Actual evapotranspiration [3])	Satellite images & remote sensing
Water availability for downstream uses	Land use [1])	Land use maps
	Rainfall [2])	Tropical Rainfall Measurement Mission (TRMM; radar) or meteostations
	Actual evapotranspiration [3])	Satellite images & remote sensing

[1]) Spatially distributed
[2]) Spatially and temporally distributed
[3]) Spatially and temporally distributed and for each land use
[4]) Calculated from the gross biomass production and the harvest indices (which can be determined through historical yield data and/or literature)

It is assumed that the consumptive water use is represented by the actual evapotranspiration. The actual domestic and industrial consumptive water uses can be neglected, as most domestic and industrial uses are non-consumptive recoverable uses (Perry, 2007). The actual evapotranspiration is the green water flow in Figure 8.1. Both the actual evapotranspiration and gross biomass production were quantified with the Surface Energy Balance Algorithm for Land (SEBAL), developed by WaterWatch, applied on freely available MODIS images which have a spatial resolution of 250x250 m and a temporal resolution of approximately 2 weeks.

The maps with the actual evapotranspiration and biomass production were combined with the land use map to obtain the consumptive water use for each land use on a pixel by pixel basis. The harvest indices can vary spatially, as certain areas are more suitable to grow a specific crop than other areas, and temporally, as climatic conditions and related yields vary from season to season. Socio-economical data such as the market prices of crops and the variable and fixed financial production costs also vary spatially and temporally. Rainfall, evapotranspiration and biomass production can be determined objectively through remote sensing techniques. The harvest indices and socio-economical data may however be subject to discussions and can therefore be specified by the user.

The water availability for downstream uses is calculated as the accumulated rainfall surplus in all upstream areas. Percolation losses (e.g. from irrigation systems), domestic and industrial waste waters are regarded as internal (recoverable) flows and volumes, as they remain within the system.

8.6 Example of application: The Inkomati basin

8.6.1 Rainfall and irrigation

The discussion support tool has been applied in stakeholders' meetings in the Inkomati river basin in Southern Africa, which is a trans-boundary river basin shared by South Africa, Swaziland and Mozambique. The Inkomati basin is a typical showcase of a river basin where many of the globally experienced problems are encountered:

- Competing claims on water resources (between sectors and areas/countries), over-allocation of water resources;
- (Increasing) water variability & scarcity, aggravated by the global climate change;
- Socio-economical developments and land reforms.

As in many other water-scarce river basins most discussions on water management focus on irrigated agriculture. In the Inkomati basin approximately 80% of the allocated blue water resources are utilized by irrigated agriculture. However, irrigated agriculture accounts for less than 20% of the total consumptive water use by agriculture (Figure 8.3). By far most of the water is used by rain-dependent agriculture, forestry and ecosystems, which reconfirms that the hydrology and water resources in the basin are primarily determined by land use.

Photo 8.1
REMCO working conference Swaziland.

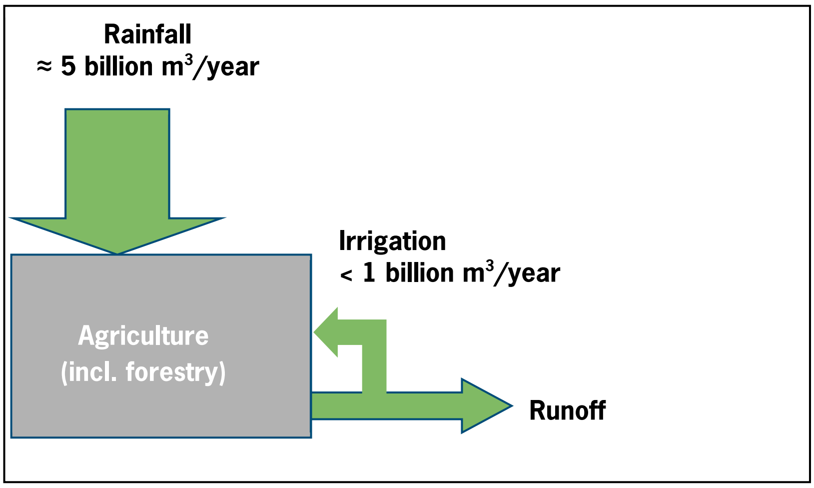

Figure 8.3
Rainfall and irrigation on agricultural lands in the Inkomati basin.

8.6.2 Interactive land use planning

The discussion support tool can quantify (spatially and temporally) the consumptive water use by various land uses, provide on-line (instantaneous) spatial and temporal information on the impact of changes in land use on the water availability and on a number of water productivity indicators, which can be used to identify the most feasible land development strategies. Periods of one year can be assessed, which thus covers a hydrological cycle. The user can introduce and assess land use changes in 24 subareas, which can be considered as "land management areas" (Figure 8.4). For these subareas the market prices, production costs and harvest indices can be specified and altered. After each adjustment the tool instantaneously recalculates the indicators, display them in tables and maps, and compare them with the current (reference) situation (Hellegers et al, submitted).

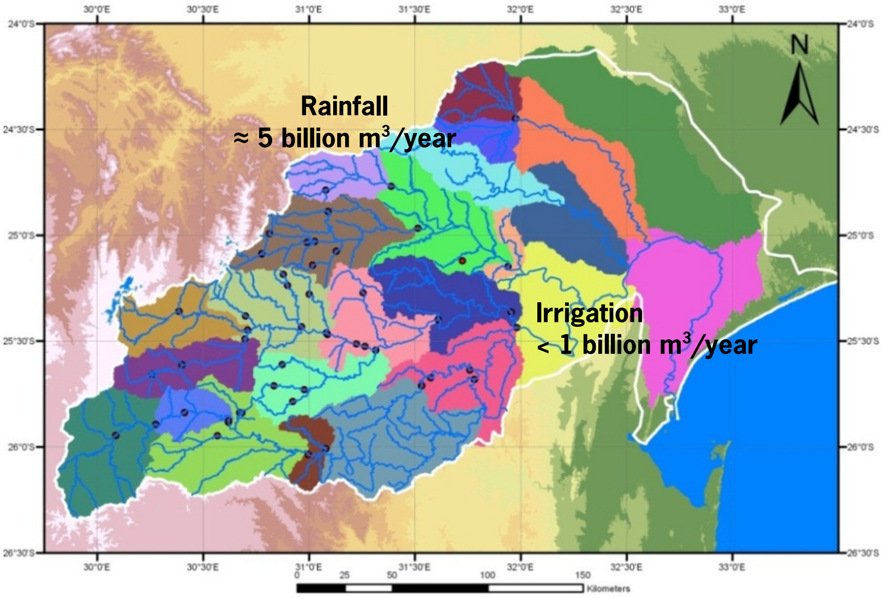

Figure 8.4
Subareas.

In stakeholder meetings representatives from the riparian states have identified and discussed land development scenarios. One of the plans that was brought forward was the conversion of 25,000 ha of bushland for biofuel production by sugarcane in Mozambique. Detailed results of these assessments are described in Hellegers et al, submitted.

The tool showed that the conversion of land for sugarcane production would cause a decrease in the rainfall surplus of approximately 50 million m^3 in an average year, as sugarcane consumes more water than bushland. The water availability for downstream areas would then decrease by 3%. In dry years the already experienced shortages would aggravate, which means that this scenario is only feasible if provisions are made to cover water shortages. Arrangements need to be made with upstream water uses to release more water. Alternatively surface water reservoirs or boreholes can be constructed (provided that their impacts are acceptable).

The water availability to downstream uses will thus reduce, but the socio-economical indicators show positive effects: Both the crop water productivity and the economic water productivity will considerably increase. The economic water production value of the area increases by more than 300 million ZAR/year in an average year. The cultivation of sugarcane also creates about 17,000 additional jobs in the area. These economic and social benefits may provide space for negotiations and compensation schemes with less productive upstream water uses.

8.6.3 Other findings

It was found that the economic water productivity is not equated among the crops in an area. Such spatial variations in the subareas can be due to management practices, random, uncontrollable events and the natural productivity of the farm resources (Hellegers et al., 2010). Examples of management practices are irrigation application practices, weed control, seed selection and the use of agrochemicals (nutrients and pesticides). Examples of random events are droughts, storms and pest attacks. The natural productivity of farms depends on the climate, local hydrology and soil properties.

8.7 Conclusions

The hydrology, the availability and quality of surface water resources and groundwater resources are primarily determined by land use and land management. In the absence of specific land planning institutions at catchment level river basin organizations should take up the responsibility to liaise with spatial planners aimed at the better incorporation of land use planning and management in water management. Effective dialogues and discussions with spatial planners require good understanding of the interaction between land and water and the (spatial-temporal) consumptive water use of the various land uses. Moreover should information be consistent, transparent, objective and verifiable in order to be accepted.

Land and water development and management strategies may serve multiple policy objectives, which can vary across river basins. Biophysical and socio-economical water (productivity) indicators can help to assess the current situation and to identify and evaluate proposed future land and water development scenarios. The discussion support tool developed by Alterra, LEI and WaterWatch can instantaneously generate spatially and temporally distributed information on tangible water productivity indicators and assist stakeholders to evaluate trade-offs between alternative land development options and courses of (social) actions. The tool promotes open discussions among stakeholders and thus contributes to confidence building.

8.8 Discussion and recommendations

Accuracy
The tool is aimed at rapid assessments, which means that promising options should be investigated in more detail. The quality of the rapid assessments largely depend on the quality of the underlying data, particularly the land use map and the economic basic data such as the market prices and production costs. It should be noted that large changes in land use can affect market prices, especially if crops are produced for the local markets, since the supply will change.

Decisions on land planning and management should particularly consider the critical periods, especially the dry season. The indicators are now calculated on an annual basis, but they vary within a year. Critical periods may thus be disregarded. More detailed follow-up assessments should specifically investigate the intra-annual variability of indicators. The tool already contains data on the rainfall, evapotranspiration and biomass production to calculate the indicators on a 2 weekly basis.

Operational land and water management
The current approach and tool are aimed at strategic land use planning. In the future operational land and water management can be incorporated, for example to respond to occurring droughts and floods. The focus on land planning and management may also be widened to incorporate options to improve water management and water saving. Assessments for short periods during the year would require a dynamic hydrological model which incorporates hydrological processes, particularly the slow components (soil moisture, groundwater recharge and –flow) and storage.

Indicators
As information on biomass production is generated, it is possible to assess carbon sequestration policies, using the indicator "mass of carbon sequestration per unit of consumed water". Ecological indicators may also be incorporated in the tool, but it should be noted that the assessment of ecological benefits from water would require that the land use map would be more specifically directed to ecosystems.

Prioritization in interventions
By investigating the stochastical characteristics of indicators options for interventions in management practices and water saving can be evaluated. For example, a high standard deviation in the water productivity for one of the land uses in a certain subarea indicates that there is scope for improvement. Possible interventions are the training of farmers and/or the introduction of modern agricultural and on-farm water management practices. The feasibility of interventions require the knowledge of local stakeholders as emerging farmers may experience other constraints than sugarcane enterprises.

The tool may also reveal water productivity differences between various areas. Apart from biophysical factors (e.g. the climate, soils) this may be due to farming practices. By evaluating these spatial differences target areas for interventions can be identified.

Optimization
With the stochastical data from the pixel-to-pixel information location-specific crop production functions (showing the yield as a function of the consumptive water use) can be derived. This can help to optimize water allocation strategies and to develop strategies for fractional irrigation in times of scarcity.

As operational water management, on-farm water management, water saving and water allocation are key issues in the Inkomati basin it is recommended to extend the tool with these functionalities.

8.9 Acknowledgement

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9 The Land, Water and Ecosystem Management Approach: a focus on rainfall

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Keywords: land, water, ecosystems, adaptation, climate change

Abstract

In the context of adaptation to climate change, much is gained by considering *rainfall* as the primary water resource, as recommended by the Comprehensive Assessment Water Management in Agriculture. This shift in focus draws attention to the interactions between land, vegetation and rainfall: it is the land and its cover that separate the rainfall into runoff and infiltration and later into a vapour outflow (evapotranspiration) and a liquid inflow that recharges the (traditional) surface and groundwater resources.

Recognition of the rainfall-processing functions of the terrestrial ecosystems would be appropriately reflected by calling this new approach: *Land, Water and Ecosystems Management* (LWEM). It could be considered as a component of IWRM for dealing with land, water and ecosystem interactions.

Today's *land use* is the result of past decisions, made by many individual landowners who mainly considered the productivity of the *land*. Even if they did consider productivity of the water resources, they will only have looked into the implications for their own property, not for the whole catchment. Also the investment decisions for public irrigation systems were largely based on the *return on capital*, not on the return on the water resources. The LWEM approach seeks to increase the value that is generated from the rain in a given river basin or catchment, through adaptations of land use and agricultural water allocations.

9.1 Introduction

The Comprehensive Assessment of Water Management in Agriculture (CA) took five years and 700 scientists from around the world to evaluate the benefits, costs and impacts of the past 50 years of water development. It formulated eight policy actions, of which the first is 'Change the way we think about water and agriculture: instead of a narrow focus on rivers and groundwater, view rain as the ultimate source of water that can be managed.' (Molden, 2007, CA, p. 3).

In this chapter, we explore the gains that can be made by shifting the focus of water resources management from the water towards the rain. Figure 9.1 represents water use by various sectors as a percentage of total withdrawals. From this perspective indeed, the water withdrawals for irrigation make agriculture the largest water user. Figure 9.2, however, shows that two third of the total rainfall on the land is consumed by evapotranspiration. When using the rainfall perspective, it becomes clear that nature consumes much more water than agriculture.

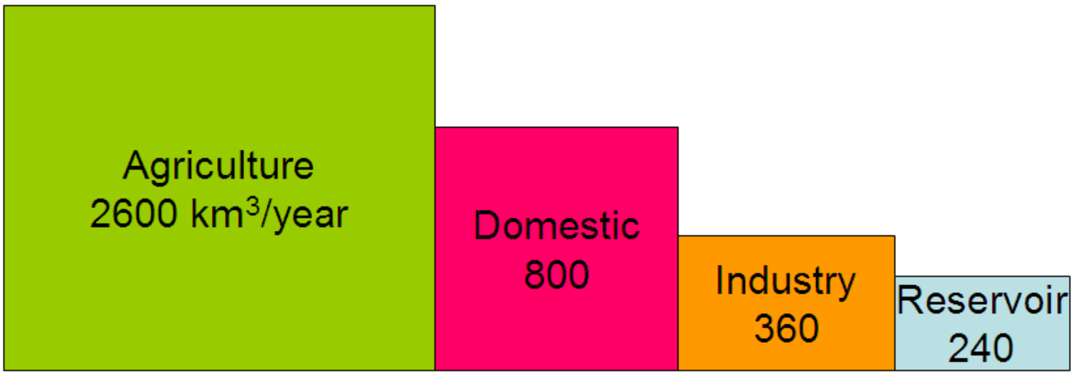

Figure 9.1
Annual water withdrawals by various sectors: (Irrigated) agriculture represents 70% of global water use.

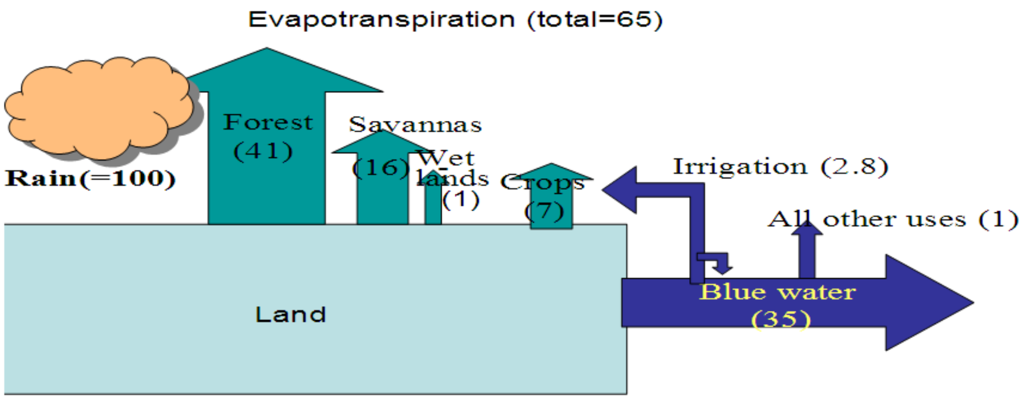

Figure 9.2
Uses of the rainfall on the earth surface: forests consume 41% against 7% for agriculture; irrigation withdrawals are just 2.8% of the rainfall.

9.2 Investment criteria: from RoI to RoR

Today's *land use* is the result of decisions made in the past by many individual landowners who mainly considered the productivity of the *land*, *not of water*. Even the investment decisions for public irrigation systems were largely based on the *return on capital investment (RoI)*, not on the return on water use.

By 1992, the international water community realised that water had become a scarce commodity in many places and that the irrigation sector was using too much of it. This view is reflected in the fourth Dublin Guiding principle, which states that '*Water has an economic value in all its competing uses, and should be recognized as an economic good*'. The implication is that in calculating the RoI for an irrigation project, the economic value of the water used by the project should be deducted from the revenues. The water sector, therefore, needs to make decisions about water allocations in such a way that society achieves an adequate return on all water withdrawals. We might dub this *Return on Water* (RoW), but we don't really need it because the term *water productivity* (in kg/m^3 or \$/m^3) already exists.

Now, let us discuss '*rainfall as the ultimate resource that can be managed*' (c.f. Molden, 2007, cited above). In fact, it is not the rainfall itself that can be managed, but what happens to it upon reaching the ground. Does it infiltrate into the soil, or does it become surface runoff to end up in a river or lake? And of the infiltrated fraction; is it used by plants for evapotranspiration and biomass production, or does it percolate beyond the root zone and recharge the groundwater? Much of this is determined by the land use. Hence: *every land use decision is also a water decision*! Not just a water-*use* decision; all renewable water resources are *generated* by the landscape from the rainfall it receives! In summary, although we cannot directly manage the rain, we should try and improve the beneficial use of rainfall in producing biomass and renewable water resources. This can be done through managing the landscape.

Rainfall does not only produce renewable water resources, but also biomass and many other ecosystem services, including various provisioning, regulating and cultural functions. When RoI is the main focus of management, these ecological services do not come into the picture. With RoW (or water productivity), the major discussion is about water withdrawals for food production at the expense of environmental flows, which are essential for maintaining *aquatic* ecosystems and services.

In parallel with RoI and RoW (or water productivity), we could define *Return on Rainfall* (RoR) as the ultimate management objective for the water sector. With an RoR focus, we also need to consider the ecosystem services provided by the *terrestrial* ecosystems, which depend on rainfall. As we have discussed above, what happens to the rainfall depends largely on the characteristics of the landscape and the way it is used. This means that the water sector, in order to achieve an adequate RoR needs to strike a deal with many - in fact all - landowners and users in the catchment. The credo *making water everybody's business* was launched at the second World Water Forum and emphasized the importance of involving all stakeholders in the distribution of water (Cosgrove and Rijsberman, 2000). The RoR perspective not only requires involvement of stakeholders in the *distribution* of water, but also their active participation in the *collection* (and subsequent use) of rain resources.

One may expect that in almost all catchments the overall value that is generated from the rain (or *RoR*) can be increased by adapting current land use and water allocations. We propose to name the approach that seeks to optimize the overall benefits from rainfall: Land, Water and Ecosystems Management (LWEM).

Variability of flow in rivers and streams is less than rainfall variability, due to the buffering effect of the terrestrial ecosystems. Water resources engineers construct dams and reservoirs to reduce this variability even further, in order to be able to meet the demand for water. At some point, however, it will not be feasible to further increase the volume of available renewable water resources by expanding storage capacity. Upon reaching this stage, we have no option but to tune our water consumption to the amount of rainfall received over a given period. Rather than waiting for this moment, we recommend adapting some of our practices already now, by seeking new ways for reducing our dependence on constructed infrastructure, e.g. by introducing cropping patterns and practices that make farmers less vulnerable to erratic rainfall.

With LWEM, there will be greater emphasis on dealing with *uncertainty of rainfall*, e.g. by seeking opportunities for increasing the buffering capacity of the terrestrial ecosystems, by increasing infiltration and retention of rainfall in the soil. These natural water reserves in the landscape may be conceived of as *virtuous dams*.

Irrigation, also, is a way of coping with uncertainty of rainfall. In LWEM, irrigation is considered as a protection against uncertainty of rainfall. Since the irrigation water supplying agency ultimately also depends on rainfall, it will not always be possible to supply farmers' irrigation demand. An important element of LWEM will be a negotiated contract between farmers and the irrigation water supplying agency, which - like in an insurance policy - specifies the extent of security offered. For a farmer, this contract provides a level of security against erratic rainfall that could also be derived from a storage reservoir on his land; the contract, therefore, may be conceived of as a *virtual reservoir*.

9.3 Some African examples of the LWEM approach

9.3.1 South Africa: Working for Water

South Africa adapted its water legislation in 1997 to reflect the recognition of the ecosystem as the *provider* of water resources. South African watershed managers now may only allocate water for commercial use (including agriculture) after having secured two basic requirements in their watershed:
1. The flow of water needed to maintain healthy aquatic ecosystems;
2. The volume of water needed to provide a minimum of 25 liters per person per day for all inhabitants (www.africanwater.org/wp3.htm#Constitution).

South African water managers, as well as (local) government officials and the general public are trained to consider rainfall as the primary water resource and evapotranspiration as the major consumer of water. This view is also reflected in a major national program called 'Working for Water'. Under this program, volunteers are paid to remove invasive tree species, thereby 'saving' the water that would otherwise be consumed by these trees through transpiration. Invasive tree species are estimated to reduce the total national Mean Annual Runoff by 7%. (www.dwaf.gov.za/wfw/docs/LeMaitreetal.2000.pdf).

9.4 Southern Africa: managing water by managing land

Jansen and Hellegers (2011) provide a tool that enables evaluation of the effects of land use changes on water productivity. The tool was developed and applied in the Inkomati basin, but may be applied to any river basin or catchment in Africa. For details, refer to chapter in this compendium.

9.4.1 East Africa (Kenya): Green Water Credits program

The Green Water Credit program explores the possibilities of letting downstream users pay for the benefits they obtain from actions by upstream land users. In a proof-of-concept effort in the Upper Tana Basin in Kenya, researchers quantified the effects of various measures aimed at increasing infiltration and reducing unproductive evapotranspiration. The measures included grassed contour strips, mulch and tied ridges. Green water management:
- reduced reservoir sedimentation by 22% in a dry year and 66% in a wet year;
- increased groundwater recharge by 4 - 57%;
- increased reservoir inflow in a dry year by 5%.

As the value of the water benefits of the conservation measures outweigh the costs by a factor 10, it seems a realistic option to pay farmers for these services.
www.isric.org/UK/About+ISRIC/Projects/Current+Projects/Green+Water+Credits.htm

9.4.2 North Africa: Re-allocation of reservoir water from perennial to supplemental irrigation

After independence in 1956, the Moroccan government embarked on an ambitious development policy that centred on large-scale public irrigation systems.
The choice for perennial irrigation initially made sense: the more intensively the system is used, the higher the return on the investments made for the construction of the dams and infrastructure.
In terms of water productivity, however, perennial irrigation does not necessarily represent the optimal choice. This becomes apparent by considering the opportunity cost of the water that is released from a storage reservoir to irrigate one hectare during summer, in terms of the higher crop value that could have been obtained by using that water for irrigating a larger area in winter. The water productivity in winter is higher because of lower evapotranspiration. It can be improved even further by making effective use of direct rainfall. This however, requires flexible irrigation delivery schedules that enable each farmer to adjust timing and volume irrigation applications according to actual rainfall. Increasing productive use of water, therefore, calls for a shift away from large-scale perennial irrigation systems to supplementary irrigation. Research by ICARDA shows that the marginal water productivity of supplementary irrigation is between 2-3 kg/m^3 while that of full irrigation is around 1 kg/m^3 (Oweis et al., 1999).This indicates that in a situation of water scarcity, shifting from perennial irrigation to supplementary irrigation is more effective in increasing water productivity than efforts aimed at increasing irrigation efficiency in perennial systems.

Just like an exclusive focus on RoI in planning irrigation development has led planners to ignore supplementary irrigation, an exclusive focus on WP leads planners to ignore rainfed agriculture as a major user of water resources. The current situation in Morocco demonstrates the usefulness of the RoR criterion: Areas with rainfed agriculture that have low RoR can be detected; remedial action consists of two options: either provide supplementary irrigation to bring RoR to an acceptable level or take the field out of production and use the land exclusively for harvesting rainfall. The rainfall harvest can be diverted to a reservoir and used for irrigation of a nearby plot or it can be allowed to infiltrate and thereby recharge the groundwater.

9.5 Implications for water policy: the way forward

1. Make most of direct rainfall; enhance infiltration by protecting soil from direct impact of the raindrops. Aim at achieving full and dense crop cover; this also reduces (unproductive) soil evaporation.

2. Make use of potential for local storage of surplus rainfall; for overcoming dry spells during growing season.

3. If after implementation of measures under 1 and 2, there is still need for additional water to overcome dry spells during the growing season, consider supplemental irrigation from an external source.

4. If necessary, shift water allocations from perennial irrigation to supplemental irrigation.

5. Consider perennial irrigation only when there is surplus supply available after having met demand for supplemental irrigation.

6. In both supplemental and perennial irrigation systems, consider the use of a differentiated tariff for irrigation water, the tariff depending on the degree of certainty of water delivery. Service levels, including certainty of delivery need to be specified in a service agreement between system users and managers.

7. The income obtained from the higher tariffs may be used to subsidize development and operation of supplemental irrigation schemes.

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Adaption and implementation

10 Integrated policies are a must to face future water scarcity in Egypt

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Abstract

'Egypt is a gift of the Nile', wrote Herodotus, and indeed, without the Nile there would be no Egypt as the world knows it. Rainfall is negligible and Egypt completely depends on its annual share of Nile water, 55.5 BCM (Billion m^3) annually, that originates from the upstream headwaters of the Nile in the humid Ethiopian and East African highlands.

Its sustainable water resources are the agreed fixed share of the River Nile discharge and the rainfall on the northern coast of 1.3 BCM annually. There is limited possibility to augment Egypt's water supply.

The growth of the Egyptian population and its economy in the near future will lead to an increase in the demand for water, and water is the key for stability and prosperity in Egypt.

Future water allocation will have to be done with keeping all water using sectors in mind. The overall priority sequence is: first drinking water, then industry, and whatever is remaining will be available for agriculture and nature. The increasing demand for the limited water resources puts pressure on the government to formulate policies and programmes to adjust water allocation among various water users, with the agricultural sector using more than 80 percent of available water. The main option available in the short term to reduce water scarcity in the priority sectors of the economy is to allocate less to the agriculture sector.

However, the issue of water scarcity has consequences and implications that can no longer be adequately addressed by any one of the Ministries alone. Many other government departments and agencies must be involved and decisions will have to be made at the highest political level.

All policies in Egypt must be conscious of the severe limitations in water availability, and water policies need to address technological developments as well as the full range of other issues, including: macro-economic factors, economic issues that influence farm-level decisions, development of human capital, governance, and financial risk management. The government will be well equipped to deal with future uncertainties if it prepares a 'scarcity outlook' that addresses the situation in 2050, and implements a 'Water Scarcity Action Plan' that will incorporate the insights that reform decisions are inherently political, that non-water policies are central to water management and that improved accountability of government agencies and water service providers to the public is essential.

10.1 Egypt, a gift of the Nile

'Egypt is a gift of the Nile', wrote Herodotus, and indeed, without the Nile there would be no Egypt as the world knows it. Rainfall is negligible and Egypt almost completely depends on its annual share of Nile water, 55.5 BCM (Billion m^3) annually, that originates from the upstream headwaters of the Nile in the humid Ethiopian and East African highlands.

The growth of the Egyptian population and its economy in the near future will lead to an increase in the demand for water, and water is the key for stability and prosperity in Egypt.

Egypt is mainly dependent on the flow in the Nile River, with an agreed share of 55.5 BCM. The Nile basin area is 3 million km^2, the area of swamps is 0.07 Mkm^2, the Nile River length is 6700 km and the river has 10 riparian States, with over 250 M inhabitants. Total rainfall in the Basin amounts to 1661 BCM, with a few percents as Egypt's share of the Nile flow (55.5 BCM).

Rainfall, mainly along the north coast, amounts to 1.3 BCM annually on average. Other water resources include e.g. re-use of drainage water; rainwater harvesting (e.g. flash floods in the Sinai); groundwater (planned to increase in future) and desalination (planned to increase in future, but mainly in remote areas and for drinking).

This implies that its sustainable water resources are the agreed fixed share of the River Nile discharge and the rainfall on the northern coast of 1.3 BCM annually. There is limited possibility to augment Egypt's water supply.

Egypt's water resources are managed by the Ministry of Water Resources and Irrigation (MWRI), with a mandate that includes to:
– Develop Egypt's water resources
– Manage the water resources efficiently and effectively
– Manage water quality

The amount of water available in Egypt is determined mainly by the volume of water flowing through the Nile. Increasing the supply of water is an option of course, but a very limited one.

10.2 Egyptian-Dutch Advisory Panel on Water Management/ APP

The Netherlands has a long-term (1976-date) bi-lateral water cooperation, that developed from technical cooperation into a think-tank on institutional and policy issues (see Chapter 15 on the Panel as a unique science-policy interface).

The Panel work on water scarcity in Egypt was carried out over the years by various Working Groups and consultancies of which the results were reported and discussed in several Workshops and Panel Meetings. An overview of all activities in this regard:
– 2004: Workshop Agricultural Water Demand Management
– 2005: National Water Resources Plan
– 2007: Consultancy study on required sectoral measures
– 2007: Workshop Facing Future Water Scarcity
– 2008: Consultancy on Climate Change Impact
– 2008: Consultancy on Drought management
– 2008: Consultancy Facing Future Water Scarcity
– 2008: Policy Note Facing Future Water Scarcity
– 2009: Consultancy on Water Awareness

This paper is intended to reflect the main message resulting from that APP work and some of the challenges will be dealt with in the next sections.

10.3 Population and water availability

In Pharaonic times, Egypt was prosperous and there were about 2-3 million inhabitants. In 1950, the population was 22 million and in 2006 there were 75 million inhabitants. For 2050, numbers as 120-150 million are estimated, depending on various possible trends. This implies that the per capita availability of water is reducing continuously as shown in Figure 10.1.

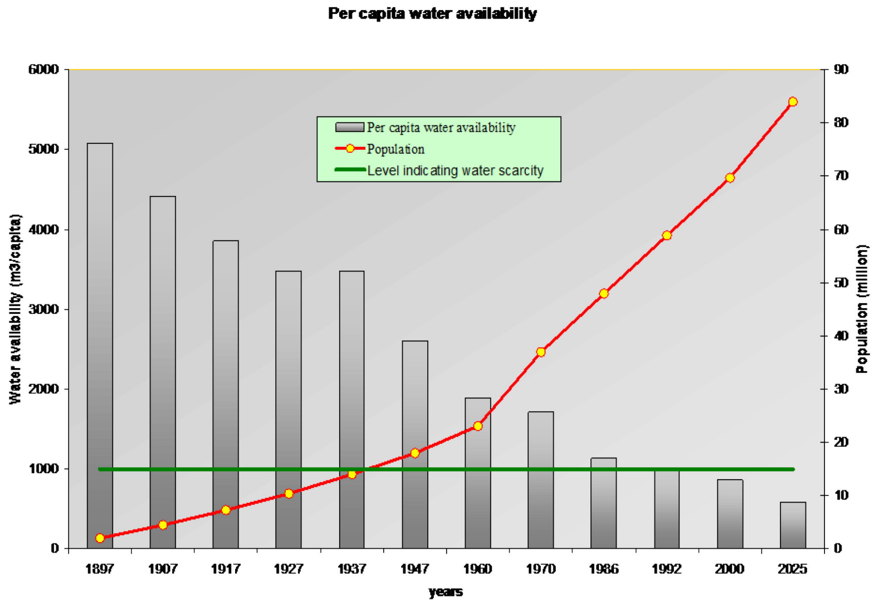

Figure 10.1
Population growth and water availability.

It is generally mentioned that a country faces *water scarcity* if the availability of water drops below 1000 m^3/capita/year. Egypt passed that threshold already two decades ago. Nevertheless, the measures outlined in the National Water Resources Plan (NWRP, 2005) will enable Egypt to cope with the current challenges (i.e. the NWRP period of 1997-2017) when implemented as planned. However, even if all the measures contained in that National Water Resources Plan are implemented, Egypt will have to cope with severe water scarcity in the future (Van Beek and Hansen, 2007).

10.4 Agriculture, water use, and food security

Because Egypt's water availability is almost fixed, any increase in water demand in one sector will have to be met by a decrease in water demand by another sector. As the priority for water allocation is basically: first drinking water, then industry and then agriculture, the main trade-off is between, on the one hand, the demand for drinking and industrial water, and on the other hand the agricultural water demand. This implies that the largest water user, being agriculture with a current share of about 80-85%, will have to do with considerably less water in the future!

As agriculture will be confronted with a drastic reduction in the availability of water, important changes need to be implemented. Changes in the agricultural structure and revised cropping patterns are among the keys to implement successful solutions.

In Egypt, as well as in many other arid and semi-arid countries in and outside the MENA region, this is an urgent need to work towards an increase in water productivity, leading to 'more crop per drop', 'more cash per splash', etc. There is an urgent need for innovation in the field of water and agriculture (Roest and Wolters, 2010), and the Government role in the process could be to reward the front runners for their entrepreneurship by sharing the risks or subsidizing initial investments if required, and to provide access to Universities and Research Institutes to solve urgent research questions.

As far as food security is concerned, Egypt is not self-sufficient (see Figure 10.2) in all its major food items (ICID, 2005), and the food gap for some main crops is expected to increase widely within the next two decades.

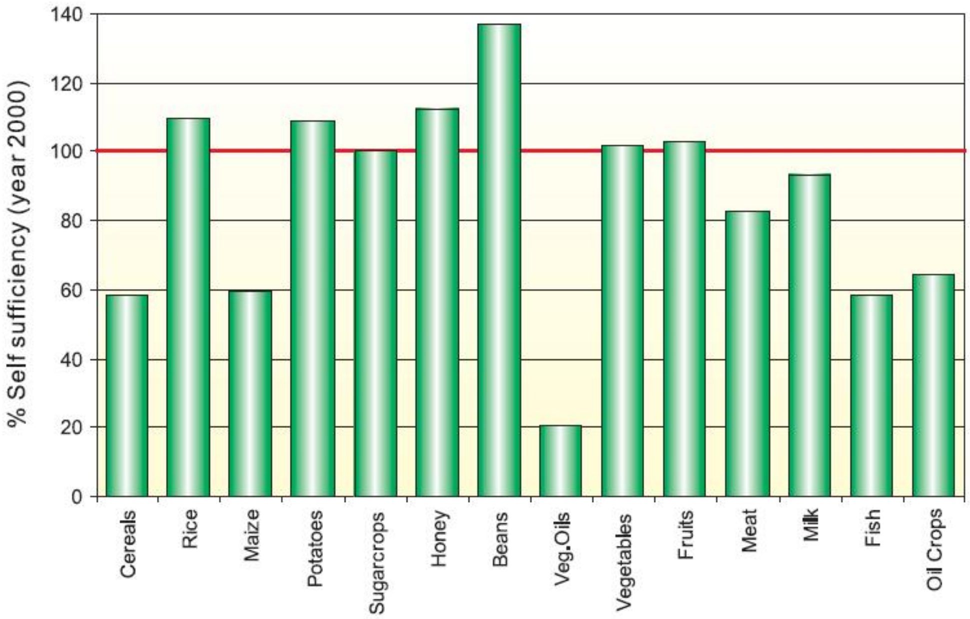

Figure 10.2
Percentage self-sufficiency for major crops.

As far as land use and expansion is concerned, most of Egypt's land is desert, 95% of the people live on about 5.5% of the land. Moreover, Egypt faces urbanisation, with the estimate that about 30.000-60.000 feddan (acre) of highly fertile land is lost annually. However, if enough fresh water resources are available, part of this desert could be reclaimed

An increasing proportion of the national demand will have to be met through the use of 'virtual water' (i.e. water imported in the form of e.g. imported food and fodder) and innovation in terms of increasing water productivity.

10.5 Climate change impacts

Egypt's climate change impacts are (Ludwig and Vellinga, 2008) include, in summary:
- Increased risk of floods and droughts
- Sea level rise
- Higher evapo-transpiration due to higher temperature
- Higher water temperature
  - impact on coral reefs (tourism)?
  - More algae blooms?

IPCC scenario's predict a rise in temperature next century. In general, the extremes get more extreme: drier areas get drier and wetter areas get wetter. This may be beneficial for Egypt, because 85% of the Nile flow is generated in the high-rainfall areas of the Ethiopian highlands. This implies that, as rainfall may increase, Nile flow may increase. Moreover, the APP study on climate change impacts (Ludwig and Vellinga, 2008) has made clear that the Nile Basin is sensitive to climate change:
- 10% rainfall reduction -> 30% less stream flow!
- 10% rainfall increase -> 30% more stream flow!

As the extremes get more extreme, also the dry and wet extremes of the natural Nile system, i.e. the seven 'fat' years and the seven 'lean' years, need to be studied in more detail and future planning should include increased risk of floods and droughts. As well, the management of Lake Nasser water level has to take this into account.

10.6 Growth of economy

The growth of the Egyptian population and its economy is expected to lead to an increase in the demand for water. Improvements in the standard of living will lead to changes in consumption patterns. The policy challenge therefore is to find new ways to ensure that this scarcity does not constrain future economic development and adversely affect the welfare of the population.

Key parameters of the economic policy of Egypt in 2003/ 2004:
- Ensure price stability in the short run
- Liberalise the economy, minimise government intervention
- Streamline regulation and simplify procedures
- Improve managerial efficiency through PPP's

Adoption of this policy should lead to improvements in economy and it has done so (Van Beek and Hansen, 2007). By 2050 some 55 - 70 million new labour force entrants must have found profitable employment. Egypt therefore needs to identify and develop economic sectors in which it can produce more internationally competitive goods and services for export. This means that to attract both domestic and foreign investment and to create the jobs needed for the growing workforce, the macroeconomic, legal, institutional and social conditions must be reformed, and these reforms must be upheld. There are many uncertainties involved. Tough decisions will have to be taken, and opponents will contest some of the substantive arguments on which these decisions are based.
Targets can only be realized through an approach that involves the business community, NGOs and citizens groups in finding win-win situations. It is crucial that all stakeholders develop a high degree of awareness of the issue.

10.7 Regional perspective

Egypt is part of the MENA region and obviously shares various characteristics with other countries in this region. In 2007, a major study concluded (World Bank, 2007) that the region can meet its water management challenge, but that coping with scarcity and high variability in a context of rising populations and changing economies, will involve some difficult choices and painful changes. By seeing water reform in the context of the political economy and working with the multi-sectoral nature of water management, the required reforms can be tackled. By introducing changes even at the local level that improve accountability to the public, reforms can bear fruit and generate improved economic, human welfare, environmental, and budgetary outcomes.

Across the MENA region, governments are implementing innovative policies and institutional changes that are already showing promising results, although these efforts have not yet led to the expected improvements in water outcomes (World Bank, 2007), with two primary reasons accounting for the lack of results:
- First, the changes have been partial: most countries have not yet tackled some of the most important reforms, because they have proved politically untouchable. The reasons vary with the context in each country, but, in most cases, politically important groups have opposed changes.
- Second: some of the most important factors that affect water outcomes are outside irrigation, water resource management, and water supply and sanitation. Policies that deal with agriculture, trade, energy, real estate, finance, and social protection, and that affect overall economic diversification may have more impact on water management than many policies championed and implemented by water-related ministries.

The path toward a situation in which water management is financially, socially, and environmentally sustainable involves three factors often overlooked in water planning processes (World Bank, 2007):
- Recognizing that reform decisions are inherently political rather than trying to separate the technical from the political processes.
- Understanding the centrality of non-water policies to water and involving non-water decision makers in water policy reform.
- Improving accountability of government agencies and water service providers to the public, because transparency is essential for the public to know why decisions are made, what outcomes can be expected, and what is actually achieved. Good accountability requires inclusiveness, i.e. a wide set of stakeholders should be involved in decision making.

10.8 Integration of all factors

Addressing water supply and demand challenges without full recognition of outside trends (population, urbanisation, economy, etc.) is unlikely to be successful. Water cannot be used efficiently and effectively without dealing with economic reforms outside the water sector (agricultural prices and subsidies; energy prices; public finance, trade and land market reforms).

A caution is that food security is important; reforms need to be socially acceptable, etc.

Of course Egypt is already taking many measures to prepare for the future and is heavily investing in improvement of e.g. integrated irrigation improvement, agricultural improvement, drinking water and sanitation, etc.

The water scarcity issue presents new challenges to the Government of Egypt as a whole. Success will depend entirely on the ability to remain focused on the implications of water scarcity and to come up with innovative and integrated national policies:

- Demographic developments are the crucial factor. It is important to reduce population growth and improve the country's human capital base.
- Loss of high-value fertile agricultural land to new urban and infrastructure development should be prevented.
- Predictable and stable conditions for both domestic and foreign investment in internationally competitive businesses are of crucial value for the country's ability to finance the necessary food and fodder imports in the years to come.
- As the agriculture sector will be affected in many ways, it is important to enable farmers to cope with the changes as well as creating appropriate social support mechanisms to provide for the exodus of agricultural workers.
- A gradual reduction of all subsidies in the agricultural, energy and drinking water sectors that lead to wasteful use of water is inevitable to avoid costly fiscal burdens and constraints on the public budget.

All these challenges require full public awareness and widespread support as well as the political will to take decisions and implement them.

Water is not the only issue. Water security cannot be separated from food security; nor can water policy be pursued independently of economic policy, agricultural policy, industrial policy, public services policy, etc.

10.9 Conclusion

The key message arising from the work on water scarcity, looking forward to 2050, is the need for policy integration. The issue of water scarcity has dimensions that can no longer be adequately addressed by any single Ministry alone. Many other government departments and agencies must be actively involved. Vital decisions will have to be made at the highest political level. This requires a robust and flexible system for decision making, as well as the ability to respond to demands from all sectors from a water scarcity perspective.

10.10 Recommendations

The key message emerging from many years of work on future water scarcity in Egypt is the need for integration of policies. Actions recommended on basis of the work done:

- Increase the availability of fresh water resources through more cooperation with the Nile countries and maximize the use of other resources (e.g. rainfall harvesting, flash flood, sea water desalination, etc.).
- Develop an Integrated land and water use plan for all Egypt.
- Implement the prepared 'Water Awareness Action Plan', to raise the public awareness and thus generate the support and political will needed to implement the tough measures required to change people's behaviour.
- Research is required, linked to the large investment programmes under implementation currently, and it should answer the many questions:
  - how to distribute water (shortage) more effectively
  - how to increase water productivity
  - how to deal with wet and dry extremes
  - how to safeguard water quality
  - etc.

– Learn from other Delta's and countries with similar issues.
– Prepare and maintain a 'Water Scarcity Action Plan 2050', that will incorporate the insights that reform decisions are inherently political, that non-water policies are central to water management and that improved accountability of government agencies and water service providers to the public is essential.

10.11 Today's context

The Panel worked on these overall policy issues for a number of years. It is understood that much in Egyptian society and government will change in the near future. Reform is the order of the day. At the same time there is a real need for stability and predictability. Reform may be the flipside of stability, and instability can only be avoided if there are demonstrable benefits to reform, or the need for change can be demonstrated (Kalden, 2006). The desired mix of reform and stability is a delicate one, and information and communication are of paramount importance.

10.12 Acknowledgement

This paper is the result of many years of APP activities, including work of Panel members as well as consultancies and Workshops, taking into account available information and lessons on the issue of water scarcity. It draws on the work of many.

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11 Integration of land and water use in the Nile Basin

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Abstract

Water resources of the Nile basin have a long history of dispute, but sharing them could unleash the basin's great hydropower and agriculture potential. The benefits of sharing water and land resources to increase basin-wide food and hydropower production were evaluated with a state of the art bio-economic model, WaterWise. The model showed that food self-sufficiency can only be reached for the basin as a whole, if countries cooperate. In Uganda and (South) Sudan there is still ample space for the expansion of rainfed agriculture. In Ethiopia, a large part of the irrigated agriculture and hydropower potential can be developed without harm to Egypt's irrigated agriculture downstream. Climate proofing of land use and infrastructure investments showed that the largest investments, mainly in hydropower, are robust under the used climate scenarios.

11.1 Introduction

The Nile, the longest river in the world, flows through ten African countries. It is vital to the agriculture and economies of Sudan and Egypt. The other Nile states largely watch the water pass by. In the past, water resources have been adequate to meet existing and emerging demands from the various economic sectors of the Nile Basin countries. However, population pressure, the use of marginal lands in upstream countries and the expansion of irrigated areas along the river have gradually increased tensions between the Nile countries. There is an increased pressure on the water resources through storage and diversion of surface water in order to serve the increasing energy and agricultural demands. Plans for reservoir development for hydro-electricity and irrigation upstream are the source of much recent debate. A critical aspect is the generation of hydro-electricity in Ethiopia. Whereas most of the water is used in agriculture, generating electricity, especially up river, doesn't use much water. Evaporation losses in Ethiopia's mountains will be much less that the ten percent losses of the valuable Nile water in the High Aswan Dam.

Figure 11.1
The Nile, countries and major tributaries.

Currently, each Nile country is planning and expecting different benefits from the control and management of the Nile water resources. The present dialogue between the riparian countries focuses on water allocation, which is a source of debate and litigation rather than a forum for cooperation. The control of river flows has long been a source of tension and dispute and an issue of sovereignty, strategic necessity, and territorial integrity. Such tensions in the Nile basin are obstacles to growth, constrain the regional political economy and prevent the sustainable use of resources.

In the future, two main pressures will greatly impact the management of the Nile Basin water resources: i.) an increased demand for food and water due to a growing population and ii.) a large uncertainty in supply (of water and food) due to climate change. The demand for food in the Nile basin will increase in the coming decades due to demographics and changing living standards (Hilhorst et al., 2009; Strzepek et al., 2001). Based on growth rates of between 2 and 3% the total population in all the basin countries will increase from 350 in 2004 to 570 million in 2025. The impact of climate change on the Nile basin is still very uncertain and predictions vary widely, from 0 to 50% increase in precipitation over the Equatorial Lakes region and from -15% to +15% over the Ethiopian Plateau (OECD, 2004). Temperatures are expected to rise, with water demands increasing accordingly.

A large potential for conflicts over water use is therefore evident, which is why achieving an integrated regional development of water resources on a sustainable basis is a critical condition for the socio-economic development of the Nile countries. To date, efforts to promote a water agreement between all Nile Basin countries have failed to materialize due to several factors. One is the lack of a clear basin-wide water resources development strategy. Hilhorst et al. (2008) argue that the hydro-political dialogue in the Nile Basin is a zero-sum game that needs to be widened to include other potential cooperation activities between the Nile countries. The most important opportunity that they identified through extensive stakeholder consultations was the promotion of agricultural trade and cooperation on food production between the Nile basin countries.

In this chapter we focus on the impact on land use and water allocations of this broader approach on basin-wide agricultural cooperation. To assess its effect, a Nile prototype of the existing bio-economic model WaterWise (Van Walsum, 2009, Siderius et al., 2011) was developed. WaterWise optimizes the land and water use based on the cost-benefits of each land use, hydropower and water management option. WaterWise is specifically designed to define sectoral and spatial trade-offs in land and water management at the basin scale.

11.2 Exploring options for trade-offs in land use and water allocation

11.2.1 Bio-economic models of the Nile basin

To facilitate investigations into a system as complex as the Nile Basin, models can be used to show the impact of climate change, the effect of measures or to simply get a better insight in critical components of the water balance. As the Nile is one of the most studied basins in the World, several hydrological models exist describing the hydrology of the Nile. There are also a number of optimization models linking hydrology to economy. Two well known optimization models are the 'Investment Model for Planning Ethiopian Nile Development' model (IMPEND; Block et al., 2007), which weighs the trade off value of hydropower and water for irrigation in the Blue Nile basin, and the 'Nile Economic Optimization Model (NEOM; Whittington et al.', 2005), which does the same for the whole Nile basin. These models make use of four hydro-economic principles:
i) use water for irrigation upstream to reduce evapotranspiration;
ii) use water for irrigation downstream to take full advantage of hydropower;
iii) store water upstream to reduce evaporation losses and;
iv) use water where its value is the most profound.

Of these four principles i and iii are specific for the Nile basins due to the geographic setting of upstream lowlands, with lower temperatures and lower evapotranspirative demand, and the desert in Sudan and Egypt downstream, with higher temperatures and higher evapotranspirative demand. Principles ii and iv are more fundamental and universally relevant and applicable. Whittington et al. (2005) showed that cooperation between the different Nile countries for an optimum use of water will give a far greater economic value than the current status quo with fixed allocations will.

In recent years WaterWise (Van Walsum, 2008; www.waterwijs.nl) has been developed. WaterWise closely resembles the NEOM model in several aspects. It also describes the whole Nile basin. All the existing irrigation schemes and hydropower reservoirs are included, as are most of the proposed plans. The economic parameters are similar. However, the NEOM and IMPEND models primarily addresses the allocation side, with irrigated area as the only land use related water consumer. Water input into the system, the runoff and drainage, is fixed, based on prior calculations. WaterWise adds to this concept the supply side, by modeling the land use as an endogenous variable within the whole catchment (i.e. not only the irrigated areas), thus covering the complete hydrological cycle. WaterWise incorporates processes in the Soil-Vegetation-Atmosphere column at pixel scale and then calculates the resultant stream flow which is dependent on the choice of land use. Land use and land use changes are thereby integrated in the approach. This broadens the optimization from a river oriented to a more comprehensive land and water oriented approach. As the Comprehensive Assessment on water management in Agriculture (Molden et al., 2007) and others (Snellen, 2006) state, thinking differently about water is essential for ensuring food security, reducing poverty, and conserving ecosystems. They argue that instead of a narrow focus on rivers and groundwater, rain should be viewed as the ultimate source of water that can be managed. WaterWise does exactly this and integrates water management with land use planning.

11.2.2 The WaterWise Nile application

The Nile Basin application of Waterwise has been constructed around a simplified hydrological model. A total of 120 sub-basins of the Nile have been delineated. At a more detailed level there are 1371 so-called hydrotopes, which in turn are comprised of 3 million 1 km^2 pixels. The 1371 hydrotopes are formed by overlaying sub-catchments, soils and land use. The general agricultural land use types of the FAO classification (FAO Land Use Systems of the World map for Sub-Saharan Africa; www.fao.org/geonetwork) were further specified using country information on the main cropping patterns. All the major rivers are included, as well as the main lakes and reservoirs (Figure 11.2). The schematization includes an aggregation to the level of the ten riparian countries.

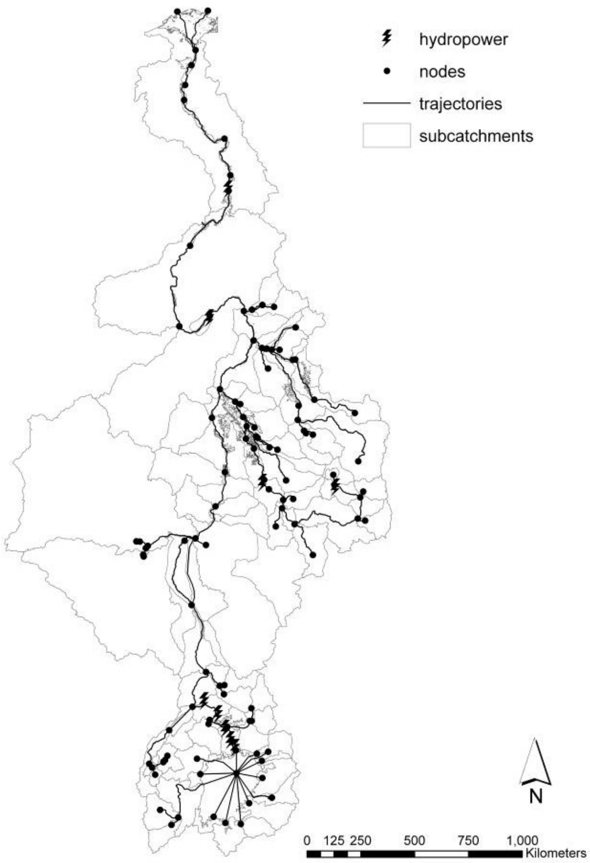

Figure 11.2
Surface water system and subcatchments of the Nile Basin with, in detail, the hydrotopes and pixels.

In WaterWise most of the spatial and hydrological options as listed in Table 11.1 can be implemented. These water and land use options, like land conversions or irrigation, are activated based on investment costs and returns on investment, if not limited by water-related constraints. For example, only the main irrigation regions can demand water from the Nile itself. All other land uses can demand water only from groundwater and local surface water. But an irrigation option will only be activated if enough water is available in the local surface water system and if the increase in crop yields will outweigh the water management costs connected to this option. For a more detailed description see Van Walsum (2008) or Siderius et al. (2011).

WaterWise optimizes land use and water allocation to achieve the highest economic returns for the whole basin without prejudice between countries or sectors. In addition, several extra constraints can be imposed to test the impact of more abstract concepts like cooperation or climate robustness. Three such questions were asked;

- Question 1: What would happen if food production (as part of the Millennium Development Goals, to reduce hunger and poverty) gets higher priority than industry (in this case hydropower)?
- Question 2: To what extent could cooperation between the Nile basin countries help in meeting food requirements for the individual countries and the basin as a whole?
- Question 3: What will be the impact of climate change, an uncertain but potentially decisive factor?

With the WaterWise Nile model we focus on the midterm future. Food self-sufficiency targets per country for the year 2030 were based on the population estimate for 2030 multiplied by the advised, conservative estimation of average calorie intake of 2300 kcal/person per day. In the case of Egypt and Uganda, with current consumption levels higher than the 2300 kcal/person per day, this consumption level was maintained. On the supply side, new high yielding crop varieties combined with best practices in water, soil and pest management can still increase yields in the coming decades, even though output of African agriculture has not increased much in recent decades. To include these agricultural improvements in the model, rainfed and irrigated production in all countries was given the freedom to reach the cost and yield levels of the countries with the current highest production levels (Rwanda for rainfed and Egypt for irrigated agriculture).

11.2.3 Results

Question 1: What is the impact of a priority for food production?

The results of shifting priorities in investments to food production (Questions 1) are shown in Figure 11.3. Clearly, in the agriculture scenario, Ethiopia is most affected as it loses revenues from the hydropower dams, which are not built because of the lower priority. Uganda and Tanzania profit most from the shift in investments to food production. In Sudan the loss of hydropwer revenues is partly compensated by an increase in land use revenues (see also Figure 11.4).

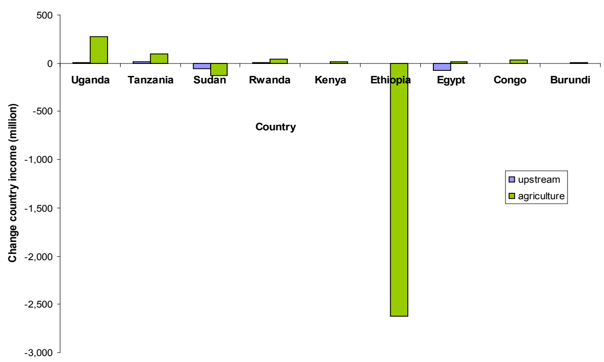

Figure 11.3
Change in country income for the upstream and agriculture priority scenarios.

Figure 11.4 shows the spatial changes in land use yield, when giving priority to agriculture. As can be seen, in a large part of the basin there is no drastic change in land use. This is not surprising, as the present land use has developed within the biophysical possibilities, which have not changed. A large part of the basin receives a very low amount of rainfall and has such a high evaporative demand that conversion to agriculture is unlikely. There is a large increase in land use revenues in (South) Sudan, where agriculture is currently inderdeveloped. In the Equatorial Lakes region in the south, a shift to more intensive agricultural land use types leads to increased revenues. In Rwanda, with a production system dominated by beans and bananas, agricultural land-use also expands at the expense of herbaceous and pastoralist land-use, according to the model. Large-scale irrigation in Egypt is maintained at the same level, which is not surprising given its high productivity and, thus, (relative) high income. Only in Ethiopia do land use revenues drop in some areas. The postponement of hydropower reservoir development, due to the priority to agricultural investments, leads not only to a reduction in hydropower revenues but also to a lower water availability for Ethiopias large-scale irrigated agriculture.

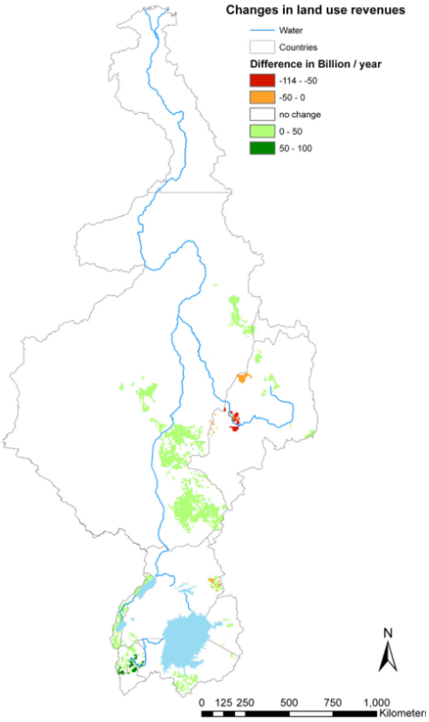

Figure 11.4
Changes in land use revenues between the standard and the 20 billion USD investment scenario.

Question 2: What is the impact of cooperation on food production?

To answer question 2 we explored the benefits of cooperation between countries and the implications of reaching food sufficiency. In the explored scenarios either the basin as a whole or each country individually strives for food self-sufficiency. When each country individually strives for food self-sufficiency and this target is reached, it is assumed that producing more food becomes less profitable due to a combination of the economic concepts of overproduction and transaction costs. Once supply exceeds demand, prices will drop and once products have to be transported to other markets, transaction costs will increase. When countries cooperate in becoming food self-sufficient, it is assumed that these transport and transaction costs will be minimal due to improved trade infrastructure. By optimizing for the basin as a whole in the cooperation scenario, food will be produced at those locations and in those countries where an investment results in the largest increase in revenue. One country can thereby offset the food shortages in another.

The model shows that only if the Nile Basin countries cooperate, the total land use revenues match the food target in the highest investment run (100 billion USD). Ethiopia, Kenya, Sudan and Uganda contribute most to the increase in revenues and compensate for the countries where the individual food requirement target is not reached due to lack of options (e.g. Egypt) or because of a lower return on investment (e.g. Burundi). When each country individually has to reach its own food target i.e. become food self sufficient, three countries are not able to reach their target: Egypt, Eritrea and Rwanda. Egypt cannot produce enough food within its existing irrigated area. In Eritrea climatic conditions are unfavorable for agriculture without large scale irrigation; this is not an option for Eritrea in the current WaterWise model. In Rwanda, even conversion of the total area suitable for agriculture in the basin into arable land is not sufficient, due to the high population pressure. As a result, without basin wide cooperation, food production targets can only partly be reached and also total basin revenues lag behind. More detailed results are described in Siderius et al. (2011).

Question 3: How sensitive are measures to climate change?

To test the sensitivity of the various water management, hydropower and land use measures (Question 3) a wet and a dry climate scenario were compared, based on the minimum and maximum estimates in the climate predictions. As expected, revenues are lower in the dry climate scenario and higher in the wet climate scenario. In the wet scenario reaching the food-self sufficiency for the basin as a whole is relatively easy. In a dry scenario, however, reaching this target becomes difficult even with large scale investments (see also Siderius et al., 2011).

When zooming in at country level, interesting differences can be found (Figure 11.4). In the dry scenario Kenya and Tanzania attract more investments at the expense of especially Ethiopia. In the wet scenario Kenya and Tanzania also show large increases in land use and total revenues together with the other countries in the lake Victoria region as a result of the increase in rainfall with 50%. Uganda's hydropower potential, affected by the higher temperatures and evapotranspiration under dryer conditions scenario, increases in the wet scenario. Interestingly, Ethiopia hardly benefits from wetter conditions. Under average climate circumstances all hydropower and irrigated agriculture potential (as based on current investment plans) is already developed and Ethiopia does not profit from additional runoff from the Blue Nile region. It is mainly Sudan that profits from additional runoff by higher hydropower revenues. Egypt is hardly affected by a dry or a wet scenario. It loses some revenues under dryer conditions and hardly gains under wet conditions. Eritrea is the only country which loses out in both scenarios. Under dryer conditions higher temperatures increase evapotranspiration and negatively effect land use revenues. Under wetter conditions the benefits of a 15% higher precipitation are offset by the higher evapotranspiration and the competition from more strongly improved circumstances in other countries.

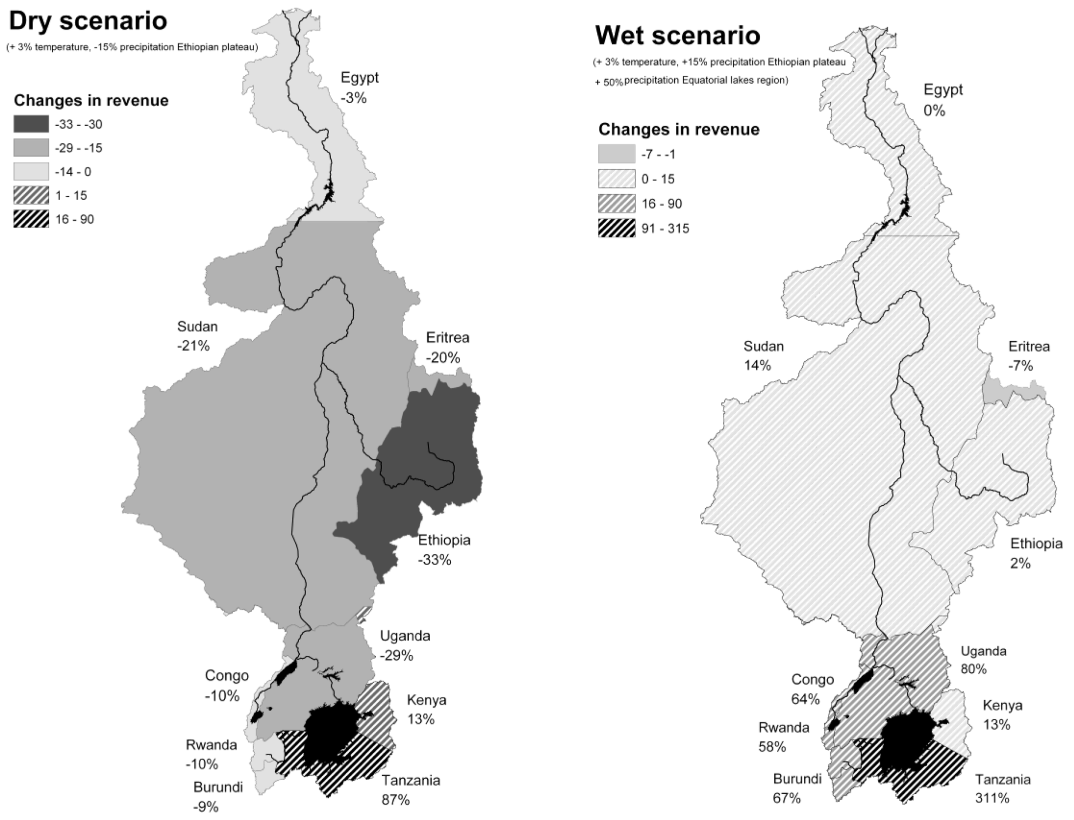

Figure 11.5
Relative change (%) against the current climate in total revenue per country for the dry and wet climate scenario.

11.3 To be WaterWise.....

With the WaterWise tool for the Nile we intended to help broaden the current discourse on water allocation by exploring the consequences of prioritizing investments, the effect of cooperation and the possible impact of climate change. The discussion in the Nile basin should not only focus on water, but also on food security, climate change and energy. This relates strongly to the FAO-NBI vision approach of Hillhorst et al. (2009) and recent scientific literature on, for example, the value of cooperation as described by Whittington et al. (2005).

A controlling factor in all scenarios is the high agriculture production in downstream Egypt. Agricultural development more upstream, at the expence of Egypts production, might require less water due to the lower evapotranspirative demand, but is not more profitable. In addition, extra hydropower results in a constant flow of water towards Egypt. The dominance of Egypts profitability, however, could change in the future with upstream countries improving their agriculture. Different investments lead to different priorities within the basin. Hydropower needs high investments but also brings instant revenues. The model shows that for certain countries, mainly Uganda and South Sudan there is still space for expansion of agricultural lands. Watershed improvement is effective only on a very small scale and in combination with intensification of agriculture, given the current model set-up. A preference for agricultural investments reduces total basin income. Especially the cancelling of large (and costly) hydropower development in Ehtiopia has a large impact on the income of this country and that of the basin as a whole. Finally, the scenarios show that reaching food self-sufficiency is only possible for the basin as a whole, but not for each country individual.

11.4 Acknowledgement

This research was carried out within the framework of the EU-funded FP7 NEWATER project on "Adaptive water management under uncertainty'. Co-financing was provided by the 'Knowledge Base' programs of the Dutch Ministry of Agriculture, Nature and Food quality. The authors would like to thank the technical committee of the Nile Basin Initiative (NBI) for their support and useful comments. Parts of the prototype WaterWise model are being used for the development of an agro-economic model which will be integrated with the newly constructed hydrological tool of the NBI.

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12 Regional assessment of water harvesting potential

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Abstract

The African agricultural sector predominantly consists of rain-fed farming systems. These farming systems are very vulnerable to the natural variability of rainfall and the climate change. Their productivity is low. The Comprehensive Assessment of Water Management in Agriculture (2007), however, indicates that the greatest potential increases in yields are in these rain-fed areas. Rain-fed farming systems should thus become more resilient and more productive. As water is generally the most critical natural resource and the limiting factor for the increase of productivity adaptation strategies for rain-fed farming systems should principally target water management measures that are aimed at managing the rainfall variability. Managed use of rainwater can be achieved through seasonal water harvesting and storage, and the use of this water as supplementary irrigation in periods of water shortage.

Water harvesting programmes for agriculture require a regional approach and careful planning, including the consultation of beneficiaries and stakeholders, and the assessment of critical biophysical and non-biophysical conditions incorporating indigenous knowledge.

This paper presents a methodology to assess the potential of various water harvesting systems. in a GIS environment. A water harvesting assessment model, incorporating a multi-objective multi-criteria evaluation of the biophysical conditions, is used for rapid assessments of different water harvesting systems for large spatial units. Thereafter detailed location-specific assessments can be executed for the siting and design of systems.

The methodology has been applied in the Central Rift Valley of Ethiopia to assess the potential of macro- (ex-situ) and micro- (in-situ) catchment water harvesting systems. The water harvesting assessment model shows that the potential for water harvesting is still largely unexploited in this area.

It is expected that the application of the water harvesting assessment model in other regions in Africa will also reveal that there is still a large potential for water harvesting in agriculture. The exploration of this potential can contribute to more productive and more resilient rain-fed farming systems in Africa.

12.1 Challenges rain-fed agriculture

12.1.1 Agriculture and climate change in Africa

Agriculture is the mainstay of many African countries, which directly or indirectly supports the majority of its population in terms of employment and livelihood. Agriculture is critical for the food security of hundreds of millions of people and also the most important economic (revenue-earning) sector, contributing to almost half of Africa's export value (information from the Word Bank).

The agricultural sector in Africa is largely made up by smallholders, who heavily depend on rain-fed agriculture. The amount of rainfall and the duration of the rainy season are, however, very variable and low crop yields, associated low incomes and food shortages are frequently experienced.

Regional projections of climate models predict a further increase in rainfall variability. Although that the expected impacts of climate change vary from region to region a common expectation is that rainfall distribution becomes more erratic (both spatial and temporal). Dry spells and droughts will occur more frequently, both from year to year and within the growing seasons.

Being heavily dependent of rainfall farmers in Africa are very vulnerable to the natural variability and change of the climate. Their ability to cope with an increasingly erratic climate is low, as they have limited access to knowledge, technology and capital.

12.1.2 Need for increased productivity

In addition to the natural variability and change of the climate the agricultural sector in Africa faces many other challenges. The production of cereals has stagnated and the continent has become a net importer of food. Food shortages frequently occur and Africa's commercial agriculture experiences increasing competition on the world market. At the same time the population growth and socio-economical developments also demand higher outputs of agriculture in Africa.

To boost the agricultural production irrigation projects can be developed, however the greatest potential increases in yields are in rain-fed areas (Comprehensive Assessment of Water Management in Agriculture, 2007). Rain-fed farming systems should thus become more resilient and more productive.

12.1.3 Adaptation strategies rain-fed agriculture

For rain-fed farming systems water is generally the most critical natural resource and the limiting factor for the increase of productivity. Farmers are hesitant to invest in other agricultural inputs (such as fertilizers) if the risk of failure due to water shortages is great. In the case of unreliable rainfall farmers will tend to opt for low-productive, low-investment and low-risk crops and farming systems. If it were possible to cope with the rainfall variability farmers are expected to invest in more productive farming systems.

Adaptation strategies for rain-fed farming systems should, therefore, principally target water management measures that are aimed at managing the rainfall variability by retaining the water. Managed use of rainwater can be achieved through seasonal water harvesting and storage, and the use of this water as supplementary irrigation in periods of water shortage. Especially if integrated with soil and nutrient conservation techniques water harvesting and supplementary irrigation can largely boost rain-fed agricultural production systems in Africa.

12.2 Water harvesting

12.2.1 Introduction

Rainwater harvesting or water harvesting[3] is the collection of rainwater from roofs, ground surfaces or ephemeral watercourses and its storage in physical structures or within the soil profile. The harvested water can be used for domestic uses, livestock and irrigation (Photo 12.1).

Photo 12.1
Community pond water harvesting near Lake Ziway.

Water harvesting is an ancient tradition, already being practiced for millennia in most of the world's drylands. It regained new interest in the past decade, as it is considered as among the important interventions necessary towards meeting the Millennium Development Goals for the African continent and an important adaptation measure to cope with the impacts of the global climate change.

Water harvesting techniques for agriculture can be subdivided in macro-catchment (ex-situ) systems, which collect runoff flows diverted from surfaces such as roads, hillsides and pastures, and micro-catchment (in-situ) systems, where the runoff is collected on-site to augment the soil moisture contents.

Water harvesting is, however, not a panacea for the African agriculture and various water harvesting programmes have failed. The successful application of water harvesting requires careful planning, considering both biophysical and non-biophysical conditions.

[3] In this compendium the expression 'water harvesting' is used, which is regarded as a more correct term than 'rainwater harvesting', as it (more explicitly) includes the surface run-off.

12.2.2 Planning of water harvesting

The suitability of a specific water harvesting technique at a specific location depends on the purpose of the water harvesting (whether for domestic water use, livestock watering or agricultural production), biophysical conditions as well as non-biophysical conditions such as the number, composition and density of beneficiaries, land tenure, legal and financial systems, literacy, technical skills, managerial capacity of operators and beneficiaries, traditions and attitudes, etc. As these conditions are highly location-specific, appropriate technologies that are developed for a particular region cannot simply be replicated to other regions.

The planning of water harvesting incorporates various phases (Figure 12.1):

1. Setting the objective(s) of water harvesting
2. Consultation beneficiaries and stakeholders
3. Identification / pre-selection of water harvesting options
4. Regional assessments (biophysical conditions)
5. Detailed local assessments

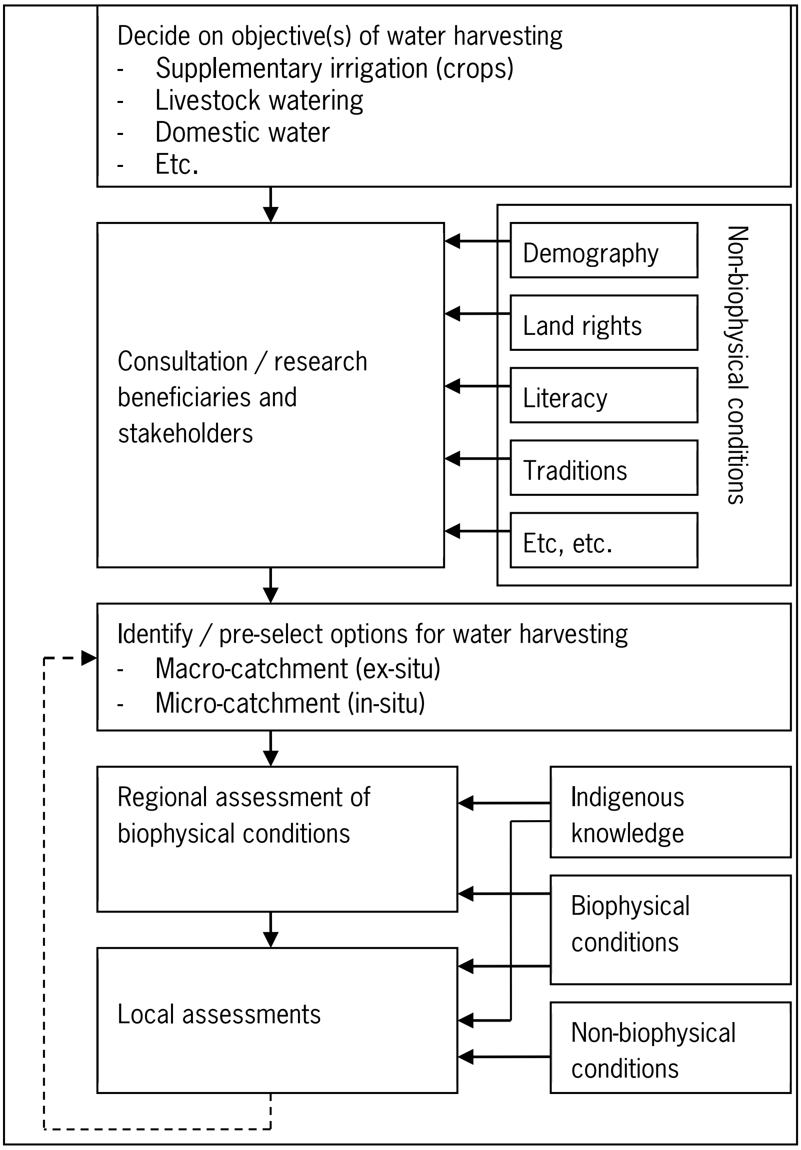

Figure 12.1
Planning process water harvesting.

As this paper aims at the enhancement of rain-fed farming systems only water harvesting techniques that serve agriculture (supplementary irrigation and livestock watering) will be considered. From the wide variety of water harvesting techniques that have been documented in international journals and books only a limited number of options can be assessed in a project. The most promising water harvesting options can be identified when the beneficiary group is consulted and portrayed in terms of socio-economical and socio-cultural setting (i.e. the non-biophysical conditions), as their support and commitment are critical.

12.2.3 Regional and local suitability assessment

It is practical to split the suitability assessment into a regional and local assessment. At the regional level only the biophysical conditions are assessed. The local assessments should consider both the local biophysical and non-biophysical conditions. This approach has some principal advantages:

- An assessment of non-biophysical conditions at regional level is relatively laborious, whereas the regional biophysical conditions can usually be assessed rapidly.
- It is generally more difficult to identify feasible indicators for non-biophysical conditions (they should be quantifiable and not subject to arbitrariness).
- Biophysical conditions are more determining than non-biophysical factors: non-biophysical conditions can sometimes be manipulated through interventions (e.g. educational campaigns, land reforms, micro-finance facilities, etc.).

The regional assessment results in a regional water harvesting potential map with respect to the biophysical conditions. Thereafter detailed local assessments can be executed for the suitable (target) locations. Based on the local assessments the water harvesting systems can be sited and designed. In the case of unsatisfactory results alternative water harvesting options may be identified, for which the regional and local assessments are then repeated.

12.2.4 Methodology regional assessments water harvesting potential

The biophysical factors that determine the potential of water harvesting may vary from region to region. These critical biophysical factors are determined from the literature and indigenous knowledge (Figure 12.1). The latter is crucial to avoid that critical location-specific biophysical suitability factors are omitted. Experiences show that farmers and local experts have substantial knowledge on water harvesting systems, especially on biophysical factors (Mbilinyi et al., 2005, Jansen et al., submitted). Generally the climate characteristics, soil characteristics and land uses are important suitability factors for water harvesting.

The water harvesting potential is calculated through a Multi-Criteria Evaluation (MCE), which is the weighted linear combination of the (standardized) values of the (i) critical biophysical suitability factors at that location:

$$P = \sum w_i x_i$$

where P = water harvesting potential
w_i = weight factor of suitability factor i
x_i = value of suitability factor i

The regional assessment of the water harvesting potential, therefore, incorporates:

1. Identification of (biophysical) suitability factors.
2. Standardizing (normalization) of suitability factors.
3. Establishment of weights factors (relative importance) of suitability factors.

4. Collection and processing of spatial data of suitability factors.
5. Construction of a (GIS) water harvesting assessment model, which incorporates the MCE.

Suitability factors have different values and units. As the application of a MCE requires comparable values and units, the values and units of the individual suitability factors are converted to standardized suitability categories. These suitability categories are: 5 (very high suitability), 4 (high suitability), 3 (medium suitability), 2 (low suitability), and 1 (very low suitability).

The suitability factors are not equally important, which implies that weight factors have to be assigned. Critical suitability factors will have a greater weight factor that less critical factors. Weight factors can also be determined using literature and indigenous knowledge. There are various methodologies to quantify weight factors, of which the Analytical Hierarchy Process (Saaty, 1977) distinguishes as a practical, easy-to-apply and transparent method.

Spatial data on the suitability factors are either available from (GIS) maps or generated by an interpolation procedure on point measurements (for example rainfall stations). To allow for the overlaying of maps vector maps are converted to raster datasets and resampled to the proper raster size.

The water harvesting potential is calculated with a GIS-based model, which has been constructed with the ModelBuilder of ARCGIS. The water harvesting assessment model can combine spatial information of all suitability factors, the processing of this information (e.g. the calculation of slopes from the terrain model, clipping, interpolation, resampling, reprojecting), normalization of the suitability factors, conduct a multi-criteria evaluation and present thematic suitability maps. The model structure is presented in Figure 12.2.

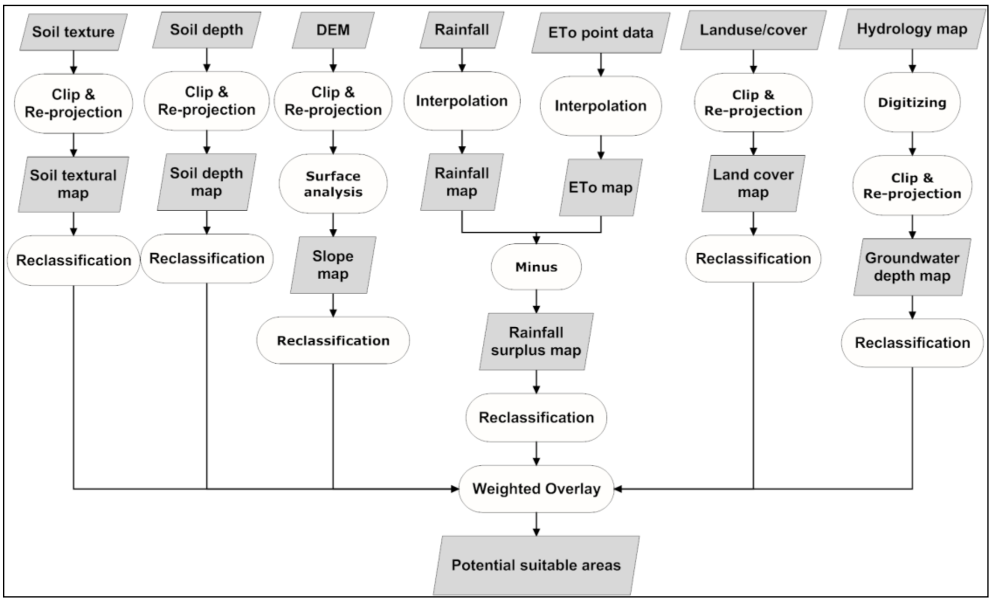

Figure 12.2
Water harvesting assessment model (from Jansen et al., submitted).

12.3 Example of water harvesting potential assessment

12.3.1 Water harvesting in the Central Rift Valley, Ethiopia

The water harvesting assessment model has been applied in the Central Rift Valley (CRV) in Ethiopia. The CRV is located at 150 km southeast of Ethiopia's capital Addis Ababa. The area predominantly consists of small rain-fed farming systems and is a typical showcase of a rural area that is very vulnerable to climate variability, climate change and other pressures.

Both the potential of a macro-catchment and micro-catchment water harvesting technique are investigated. The macro-catchment water harvesting refers to individual and communal ponds (an example is presented in Figure 12.3). The micro-catchment water harvesting refers to storage in the soil profile without special treatment (such as tillage).

Figure 12.3
Examples of macro-catchment water harvesting.

During field surveys 30 randomly selected households were interviewed, using a semi-structured questionnaire. In addition there have been informal group discussions with farmers, visual inspections of existing water harvesting structures and discussions with planners and experts. This information (indigenous knowledge) is integrated with information from the literature, resulting in the following suitability factors and weight factors (Table 12.1).

Table 12.1
Weight factors.

Suitability factor	Weight factor (%)	
	Macro-catchment	Micro-catchment
Rainfall surplus	20	18
Topography/slope	7	8
Land cover	5	5
Soil texture	43	43
Soil depth	14	26
Groundwater depth	11	Not applicable
Sum	100	100

The weight factors are determined through the Analytical Hierarchy Process (Saaty, 1977) applied on the suitability factors. The soil texture and the rainfall surplus turn out to be very determining suitability factors for both water harvesting systems. The soil depth is particularly important for micro-catchment water harvesting.The water harvesting assessment model has generated two water harvesting potential maps (Figure 12.4).

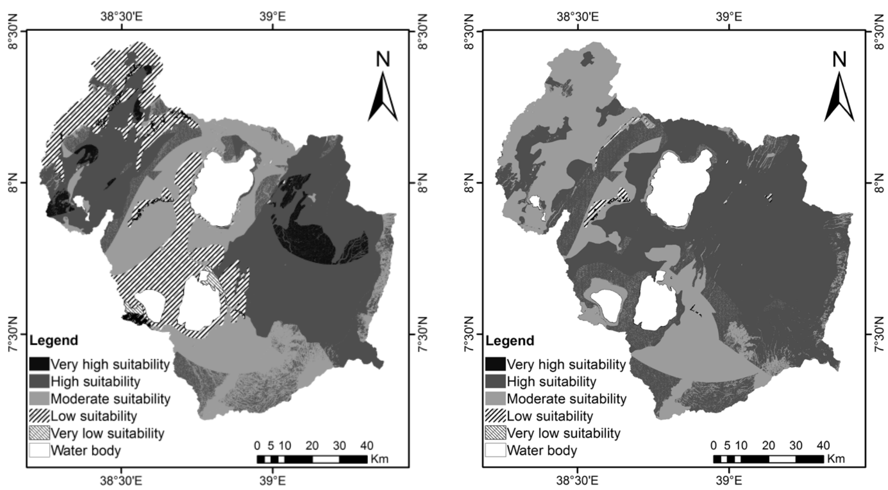

Figure 12.4
Macro-catchment (l) and micro-catchment (r)water harvesting potential (from Jansen et al., submitted).

The maps show that from a biophysical perspective almost half of the area is suitable for macro-catchment water harvesting (high or very high suitability), whereas 60% of the area is suitable for micro-catchment (in-situ) water harvesting. These results indicate that the potential for water harvesting is still largely unexploited in the CRV.

12.3.2 Accuracy of results

During the valuation of the relative importance (weight factors) of suitability factors errors and/or inaccuracies may occur. Potential errors can be investigated through an arbitrariness test, in which consistency in the application of the Analytical Hierarchy Process is assessed. For this purpose consistency ratios are calculated (see for details Saaty, 1977). The calculations for the Central Rift Valley in Ethiopia show that the weight factors are calculated in a consistent way (Jansen et al., submitted).

The impact of possible inaccuracies in the weight factors can be investigated through a sensitivity analysis, in which the results of the water harvesting assessment model are compared using various weight factors. The sensitivity analysis consists of increasing and decreasing the weight factors of each suitability factor by percentages that represent the expected accuracy, whilst proportionally increasing, respectively decreasing, the weight factors of the other suitability factors, and calculating the water harvesting potential again.

It is easy to conduct an comprehensive sensitivity analysis, as the process of generating and processing thematic maps, standardizing (normalization), the MCE and the generation of the water harvesting potential maps is fully automated in the water harvesting assessment model.

The sensitivity analysis for the Central Rift Valley in Ethiopia showed that the rainfall surplus is the most sensitive suitability factor. The soil texture is the least sensitive factor for macro-catchment water harvesting, whereas the topography is the least sensitive factor for micro-catchment (in-situ) water harvesting. The sensitivity analysis thus helps to identify the most critical suitability factors, so that the right priorities can be set in the collection of information.
In the case that (some) water harvesting systems have already been implemented in an area field checks on the state of these systems will provide valuable additional information on the reliability of the water harvesting potential assessments.

12.4 Conclusions

Water harvesting programmes for agriculture require a regional approach and careful planning, incorporating the assessment of biophysical and non-biophysical factors. It is practical to use a GIS-based water harvesting assessment model, incorporating a multi-objective multi-criteria evaluation of biophysical suitability factors, for the regional assessments of different water harvesting systems, followed by detailed location-specific assessments to site and design systems.

The methodology has been applied in the Central Rift Valley of Ethiopia, indicating that the potential for water harvesting is still largely unexploited in this area. It is expected that the application of the water harvesting assessment model in other regions in Africa will also reveal that there is still a large potential to apply water harvesting in agriculture. The exploration of this potential can contribute to more productive and more resilient rain-fed farming systems in Africa.

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13 Risk Reduction of Soil Contaminated by Obsolete Pesticides in Africa

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Abstract

The FAO Africa Stockpiles Programme (ASP, 2011) is designed to rid Africa of stockpiles of obsolete pesticides. Pesticides have been shipped to Africa for locust control but did not arrive on the proper place or proper moment thereby becoming obsolete. Also storage depots with pesticides for normal agricultural practices are contaminated

High concentrations of pesticides can be found in soils on the stockpiles and in depots. Removal of these concentrations using northern technologies (e.g. incineration, bioreactor) or removal and transport of high amounts of contaminated soil was not found to be feasible. From a risk-based point of view, contaminations are only a risk if they are or may become available in the environment. This widens the range of options and therefore can facilitate more tailor-made solutions for individual sites.

Three sites in Mali and three sites in Mauritania have been investigated in 2007, using a risk based approach. Most important risks identified were a) inhalation, b) transport to groundwater, c) physical contact by human and cattle d) run-off by rain (Mali) and e) wind erosion (Mauritania). Based on the results obtained, risk reduction proposals have been made and discussed locally. All proposals are based on the use of local conditions to stimulate biodegradation and/or to prevent rain water to transport the pesticides both vertical as horizontal. Implementation of these simple and cheap methods has been started in 2008. Result were presented and discussed in an international workshop in Bamako in 2010 and the approach is extended to other African countries, starting with Botswana in 2010.

13.1 Introduction

A large number of sites in Africa are contaminated by pesticides that were spilled during the course of desert locust control operations, spilled during storage and also during normal agricultural practice (pesticide depots). The risk at each site differs according to a variety of factors, and in certain cases remedial action will be needed in order to protect both human health and the environment.

The Africa Stockpiles Programme (ASP), launched in September 2005, is designed to rid Africa of stockpiles of obsolete pesticides and to ensure that new stockpiles do not accumulate. A key objective of ASP is to ensure that stockpiles are disposed of in an environmentally sound manner.

The experience within ASP has shown that regular methods to assess the risks of contaminated soils (FAO, 2000) are often too theoretical, difficult to complete at African conditions, necessary laboratory facilities are lacking and this all results in a wait and see attitude (Figure 13.1). This wait and see attitude becomes even stronger if the assessment procedure is followed by recommendations based on too expensive or not realizable northern technology. Suitable technologies for disposal operations were evaluated in the first part of the project in the Disposal Technology Options study managed by World Wildlife Fund (Dyke, 2008). Because of logistic reasons, on-site treatment of waste and removal of the pesticides from contaminated soil was found to be a difficult task. Solutions have been found for repacking, removal and off-site treatment of the pesticides residues, but difficulties are still encountered in treatment of high amounts of soil contaminated by leaking vessels. Physically transport of cleaning equipment and applying this equipment and transport of high amounts of contaminated soils was found to be not feasible. The result is that no real actions to reduce risks are taken, nothing will happen till a new assessment will be started in future; an infinite circle (Figure 13.1)

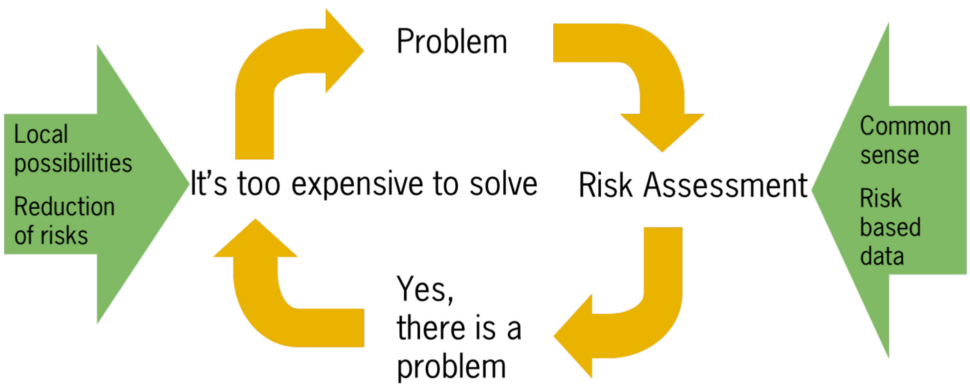

Figure 13.1
The assessment circle.

This paper presents another entry in order to break the assessment circle; assessment is not the primary goal, because for most suspect depots and sites a visit and expert judgment is already enough to conclude that there is a potential risk for human health and environment. There is a strong need for immediate action and measures to reduce the risks of the pesticides. Common sense and risk based data are important inputs to decide that measures are necessary. To solve the problems it is important to use local possibilities and concentrate on the reduction of risks instead of removal of the pesticides. This African approach has been tested starting in 2007 and has led already to first implementation on risk reduction in 2008 (Harmsen, 2009).

The work carried out and described in this paper provides an assessment of the current nature and extent of the contamination, the risk posed to health and environment and gives potential local solutions that may be applied to eliminate or substantially reduce the risks. High concentrations of pesticides can be found in soils where pesticides have been stockpiled. Regulations are mostly focused on these concentrations, but from a risk-based point of view, contaminations are only a risk if they are or may come available. A risk-based approach can be more useful than a concentration standards-based approach. This widens the range of options and therefore can facilitate more tailor-made solutions for individual sites that address the problem and are more viable. In a risk based approach stimulation of biodegradation of the pesticides and/or immobilization and isolation of the contaminant may play a role.

A site-specific assessment is necessary to provide a sensible solution. Some clean up approaches are also highly sensitive to the site and the conditions so there is no simple prescription to fix all problems. The following steps are necessary:

1. Investigation of the site, including historical use, the spread in the soil system, possibilities of transport, hydrology, climatologically conditions, etc.
2. Defining of the site specific risks.
3. Gathering of missing information; based on all the information a remediation plan can be made to reduce risks, which has to be locally discussed.
4. Possibilities for site specific and sustainable remediation by risk reduction. After reaching agreement on the measures to be taken, realizing the local possibilities the last step follows.
5. Implementation of the risk reduction measures.

13.2 Field investigations

Establishing of potential risks

It has already been established in earlier investigations that the visited sites were heavily contaminated. Therefore, the investigations in this project were not focused on the extent of the contamination, but on the possibilities of transport in the environment of the pesticides and establishing by specific sampling and analysis if this transport really did occur. In the approach used within the African Stockpile Program, reduction of risks for people living in the surroundings of a contaminated site is considered as a primary goal to achieve. Risks are associated with the possibilities of transport of contaminants to target organisms. In the project we concentrate on humans as primary target organisms and cattle as secondary. Cattle are important because they are of economic interest and supply food (meat and milk) for the local population. Contact with pesticides is possible by (see Figure 13.2):

– Direct, physical contact on the site
– Inhalation of volatilized/airborne pesticides
– Contact with pesticides that are transported from the site by 1) run-off in water facilitated by rain and 2) Transport of pesticides adsorbed to soil by wind erosion
– Consumption of groundwater, polluted by the pesticides as a result of leaching
– Consumption of forage/crops cultivated in the site that take up contaminants.

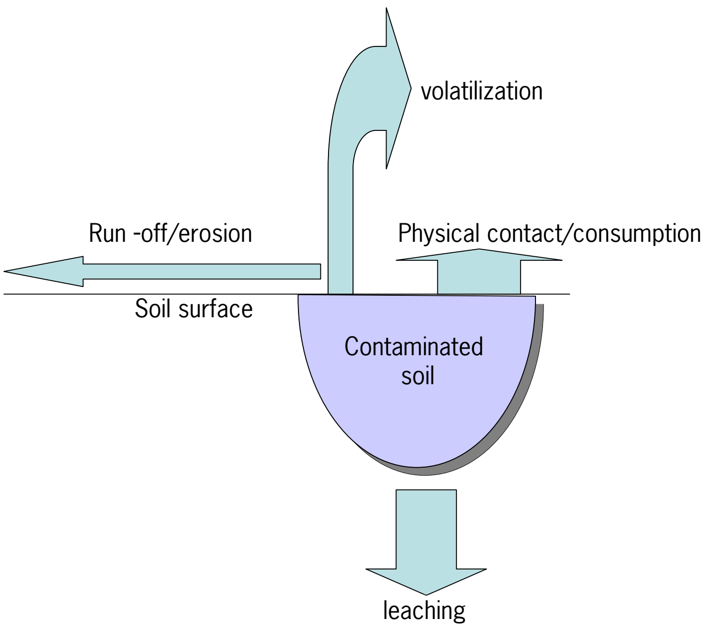

Figure 13.2
Risks to be considered on a contaminated site.

13.3 Field activities

The research has started with the investigation of three sites in Mali (Molodo, Sévaré and Niogoméra) and three sites in Mauretania (Nouakchott, Kiffa and Letfatar) according the first four steps in the summer of 2007.

In August 2010, the working area of the project was extended to Botswana. Contaminated sites in Gaborone and Kasane were investigated also with the intention to find a local solution and to reduce the risks of the sites.

13.4 Results of field observations

There were very large differences between sites: small airports, an irrigated agricultural area, urban areas, and sites at the boarder of the desert. All sites needed a specific approach.

The following general conclusions could be drawn from the site visits:
- On all locations vegetated and biological active zones were present, in which biodegradation could occur.
- The amount of precipitation is limited, from 20-200 mm/year in Nouakchott (Mauretania) to 250-600 mm/year in Molodo (Mali). Most rainfall falls in the period June-September. The mean annual rainfall for Botswana is 400 mm/year, ranging from 250 mm/year in the southwest to a maximum of 650 mm/year in the extreme north (Pallett, 1997). The evaporation is higher and if it is possible to use vegetation, all precipitation can be evaporated, thereby preventing leaching to the groundwater system.
- In Mali, transport of contaminants by surface run-off caused by heavy rains may occur.
- In Mauretania polluted soils can be transported by wind.
- In Mauretania formation of sand dunes can be used to cover the pollution and prevent. Vegetation can be used for stabilization of these dunes and to evaporate the small amount of rain.
- In Botswana all rain infiltrates in the soil

– Groundwater in Gaborone (Botswana) is very deep, In Kasane shallow, and this shallow water table makes phytoremediation of the groundwater possible.

As an example the site of Molodo (Mali), which is situated in the Inner Delta of the Niger in an agricultural area, is discussed. There was an old storage for pesticides and a large soil contamination was present at the corner of the storage. The yearly rain fall is between 250 and 600 mm. Most important identified risks were surface run-off by rain and leaching to the groundwater. The clay present acts as an isolation to the groundwater. This layer was very compact and dry, also on a depth were groundwater could be expected (depths of surrounding wells. This was confirmed by the experience of the local population. By digging a well it was necessary to pass this clay layer.

Figure 13.3
Soil sampling in Molodo.

So two gradients were distinguished, one in the direction of the groundwater (depth) and a horizontal one following the run-off water. Soil samples have been taken by augering (Figure 13.3). The samples have been analyzed on different pesticides on the laboratory of the Central Veterinary Institute in Bamako. Further a concrete construction was present in which old vessels were dumped. In the center of the pollution, pesticides could be observed also on higher depths. The biodegradable parathion ethyl and the non biodegradable dieldrin were the most important pesticides present. In the area influenced by run off, only the surface soil was slightly contaminated with dieldrin, showing that transport by run-off has occurred. Parathion ethyl was only present in high concentration in the hot spot, but not on distance from the hotspot. Parathion is biodegradable and could be degraded in the vegetated and biological active surface soil.

13.5 Implementation of risk reduction

For remediation, the following general strategy has been followed.

1. If possible, removal of the contamination in the source and more diffuse contaminated soil by biological treatment using landfarming[4]. Landfarming is a simple and cheap technology, applicable all over the world.
2. Isolation of the contaminant, by evaporation of the precipitation using vegetation
3. Isolation of the contamination by using natural covers (e.g. sand dunes in Mauretania).
4. Planting of trees to remediate the groundwater (Botswana).
5. Increasing adsorption capacity of soil by adding local available black carbon (Charcoal). Organic contaminants are strongly adsorbed by black carbon (Koelmans et al., 2006).
6. In parallel activities in Mali and Mauretania, a management system has been made to prevent future contamination. Such a system is lacking in Botswana and should be developed to prevent that cleaned sites will become contaminated again.

For the in this paper discussed site in Molodo (Mali) this general approach has been worked out as follows: A proposal has been made to reduce the risks of the pesticides on this location, which measures were discussed in a meeting in May 2008 of the whole project team in Bamako. The results of this meeting were worked out in detail (SYLLA, 2008) and the first implementation was started in July 2008 in Molodo.

The soil in Molodo is mainly contaminated with dieldrin and parathion ethyl, which are respectively non-degradable and degradable. The surface soil besides the contaminated center is biological active and can be used as the start of a landfarm.

As part of the activities in Molodo the vessels from the three concrete constructions were removed and these constructions were large enough as final destination of the landfarmed soil. A final safe destination is necessary, because dieldrin is not degradable. To prevent leaching from the concrete constructions, the adsorption capacity of the soil on the bottom has to be increased by adding grinded charcoal (Figure 13.4). For logistical reasons, it was necessary to start with the excavation of the hot-spot. One of the concrete constructions has been used for temporary storage. Care was taken not to break the clay layer to prevent direct contact with the groundwater. For refilling of the hole, bioactive surface soil has been used. Doing this, biological activity was introduced at the contact layer of the residual hot-spot soil and the soil used for refilling. It is expected that this activity will slowly decrease the residual concentration. After filling the soil has been enriched with local available compost and vegetated.

[4] Landfarming is a remediation technology were biodegradation of contaminants is stimulated. It is applicable in situations where the surface soil are contaminated. In this surface the proper conditions for biodegradation are stimulated by activities like cultivation, adding of compost or manure and also stimulation of vegetation (Harmsen 2004; Harmsen et al., 2007). Doing this biological activity is stimulated which will result in biodegradation of the pesticides.


A


B

Figure 13.4
A) Adding of char coal to increase the adsorption capacity for Dieldrin in Molodo (2008).
B) Vetiveria and Jatropha growing on the old hot spot in Molodo, to prevent infiltration of water (2010).

A small landfarm has been constructed, just besides the center. This landfarm has been enriched with compost for further biological activation. A first charge of the contaminated soil has been spread on the landfarm. It was expected that parathion ethyl, in soil from the hot spot mixed with the surface soil, will be degraded and this was confirmed by the measurements. The parathion-ethyl concentration in the landfarm, calculated from a five fold replicate, decreased in the period July- November 2008 from 1.5 ± 1.0 to 0.011 ± 0.006 g/kg d.m. while the dieldrin concentration remained unchanged 0.74 ± 0.26 to 1.0 ± 1.0 g kg d.m. In the following step part of the soil will be transported to the final destination in the concrete construction and replaced by a new charge. After the last charge, all the soil in the landfarm will be transferred to the concrete construction and replaced by clean soil. The concrete construction will be covered with clean soil and permanent vegetation will be planted.

In the final situation the origin of the pollution (hot spot), the area used for landfarming and the final destination have to be vegetated using deep-rooting vegetation that can survive under local dry conditions and are not eaten by cattle (Boumediana, 2001). *Vetiveria* (Mafei, 2002) and *Jatropha* have been selected. The vegetation increases the evapotranspiration, thereby preventing rain water to reach the groundwater (Figure 13.4). In 2010 *Vetiveria* was the best growing vegetation. The growth of the vegetation will be followed in coming years.

13.6 Knowledge transfer

The implementation in Molodo was followed by implementation on the other two sites in Mali and the site of Letfatar in Mauretania. In Mali the experience was used by the African Stockpile program team of Mali (PASP) on other sites and risk reduction activities were started in. On a site in Dialakoroba (Figure 13.5B) landfarming has been applied.

An important result of the project was that results were shared with other African countries during an International Workshop in Bamako in the period 20-24 February, 2010 (Figure 13.5A). Results from Mali and Mauretania were presented and it was discussed how the experiences could be used in the rest of Africa (PASP, 2010).

A

B

Figure 13.5
A, The Mali-team active in Dialakoroba.
B, Regional workshop on risk reduction of pesticide-contaminated soils, 21-24 February, 2010, Bamako, Mali.

13.7 Conclusions

A lot of sites in Africa are polluted with obsolete pesticides, sent to Africa for locust control. In pilots in Mali, Mauretania and Botswana remediation strategies are developed that reduce risks and can be used under difficult African conditions. The remediation strategies are based on application of bioremediation using landfarming and isolation of the center of contamination. Implementation of this African approach on risk reduction has been started in 2008 and is successful.

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Knowledge transfer

14 Innovating agricultural water management through science and technology

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14.1 Introduction

To feed the growing world population food production has to be doubled in the coming 25 years. The majority of this increase will have to come from investments in existing agricultural lands as there is not much scope for horizontal expansion. However, the growth rates of yields of the major crops in most countries in Africa are currently declining. To reduce poverty in rural areas the productivity, profitability and sustainability of (small-scale) agriculture should increase substantially. Research plays an essential role in achieving these ambtious goals. Good quality applied research, e.g. on specific topics in agricultural water management such as irrigation and drainage, is generally cost-effective, as the costs of the research is only a fraction of the investment costs. The value for money in research is widely acknowledged in the Western World. For instance, in the Netherlands various research organizations have been privatized and became self-supporting. In Australia returns on investments in research are closely monitored and prove to be very positive. Contrarily to the western world, research in the emerging and least developed countries is less incorporated in development and investment programmes. Continuous support is often lacking, which disregards the general appreciation of research results by international donors, see for example (World Bank, 2004). In this paper examples of impacts and 'value for money' of applied research on irrigation and drainage in some North African countries are presented (Kuper et al., 2009; Ritzema et al., 2007). The analysis is based on more than 40 years of partnerships in applied research between Alterra and research institutions in Northern Africa. It shows that benefits resulting from research can largely outweigh the costs, especially if research is linked to implementation. The results of these programmes have largely contributed to the modernization of agricultural water management practices and increased productivity. Considerable savings have been achieved by introducing new methods for surveys and investigations, planning, design, installation (including new materials and equipment), operation and maintenance (Photo 14.1). Research has also contributed to institutional development. These positive results of applied research could only be achieved because the concerned governments also invest in human resources developed. The combination of applied research and and human resource developed proved to be very successfully as is show in the following examples.

Photo 14.1
In the 1970's, mechanized installation practices for subsurface drainage were introduced in Egypt. Note that in that period concrete pipes were used.

14.2 Assessment of irrigation and drainage needs

The traditional method to assess the salinity status of the soil is the sampling of the soil followed by an analysis in a laboratory. This is a labour-intensive and expensive method. To reduce costs and to increase the accuracy, a new method was tested in Egypt, using electromagnetic induction (the EM38). The research showed that the EM38 can be used in pre-drainage investigations, in monitoring the performance of drainage systems, and to assess mitigating measures when problems arise during O&M. The costs of using the EM38 are substantially lower than those of the traditional method. Furthermore, the salinity data are more accurate as the instrument measures larger soil volumes, resulting in more representative data. Moreover the measurement is direct and fast. Research also showed that it is not always necessary to install subsurface drainage systems to manage salinity problems induced by irrigation. Farmers can also adapt their practices. In Tunisia and Algeria, a new approach was developed to assess how farmers can deal with the dynamics of soil salinity and water quality in a traditional faming system in an oasis (Fatnassa, Tunisia) and in recently developed large irrigation schemes (Lower Chelif, Algeria). The salinity patterns in these two contrasted situations were analysed and linked to physical factors and farmers' practices. The new approach combines surveys on farmers' perceptions and practices with salinity measurements and geochemical analyses. This approach gives a better understanding of possible adaptation methods of individual farmers to cope with salinity problems. It can be used to improve assessment studies, which in the past used to neglect the dynamics of physical processes and often ignored the strong links between farmers' practices and physical processes.

The economic lifetime of subsurface drainage systems varies between 25 and 30 years. Research in Egypt helped to develop a methodology to assess when the operation and maintence costs become so high that it is better to rehabilitate or to replace a system. A three-step performance assessment methodology was developed that combines a number of indicators, i.e. the age of the system, number of complaints, depth of the water table and maintenance cost (Drainage Research Project, 2001). The next step in the assessment is only undertaken if the previous step has confirmed the necessity to rehabilitate considerable savings are obtained.

14.3 Planning and design

Irrigation and drainage systems are often based on technical and economic considerations without substantial involvement of the beneficiary farmers. In a study conducted in the Fatnassa oasis in southern Tunisia both farmers' perceptions and engineers' diagnosis were analysed to highlight the opportunities and risks associated with participatory and engineering approaches in a community-managed irrigation scheme. The study revealed that the farmers are reasonably aware of – and can adapt to – the constraints of their environment, as a result of their long-term practical experience. However, the farmers' perceptions also showed poor understanding of certain processes and that their individual strategies jeopardize efficient water management. On the other hand, engineering approaches favoured typical technical solutions while the farmers fovour more community management issues and more robust and locally suitable solutions. This result is in line with other studies that showed that linking the knowledge of the researchers/designers to the tacit knowledge of the stakeholders is a prerequisite for success.

The current strategies to save water and increase water productivity are generally focussing on improving irrigation performance, disregarding the drainage needs. In North Africa's semi-arid climate, agricultural production is adversely affected by waterlogging in winter (due to rainfall) in combination with low soil infiltration capacities. A field study in the Garb plain in Morocco revealed that irrigation furrows can play an important role in surface drainage: in less than twelve hours more than 20% of the excess water was removed by these furrows. As a result, higher yields of sugar beet were observed in levelled furrow-irrigated fields compared to unlevelled sprinkler-irrigated fields. This study clearly illustrates that efforts to improve irrigation and drainage at field level require an integrated approach. An integrated approach, however, includes more than the integration of irrigation and drainage. In many countries, farmers are exploring groundwater to cope with surface water scarcity. Even in large-scale irrigation schemes that are based on surface water groundwatermining is practiced. The conjunctive use of surface and groundwater was studied in two irrigation schemes in Tadla (Morocco) and Mitidja West (Algeria). The results showed that groundwater resources had decreased, that farming systems depend to an increasing extent on these groundwater resources, and that individual and collective access to groundwater depends on informal arrangements. To develop scenarios for agricultural development in relation to the use of groundwater, stakeholder platforms on water management were established. Currently, the consequences of the scenarios are assessed so that management rules can be formulated and implemented.

Rice is often cultivated in rotation with 'dry-foot' crops. The introduction of conventional free-flowing subsurface drainage systems serving a mixed pattern of crops has caused excessive drainage from the rice fields. To reduce water losses from rice fields without restricting drainage from other crop areas, a modified layout of the subsurface drainage system was developed in Egypt. A monitoring programme showed that farmers adjusted themselves very well to the system and managed to reduce irrigation water use with 43%, saving an equivalent value on pumping costs. In the Nile Delta, where an area of approximately 0.4 million ha is cultivated with rice, the potential annual saving would be in the order of € 10 million (Note, in this paper all prices are converted to 2006 prices: € 1.00 ≈ US$ 1.20). On top of these savings, the design discharge rate for collector drains (4 mm per day) could be reduced to 3 mm per day, equivalent to the design discharge for non-rice areas. As a result smaller diameters for the collector drains can be applied, which saves investment costs.

Most subsurface drainage systems in irrigated lands have free-flow outfall conditions. High water tables, being one of the principal design parameters, only occur for short periods, e.g. after extreme rainfall or irrigation events. This can result in (too) low water tables and high drain discharge in other periods. To investigate whether controlled drainage can avoid excessive drainage without increasing the soil salinity, the simulation model DRAINMOD-S was applied for the western Nile Delta, Egypt. The results showed that controlled drainage can maintain and even increase crop yields, while simultaneously the irrigation water use efficiency can be increased with 15 to 20%. Consequently, the downstream environmental imapcts are reduced as the total load of salts is reduced proportionally with the water savings. Controlled drainage also reduces the losses of nutrients and agrochemicals. These savings can be obtained with low-cost and easily operated devices.

In Egypt, various studies to verify drainage design criteria in pilot areas have shown that in general the design criteria are too conservative and can be reduced. It was found that the discharge rate that is required to cope with the prevailing losses of irrigation water and to maintain favourable soil salinity levels can be 10% lower than the design rate. As a consequence, the design discharge rates for collector drains can also be reduced. The same applies for the depth of the drains: research in pilot areas showed that a design depth of the water table of 0.80 m is sufficient. These research results support the view that it is not necessary to install deep drains for salinity control in irrigated lands.

In the 1960s and 1970s, at the start of the large-scale drainage implementation programmes, designs were made by hand. Gradually the design process became computerized. The computerization and software development has largely improved the quality of the entire planning and design process. The pace of implementation could increase and costs reduced, which was especially beneficial for large-scale projects. The introduction of simulation models in the 1980s greatly improved the knowledge of the underlying hydrological processes and functioning of subsurface drainage systems. Special design sofware was developed, as well as software to simulate water and salt movement under varying and complex field conditions. This software is used to improve operational mangement.

14.4 Implemetation

Numerous research activities were conducted to develop new drainage materials and installation methods (Ritzema et al., 2006). The savings are difficult to quantify in monetary terms but the impacts on pace and quality of construction were huge. For example, the introduction of flexible corrugated plastic drain pipes in Egypt increased the installation rate by about 20%, reducing installation cost with the same percentage (Photo 14.2). The introduction of these pipes also significantly reduced sedimentation, one of the main drawback of the formerly used clay and cement pipes. Laser equipment was introducted to improve grade control. In Egytp, field research trials showed that the introduction of trenchless drainage will reduce the installation cost per hectare by about 18%. In addition to the introduction of new materials and methods installation practices were also improved with the introduction of better methods for quality control, like rodding and video inspection. To introduce all these innovations in drainage equipment, materials, installation techniques and procedures, training and capacity building programmes were developed and implemented. For example, in Egypt a Drainage Training Center (DTC) in Tanta was established in 1991 Tanta (Photo 14.3). In this vocational training centre personnel of the Egyptian Public Authority for Drainage Projects, public and private contractors are trained. The added value of these research and capacity building programmes can be best illustrated by the fact that Egypt has nowadays one of the largest, most modern and effective subsurface drainage programmes in the world.

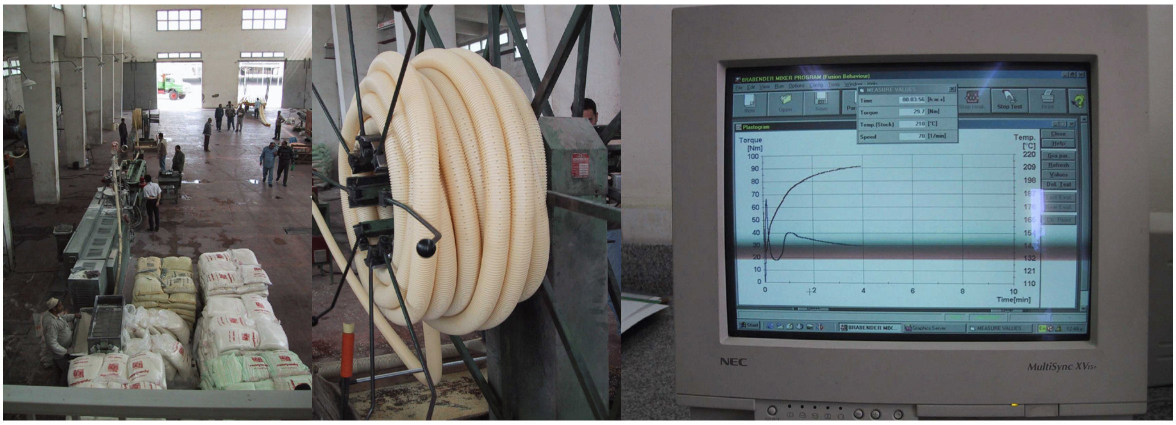

Photo 14.2
Introduction of flexible corrugated plastic drain pipes in Egypt: perforated corrugated plastic drain pipes (middle) are produced in a mechnized production line (left) under strict quality control (right)

Photo 14.3
Field staff of contractors is trained at the Drainage Training Centre in Tanta, Egypt

14.5 Organization

In 1975, the Egyptian Government established the joint Egyptian-Dutch Advisory Panel on Land Drainage (APP) with the aim to improve the implementation of its subsurface drainage programme (Advisory Panel Project on Water Management, 2003). The panel members are high-level Egyptian and Dutch administrators, scientists and consultants. The Panel initially focussed on technology and design criteria of land drainage. It gradually shifted its focus to water management. The Panel acts as a think-tank for policy making and strategic planning. The Panel stands as a unique model of bilateral cooperation. This is best illustrated by a quote of Dr. Abu Zeid, the former Egyptian Minister of Water Resources and Irrigation. In an interview with one of the Dutch national newspapers (NRC Handelsblad 28-01-2007) he said *The Netherlands are not our only partner, but without doubt the most important and most effective one. Without, we would never have reached our current level.* A specialized institution, the Egyptian Public Authority for Drainage Projects (EPADP), was created to organize the implementation of large-scale drainage projects. EPADP is responsible for the planning and design, while the actual implementation is done by public and private contractors employed by EPADP. The success of the implementation mode adopted in Egypt can be demonstrated by the high implementation rates of subsurface drainage system projects. Each year, new subsurface drainage systems are implemented in about 63,000 ha and existing drainage systems are upgraded in about 12,600 ha.

Sustainable drainage projects require the participation of farmers. The transfer of the irrigation and drainage system management is often initiated by governments. To effectively deal with this complex and time-consuming process, research is also indispensable. In the Miyen Sebou irrigation scheme in Morocco, a study was conducted to analyse the participation of farmers in state-initiated Water User Associations. The original model, which was imposed by the authorities and the donor agency, was gradually adopted and transformed by farmers according to their needs and capacities. The study showed that it is essential for the sustainability of the scheme that the farmers feel ownership for these institutional innovations. These farmers' organizations are slowly building up autonomy and this emancipation process proved to be an important building block for the development of the area. Another example is the participation of farmers in the operation of the modified drainage system for rice area in Egypt and their growing role in the newly established Water Boards. In addition to the monetary benefits, the socio-economic benefits, such as labour opportunities, reduced workload, increased income, improved position of women, landless and tenants, are also high. Thus value for money goes beyond monetary benefits.

14.6 Operation and maintenance

Research helped to improve operation and maintenance practices through the introduction of improved design concepts. For example the introduction of the modified drainage system in Egypt (see the previously mentioned case on the layout for rice areas) not only reduced operational costs, but also reduced maintenance needs, because farmers stopped to illegally block drains to reduce irrigation water losses. The introduction of plastic field- and collector drains, often in combination with pre-wrapped synthetic envelopes, greatly reduced sedimentation and thus the need for flushing. Improved flushing equipment and methods to remove sediment from the drains have also been developed. Increased farmer's participation resulted in more ownership and reduced cases of misuse or illegal blocking.

14.7 Conclusions

In North Africa, which its (semi-)arid climate, irrigation is a tool that allows farmers to cope with inadequate and unreliable rainfall. Drainage is a strategy for enabling farmers to cope with irregular rainfall and to safeguard investments in irrigation by removing excess water and salts brought in by the irrigation water. Proper drainage systems contribute to safeguard investments in irrigation, promote economic growth, and ensure the sustainability of irrigated agriculture. Research in agricultural water management is needed to ensure that investments in irrigation and drainage are sound and sustainable. The presented examples from Northern Africa show that research programmes can be very cost-effective and give value for money. Modern, large-scale, irrigation and drainage programmes are being implemented with huge cost savings, thanks to the link between research, design and implementation practices. Over the past 40 years, applied research activities have contributed to modernize agricultural water managenent practices with the introduction of: (i) new methods to identify and assess the needs of agricultural water management, (ii) new design and planning methods, (iii) new materials for pipes and structures, (iv) improved machinery and equipment, and (v) improved installation, operation and maintence methods and practices. Last but not least, research has helped to improve institutions and the organization of project implementation. These results could be achieved because countries not only invested in research but also in the training of personnel involved in applying the new and innovative practices. That these activities can be considered 'value for money' is illustrated in Table 14.1, in which a summary of benefits and savings due to research activities conducted in Egypt is presented.

The present challenges for food production in Afrika require the continuation of research in irrigated agriculture. The introduction of new crop varieties and crop diversification will have implications for water management practices. New approaches and methods will be required to upgrade aging irrigation and drainage systems. Due to increased pressure on the resources and the global climate change, many countries in Africa also experience increased variability and shortages in water resources. In addition water quality issues become more important and new legislation often impose restrictions to the discharge of effluents water from agricultural lands. Finally, socio-economic conditions are also changing. More stakeholders put claims on scarce resources, which puts new challenges on participatory approaches. Continuous support to research is required to sustain irrigated agriculture under these changing conditions. This is costly, this paper, however, has shown that research has its value for money.

Table 14.1
Summary of the benefits and savings due to research in Egypt (Ritzema et al., 2007).

Reseach finding	(Potential) savings
Measuring soil salinity with EM38	Financial benefits hard to quantify, but substantial improved quality of monitoring
Criteria for upgrading	Better planning of upgrading works
Improving surface drainage	Lower investments costs
Modified lay-out for area with rice in the cropping pattern	Savings of € 10 million in irrigation water and pumping costs and a 25% reduction in the design discharge rate
Controlled drainage	Irrigation water efficiency is increased by 15 to 20%
Design depth	Lower design drain depths result in lower installation costs
Design discharge	Smaller pipe diameters and thus lower material costs
Automation of the design process	Better systems
Plastic drain pipes	20% increase in installation rate
Synthetic envelopes	Savings of € 1.5 million per year
Trenchless drainage	Potential saving of € 2.25 million per year
Improvement of installation practices	Savings tens of millions EURO.
Organization	As above
Advisory panel	As above
Modified system for rice areas	Savings of € 10 million in pumping costs and maintenance
Flushing	33% cost reduction
Farmer's participation	10% savings in labour cost

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15 A unique science-policy interface, the Advisory Panel and its scope of work

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Abstract

Established in 1976, the Advisory Panel for Water Management has acted as a basis for the Egyptian–Dutch bilateral water sector co-operation program. Initially the purpose was to advise the Egyptian government, and more specifically the Ministry of Water Resources and Irrigation, on the large-scale implementation of land drainage as required after the construction of the High Aswan Dam.

The Panel gradually became involved in formulating and supervising a number of projects on land drainage implementation and research, thereby evolving into an umbrella organisation that encompassed all Egyptian-Dutch activities in the drainage sector. Since 1992, the Panel role became mainly directed towards advising the Ministry of Water Resources and Irrigation on water policy issues.

At the start of the Panel, its work encompassed mainly drainage technology transfer on basis of Dutch knowledge, guided by joint Egyptian-Dutch research activities. In its present role, the Panel functions as a science-policy interface. This is unique in the sense that there is no second set-up of the same kind anywhere in the world. Before the annual Panel Meetings, that are chaired by the Egyptian Minister of Water Resources, the Panel's secretariat develops all water management issues, as supplied by the Ministry, to a level where the Panel members can discuss and decide on recommendations on how to move forward on often complicated issues. The Panel Secretariat has tools as consultancy missions, studies, workshops, etc.

The purpose of this paper is to highlight the development of the Panel in the 35 years of bilateral water sector cooperation with Egypt into the unique science-policy interface that it is today.

The paper addresses a number of 'critical success factors', without which the cooperation could not have been successful. Those who wish to create a similar science-policy interface could use these factors as corner stones for development of a successful partnership.

15.1 Background

Since the Aswan High Dam became operational, seasonal irrigation changed to perennial irrigation, resulting in a need for drainage, i.e. the need to implement a land drainage system in all of Egypt's cultivated lands. Egypt started a large-scale national drainage programme with the World Bank. As well, the Netherlands responded favourably to the Egyptian request for cooperation and this resulted in the 'Egyptian-Dutch Advisory Panel on Land Drainage'.

The Panel has been the basis for the current long-term Egyptian-Dutch water sector partnership (1976-date). It started in 1976 with an integrated set-up of a Panel of high-level officials and scientists from both countries, with as secretary a Resident Expert who guided a team of junior researchers from both countries who worked together on a number of specific studies. The Panel met twice per year to discuss the large-scale implementation of the piped land drainage system and so the Panel activities functioned, throughout the first years, as (grant funded) Technical Assistance (TA) in relation with the National Drainage Programme. A World Bank representative was always present as observer during the first Panel Meetings.

Actually, the Dutch government decided favourably to the Egyptian request for many reasons, including that it was politically interesting to have a water sector cooperation with a Middle Eastern country following the 1972 and 1974 oil crises.

15.2 Adaptive capacity

The Panel was successful in its work for drainage and after the jointly developed implementation system was on the rails, the Egyptian government chose to continue its bilateral cooperation with the Netherlands, but with a gradually changing focus towards what the Panel is today, a think-tank on a wide variety on water issues, with emphasis on water policy. In the present set-up, the Panel is chaired by the Egyptian Minister of Water Resources and Irrigation, and the present objective of the cooperation is:

> *… to assist, in an advisory capacity, the Ministry of Water Resources and Irrigation in carrying out its responsibilities with regard to managing the water resources of Egypt more efficiently and effectively…*

Any future adjustments to the objective of the cooperation can be absorbed in the process as it happened throughout the years.

15.3 Panel structure and tools

The Panel structure at present is that it consists of twelve high-level Panel members, representing the sectors Water, Agriculture, Economy, Water Boards, Drinking water, Private sector, Research. The Panel is chaired by the Egyptian Minister for Water Resources and Irrigation, with an independent Dutch co-chair. It is supported by an instrumental full-time Secretariat, that includes a part-time Support Office in the Netherlands.

The 'tools' of the Panel are:
– Annual meeting
– Annual workshop(s)
– Working group and Task Force meetings
– Consultancy missions
– Training programmes

The Panel's Secretariat develops all water management issues, as suggested by the Ministry, to a level where the Panel members can discuss on how best to move forward on often complicated issues. The Panel's Agenda usually features a day for a specific workshop, a study visit of one day, and three days annual Panel meeting. All agenda items and the discussions during these Meetings lead to implementable recommendations.

As mentioned before, the scope of the Panel's work is quite wide, it includes for instance:
- Water resources planning
- Water policy development and policy evaluation
- Water financing; Public expenditure review
- Environmental protection, Water quality management, Environmental Impact Assessment, Climatic change, Wetlands
- Water user's involvement, participatory water management, Water Boards
- Public private partnership
- Institutional development, decentralization, legislation, MWRI reform
- Socio-economic aspects: water economy, poverty alleviation, gender
- Ground water management, potentiality, protection
- Nile Basin Initiative
- Water Governance
- Water Awareness
- Human Resources development (incl. a Young Professionals Organisation & capacity building
- Management development

15.4 Panel achievements

The Panel's achievements and benefits include:

- Many technical problems solved, especially in the early years, often through technological innovations. There were many involved parties, but surely the Panel contributed to the successful implementation of an agricultural drainage system in over 2.5 million hectare. This had an important effect on the Egyptian national economy and the annual income of the farming community, estimated at 25%! Next to the economic benefits, there were also others, like less water-borne diseases, better sanitation, less animal disease, less damage to houses and in general better living conditions.
- Policy advice given and assistance provided with policy formulation. This touches of core of the current Panel, that has the objective *… to assist, in an advisory capacity, the Ministry of Water Resources and Irrigation in carrying out its responsibilities with regard to managing the water resources of Egypt more efficiently and effectively…*
  Policy advice is given on many issues and assistance was provided with policy formulation. Examples include drainage water re-use policy, participatory water management policy (Water Boards), water demand management policy, policy to face future water scarcity, etc. The benefits of the development of Water Boards include a better, more targeted, application of the annual maintenance budget of the Ministry and less conflicts between farmers, of whom, by the way, 20% appears to be female. The Panel also guided the development of the National Water Resources Plan (1997-2017). This Plan is the basis for Egypt's current water policy.
- Many institutional issues were dealt with, institutional arrangements improved, and institutions were reformed/ established.
  There is a long list of institutional reform that resulted from the Panel's advice through the Panel Recommendations, including e.g. the establishment of the Groundwater Sector, the Water Quality Management Unit, Strategic Research Unit, the Institutional Reform Unit.
- Human resources developed.
  The entire system, starting from the work on the drainage implementation, all joint research (both directly related to drainage and also more general studies into water management), all related training and education possibilities, and all activities following the Panel's work over the years, acted as a 'school' for persons involved. Both from Egypt and the Netherlands. The Panel's contribution to this is not easily underestimated. In total joint work for 100's of person years has been conducted by Dutch professionals,

with more that 300 person years on the Egyptian side, by both young professionals as well as mid-career professionals. People have gained experience in the field of drainage, IWRM, policy formulation, techniques for participatory work, etc. Some 'pupils' of the Egyptian-Dutch 'school' have moved on to high positions in their Ministry, in companies, and with international organisations and international banks.

- Business generated.
  Although not the focus of the independent ('no strings attached') representations from the Dutch side in the Panel, a recent assessment of the benefits for the Dutch 'knowledge' and 'business' sectors resulting from the long-term bilateral relationship, showed that upon the Dutch 'investment' of about 150 M€ in the bilateral programme, an amount with the same value was generated by the Dutch 'knowledge' and 'business' sectors, in Egypt and in many other countries. This deals with knowledge, experiences, improved machinery, etc. that could be applied in both Egypt and elsewhere. It includes e.g. water related 'software' (project management and implementation, research and consulting services, etc.) and 'hardware' (drain machinery, drainpipe factories, machinery for ditch cleaning, etc.)
- Cost savings.
  The Panel's advice yielded huge cost savings for Egypt, starting with the Recommendation to omit a drain envelope in certain soil conditions. As well, the institutional improvements also were cost-effective. The entire set-up of the Panel, i.e. 'TA' parallel to implementation of always expensive water infrastructure, led to a successful partnership with a value that ensured its continued existence over the decades. And although the current focus has changed towards policy, there is clear 'wisdom' in linking research, training and advisory services to large implementation projects. The benefits are huge.

15.5 Critical success factors

From the long-term experience, a number of 'critical success factors'
can be extracted, factors without which the cooperation could not have been successful. Those who wish to create a similar science-policy interface could use these factors as corner stones for development of a successful partnership. The word development is important here, as 'Panel insiders' know that it will be impossible to just copy and implement the Panel's set-up and then wait for things to happen by themselves!

A listing of these 'factors for success' includes:
- Structure and set up of the Panel, i.e. with high-level experts involved, from a broad water spectrum (including agriculture, drinking water, sanitation, etc.), an Annual Meeting, a dedicated secretariat with tools
- Independency and flexibility
- Demand driven
- Restraint on politically sensitive issues
- Transparency and mode of operation
- Access to public and private knowledge
- Common understanding and mutual trust
- Similarity of issues between the two Deltas
- Commitment to discuss sensitive issues
- Chairman H.E. The Minister
- Financial commitment of both countries

15.6 Science-policy interface

In many countries (including Egypt and the Netherlands) there are missing links between science and knowledge on the one hand and policy and administration on the other hand.

Often -large- amounts of funding are allocated to research or science, that in the end does not always directly answer the challenges faced by the authorities that contracted the research. Sometimes policy makers exaggerate by stating that 'research leads to more questions than it solves' and 'researchers always need more time and money to complete their research'. However, through the approach as developed over the years in Egypt, the scientific results are processed in a way that they become directly useful for policy recommendations through discussions in the Panel, a high-level think-tank.

The tested Panel structure and set-up show that in the right setting, with the right persons involved, i.e. fulfilling the various 'critical success factors', the results of 'science' and 'knowledge can be presented in such a way that policy makers and even administrators, can directly choose to follow-up on Recommendations towards policy or other actions. In its present role, the Panel functions as such a science-policy interface.

15.7 Concluding remarks

The first and foremost objective of the Panel is … to assist, in an advisory capacity, the Ministry of Water Resources and Irrigation in carrying out its responsibilities with regard to managing the water resources of Egypt more efficiently and effectively… The objective of the Panel was achieved, over the many years, as it was instrumental in solving many technical problems; gave policy advice and assisted with policy formulation; improved institutional arrangements and assisted with institutional reform; developed human resources; generated business and brought about cost savings.

The Panel has evolved into a successful 'science-policy interface', that is 'translating' science and experience into discussion items to be fed into the 'high-level think tank' in such a way that policy makers and even administrators can directly choose to follow-up on Recommendations towards policy or other actions. Any future adjustments to the objective of the cooperation can be absorbed in the process as it happened throughout the years.

The 'Panel formula' could be applied by other countries that are seeking a sincere dialogue on water issues and that are looking for a better connection between 'science' and 'policy'. Various 'critical success factors' are available to be used as corner stones for development of successful partnerships.

15.8 Suggested further reading

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15.9 Advisory Panel Publications

(not all publications are publicly available but exceptions are possible upon request)

- Minutes of Panel Meetings (most recent Meeting was the 45th, Cairo, 2011)
- Proceedings of Panel Workshops:
  - Farmer participation (WS Cairo,1999)
  - Stakeholder Involvement (WS Ismailiya, 2000)
  - Stakeholder Involvement (WS Rotterdam, 2000)
  - Privatisation (WS Cairo, 2001)
  - Cost recovery (WS Haarlem, 2002)
  - Water Management Development in Egypt (Results of long-term Egyptian-Dutch Co-operation (Hurghada, Seminar, 2002)
  - From pilot to policy (WS Cairo, 2003)
  - Water demand management (WS Nijmegen, 2004)
  - Integrated water resources management (WS Cairo, 2005)
  - Water Policy Evaluation (WS Groningen, 2006)
  - Facing Future Water Scarcity (WS Marsa Alam, 2007)
  - River Management (WS Den Bosch, 2008)
  - Governance in Water Management (WS Cairo, 2009)
  - Management Development in MWRI (WS Deventer, 2010)
  - Crisis and Disasters Management (WS Cairo, 2011)

16 Role of science in multi-stakeholder processes: A case study in the Central Rift Valley in Ethiopia

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Abstract

Multi-stakeholder platforms have been coined as new forms of cooperation in the face of emerging or actual resource conflicts. Such platforms can serve to resolve disputes, to identify adaptation strategies or to empower the local poor with weakest voice. This paper describes the collaboration of science and the multi-stakeholder platform Central Rift Valley Working Group in promoting integrated land and water resources development and management in the Central Rift Valley of Ethiopia. This region faces different forms of environmental degradation as a consequence of both the uncontrolled economic development and the poor's short-term needs for survival. The Central Rift Valley Working Group acts as major platform for collaborative research and knowledge dissemination to support the sustainable development in the region. Evidence-based knowledge demystified prejudices and revealed various misconceptions with respect to past and on-going developments in the Central Rift Valley. Science has contributed to the understanding that current developments in the Central Rift Valley are unsustainable and that the policy of various stakeholders is part of the problem. In addition, the role of science as knowledge broker and facilitator of new stakeholder alliances was important in stakeholder processes. However, the case also illustrates that policy and development discourses take place at different scales, which are not all easily accessible for science. Interaction of science with stakeholders was useful to verify information and knowledge, to better able to identify locally-supported R&D trajectories, but also to learn to be modest about the role that science can play in complex resource-constraint situations.

16.1 Introduction

Competing claims for land and water and associated environmental problems often occur at spatial, temporal and complexity scales beyond those that individuals are able to address. Multi-stakeholder platforms have been coined as new forms of cooperation in the face of emerging or actual resource conflicts. Such platforms can serve to resolve disputes, to identify adaptation strategies or to empower the local poor with the weakest voice (Warner, 2006). The question is how science can facilitate and contribute to complex societal negotiation processes in multi-stakeholder platforms involving stakeholders with different interest and from different levels of organization (scales).

In this paper we describe and analyze how science facilitated and contributed to the decision-making process of stakeholders in a situation with emerging resource conflicts, specifically on water resources. We use the Central Rift Valley in Ethiopia as a case study because Wageningen UR has been involved in this river basin since 2006 through different projects. In various research activities scientists of Wageningen UR have closely liaised with the Central Rift Valley Working Group to support a policy dialogue on the sustainable development of this basin. The Central Rift Valley Working Group consisting of development professionals is a major platform for collaborative research and knowledge dissemination in the Central Rift Valley.

This paper has a highly narrative character of how science and a multi-stakeholder platform interact in a specific environment. We realize that such interactions between science and stakeholders are often context specific. Yet, we think that it is possible to draw some common lessons on the role of science in multi-stakeholder processes.

First, we describe the study area in more detail and the emerging problems related to resource scarcity that formed the starting point for research involvement of Wageningen UR. Subsequently, we briefly describe the background, organization and objectives of the Central Rift Valley Working Group. The role of science is described using the methodological framework that has been applied to interact and collaborate with stakeholders. Results of various studies that have been conducted are only summarized as they are less relevant than the issue how evidence-based knowledge contributed to stakeholder processes. Therefore, the interaction between science and stakeholders is presented in more detail. The paper ends with an extensive discussion and conclusions on the role of science in multi-stakeholder processes.

16.2 Study area: The Central Rift Valley

The Central Rift Valley of Ethiopia (about one million ha) is situated 150 km southwest of Addis Ababa and is bounded by the east and west by highlands, with altitudes of more than 3000 m above mean sea level. The central lowlands at about 1500 m above mean sea level consists of a chain of lakes connected by rivers with unique hydrological and ecological characteristics (Figure 16.1). Since the Central Rift Valley is a land-locked basin, i.e. there is no surface inflow and outflow of surface water from the basin, various lakes are saline while interventions in land and water resources can have far reaching consequences for ecosystems goods and services (Legesse and Ayenew, 2006). The wide diversity of landscapes and ecosystems comprise extensive wetlands that are rich in biodiversity.

The majority of the population (about 2 million) is originally pastoralists, but the main present livelihood is the small mixed rain fed farming system comprising both cereal and livestock production. Agricultural productivity of these systems is generally low associated with highly variable rainfall (especially in the central lowlands) and low external input levels. As a consequence, part of the population depends structurally on aid through the Productive Safety Net program indicating the extreme poverty and food insecurity.

Over the past decade, economic liberalization and the globalization of food and non-food systems have fostered investments in agriculture in many parts of Africa, including Ethiopia. The Government of Ethiopia embraced these developments within its Agricultural Development Led Industrialization (ADLI) strategy, which forms the cornerstone of Ethiopia's poverty reduction strategy (MoFED, 2006). As part of the ADLI strategy, the Government of Ethiopia and international donors actively support the diversification and commercialization of smallholder agriculture and the development of large-scale export-oriented agriculture, among others in the Central Rift Valley of Ethiopia. Thanks to tax holidays, financing schemes and technical support from both the Ethiopian Government and civil society organizations the area with irrigated agriculture has increased strongly over the last decade, especially near Lake Ziway being the only freshwater lake in the basin.

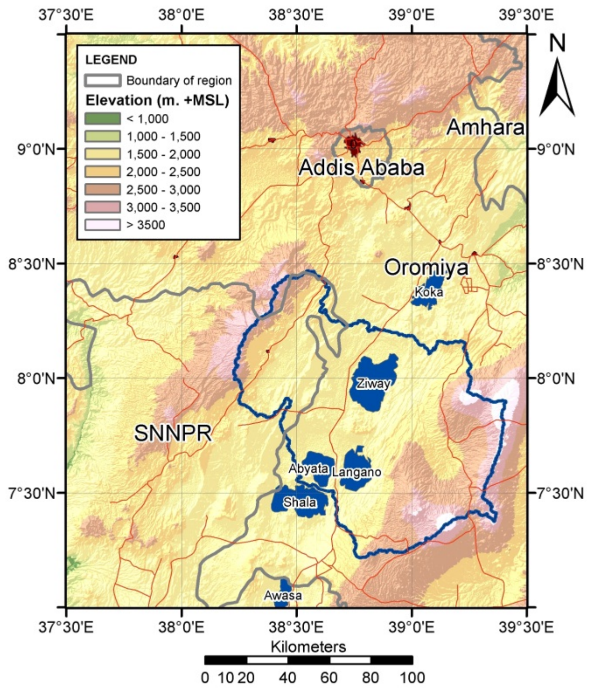

Figure 16.1
Location of the Central Rift Valley and its borders indicated with the blue line.

Recently, surface water levels have dropped across the Central Rif Valley, but most dramatically in Lake Abyata that shrunk to about half of its pre-2000 level (Hengsdijk et al., 2009). Lake Abyata is part of the Abyata-Shala National Park and famous for its water fowl. The basin-wide drop in surface water tables has been associated with the mining of soda ash along the shores of Lake Abyata and the increase in water extraction for irrigation in the Central Rift Valley (Legesse and Ayenew, 2006; MoWR, 2008). In addition, there are a number of other forms of environmental degradation in the Central Rift Valley which are common for other parts of Ethiopia as well and include the gradual erosion of woody stocks, the over-grazing of common pastures and the decreased land productivity in rain fed areas resulting in the expansion of cultivated land to marginal areas.

16.3 Central Rift Valley Working Group

The environmental degradation in the Central Rift Valley, especially the drop in the water table of Lake Abyata received public attention and laid the foundation for the multi-stakeholder Central Rift Valley Working Group, established early 2006 by a group of professionals with a stake in the sustainable development of the area. The objective of the Central Rift Valley Working Group is to promote a basin wide integrated land and water resources development and management approach in the Central Rift Valley. The activities of the Working Group to realize this objective encompass the (i) generation, documentation and dissemination of information and knowledge, (ii) fostering collaborative response to development issues, (iii) lobbying, advocacy and awareness raising and (iv) networking and experience sharing.

The Central Rift Valley Working Group consists of representatives of the public sector (e.g. federal and regional government organizations), private sector (e.g. tourism enterprises), academia, and particularly civil society organizations implementing different types of development projects in the area. The Central Rift Valley Working

Group does not have a formal governance structure and membership. It is rather a loose network of interested organizations and individuals that are devoted to the sustainable development of the Central Rift Valley. Core members take the responsibility for organizing regular meetings, often with rotating chairmanship. Participation in the meetings of Central Rift Valley Working Group is on voluntary basis implying that size and composition of the meetings varies. In the first two years of its existence the Working Group organized 19 official meetings, in which on average 16 members participated. In addition, smaller group meetings were organized, for example, to prepare project proposals or to develop advocacy strategies on specific issues. Two important incentives for attending the meetings are the possibility for networking and the presence of donors. For example, one of the civil society organizations provides funds for demand-driven action research facilitating joint research activities of academia and civil society organizations.

The Central Rift Valley Working Group does not fulfill completely the much used definition of multi-stakeholder platform namely 'a decision-making body comprising different stakeholders who perceive the same resource management problem, realize their interdependence for solving it, and come to agree on action strategies for solving the problem' (Steins and Edwards, 1998). The Central Rift Valley Working Group has no legal mandate in Ethiopia and its members can therefore only decide on joint actions to solve problems of which the solutions are within their control and capacity. Complex issues requiring broad solutions such as new legislation can only be addressed by the federal or regional government. The Working Group can, however, influence government policy through advocacy, lobbying and awareness raising, which is one of the activities of the Working Group to achieve its objective.

16.4 Role of science

The establishment of the Central Rift Valley Working Group was a response to the failure of Ethiopian policy to address the emerging resource conflicts adequately. One of the problems to address environmental degradation properly in policy formulation is the general lack of knowledge and information on resource use, which is also related to the fact that federal and regional government institutions poorly cooperate and share information. The need for generation, documentation and dissemination of information and knowledge is also expressed in one of the major activities of the Central Rift Valley Working Group (Section 1.3).

Mid 2006 Wageningen UR became involved in the Central Rift Valley to give support on sustainable water use, agricultural practices and sound environmental planning and management. The objective was to support and facilitate a policy dialogue with local stakeholders aimed at mitigating the environmental problems associated with the rapid increase in the use of water by agriculture and industry. The Central Rift Valley Working Group was deemed a suitable platform to support such a dialogue, while carrying out research in collaboration with its members.

From the start of the collaboration between science and the Central Rift Valley Working Group, there was a need for more insight of the resource use by different stakeholders and the magnitude of resource degradation through expansion and deepening of the existing knowledge base. Subsequently, improved understanding of resource use and degradation could be used to identify, design and test alternative resource management options in collaboration with stakeholders. Therefore, the NE-DEED framework (Giller et al., 2008) has been applied that consists of four analytical steps feeding into different phases of stakeholder **Ne**gotiation processes, i.e. **D**escribe, **E**xplain, **E**xplore and **D**esign (Fig. 1). These four steps are completed in an interactive and iterative process with stakeholders and assist stakeholders in developing creative and integrative solutions that cross disciplinary borders.

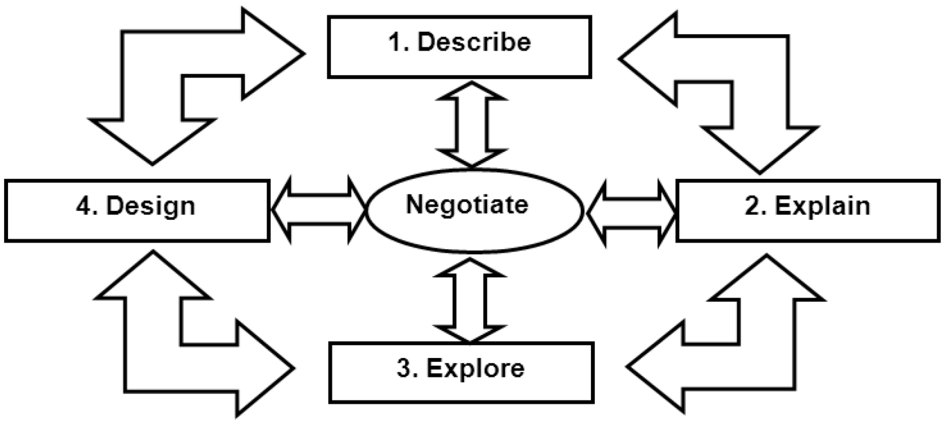

Figure 16.2
Methodological framework to analyze competing claims on natural resources and to support negotiation processes of stakeholders (modified from Giller et al., 2008).

Focus in the first step (**Describe**) is on identifying the various driving forces of the competing claims in an area and the relevant stakeholders. Analysis of the resource base and its dynamics may shed light on the rate of change and future developments under business-as-usual conditions. The second step (**Explain**) aims at better understanding of the resource dynamics and the magnitude of the competing resource claims by developing and applying a suit of simple and complex quantitative approaches. The third step (**Explore**) includes the identification of alternative resource management options including institutional barriers based on scenarios, participatory needs assessments, etc. Step four (**Design**) consists of concerted research and development (R&D) actions aimed at alleviating competing resource claims, improving resource use efficiencies, and getting a process going to address required changes in the policy and institutional system at different levels to provide sufficient innovation space to reconcile competing claims. New insights and knowledge gained in the four steps can support societal negotiation processes that are ongoing in different policy arenas and stakeholder networks in a given conflict situation.

It is beyond the scope of this paper to describe in detail the scientific results that are part of the first two steps of the methodological framework, i.e. **Describe** and **Explain**. Different studies have been conducted often together with members of the Central Rift Valley Working Group that helped to better understand the Central Rift Valley as a dynamic socio-ecological system. Results of these studies can be found in reports, presentations and policy notes available at the website www.crv.wur.nl.
Here, we summarize the major findings and recommendations:
- Recent reductions in the lake levels in the Central Rift Valley are associated with land developments especially the expansion of furrow-irrigated horticulture.
- In contrast with the common believe among stakeholders, the soda ash factory at Lake Abyata nor are the greenhouses in Ziway the major water consumers. Furrow-irrigated horticulture is by far the largest consumer of fresh water resources in the Central Rift Valley.
- There is no evidence that the amount of rainfall in the Central Rift Valley has decreased over the past 30 years. Hence, the rapid shrinkage of Lake Abyata in the last 10 years can not be related to lower rainfall.
- Although furrow-irrigated horticulture provides income to a growing part of the population in the Central Rift Valley, the little information available suggests that its economic performance is generally poor and associated with low water use efficiencies.
- The potential impacts of emissions (nutrients and biocides) from horticulture and floriculture on the surface water resources is unknown and requires further study.

– The rapid expansion of the horticulture and floriculture puts pressure on the available urban and social infrastructure.
– There is an urgent need to identify alternative livelihood strategies for the local population that consume less fresh water resources such as tourism, rain fed agriculture and fisheries/aquaculture.
– Further uncoordinated exploitation of the land and water resources may have dramatic consequences for the local population and development options as the only fresh water lake (Lake Ziway) may become a closed lake resulting in increased salinity levels.

Uncertainty and lack of data hampered quantification, and thus the full understanding of the system, such as the performance of the furrow-irrigated horticulture sector (Van Halsema et al., 2011), or the potential impact of emissions of the horticulture and floriculture sector. Therefore, some of the recommendations were targeted at setting the research agenda, implying a feedback loop in the methodological framework as illustrated by the double-sided arrows in Figure 16.2. Overall, generation of the knowledge base resulted in extensive, although still imperfect knowledge on many aspects of the Central Rift Valley system. However, the newly generated knowledge was sufficiently robust to engage in stakeholder processes.

16.5 Science-stakeholder interaction

Through meetings of the Central Rift Valley Working Group and organization of stakeholder workshops research findings were verified and, if needed local knowledge incorporated before taking the next step of the methodological framework. This process of knowledge verification and generation contributed both to the social learning of participants of the Central Rift Valley Working Group and the broader policy dialogue required for improving natural resources planning, management and decision making in the Central Rift Valley. An important task of science in the descriptive and explanatory steps of the methodological framework (Figure 16.2) was to demystify prejudices and to reveal misconceptions with respect to past and on-going developments in the Central Rift Valley. Some of the findings and conclusions were difficult to accept by members of the Central Rift valley Working Group as they conflicted with government policies, with on-going activities of civil society organizations and with the common believe and opinions of stakeholders. Especially, the finding that the open-field furrow irrigated horticulture sector was the largest consumer of fresh water was an eye opener for many stakeholders and difficult to accept by policy, and by civil society organizations participating in the Central Rift Valley Working Group. The furrow-irrigated horticulture sector consists mainly of smallholders that receive financial and technical support from government institutions and civil society organizations as part of development programs to reduce poverty and to spur economic growth. Other conclusions indicated the need for more research, for example, on the possible environmental impacts of agro-chemicals associated with the increased intensification of agriculture in the Central Rift Valley. This conclusion was more easily accepted by stakeholders but revealed that public institutions in Ethiopia are lacking that are in charge of monitoring water quality. This indicated at the need for new institutional arrangements at a level beyond the acting ability of the Central Rift Valley Working Group.

In general, multi-stakeholder platforms do not automatically lead to solving complex resource problems and the active participation of stakeholders in solutions aimed at alleviating competing resource claims (Warner, 2006). Therefore, a participatory land use planning workshop was organized with representatives of more than 30 local organizations to raise broader awareness of emerging resource problems among those policy makers and other stakeholders that had been less involved in the dialogue, such as representatives of local municipalities, the local water supply enterprise, investors and peasant associations. In addition, the workshop supported policy makers in the development of integrated policies and strategies as part of the Master Plan for the entire Ethiopian Rift Valley being developed by the Federal Ministry of Water Resources (MoWR, 2008). The Ethiopian Rift Valley encompasses the Central Rift Valley but its area is five times larger. One of the institutional changes proposed in the Master Plan is the establishment a River Basin Authority for the Rift Valley with overall policy responsibility for water management and includes the development and implementation of policies related to the regulation and legislation of resource use (MoWR, 2010). The main objective of the workshop was to jointly develop a vision for the future development of the shoreline of Lake Ziway, including the identification of priority R&D activities contributing to the realization of this vision (Hengsdijk et al., 2009). This explorative phase of the methodological framework (Figure 16.2) resulted in the identification of four priority areas for action-oriented R&D activities talking into account the understanding of resource claims and acting ability of the local stakeholders:

1. A pilot on commercial smallholder horticulture to support the sustainable intensification of the sector, i.e. improving its socio-economic performance while reducing its environmental impact.
2. Water quality monitoring in response to the risks for pollution of fresh water resources by the agricultural intensification in the Central Rift Valley.
3. Buffer zone development along water bodies to conserve soil and water resources and the natural landscape.
4. Tourism promotion as an alternative livelihood strategy for the local population that consumes considerably less water than the agricultural sector. This initiative connected to a larger eco-tourism partnership program whereby several community conservation areas are being established to boost the local economy.

These four R&D areas are currently being implemented in collaboration with local partners and represent the design stages of the framework presented in Figure 16.2. All four R&D areas involve new public-public and public-private partnerships supported by scientific research, and they address different scales. For example, the horticulture pilot is mainly embedded in local development organizations and local government authorities, but the water quality monitoring and buffer zone activities go beyond the local level as they also involve the liaison with the private sector and knowledge of current legislation defined at national level, such as different environmental proclamations and land ownership rights.

16.6 Discussion and conclusions

Systems facing competing resource claims require transdisciplinary approaches across different scales as such systems are used, managed and governed by different groups of people operating at different scales (Giller et al., 2008). Since these groups have often conflicting objectives solutions are complex and involve political considerations and decisions. Collaboration with multi-stakeholder platforms is attractive from a scientific point of view as these institutional innovations have the potential to be problem-solving and to manage conflicts over resources (Warner, 2006). However, in practice these roles of multi-stakeholder platforms are hard to realize for a number of reasons among others because they do no have a legal mandate and they are not all-inclusive, i.e. not all stakeholders participate. This was also the case with the Central Rift Valley Working Group despite our efforts to broaden the group of stakeholders through the organization of a dedicated land use planning workshop.

One important lesson of this case study is that development discourses take place through a variety of platforms and dialogues at different levels of organization (scales). These different discourses can involve (partly) the same stakeholders, but can also involve other groups of stakeholders not aware of each other. In our case the Master Plan for the Rift Valley was developed in parallel with the dialogues in the Central Rift Valley Working Group. We did not only exchange important scientific information with the developers of the Master Plan, but the Central Rift Valley Working Group was also officially invited in the public inquiry procedure for the Master Plan. At a certain stage in the development of the Master Plan the vision was that the Central Rift Valley Working Group could evolve into an advisory platform for the River Basin Authority to be developed for the entire Rift Valley. However, the development of the River Basin Authority is severely hampered by a lack of finances and expertise and thus the advisory platform has not (yet) been established. In this case different discourses converged, i.e. that of the Central Rift Valley Working Group and the Master Plan, reinforcing on-going dialogues. However, other policy arenas were hard to trace and to access because of the little transparent bureaucracy of governmental institutions in Ethiopia. For example, we were not able to get formal confirmation of a plan from the regional government to expand the irrigated area by constructing a dam in one of the rivers. Damming of this river would significantly increase the risk of salinity of Lake Ziway, and thus potentially undermining the sustainable use of the lake in the future. Until the construction of the dam actually began these rumors could be confirmed. It is rather an art to identify, access and connect the different on-going discourses and, to provide them with evidence-based information.

The question remains whether science did make a difference to stakeholder processes in the Central Rift Valley Working Group and decision-making on issues related to natural resources management. One could be skeptical when looking at the rate of water extraction for irrigated horticulture and the on-going degradation of water and other resources in the Central Rift Valley. Both the public and private sector focus on irrigated agriculture as one of the important means to alleviate poverty and increase economic growth. The stakes are high and many of the civil society organizations participating in the Central Rift Valley Working Group depend on long-term donor funding for the promotion of irrigation as a means to alleviate poverty under smallholders. Science has contributed to better understanding that current developments in the Central Rift Valley are unsustainable and that the policy of various members of the Central Rift Valley Working Group is part of the problem. At least one of the donors in the Central Rift Valley Working Group changed its policy concerning the support of civil society organizations focusing on irrigated smallholder horticulture. Emphasis in the donor program shifted from promoting irrigation towards stimulating water use efficiency and service provision to improve the performance of existing smallholder irrigation.

Maybe more important has been the role of science as 'knowledge broker' and the Central Rift Valley Working Group as 'the floor of the stock exchange' (Sterk et al., 2009). Generally, information networks in developing countries are poorly developed and those in Ethiopia are no exception. Due to the recent Governmental decentralization process in Ethiopia collaboration among the federal, regional and district authorities has not yet been well established resulting in little coherent policies and poorly structured information flows among authorities, but also with other stakeholders from both the public and private sector. Support of science to stakeholder processes in the Central Rift Valley has not only been important for providing evidence-based knowledge enabling to disentangle facts from fiction but also for connecting various stakeholders that did not know each other but had similar objectives and interests. Scientific support also has been instrumental in bringing together stakeholders with conflicting interests facilitating the shared understanding of problems, and the development of new projects aimed at alleviating resource competition. Information exchange and networking among participants allowed building new alliances to jointly identify R&D issues within the own mandate and authority of stakeholders. This led to new public-private-civil society partnerships but also new coalitions among public institutions addressing, for example water quality monitoring, for which institutional responsibility is currently lacking at federal and regional government levels in Ethiopia.

A boundary condition for the fruitful cooperation among stakeholders and science is the long-term commitment of stakeholders, donors and science since no quick fixes can be expected in complex and resource constrained situations. In contrast, rural development in the context of resource competition is a long-term process that requires frequent adjustment of research strategies and approaches. Key for a successful scientific contribution to this process is the nuanced understanding of the complex issues involved through evidence-based analyses, and the continuous debate on the pros and cons of alternatives and options (Giller et al., 2008). The methodological framework used in the case study provided a new role for science. The users/stakeholders are central and analyses need to be continuously updated and elaborated depending on the information needs of the stakeholders. Participation of stakeholders in the data collection and in demand-driven action research increased the relevance and impact of research outputs. Interaction with stakeholders was useful from a scientific point of view as to verify information and knowledge, to better able to identify promising and locally-supported R&D trajectories, but also to learn to be modest about the role that science can play in complex resource-constraint situations.

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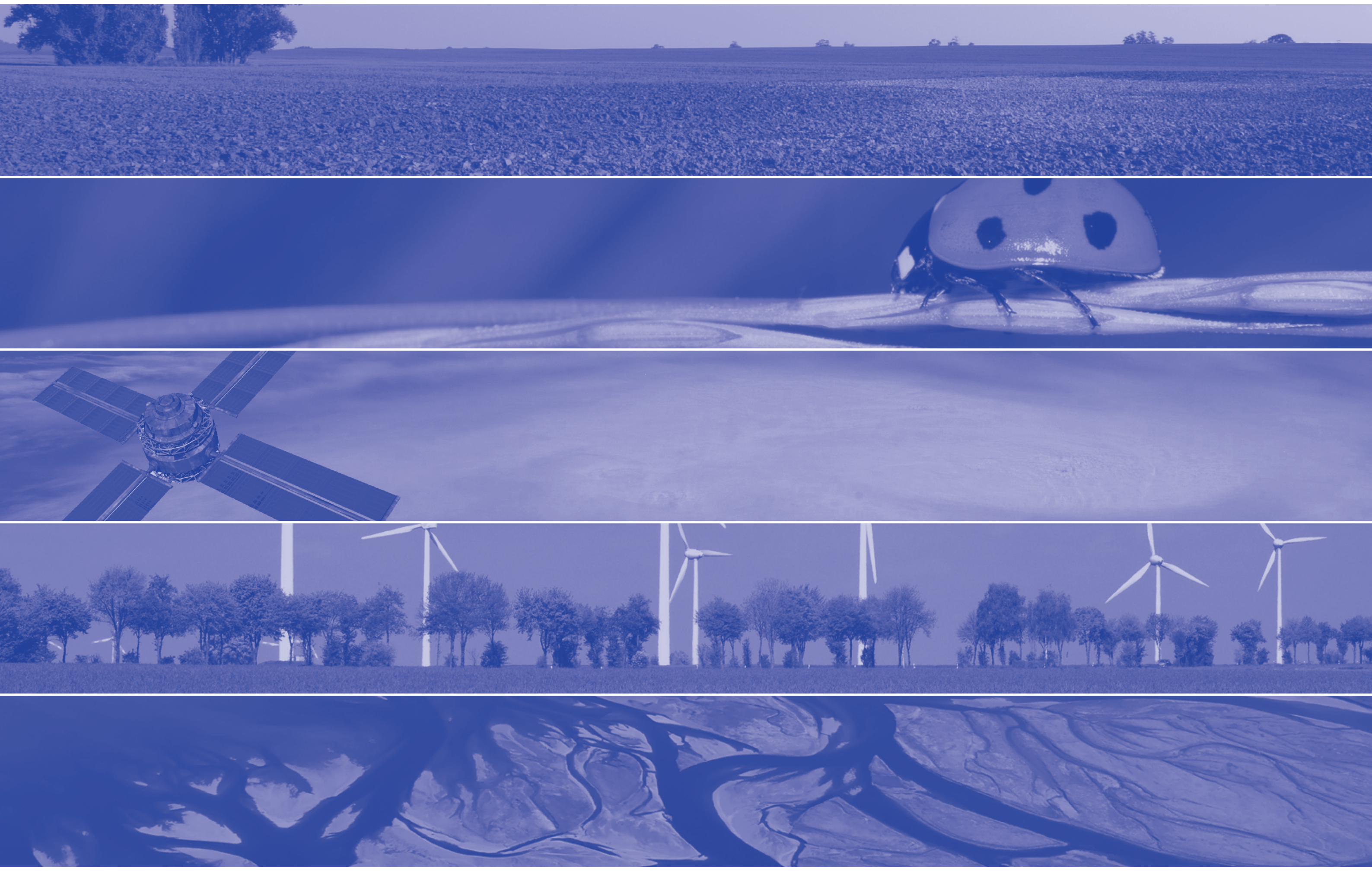

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