CPWF Project Report

Small Multi-Purpose Reservoir Ensemble Planning

Project Number PN46

Marc Andreini, Tonya Schuetz, Aiden Senzanje, Lineu Rodriguez, Winston Andah, Philippe Cecchi, Eline Bolee, Nick van de Giesen, Eric Kemp-Benedikt, and Jens Liebe

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Program Preface

Planning and Evaluating Ensembles of Small, Multi-purpose Reservoirs for the Improvement of Smallholder Livelihoods and Food Security: Tools and Procedures

People living in arid areas with highly variable rainfall, experience droughts and floods and often have insecure livelihoods. Small multi-purpose reservoirs are a widely used form of infrastructure for the provision of water. They supply water for domestic use, livestock watering, small scale irrigation, and other beneficial uses. The reservoirs are hydrologically linked by the streams that have been dammed. Although reservoirs store a large quantity of water and have a significant effect on downstream flows, they have rarely been considered as systems, with synergies and tradeoffs resulting from the number and density of their structures. Often reservoirs were constructed in a series of projects funded by different agencies, at different times, with little or no coordination among the implementing partners. A significant number are functioning sub-optimally and/or are falling into disrepair. This indicates that there is room for improvement in the planning, operation, and maintenance of small reservoirs. The water management institutions in Volta, Limpopo, and Sao Francisco Basins are being revamped to better serve their constituencies. We have an opportunity to collaborate with government officials, stakeholders, and farmers who are actively looking for ways to improve the planning process.

The Small Reservoir Project team developed a tool kit to support the planning, development, and management of small reservoir ensembles on the basin level and the use of small multi-purpose reservoirs that are properly located, well designed, operated and maintained in sustainable fashion, and economically viable on the local/community level. There are tools to improve intervention planning, storage estimation and the analysis of the hydrology, ecology and health of small reservoirs. There ara also tools for the analysis of institutional and economic aspects of the reservoirs. The toolkit not only includes the necessary analytical instruments, but also a set of process oriented tools for improved participatory decision making. The Tool Kit is meant to be a living "document" with additional tools and experiences to be added as they are developed.

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RESEARCH HIGHLIGHTS

Whether allocation of water through distributed storage is a good policy rests on two questions: 1) are the evaporation losses from these relatively small reservoirs excessive and 2) does the collective impact of large number of reservoirs place an inequitable burden on downstream users. Our work demonstrates that the evaporative losses are less than 50% of what had been assumed before. These earlier assumptions were based on analogies with oases in deserts, which do indeed evaporate excessively. Our research shows that open water of a small reservoir in a savanna setting looses even less than a similar area under crops! Our water balance measurements, based on combined satellite and field measurements, show that the collective downstream impact of the present number of small reservoirs is minimal. Although prudent practice would demand an analysis of the impact of new reservoir construction to be done before system expansion is contemplated, it can be anticipated that new construction will often be justified, especially when compared to the other two more expensive and less reliable alternatives. Even after quadrupling the present number of small reservoirs, their combined impact will be less than 1% of the total water balance. The reservoirs do not deprive downstream users of the water for hydropower, agriculture, and environmental flows.

The Small Reservoirs project supported the research work of 4 PhD's, 36 MSc's and 23 BSc's. Fifty percent of the PhD students and two thirds of the MSc and BSc students were from the south. The final output of the Small Reservoirs Project (SRP) is a tool kit (see www.small reservoirs.org). At the time of this report 22 articles and book chapters were produced (see Publication section below), there are also other publications, theses, conference papers, and posters listed in the publication section, approximately 15 more articles have been submitted, accepted and/or are currently under review for publication.

Executive summary

People living in arid areas with highly variable rainfall, experience droughts and floods and often have insecure livelihoods. Small multi-purpose reservoirs are a widely used form of infrastructure for the provision of water. They supply water for domestic use, livestock watering, small scale irrigation, and other beneficial uses. The reservoirs are hydrologically linked by the streams that have been dammed. Although reservoir ensembles store enough water to have a significant impact on the livelihoods of smallholders who use them, they have rarely been considered as systems, with synergies and tradeoffs resulting from the number and density of their structures.

Often reservoirs were constructed in a series of projects funded by different agencies, at different times, with little or no coordination among the implementing partners. That a significant number are functioning sub-optimally and/or are falling into disrepair indicates that there is room for improvement in the planning, operation, and maintenance of small reservoirs. The water management institutions in Volta, Limpopo, and Sao Francisco Basins are being revamped to better serve their constituencies. We have an opportunity to collaborate with government officials, stakeholders, and farmers who are actively looking for ways to improve the planning process.

We proposed a project with two paired objectives. The basin/watershed level objective was to promote and support the planning, development, and management of small reservoir ensembles. Planning reservoirs at this scale limits conflicts over water, markets, and other resources and minimizes undesirable environmental interactions among the reservoirs. The local/community level objective was to support use of small multi-purpose reservoirs that are properly located, well designed, operated and maintained in sustainable fashion, and economically viable while assuring they improve the livelihoods of the local residents.

To reach our objectives, we assembled a multi-disciplinary team to develop, two purpose built sets of analytical tools and implementation procedures based on economic and biophysical research. The hydrologic, economic, ecological, health, and institutional dimensions of small reservoirs were considered. The first set of tools will assist stakeholders to site, build, and manage ensembles of small multi-purpose reservoirs. The second set of tools will assist planners and stakeholders, particularly farming families, to develop economically and environmentally sustainable small multi-use reservoirs and institutions for their communities. The project team worked with planners, decision makers and farmers in an iterative, consultative process to develop tools appropriate for the use of the stakeholders who will use them. The toolbox is comprehensive and not only includes the necessary analytical instruments, but also a set of process oriented tools for improved participatory decision making, and yet encourages other researchers to add effective tools they developed to the toolkit in an dynamic process.

By harmonizing the interests of individuals served by small multi-purpose reservoirs and other people living in the basin we reached our paired goals: 1) to maintain water related ecosystem services, the long-term sustainability of local water supplies, and adequate downstream flows as we make use of small reservoirs and 2) to improve food security at the household level and increase sustainable livelihoods through the provision of those small multi-purpose reservoirs.

The small reservoirs team developed tools that fall into four thematic areas: a) planning, b) storage and hydrology, c) ecosystems and human health, and d) institutions and economics. The tools themselves are project outputs. Although the Tool Kit final version is finalzed for release some of the tools are already being used be people associated with the project. These tools are international public goods and will be used to make locations specific recommendations and inform policies.

The quality of the water in these systems is of great importance. We have developed tools to help us understand the impacts of the reservoirs and their use on the quality the water in these systems. Our tools will assist planners to study their own reservoir ecosystems and formulate policy recommendations specific to their areas of interest. In Burkina Faso, we discovered Cyanobacteria (e.g. potentially harmful microalgae) in almost all water bodies in the Nakambe (White Volta) Basin. Its origins remain uncertain: but both past and present anthropogenic pressures are probably responsible. The sustained use of pesticides as well as current agricultural practices represents fundamental challenges to the preservation of water quality. Using their imaginations and our tools for evaluating ecosystem performance and human health impacts planners will be able consider various policy options for improve the situation.

Our work on the hydrology of reservoir ecosystems resulted in the development of tools to answer questions about the allocation of water for distributed storage. In addition, by using them we were able to answer two questions of of interest to policy makers: 1) are the evaporation losses from these relatively small reservoirs excessive and 2) does the collective impact of large number of reservoirs place an inequitable burden on downstream users. Our work demonstrates that evaporative losses are less than 50% of what had been assumed before. These earlier assumptions were based on analogies with oases in deserts, which do indeed evaporate excessively. Our research shows that open water in a small reservoir in a savanna setting looses even less than a similar area under crops. And our water balance measurements, based on combined satellite and field measurements, show that the collective downstream impact of the present number of small reservoirs is minimal. Even after quadrupling the present number of small reservoirs, their combined impact will be less than 1% of the total water balance.

The work was done primarily in the Volta Basin. However, using our tools planners located elsewhere will be able answer specific questions of interest in their areas. Although prudent practice would demand an analysis of the impact of new reservoir construction to be done before system expansion is contemplated, it can be anticipated that new construction will often be justified, especially when compared to the other more expensive and less reliable alternatives.

In conclusion, the project developed many useful tools for various stakeholders. However, as these first tools are used and improved, it is anticipated that new tools applicable to other social and biophysical environments will be added to the Tool Kit making it of increasing value to more and more stakeholders.

INTRODUCTION

People in the Limpopo, Volta, and Sao Francisco Basins live with variable rainfall, droughts, floods, and resulting insecure livelihoods. Reservoirs have often brought about positive changes in people's lives. For the purposes of this project, small reservoirs are engineered structures with surface areas from approximately one hectare to 20 hectares. They typically serve several functions. They provide water for domestic use, livestock watering, small scale irrigation, brick making, and the largely undocumented environmental function of supporting wild life.

They are an important source of water for many communities. Although there is no comprehensive record of the numbers of small reservoirs, in the Volta, Limpopo, and Sao Francisco Basins, thousands of small multi-purpose reservoirs have been constructed. These reservoirs were constructed in a series of projects funded by different agencies, at different times, with little or no coordination among the implementing organizations. The implicit assumption of those funding new construction is that there are social and economic benefits that can best be achieved by building ever more dams. That a significant number are functioning sub-optimally and/or are falling into disrepair indicates that there is room for improvement in the planning, operation, and maintenance of small reservoirs systems.

The reservoirs are hydrologically linked by the streams that have been dammed. Although, in arid areas, these reservoir ensembles store a significant quantity of water, they have rarely been considered as systems, albeit diffuse ones, with synergies and tradeoffs resulting from the number and density of their structures. In addition, the impact of small multipurpose reservoirs on people's health is largely unknown. And thus far little or no consideration has been given to the collective impact of small reservoirs on the social and economic fabric, health, or the natural environment. Therefore, a concerted effort to plan and manage small reservoirs will have a significant impact on the livelihoods of the communities served by these structures.

Dissatisfied with the way water was allocated and used previously, the people in Volta, Limpopo, and Sao Francisco Basins have begun to create new more responsive water management institutions. This state of flux presents us with an opportunity to collaborate with government officials, stakeholders, and farmers who are actively looking for new solutions. Participatory, science based research rarely takes place in an environment as open to change, only rarely does it have such a good chance to make an impact. This window of opportunity was taken by the project.

Our two research hypotheses were:
1) that by using a purpose built set of analytical tools and implementation procedures based on sound economic and biophysical research, stakeholders can: properly site, build, and manage ensembles of small multi-purpose reservoirs to: a) optimize the density of small reservoirs in a given area with respect to social returns and health and ecological impact, b) insure that ensembles do not disrupt environmental flows, c) maintain downstream availability of water resources to the riparian countries, and d) contribute substantially to improved water productivity

at the basin scale, and

2) that a second, paired, purpose built set of analytical tools and implementation procedures also based on research and focused on the management of individual, reservoirs can: a) assist planners and stakeholders, particularly farming communities, to develop economically and environmentally sustainable small multi-use reservoirs that contribute significantly to increased rural livelihoods and pro-poor development.

The target groups of beneficiaries were 1) residents of the basins who will enjoy the more appropriate and equitable allocation of water within the basin and 2) the rural communities .

PROJECT OBJECTIVES

1 Project Objectives

The objective of this project was to develop a tool kit that includes tools to address both the community and basin level concerns for the use of stakeholders planning, building, managing, operating, maintaining and using small reservoirs.

The final output of the SRP includes several peer reviewed articles, BSc and MSc theses and PhD dissertations, and a tool kit. The tool kit contains tools developed to support technical professionals, decision makers, water user associations, agricultural extension workers and/or other stakeholders working with small reservoirs. It is expected that more tools and experiences with the application of the tools will be added in the future. These tools were developed by the Small Reservoirs scientific team members from their research results. Most of these tools result from peer reviewed publications and are intended to make the research findings more accessible. Each of the tools follows a format describing the scope of the tool, the target group, tool application (methodology), requirements, lessons and recommendations, limitations, references, contacts and links. Below is a list of all the tools that will be available at (www.smallreservoirs.org) and in the tool kit, followed by a few example tool summaries.

Intervention Planning

- Participatory Impact Pathways Analysis
- Stakeholder and Conflict Analysis – Theory, Case Studies from Ghana
- Creating Common Ground for Dialogue, Volta, Ghana
- Monitoring Change and Adoption – Outcome Mapping

Storage and Hydrology

Reservoir ensembles measurements

- Reservoirs Inventory Mapping - Remote Sensing (Satellite Imagery)
- Towards an Atlas of Lakes and Reservoirs in Burkina Faso - Mapping Reservoirs Inventory – **M**aquette d'un **A**tlas interactif des **B**arrages et réservoirs du Burkina **Faso** (FASO-MAB) (secondary data)
- Small Reservoir Capacity Estimation, Measure storage, Area-Volume relations
- Near-Real-Time Monitoring of Small Reservoirs with Remote Sensing
- Hydrological Impact Assessment of Ensembles of Small Reservoirs

Hydrology and physical measures of performance

- Inflow Estimation: Calibration of Runoff Models with Remotely Sensed Small Reservoirs - Runoff Generation in Semi-arid Areas
- Rainfall-discharge relationships for monsoonal climates
- Deep Seepage Assessment in Small Reservoirs

- Evaporation Losses from Small Reservoirs

Sedimentation

- Water Quantity Assessment of Silted up Small Reservoirs
- 137Cs radionuclide tracer method to quantify soil erosion and sedimentation at hillslope and reservoir scale (Almut Brunner, ZEF PhD student)
- Soil erosion modeling at small reservoir scale by WaTEM/SEDEM (Almut Brunner, ZEF PhD student)
- Bathymetric survey by depth-sonar and lake sediment coring by Beeker sampler to identify sediment budges and siltation rates of small reservoirs (Almut Brunner, ZEF PhD student)
- Small reservoir risk-of-failure evaluation

Ecosystems and Health

- Participatory Health Impact Assessment
- Health Questionnaires
- Epidemiological Survey
- Vector studies for water-related diseases
- Water Quality Assessment
- Cyanobacteria, cyanotoxins and potential health hazards in small tropical reservoirs
- Agricultural intensification and ecological threats around small reservoirs
- Small reservoirs water quality monitoring using plankton abundance and diversity
- Impacts of reservoirs: towards the definition of indicators

Institutions and Economics

Water Allocation

- Water Evaluation and Planning (WEAP) (incl. PEST – Parameter Estimation Tool)
- Financial Accounting Model
- Water-Limited Yield Model
- Small Reservoir Water Allocation Strategy Water productivity based water allocation

Institutions and Governance

- Institutions and Governance of Small Reservoir Water Resources - Local Water Governance Institutions Case studies from Volta & Limpopo Basin
- Net-Map (Influence Network Mapping) - Theory, Case study 1 : Organizational learning in multi-stakeholder water governance
  Case study 2: Research on Fisheries Management in Small Multipurpose Reservoirs
- Social Capital

As can be seen from the above list of the tools, the toolkit is organized in four thematic areas: I. Intervention Planning; II. Storage and hydrology (*Reservoir ensemble measurements* and *Hydrology and physical measures of performance*); III. Ecosystems and human health; and IV. Institutions and economics (*Water Allocation* and *Institutions and Governance*).

I. Intervention Planning

The tools in this section are designed to assist implementers planning interventions, e.g. they may be used at the early stages of reservoirs planning or when exploring how to improve existing reservoirs. They can also be used if you are at a stage of revision and reflection. These tools, developed or applied in the context of small reservoirs, are participatory in their approach. However, they all allow users to define the level and extent of participation suitable to their situations. They all enable users to look for solutions by including multiple perspectives and interests. They encourage communication among the various stakeholders. These tools allow researchers to approach the challenges and research questions at hand in a more integrated and interdisciplinary, and demand driven way. The application of these tools to cases during the course of the project was presented in various publications and presentations (Section 6).

<u>Participatory Impact Pathways Analysis</u>

This tool will assist those planning research on or interventions for small reservoirs systems to use Impact Pathways Analysis to develop a plan to better bring about desired outputs, outcomes and impacts. By helping make explicit the links between project activities or program interventions on the one hand, and partner roles and inter-relationships on the other. The likelihood of achieving better impacts may be improved.

<u>Stakeholder and Conflict Analysis</u>

This tool assists in the analysis of the stakeholders' goals, aims, and interest in the project's envisioned outcomes; it also assists in identifying their relationships with other stakeholders and assesses their relative power and capacities. The conflict analysis tool allows the user to assess the degree to which identified interests and goals, conflict with or complement each other, related to the specific goals of the development project, are influenced by relationships among stakeholders, and will likely determine future relationships between the stakeholders.

<u>Creating Common Ground for Dialogue</u>

This tool describes how to use drawing as a means of fostering better communication, and improved mutual stakeholder understanding of the aims, views and goals of a proposed activity. The drawing approach helps water-users take a larger role in the design and implementation of small reservoir improvements. It introduces the water users' perspectives into problem identification and the design process. By clarifying messages and focusing the discussion this tool can facilitate the development of improved reservoir design strategies.

<u>Monitoring Change and Adoption – Outcome Mapping</u>

The outcome mapping tool presents an approach to assist planners to monitor the implementation, adoption, and changes in attitude and behaviour of the stakeholders. Outcome Mapping is a participatory planning, monitoring and evaluation methodology which focuses on the contribution of a program to changes in the actions and behaviours of the 'boundary partners'. Applied to knowledge and learning strategies, Outcome Mapping facilitates communication and has a number of potential other benefits.

II. Storage and Hydrology

Small reservoirs have been largely neglected in hydrological and water resource research because of the combination of several characteristics: small size, existence in large numbers, and widespread distribution. These characteristics constitute their main advantages for the scattered rural population but make their monitoring difficult. Adequate ground-based data on small reservoir storage volumes are commonly not available, and conducting ground-based surveys and measurements is prohibitively expensive and time consuming on a regional scale. To overcome the lack of baseline data, and to provide practitioners and scientists with tools to assess water resources and hydrological questions, the Small Reservoirs Project developed a number of innovative tools and research approaches concerning small reservoir storage and hydrology.
Despite the importance of small reservoirs for the livelihood of the rural population in most semi-arid areas of the world, tools and information on the hydrological and water resources aspects of these structures did previously not exist. The tools presented in the Storage and Hydrology section are innovations that fill this information gap, providing tools and resources available for the assessment of and work with small reservoirs. Using these types of tools has provided a greatly improved assessment of small reservoirs in the Volta Basin. Such application of these methods to cases during the course of the project was presented in various publications and presentations (Section 6).

II. a) Reservoir ensembles measurements

Reservoirs Inventory Mapping - remote sensing (using satellite imagery)
In most semi-arid areas of the developing world, the number, size, and location of small reservoirs is generally unknown. To facilitate planning activities, an inventory of existing dams is necessary. This tool outlines the steps required to obtain a regional reservoir inventory using satellite imagery.

Towards an Atlas of Lakes and Reservoirs in Burkina Faso - Mapping Reservoirs Inventory - FASOMAB (using secondary data)
To facilitate planning activities, an inventory of existing dams is necessary. This tool outlines the steps required to obtain a regional reservoir inventory using secondary data. It demonstrates how databases provided by official sources may be merging and interconnected to create a "homogenized" metadata base. And how subsequently a customized GIS may be used with the data to generate maps.

Small Reservoir Capacity Estimation - Measuring storage - Developing Area Volume relations
Measuring the storage capacity of large numbers of small reservoirs by conventional means is labor-intensive, costly, and time-consuming. This tool explains the estimation of reservoir storage capacity as a function of remotely-sensed surface area.

Near-Real-Time Monitoring of Small Reservoirs with Remote Sensing

This tool describes use of radar satellite imagery to monitor changes in small reservoir surface area and therefore storage volumes. Because radar is not affected by clouds, a near-real time record of water stored in small reservoirs can be produced every two to four weeks. Such records are of interest to hydrologists and are useful in drought monitoring.

Hydrological Impact Assessment of Ensembles of Small Reservoirs

This tool illustrates methods to assess the hydrological impact of an ensemble of small reservoirs, particularly evaporative losses, spillage, water used for irrigation, and excess irrigation drainage. The tool uses stochastic simulation and assumes that the main statistical properties of the ensemble do not change when new reservoirs are added. This tool is an analytical framework or algorithm, not a globally ready-to-run model. Tools based on this model could be used to predict what may happen when the number of reservoirs is increased without defining the location of each new reservoir as it is added.

II. b) Hydrology and physical measures of performance

Inflow Estimation: Calibration of runoff models with remotely sensed small reservoirs - Runoff generation in semi-arid areas

In most semi-arid areas, small reservoirs are located in upland watersheds. To understand the filling process of reservoirs, and to determine their impact on flow, hydrological models are needed. Most existing runoff models are, however, geared towards temperate climates and may not capture the relevant hydrological processes and runoff production in semi-arid areas. This tool presents a method to develop simple hydrological models for dammed upland watersheds based on monitoring reservoir surface areas with radar remote sensing.

Run-off of monsoonal climates

Methods for estimating runoff that have been developed for temperate climates may not be suitable for use in the monsoonal climates of Africa, where there is a distinct dry season in which soils dry out to a considerable depth. Water balance models have been shown to better predict river discharge in regions with monsoonal climates than alternative methods based on rainfall intensity, or on the USDA-SCS (USDA Soil Conservation Service) curve number. This tool can be used to develop a simple water balance model for predicting river discharge.

Deep Seepage assessment in Small Reservoirs

Evaporation and seepage are the principle non-productive reservoir losses. Seepage is sometimes ignored when reservoir water balance calculations are made because it is considered so difficult to estimate or measure. However, a large number of small reservoirs exhibit significant seepage losses and it is therefore important to understand their seepage behavior. This tool provides a simple methodology to estimate seepage losses through the bottoms of small reservoirs.

Evaporation losses from small reservoirs

Because water that evaporates directly from the reservoirs is unused water, it is called an unproductive loss. Many planners and decision makers feel that small reservoirs are unsuitable for rural water supply because they assume that evaporation losses are extremely high. In a detailed study in the Upper East Region of Ghana we measured evaporation from water bodies using various methods. This tool demonstrates that observed evaporative losses were moderate.

Water quantity assessment of silted up small reservoirs

There many small reservoirs in the Limpopo Basin that are filled with silt. This creates difficulties for local communities as there is often no other nearby sources of water (especially in the dry season). This tool may be used to estimate the quantity of water stored in silted-up reservoirs, and to estimate how much of it can be abstracted for community use.

137Cs radionuclide tracer method to quantify soil erosion and sedimentation at hillslope and reservoir scale

Quantifying soil erosion and soil deposition processes is often important in understanding their dimensions in semi-arid environments and in identifying land management methods to reduce their effects. This tool presents an innovative method using measurements of ^{137}Cs concentrations in soil samples collected in the watershed to estimate the amount of sediment eroded from fields, redistributed downstream, and accumulated in reservoirs.

Soil erosion modeling at small reservoir scale by WaTEM/SEDEM

Reservoir siltation is an important “off-site” consequence of soil erosion. When fertile topsoil is eroded from hill-slopes, it is transported downstream and ultimately accumulates in valleys and reservoirs. The loss of nutrient-rich topsoil can reduce the productivity of hillside agricultural systems, while siltation of small reservoirs lessens reduces their storage capacity. This tool uses soil erosion models to simulate soil erosion and sedimentation rates at the catchment scale and to produce soil erosion hazard maps. These maps can help identify suitable locations for implementing soil conservation techniques.

Bathymetric survey by depth-sonar and lake sediment coring by Beeker sampler to identify sediment budgets and siltation rates of small reservoirs

Accumulating soil particles can lead to changes in reservoir morphology, which may reduce their water storage capacity. Small reservoirs may be particularly vulnerable because the maximum water depth is often only a few meters and an accumulated sediment layer of a few decimeters at the bottom of the reservoir may cause a comparatively large reduction in water volume. This tool presents methods for bathymetric surveys and lake sediment retrievals to monitor changes in reservoir morphology, to measure the thickness of accumulated sediment, and to calculate siltation rates.

III. Ecosystems and Health

Small reservoirs provide water for agricultural production, crops, livestock, fisheries, other services such as domestic uses, recreation, and less visible benefits such as groundwater recharge. Some of these water uses lead to environmental and health impacts, both positive and negative. Crucial negative impacts such as pollution and health risks can be addressed in planning, design, construction, use and management of the small reservoirs.

We analyzed the health status of small reservoirs in Burkina Faso and identified two main threats to water quality: first an impressive dominance of cyanobacteria in phytoplankton, indicating some deregulation in the metabolism of these aquatic ecosystems; and secondly focal and toxic chemical pollution due to the intensification of agricultural production around small reservoirs. The limited understanding of the types of chemicals has identified options for further research linking the intensification of agricultural practices to the health status of aquatic ecosystems.

The collection of detailed health data is often extremely expensive and constrained by logistical difficulties. Therefore, supported by experience in Morocco, after collecting and analyzing of secondary information on especially schistosomiasis and malaria, innovative methods were developed and integrated into participatory approach for assessing health impacts.

The responsibility for mitigating possible negative impacts of small dams should be taken seriously by the responsible authorities, NGOs and other stakeholders right from the planning stage. The section on environment and health aims at using, managing, designing, and planning small reservoirs with fewer health and environmental risks and more benefits to ensure more sustainable exploitation of small reservoirs.

<u>Participatory Health Impact Assessment</u>

This tool contains guidelines intended to reduce the health risks and increase the health benefits from small reservoirs. Guidelines are structured in a step-wise manner, beginning with the identification of relevant health issues and concluding with small reservoir design and operation for improved human health. The guidelines focus on: major water-related diseases associated with small reservoirs in Africa, the added value of community participation in health impact assessment, opportunities to mitigate risks and improve human health through better planning and operation of small reservoirs, and improved planning, design, and management options.

<u>Health Questionnaires</u>

This tool describes the use of school surveys, an important tool that supports both participatory and biomedical research. When epidemiological studies are carried out at the same time, a local quantitative relationship between measured and reported infection rates can be established and the questionnaire can be applied in a larger area to assess prevalence at the level of the reservoir cluster or river basin. Such questionnaires can be adapted for other diseases and to fit varying local circumstances.

<u>Epidemiological Survey</u>

This tool uses standard biomedical methodologies to determine infection rates for key water-related (or "reservoir-related") diseases including schistosomiasis and other intestinal parasites, and malaria. In any particular locale there may be a completely different set of priorities with regard to reservoir-related health issues. Therefore, it is always wise to check with local health personnel about priorities, and to sample local communities' perceptions with respect to reservoir-related problems. For diseases and infections not described in this tool, local health professionals, literature, and the internet provide good starting points.

Vector Studies

One of the health risks of small reservoirs is the potential for increased transmission of water-related diseases, in particular, parasitic infections dependent on water-based "vectors". The design, use, and management of reservoirs all influence their suitability as breeding grounds for disease vectors. This tool describes the use of selected methods to help stakeholders understand the ecological preferences of vector organisms in relation to small reservoirs. This is an important step in identifying management options for environmental disease control.

Water Quality Assessment

Some rural populations are dependent on small reservoirs for their water supply and are concerned about the quality of this water for direct consumption and other uses. Chemical and biological water quality measurements can be made to ascertain the suitability of water for different uses. Water "suitability" of course, depends on the use for which it is intended. This tool describes selected methods for assessing the suitability of reservoir water quality.

Cyanobacteria, cyanotoxins and potential health hazards in tropical small reservoirs

Cyanobacteria, photosynthetic prokaryotes, also called blue-green algae, may be a source of considerable nuisance, particularly when proliferating as the ultimate state of the eutrophication process in water masses. The building of dams and regulation of rivers may create more habitats suitable for cyanobacteria. There is growing concern related to the development of toxic cyanobacterial populations. Cyanobacterial growth is constrained by low levels of light, temperature, and nutrients. In tropical areas, the first two of these are rarely limiting so nutrient availability is usually the key determinant of their proliferation. This tool documents the situation as recently observed in Burkina Faso. It aims to contribute to a better understanding of this issue in less developed countries in tropical basins.

Agricultural Intensification and Ecological Threats around Small Reservoirs

Small reservoirs have the potential to improve the lives of people who irrigate crops and fish, water livestock, and use water in their households. This positive statement needs to be revised, however, when farming practices near reservoirs generate deleterious by-products that degrade water quality in aquatic ecosystems, and reduce the level of goods and services that reservoirs produce. Agricultural intensification and urban expansion both lead to increased levels of anthropogenic inputs into reservoirs. Ultimately, these human activities may undermine reservoirs' integrity and sustainability. This tool demonstrates how to begin the process of analyzing the impact of mans activities on the reservoirs.

Small Reservoirs Water Quality Monitoring using Plankton Abundance and Diversity

Rural populations often are very dependent on small reservoirs for their water supply, and it is widely accepted that land use impacts on water quality in these reservoirs. Therefore stakeholders are often concerned with assessing the reservoirs water quality. Approaches that look at ecosystem integrity can be used to assess water quality. This tool uses plankton (zooplankton and phytoplankton) abundance and diversity to measure water quality. Changes in abundance and diversity of these organisms represent direct and profound responses to pollution entering reservoirs.

Indicators

Using mutually agreed indicators facilitates communication among the key stakeholders and is helpful when planning new small reservoirs. Indicator definitions chosen from the literature should be tailored to local conditions to take into account of the field experience of local experts. Planners should pay special attention to the development and use of impact indicators, including those defined together with the community as being most efficient in measuring change. This tool based on a case study conducted in Morocco demonstrates how this may be done.

IV. Institutions and Economics

This section has two categories of tool sets. One addresses Water Allocation issues (a) and Reservoir ensembles measurements and the other focuses on Institutions and Governance (b). The research behind these tools suggests that a combination of traditional (indigenous) and modern institutions is most effective in ensuring the success of rural livelihoods. The effectiveness of these institutions for the people whom they impact is dependent both on a clear understanding of which actors within the network can influence the implementation of policies. Social cohesion and inclusion, measured as "trust" were found to be very influential in successful cooperation around small reservoirs. Furthermore, expanding the definition of water productivity beyond physical water productivity, to include social values, provides a more comprehensive approach to poverty alleviation. In fact, reallocation based on a combination of physical water productivity and social values can generate new ideas that lead to a significant increase in incomes. In addition to these research findings, a further outcome was the release of new and freely available software tools designed to solve problems encountered when planning and managing small reservoirs.

IV. a) Water Allocation

Water Evaluation and Planning (WEAP) (incl. PEST – Parameter Estimation Tool)

WEAP is a modeling tool for water planning and allocation that can be applied at multiple scales, from community to catchment to basin. WEAP uses scenarios as a way to evaluate different water allocation schemes, given water demand and associated priorities. It includes a hydrological model and links to the groundwater model MODFLOW and the water quality model QUAL2K. WEAP has also been linked to socio-economic models, some of which can track changes over time in livelihood assets given changes in water allocation. It has a global user base, and is available in Arabic, Chinese, English, Farsi, French, Korean, Portuguese, Korean, Spanish, and Thai. In this project, it was applied in …. ???

Financial Accounting Model

This tool converts the outputs of a water planning model like WEAP into variables useful for decision-making by planners and farmers. It can also be used in a stand-alone fashion, without links to such models. The tool is designed for the following purposes: to estimate the initial and recurring farm-level costs of water-related infrastructure, including capital investment and amortization, and operational expenses and to estimate the price and income consequences for farmers of increased production (higher yields, increased planted area) of particular crops. It is meant to be applied to a small number of farmers located in the same watershed.

Water-Limited Yield Model

This tool is designed for the following purposes: to estimate the effect on yields of climate and weather (deviations from average rainfall patterns such as drought; climate change) and to estimate the effect on yields and water consumption of improved irrigation practices. It is intended for use at the field level and it allows for multiple cropping systems. In essence, this tool implements the WEAP two-bucket soil moisture model. The upper bucket is represented by a loss term to the lower bucket or to interflow through percolation losses. Soil moisture in the lower bucket is not tracked. It also provides two new features not present in the WEAP soil moisture model. It models crop yields under water-limited conditions and irrigation efficiency for different irrigation techniques.

Small Reservoir Water Allocation Strategy Water productivity based water allocation

Water is a limited resource, with many users and uses. Water allocation strategies need to recognize this. This tool uses estimates of water productivity and social values to inform decisions on the allocation of scarce water resources. The tool shows how estimates of water productivity can help in the evaluation of the socio-economic contributions of small multiple-use reservoirs.

IV. b) Institutions and Governance

Institutions and governance of small reservoir water resources

Before indigenous practices and institutions can be evaluated, they first have to be identified, described and characterized. This tool describes the methods used to answer a specific question: "Which indigenous practices, legal frameworks and institutions are most conducive to equitable, win-win, and pro-poor investments within sub-Saharan African transboundary basins"? It describes case studies_on transboundary issues and local water governance institutions from the Volta & Limpopo Basins.

Net-Map (Influence Network Mapping)

Net-Map is an interview-based mapping tool that helps stakeholders understand, visualize, discuss, monitor, evaluate and improve situations in which many different actors influence outcomes. By creating Influence Network Maps, individuals and groups can clarify their own views of a situation, foster discussion, and develop a strategic approach to networking activities. It helps users answer such as questions: "Should we strengthen our links to influential supporters who share our goals? Which influential actors do not share our goals? Can increased networking help empower otherwise powerless stakeholders? Which actors typically cause conflicts? Which actors are parties to a conflict? Where are the bottle-necks that prevent a free flow of information? This toolkit includes a theoretical framework and two case studies one on *Organizational learning in multi-stakeholder water governance,* and the other one on *Research on Fisheries Management in Small Multipurpose Reservoirs*

Social Capital

The sustainability of technological interventions in rural settings often depends on socio-environmental interactions among local stakeholders. In principle, the concept of "social capital" makes it possible for relationships and networks to be quantitatively and qualitatively measured. This tool describes a method to assess and analyze social networks within a community to determine how cooperation in that community influences "who participates, and how" in the development of a collective good such as a small reservoir.

OUTCOMES AND IMPACTS

2 Summary Description of the Project's Main Impact Pathways

Because of the sophistication of the tools and the material and intellectual inputs required to use most of them the SRP's most important impacts will be among second tier stakeholders who are scientists, planners and policy makers.

Actor or actors who have changed at least partly due to project activities	What is their change in practice? I.e., what are they now doing differently?	What are the changes in knowledge, attitude and skills that helped bring this change about?	What were the project strategies that contributed to the change? What research outputs were involved (if any)?	Please quantify the change(s) as far as possible
Local stakeholders living in Burkina Faso	They are supposed to be more protective regarding the usage of water resources.	They are now convinced that some hydrological continuum links together reservoirs.	Direct and recurrent discussions, and maps (FasoMAB Atlas)	N/A
Water Resources Managers in Burkina Faso	They probably have a better understanding of the issues surrounding ecosystem health.	They became better informed.	The regular diffusion of results has been essential. The description of the cyanobacteria prevalence and preliminary interpretations hypothezised to explain it	N/A
Universities in Ghana	Are teaching, using a set of tools developed in the SRP as part of their curriculum for an MSc course of on IWRM		Master's student working on SRP became lectures at the Kwame Nkrumah University of Science and Technology (KNUST), We are using established networks to integrate tools into teaching curriculum	N/A
Regional Water Resources Commission and Environmental Protection agency	They are using SRP tools		Collaboration and data exchange	N/A
Agricultural extension agents in Ghana	They are using tools to improve communication with farmers		We developed the tools together with them.	

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

The hydrological inventorying assessment tools are extremely important to planners working in water scarce environments, and there is a growing concern about the use of surface water for domestic consumption. The SRP contributed to increased awareness of the problem of compromised water quality i.e. the prevalence of cyanobacteria. It is now documented, and stakeholders have been informed.

What still needs to be done to achieve this potential? Are measures in place (e.g., a new project, on-going commitments) to achieve this potential? Please describe what will happen when the project ends.
Strategies for the appropriate management and use water within reservoirs should be developed. Important questions remain regarding the production systems for foods (fish, vegetables) produced within or in the vicinity of reservoirs. Specific projects should be developed to learn how to better use the reservoirs.

Each row of the table above is an impact pathway describing how the project contributed to outcomes in a particular actor or actors.
Which of these impact pathways were unexpected (compared to expectations at the beginning of the project?)
From the beginning the collaborations that resulted in these pathways were implicit in our planning. However, we were not aware of the name "impact pathway".

Why were they unexpected? How was the project able to take advantage of them?
They weren't completely unexpected. At the outset of the project, we weren't aware of the interest others would have in our reporting what was going on.

What would you do differently next time to better achieve outcomes (i.e. changes in stakeholder knowledge, attitudes, skills and practice)?
Our collaborations with universities in the basins, Europe, and the US and with local institutions were extremely productive. Although these collaborations developed quickly, next time we would make our intentions explicit from the beginning and devote even more of our resources to them. CPWF's "impact pathway" activities were very useful because they made it more apparent what was going on. In future projects we will make sure resources are available from the outset for these activities and we will think through the process in greater detail so as to optimize to it by acting more deliberately to nurture it.

3 International Public Goods

All outputs of the SRP: peer reviewed articles, PhD dissertations, MSc and BSc theses, and the tools in the tool kit are international public goods (please see www.smallreservoirs.org).

4 Partnership Achievements

We developed a style of research that should be used again. The CPWF encouraged work in more than one basin. Scientific exchanges between teams in Morocco, Ethiopia, Burkina Faso, Zimbawe, Ghana and Brazil were the result. The CPWF also encouraged the collaborations between ARIs, NARES, CGIAR centers and local stakeholders. This mix, particularly that of students from the south and the north, is beneficial to everyone. It creates synergies that cannot be found in any other way. For instance partnerships have been established with Kwame Nkrumah University of Science and Technology (KNUST) and ESA's Tiger project. This partnership has led to continued research in the application of remote sensing (specifically radar images) for the monitoring of small reservoirs. The collaborations with local stakeholders resulted in continuing relationships and in some instances the use of our tools.

5 Recommendations

Research - The Small Reservoirs Project Tool Kit is a good beginning. Nonetheless there are five aspects of this technology that deserve special mention as subjects for further study.

Our work on the hydrology of the reservoirs was particularly productive. It may form the basis of for the development of more refined methods that are fine grained and increasingly reliable in data poor environments. We recommend that the analysis using remote sensing techniques of the hydrology of systems in data poor environments should be continued. This work will have application beyond the analysis of small reservoir systems and will in all likelihood yield results useful for a variety of data scarce environments.

The Bill and Melinda Gates Foundation is funding a study to look at the community management of the reservoirs in the Volta Basin. The improved management of individual reservoirs is critical to the improvement of small holders' livelihoods. Management styles are very heterogeneous and it is probable that studies in other locales should be repeated to develop recommendations that are tailored to the needs of the people adopting them.

There is also a need for us to understand in detail the business options available to smallholders. There are undoubtedly farmers who adopt profitable business models and make good use of the reservoir. And there are many who don't either because they make poor choices or because they are constrained in some way. This is an unglamorous area of research that deserves far more attention than it has received so far.

The ecology and human health impacts of these systems at the catchment and reservoir scales are now beginning to be understood. We have demonstrated that the reservoirs' water quality is generally poor. These vital structures are subject to abuse by the people who made them and use them. If they are to be sustainable as useful tools for the supply of water we must develop intelligent techniques for their use. Therefore we recommend that the study of the ecology of these systems is also a high priority.

Extension – Researchers should continue to work closely with extension workers for at least two reasons: 1) because of their close relationships with the people who use the reservoirs extension workers are an invaluable source of information and ideas for tailoring the research so that it addresses real needs., and 2) if extensionists are involved from the outset of the research they are more likely to understand the researchers findings and to use the insights that are developed.

Policy - With the changing climate, in many semi-arid locations reliable water supply will become increasingly important to the livelihoods of rural people. In these relatively flat areas there are very few sites suitable large reservoirs. Cost, environmental concerns, and the lack of management capacity make them an unattractive option. Where there is choice between pumping groundwater and the use small reservoirs policy makers should consider supporting the construction and use of small reservoirs for the following reasons: 1) Small Reservoirs are less costly to operate and maintain than pumped systems. Small reservoirs do not require recurrent expenditures for parts and fuel. 2) Groundwater mining can result in escalating costs of extraction and eventually reduction in the available supply. The annual supply from a small reservoir is self limiting, therefore there is a reduced risk that the resource will be unsustainable exploited. And 3) Fish production, recreational, and other non-consumptive uses are supported by small reservoirs, but not by groundwater pumping. Where groundwater is unavailable, polluted, or at great depth small reservoirs may be the only available option.

6 Publications

- **Peer-reviewed Articles / Book Chapters**

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- **Software**

For the assessment of the impact of reservoir ensembles, a simple MatLab script has been produced which is available through SRP and Nick van de Giesen (n.c.vandegiesen@tudelft.nl).

- **Training materials**

Training manual remote sensing, an introduction to WEAP, and on Environmental Impact of SR for IWRM MSc course at KNUST.

Training materials, papers, and other resources to assist in developing WEAP applications can be found at http://www.weap21.org/.

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PROJECT PARTICIPANTS

- **Project researchers**

Andah, Winston, Water Research Institute, Ghana

Andreini, Marc, International Water Management Institute, USA

Azevedo, Juscelino Antônio de, Embrapa Cerrados, Brazil

Boelee, Eline, International Water Management Institute, Ethiopia

Cecchi, Philippe, Institut de Recherche pour le Développement, France

Correia, João Roberto, Embrapa Cerrados, Brazil

Giesen, Nick van de, TU Delft, Netherlands

Guimarães, José Eloi, Universidade de Brasília, Brazil

Huber-Lee, Annette, international Food and Policy Institute, USA

Kemp-Benedict, Eric Stockholm Environment Institute-US Center, Somerville, USA

Laamrani, Hammou, IDRC, Egypt

Liebe, Jens, Cornell University, US/ Center for Development Research (ZEF) Bonn University, Germany

Munamati, Muchaneta, University of Zimbabwe, Zimbabwe

Parron vargas, Lucilia Maria, Embrapa Cerrados, Brazil

Purkey, David R. Stockholm Environment Institute-US Center, Sacramento, USA

Rodrigues, Lineu Neiva, Embrapa Cerrados, Brazil

Sano, Edson Eiji, Embrapa Cerrados, Brazil

Schuetz, Tonya, International Water Management Institute, Ghana

Senzanje, Aidan, University of Zimbabwe

Sieber, Jack, Stockholm Environment Institute-US Center, Somerville, USA

Sithole, Personal Nontando, Agricultural & Technical Services (Agritex), Zimbabwe

Souza Martins, Éder de, Embrapa Cerrados, Brazil

Steenhuis, Tammo, Cornell University, US

Sullivan, Amy, International Water Management Institute, South Africa

- **Theses Students**

Annor, F.O., UNESCO-IHE Institute for Water Education, Delft, the Netherlands, Kwame Nkrumah University of Science and Technology, Ghana

Balazs, C., University of California, Berkeley, USA.

Chikati, R., University of Zimbabwe

Dekker, T., Technical University Delft, The Netherlands

Dufour R.A., Université Montpellier II, France.

Faulkner, J., Cornell University, USA.

Gower, Drew, Wisconsin University, USA

Hyrkäs, W., Lund University, Sweden

Liebe, J.R., Cornell University

Linsen, M., Technical University Delft, The Netherlands

Masona, C., University of Zimbabwe

Michel, A., University of Paris VII, France.

Moiroux, N., Université Paul Sabatier, Toulouse, France.

Mufute, N.L., University of Zimbabwe

Mutepfa, J.E., University of Zimbabwe

Pernholm, S., Lund University, Sweden

Poolman, M. I., Technical University Delft, The Netherlands.

Rukuni, S., University of Zimbabwe.

Rusere, S.. University of Zimbabwe.

Sawunyama, T., University of Zimbabwe.

Thomazeau S., Museum National d'Histoire Naturelle, France,

van Kinderen I., Technical University Delft, The Netherlands

Woch, M., University of Zimbabwe.

Zerbo P., Université de Ouagadougou, Burkina Faso.

- **Project work students**

Abarike Apuswin Mercy, University of Development Studies, Tamale, Ghana

Bordoh Paa Kwesi, University of Development Studies, Tamale, Ghana

Cimara Monteiro, Universidade de Brasília, Brazil

Denilson Pereira Passo, Universidade Estadual de Goiás, Brazil

Dramana Zongo, Université de Ouagadougou, Burkina Faso.

Galgane Patricia Luiz, Universidade Estadual de Goiás, Brazil

Geertjo van Djik, Delft University of Technology, The Netherlands

Juliana Marioti, Universidade Estadual de Santa Catarina, Brazil

Kate Emans, Harvard University, USA

Korese Joseph Kudadam, University of Development Studies, Tamale, Ghana

Leison Simão Amaral, Universidade Estadual de Goiás, Brazil

Linda Liang, Harvard University, USA

Martin Bloemendal, Delft University of Technology, The Netherlands

Martine Rutten, Delft University of Technology, The Netherlands

Maura Allaire, Tuft University, Medford, Massachusetts, USA

Monique Sanders, Delft University of Technology, The Netherlands

Nienke Kramer, Delft University of Technology, The Netherlands

Patricia Ammerlaan, Delft University of Technology, The Netherlands

Reinaldo Néris da Silva, Universidade Estadual de Goiás, Brazil

Saint-clair Pereira de Oliveira Neto, Universidade Estadual de Goiás, Brazil

Appendix A

Boelee E & Koné A: *Health impacts of small reservoirs in Burkina Faso (2009)*. IWMI Working Paper 136. International Water Management Institute (IWMI), Colombo, Sri Lanka.

This working paper discusses health impacts of small reservoirs in Burkina Faso. Small earth reservoirs have been increasingly promoted in several West-African countries since the 1980s but the environmental and health impacts resulting from this type of intervention are not well researched. However, some secondary information turned out to be available in "grey" literature such as students' theses. Data from different sources have been combined into national maps and synthesized for small reservoirs in different climatic zones.

In Burkina Faso, around 1500 small dams have been constructed, most of these since 1974, to provide water to people and livestock in drought-prone areas. In the drier parts of the country, these reservoirs are still mainly used for watering livestock, sometimes leading to heavy local population pressure. In other areas the water is increasingly used for irrigation of vegetables. A new government strategy initiated in 2002 foresees the construction of more dams and 20,000 hectares of new village irrigation systems. In many places, the creation of small reservoirs in Burkina Faso has resulted in increased household income through productive agricultural activities upstream and downstream of the reservoir. However, in almost all cases no preventive measures were taken to ensure that the small reservoirs do not have adverse environmental and health impacts. Significant environmental degradation can occur in the vicinity of small reservoirs as result of increased pressure from people and livestock arising as a direct result of improved water resources. Pollution and sedimentation of small reservoirs can occur as a consequence of inappropriate land-use practices and poor catchment management.

The water-related diseases most directly linked to the construction of small dams are schistosomiasis and malaria. For schistosomiasis, some field studies found increased transmission after implementation of the reservoir, especially in the semi-arid north, where the reservoirs provided perennial water bodies in an area where previously the intermediate snail host depended on temporary pools. Human behavior regarding water use and hygiene however is more important than the presence of snails as a determinant of transmission. For malaria the link is even more complicated as mosquitoes hardly breed in the reservoir itself and an increase in vector mosquitoes does not necessarily lead to increased malaria transmission.

Knowledge of water related diseases, including causes and avoidance measures, is low in Burkina Faso. Public awareness campaigns are necessary to explain to communities the possible impacts of reservoirs and irrigated agriculture on their health. This should be done even before the promotion of preventive and curative measures against the water-related diseases. Alternative water sources for domestic supply should be developed if possible. The reduction of the negative impacts of small reservoirs on the environment and public health requires an integrated approach that specifically identifies the enhancing and limiting factors that influence environmental impacts and the transmission of diseases in the reservoir environment. It is only from a good knowledge of the risks that effective environmental management and disease control programs can be developed in a way that fits with regional strategies for poverty eradication and sustainable development.

Laamrani H., Boelee E., Ait Lhaj A., (2007) Les petits barrages au Maroc, de la dimension sociale à l'impact économique, sanitaire et environnementale. P 61-71 in AMAECO (ed): *Actes du Séminaire Développement Durable des Zones de Montagne*, 1-2 Décembre 2005, Rabat. Association Marocaine de l'Agro-Economie/DPAE

Depuis les années 80, le Maroc comme de nombreux pays du continent Africain s'est lancé dans une politique de petits barrages en parallèle aux grands ouvrages de mobilisation des ressources en eaux de surface. Cette politique répond aux défis des sécheresses récurrentes qui ont secoué le pays. Mais aussi, aux besoins de développement des zones qui ne se prêtent pas à des projets de plus grande envergure. Le nombre de sites de ce type de barrages techniquement faisables est estimé à cinq cents. Le but de ces ouvrages est de collecter les eaux destinées à des usages multiples, notamment l'irrigation, l'abreuvement du bétail, la recharge de la nappe, la prévention des inondation et dans certains cas l'alimentation en eau de boisson. Plus récemment, la politique des petits barrages a été réitérée par le gouvernement. Ce qui laisse entendre que leur construction va se poursuivre dans le futur. A présent, le nombre de petits barrages tous types confondus a dépassé la centaine. Cependant, leur impact sur la santé et le bien être des populations bénéficiaires, sur l'environnement ainsi que leur valeur ajoutée au niveau local et national reste à déterminer. L'expérience de certains petits barrages au Maroc et dans d'autres pays africains démontre qu'ils peuvent dans certains cas poser des problèmes liés au faible impact social et économique, favoriser l'introduction de maladies eaux dépendantes et posent parfois des problèmes techniques liés au choix du site, à l'envasement ou aux fuites et ruissellement de l'eau du réservoir. Le manque de mesures d'accompagnement peut dans certains cas limiter l'élan de développement escompté. La présente communication a pour objectif de discuter, sur la base d'études de cas, les solutions envisageables et pouvant optimiser l'impact des petits barrages pour en faire un levier de développement durable dans les zones enclavées notamment de montagne.

Laamrani H., Ait Lhaj A, Boelee E, Lyaagoubi M, Rhajaoui M (2007) Approche éco-systémique de la sante humaine: vision inclusive et intégrée du développement. P 112-116 in AMAECO (ed): *Actes du Séminaire Développement Durable des Zones de Montagne*, 1-2 Décembre 2005, Rabat. Association Marocaine de l'Agro-Economie/DPAE.

Au cours des quatre dernières décennies, un foisonnement des méthodologies élaborées pour une gestion harmonieuse des ressources naturelles pour le développement des zones enclavées en particulier des montagnes a eu lieu. Au niveau global, la prise de conscience croissante du lien inextricable entre le bien être des communautés et la gestion durable des ressources a été entre autre parmi les catalyseurs du développement de l'approche éco-systémique de la santé communément connue sous le nom d' «ECOSANTĖ ».

L'approche part du paradigme simple qui considère la santé comme étant le résultat de l'interférence dynamique entre les déterminants socioculturels, économiques, institutionnels et environnementaux. Ces éléments étant considérés dans la définition même de l'écosystème. L'approche est basée sur trois piliers méthodologiques permettant une meilleure compréhension des réalités souvent complexes des zones de montagnes.

Le premier pilier est la participation active des communautés cibles en tant que partie prenante dans l'élaboration des questions de recherche (définitions des objectifs) et de leurs retombées en termes d'actions de développement. Cette vision inclusive permet d'assurer à la fois la pertinence des questions de recherche développement mais aussi la durabilité des actions visant à améliorer la réalité des communautés impliquées. En plus la participation active permet l'implication de tous les acteurs et preneurs de décision qui détiennent parfois à eux seuls le pouvoir de définir les solutions.

Le second pilier consiste à adopter une méthodologie transdisciplinaire qui dépasse les frontières disciplinaires à travers des passerelles d'échange mutuel et permanent entre les différentes disciplines impliquées dans la recherche. La transdisciplinarité permet ainsi une vision intégrée ou les différents spécialistes mettent en synergie leur savoir faire complémentaires pour une meilleure compréhension des réalités à changer et des alternatives et mesures à mettre en place.

La question du genre et d'équité sociale constitue un troisième pilier tout aussi important que les précédents. Elle permet une visibilité des rapports de pouvoir entre composantes et sous groupes communautaires en rapport avec les ressources, leur gestion et leur impact sur le bien être respectif des différentes composantes socioculturelles.

La mise en application de l'approche «ECOSANTẺ » au Maroc et dans d'autres pays d'Afrique, du Moyen Orient, d'Asie et d'Amérique latine a démontré les prouesses et les défis de l'approche. Cette présentation vise à élucider à travers des exemples puisés dans le concret, la portée et les limites de l'approche. Nous discuterons également des perspectives de recherche-développement qu'elle permet aux différentes disciplines visant à contribuer au bien être des populations des zones de montagne au Maroc.

Boelee E, Laamrani H, Ait Lhaj A, Zongo D, Rhajaoui H, Yohannes M (2006) Health impact assessment of small reservoirs. Abstract accepted for Session 8 on Positive Management of Dam Reservoirs at the *International Forum on Water and Food*, 13 November 2006, Vientiane.

While the health impacts of large dams have been documented extensively, much less is known about small reservoirs. Over the last two decades, multiple purpose small dams and reservoirs mushroomed over the African continent to provide water for rural development, as affordable alternative to large dams and large-scale irrigation systems. In Burkina Faso alone some 1500 reservoirs have been constructed. Many benefits are generated by small dams, particularly improving the livelihoods as water is used for irrigated agriculture, livestock, fish production, drinking and domestic uses. Subsequently, better hygiene and nutrition are expected to lead to improved community health.

However, in many settings, water impoundment in small dams led to negative health impacts. The reservoirs have been reported to aggravate existing health problems or to introduce new water related diseases such as malaria and schistosomiasis, leading to high child morbidity and mortality. The reservoirs created suitable micro-environments for mosquitoes and snails and new settlers sometimes introduced the pathogens to the ecosystem. Hence, anticipated benefits in some cases were undermined as linkages between the environmental changes and the social determinants of human health were not given enough attention.

By looking at the ecosystem as a whole, complex linkages between the environment and human health can be understood and health determinants can be analyzed. Combining classical biomedical methods with participatory tools, this so-called ecohealth approach helped to identify the multiple benefits and limitations of a small dam in southern Morocco. These findings went beyond the health domain and showed that the local communities had varying and quite different perceptions than the planners. In Ethiopia, community involvement in mosquito control helped to reduce malaria risk in the long term. This approach could be up-scaled and thus provide an interesting alternative to the traditional methods of malaria control that have become too costly for the public health system. However, this requires full commitment of the users of the dams and its downstream water infrastructure.

In a CPWF project in Burkina Faso, it was found that classical data collection showed a relation between small reservoirs and urinary schistosomiasis. For malaria no differences were found between areas close to a small reservoir and those further away (to be confirmed in November with recent data). Hence the multiple uses of water created multiple health benefits and risks to multiple stakeholders. Again, this will lead to recommendations on how to plan and manage small reservoirs differently so as to enhance health benefits and reduce health risks. The difference with large reservoirs is that with small ones, the management is done at the community level, where people may perceive the health impacts but do not have access to means of influencing these.

Laamrani H, Boelee E, Ait Lhaj A, Rhajaoui H, Yohannes M, Zongo D (2006) Strengths and challenges of Ecosystem Approaches to Human Health: Lessons learnt from health impacts of small dams' case studies in Ethiopia, Burkina Faso and Morocco. Abstract accepted for Ecohealth One conference, October 6-10, Wisconsin.

Over the last two decades, multiple purpose small dams and reservoirs mushroomed over the African continent to provide water for rural development, (e.g. in Burkina Faso, nearly 1500 reservoirs). Many benefits were generated by small dams particularly improving the livelihoods as water was used for irrigated agriculture, livestock, fish production, drinking and domestic uses. Subsequently, better hygiene and nutrition are expected to lead to improved community health.

In many settings, water impoundment in small dams exacerbated existing health problems or introduced new water related diseases that emerged as new settlers introduce new pathogens to the ecosystem. Child mortality and morbidity associated with malaria and schistosomiasis are eloquent examples. Hence, anticipated benefits in some cases were undermined as linkages between the environmental changes and the social determinants of human health were not given enough attention.

Indeed, ecosystem approaches to human health provide an extremely suitable conceptual framework to understand complex linkages between environment and human health determinants. Such holistic, *de facto* inclusive vision is a key element to consider at the planning and design stages of small reservoirs to optimize their impact on people's health and well being. An EcoHealth approach will help to anticipate and mitigate health hazards while optimizing health benefits.

We report on results of case studies on health impacts of small reservoirs in three very different settings in Africa: 1. Community involvement in mosquito control in Ethiopia helped to reduce malaria risk in the long term. 2. Multiple uses of water in Burkina Faso create multiple health benefits and risks to multiple stakeholders 3. Participatory health impact assessment in Morocco showed that the local community has different perceptions of benefit than planners.

The diversity of issues and constraints in implementing Ecohealth approaches raised the relevance of politico-cultural specificities and contingencies of the communities using the small reservoirs.

Senzanje, Aidan, Boelee, Eline and Rusere, Simbarashe (2008): Multiple use of water and water productivity of communal small dams in the Limpopo Basin, Zimbabwe, in Irrigation and Drainage Systems Published online: 22 Nov. 2008, **http://dx.doi.org/10.1007/s10795-008-9053-7**

The history of dam construction in Zimbabwe dates back to the 1920s and since then over 7,000 small dams have been constructed countrywide. Small dams are multipurpose structures used for improving rural livelihoods. The multipurpose nature of these dams has largely gone unquantified in terms of importance of the uses to the community and influence of management practises. The current study made use of a questionnaire among small dam users, key informant interviews, secondary data and observation on four communal dams in the Limpopo basin to establish the uses, volume of water abstracted and water productivity for some uses and the interrelationship between various organisations and the community in the management of small dams. Uses on all dams in order of importance were livestock watering, domestic use, irrigation, fishing, brick making, and collection of reeds used for roofing. Livestock consume on average over 70% of water for consumptive uses. Water productivity in terms of yield per volume unit of water used ranged from 0.025 kg m^{-3} for vegetables to 7,575 kg m^{-3} for bricks, and monetary values per volume unit of water used were Z$ 389,434 m^{-3} for brick making and Z$ 1,874 m^{-3} for irrigation. Traditional leadership and the community are pivotal in the management of the small dams, with some organisations giving technical, financial and input assistance. The management and conservation of small dams needs to be well coordinated between the communities, NGOs and government if the full benefits of these national resources are to be realised in the long term.

Mufute, N., A. Senzanje and E. Kaseke. (2008). The development of a risk of failure evaluation tool for small dams in Mzingwane Catchment, Zimbabwe. ***Journal of Physics and Chemistry of the Earth. Vol. 33, Issues 8 – 13:pp926 – 933*** **http://dx.doi.org/10.1016/j.pce.2008.06.029**

Small dams in Mzingwane Catchment in southern Zimbabwe are mostly in poor physical condition mainly due to lack of resources for repair and maintenance. Most of these dams are likely to fail thereby adversely affecting water availability and livelihoods in the area. To assist those involved in maintenance, repair and rehabilitation of small dams in resource poor and data sparse areas such as Mzingwane Catchment, a non probabilistic but numerical risk of failure evaluation tool was developed. The tool helps to systematically, and objectively classify risk of failure of small dams, hence assist in the ranking of dams to prioritise and attend to first. This is important where resources are limited. The tool makes use of factors such as seepage, erosion and others that are traditionally used to assess condition of dams. In the development of the tool, an assessment of the physical condition of 44 (1 medium sized and 43 small dams) dams was done and the factors were identified and listed according to guidelines for design and maintenance of small dams. The description of the extent to which the factors affect the physical condition of small dams was then standardised. This was mainly guided by standard based and risk based approaches to dam safety evaluation. Cause-effect diagrams were used to determine the stage at which each factor is involved in contributing to dam failure. Weights were then allocated to each factor depending on its stage or level in the process of causing dam failure. Scores were allocated to each factor based on its description and weight. Small dams design and maintenance guidelines were also used to guide the ranking and weighting of the factors. The tool was used to classify 10 dams. The risk of failure was low for one dam, moderate for one, high for four and very high for four dams, two of which had already failed. It was concluded that the tool could be used to rank the risk of failure of small dams in semi-arid areas. The tool needs to be tested in a wider geographical area to improve its usefulness.

Sawunyama, T., A. Senzanje and A. Mhizha (2006): ***Estimation of small reservoir storage capacities in Limpopo River Basin using GIS procedures and remotely sensed surface areas – Case Study of Mzingwane Catchment, Zimbabwe.*** **Physics and Chemistry of the Earth. Vol.31, Issues 15-16:935 – 943. http://dx.doi.org/10.1016/j.pce.2006.08.008**

The current interest in small reservoirs stems mainly from their utilization for domestic use, livestock watering, fishing and irrigation. Rarely were small reservoirs considered in the water resources system even though they are important in water resource planning and management The main limitation being lack of knowledge on small reservoir capacities, for the methodologies used to quantify physical parameters of reservoirs are costly, time consuming and laborious. To address this challenge an attempt has been made in this study to estimate small reservoir storage capacities using remotely sensed surface areas. A field study on 12 small reservoirs was carried out in Mzingwane

Catchment in Limpopo River Basin; Zimbabwe. The depths of water accompanied with their coordinates were measured; from which area and capacity were calculated for each reservoir using geographical information system based on data acquired from the field and that from satellite images. The output data was compared and a linear regression analysis was carried out to establish a power relationship between surface area and storage capacity of small reservoirs. The Pearson correlation analysis at 95% confidence interval indicated that the variances of the two surface areas (field area and image area) were not significantly different ($p<0.05$). The findings from linear regression analysis (log capacity-log area) show that there exist a power relationship between remotely sensed surface areas (m^2) and storage capacities of reservoirs (m^3), with 95% variation of the storage capacity being explained by surface areas. The relationship can be used as a tool in decision-making processes in integrated water resources planning and management in the river basin. The applicability of the relationship to other catchments requires further research as well as investigating the impacts of small reservoirs in water resources available in the river basin by carrying out a hydrological modelling of the catchment.

Busane Basima, L., Senzanje, A., Marshall, B., and Shick, K., (2006): *Impacts of land and water use on plankton diversity and water quality in small man-made reservoirs in the Limpopo Basin, Zimbabwe: A preliminary investigation.* Physics and Chemistry of the Earth. Vol.31, Issues 15-16:821 – 831. http://dx.doi.org/10.1016/j.pce.2006.08.026

This paper reports on a study carried out from February to April 2005 in the southern part of Zimbabwe in the Mzingwane catchment, Limpopo basin to investigate the impacts of land and water use on the water quality and ecosystem health of eight small man-made reservoirs. Four of the reservoirs of were located in communal lands while the remaining four were located in the National Park Estates, considered pristine. Plankton community structure was identified in terms of abundance and diversity as an indirect assessment of water quality and ecosystem health. In addition, phosphorus, nitrogen, pH, transparency, electric conductivity and hardness were analysed. The results obtained indicate that a significant difference in abundance of phytoplankton groups was found between the communal lands and the National Park Estates ($P<0.01$). Though the highest phytoplankton abundance was observed in April, February showed the highest number of taxa (highest diversity). Chlorophytes was the major group in both periods with 29 genera in February and 20 in April followed by Diatoms with 17 genera in February and 12 in April. The zooplankton community was less diverse and less abundant and did not show any seasonality pattern. Phosphorus (0.022 ± 0.037 mg/l) and nitrogen (0.101 ± 0.027 mg/l) had similar trends in the study area during the study period. Transparency of water was very low (ca. 27 cm secchi depth) in 75% of the reservoirs with communal lands' reservoirs having a whitish colour, likely reducing light penetration and therefore photosynthetic potential. Evidence from the study indicates that, at this time, activities in the communal lands are not significantly impacting the ecosystem health of reservoirs, as water quality characteristics and plankton diversity on communal lands were not significantly different from the pristine reservoirs in National Park. However, water managers are urged to continuously monitor the changes in land and water uses around these multipurpose reservoirs in order to prevent possible detrimental land and water uses that might occur in the future.

M. Munamati, A. Senzanje, **(2008) Dimensions of Stakeholder Interactions in Small Reservoir Development in Zimbabwe, in *Development Southern Africa*, (submitted)**

Small reservoirs have multiple functions and are exploited by a variety of user groups. These heterogeneous stakeholders have different objectives, production strategies and priorities in small reservoir development. It therefore could be anticipated that there are likely to be conflicts in their development process. The different interest and preferences of these various stakeholders need to be investigated and reconciled to ensure sustainable development of small reservoirs. This paper is based on research done in Zimbabwe and discusses the various stakeholders involved in small reservoir development, with emphasis on the role they play, their interactions with each other and conflicts that result through these interactions. The research approach was based mainly on interviews with key informants who have a stake in small reservoir development. These are mainly government departments, politicians and rural communities. It was shown that small reservoir development causes a shift in existing relationships and control among stakeholders. These relations affect how each group of stakeholders interacts with others and how stakeholder groups participate in the development process. Cooperation and conflict arise from relational issues, such as trust, and disagreements over decisions and actions. Differences in interests, power, influence and knowledge among the stakeholders contribute to shaping the nature of stakeholder cooperation and conflict. The kind and level of knowledge possessed by stakeholders affects their participation or participation by other stakeholders. It is important for these stakeholders to understand the each others' roles in small reservoir development and to appreciate and acknowledge their influence to avoid conflicts.

Sithole, P.N., Senzanje, A., Sawunyama, T., Rusere, S. (2008): An analysis of the socio-economic issues pertaining to small reservoirs usage, livelihoods implications and management in the Limpopo basin, Zimbabwe. *Natural Resources Forum Journal* (submitted)

Small reservoirs are multipurpose systems common in semi-arid Africa with Zimbabwe having an estimated 7000 of these. Small reservoirs are central to rural livelihoods, but a number of issues about them are not fully understood. This paper presents the findings of a study carried out on communities served by 6 small reservoirs in semi-arid Limpopo basin in Zimbabwe. The study sought to understand the uses put to the small reservoirs and their impact on livelihoods as well as the managerial issues of concern. The study comprised a representative survey of 100 households from 14 villages and key informant interviews in the area. The major uses of the small reservoirs were livestock watering, domestic water supply, small scale and garden irrigation, brick making and fishing. Predominantly, the reservoirs were for livestock watering as livestock are central to the rural livelihoods in the area for both supply of protein, income from sales, draft power and transportation. During the study, an average ox for sale fetched about US$400. The small reservoirs supplied water to livestock from a radius as large as 10 km. Domestic supply was for drinking, bathing and laundry and a household fetched on average 140 l/day. Most reservoirs had some form of garden – either individual or group gardens for producing various vegetables for consumption and for sale. On average, income from vegetable sales was US$48/ per household per year for those with gardens. Brick making consumed about 580 l of water per 1000 bricks which fetched, on average, US$136/1000 bricks when sold. The development, operation and management of small reservoirs are different to that of large dams, and involve a number of stakeholders. These include the beneficiary communities, government departments and NGOs.

Sawunyama, T., G. Chinoda, D. Love, A. Senzanje, P. Mangeya and N. Matura (2007): *Characterisation of the hydro-geology and the capacity of a small reservoir using remote sensing – Sibasa dam, Limpopo Basin, Zimbabwe*. WaterSA*. (Accepted for publication)*

The middle reaches of the Limpopo Basin in Zimbabwe contain some of the country's poorer communities, whose livelihoods are periodically threatened by recurrent droughts. One of the most common interventions by government and NGOs is construction of small dams - and a major construction drive is being initiated this year. An integrated case study of a small dam was undertaken at Sibasa in Insiza District to determine the characteristics of the reservoir that affects rural livelihoods. Sibasa Dam, capacity 30,000 m^3, lies in the source of an ephemeral stream, which drains into the Insiza River. The average rainfall is 550 mm/a (40 year range 250 - 1100 mm/a). This dam is located above an important fracture in the crystalline basement, providing perennial recharge to the dam from the aquifer. This has ensured that the dam never dried up since construction fifty years ago although variable rainfall has led to variations in its water storage, clearly visible from satellite images (1991-2005 range 10,000 to 35,000 m^3). The application of remote sensing techniques has thus allowed for rapid characterisation of the hydrogeology and capacity of the dam. With this information known, planners and water managers will quickly make decisions on how to utilize and manage the available water given the various competing uses.

F.O. Annor, N. van de Giesen, J. Liebe, P. van de Zaag, A. Tilmant, S.N.Odai, Delineation of small reservoirs using radar imagery in a semi-arid environment: A case study in the Upper East Region of Ghana, in Irrig. and Drain. 57: 151–163 (2008)

Small reservoirs serve many people living in semi-arid environments. Water stored in these reservoirs is used to supplement rainfed agriculture, allow for dry season irrigated agriculture and ensure the availability of water for domestic purposes. In order to manage the water effectively for competing uses, the actual storage of these reservoirs needs to be known. Recent attempts to delineate these reservoirs using remote sensing with Landsat imagery have been successful, especially in the Upper East Region of Ghana, West Africa. This paper shows that radar images (ENVISAT ASAR) can be used to provide similar information all year-round. Radar images have as an important advantage that they are not impaired by cloud cover and thus can be used during the rainy season. Another advantage of radar images is that images taken during night time are usable. The paper compares satellite derived data with field measurements of 21 small reservoirs. Whereas ENVISAT images on the average tend to overestimate the surface areas of small reservoirs, in certain reservoirs these areas are systematically under-estimated due to the shallow tail-ends of reservoirs that tend to have reed vegetation. These cannot be readily distinguished from the surrounding vegetation outside the reservoirs. This paper therefore provides a proof of concept of the monitoring of small reservoir volumes by radar imagery.

Faulkner, J.W., Steenhuis, T., van de Giesen, N., Andreini, M., Liebe, J., (2008): Water Use and Productivity of two Small Reservoir Irrigation Schemes in Ghana's Upper East Region, in *Irrigation and Drainage* 57: 151–163 (2008), Published online in Wiley InterScience (www.interscience.wiley.com) DOI: 10.1002/ird.384

To examine the impact of small reservoir irrigation development in Africa, the performance and productivity of two small reservoirs and irrigation schemes in the Upper East Region of Ghana were investigated in this study. Hydrologic data measured included daily irrigation volumes and daily evaporation. Farmer cost inputs, excluding labor, and harvest data were also recorded. There was a strong contrast in water availability between the two systems, the Tanga system having a higher amount of available water than did the Weega system. The concept of relative water supply was used to confirm this disparity; Tanga was an inefficient system with a relative water supply of 5.7, compared to a value of 2.4 for the efficient Weega system. It was also concluded that the dissimilar water availabilities resulted in the evolution of very different irrigation methods and coincided with different management structures. Where there was more water available per unit land (Tanga), management was relaxed and the irrigation inefficient. Where there was less water available per unit land (Weega), management was well structured and irrigation efficient. The productivity of water (US$ m_3) of the Tanga system was half that of the Weega system, when analyzed at a high market price for crops grown. In terms of productivity of cultivated land (US$ ha_1), however, the Tanga system was 49% more productive than the Weega system. The difference in the productivity of land is primarily a result of increased farmer cash inputs in the Tanga system as compared to theWeega system. The difference in the productivity of water can be attributed to the varying irrigation methods and management structures, and ultimately to the contrasting water availability.

MOHSIN HAFEEZ, MARC ANDREINI, JENS LIEBE, JAN FRIESEN, ANDREAS MARX, NICK VAN DE GIESEN, Hydrological parameterization through remote sensing in Volta Basin,West Africa, in *Intl. J. River Basin Management* Vol. 5, No. 1 (2007), pp. 49–56, © 2007 IAHR, INBO & IAHS

Ground-based hydrological data collection tends to be difficult and costly, especially in developing countries such as Ghana and Burkina Faso where the infrastructure for scientific monitoring is limited. Remote sensing has the potential to fill the gaps in observation networks. The GLOWAVolta Project (GVP) seeks to maximize the information to be gained from satellite imagery by combining remotely sensed data with strategically chosen ground observations. However, there is very limited information about the coupling of remotely sensed data with ground based data over the mixed savanna terrain of West Africa. This paper provides an overview of innovative techniques to measure hydrological parameters as actual evapotranspiration, rainfall, and surface runoff over mixed savanna terrain in a semi-arid region inWest Africa, and their potential use. Evapotranspiration – The Surface Energy Balance Algorithm for Land (SEBAL) was used to calculate sensible heat flux and evapotranspiration through the energy balance. The SEBAL parameterization is an iterative and feedback-based numerical procedure that deduces the radiation, heat and evaporation fluxes. Along a 1,000 km gradient in the Volta Basin, three scintillometers were installed to measure sensible heat flux over distances comparable to *NOAA-AVHRR* pixels, approximately two kilometers. The comparison of sensible heat flux measured from remotely sensed data and scintillometers provide accurate results. This will help to increase the reliability of SEBAL parameterization.

Rainfall – Depending on the region within the Volta Basin, up to 90% of the precipitation in originates from squall-lines. The Tropical Rainfall Measuring Mission (TRMM) imagery provides a valuable tool to monitor such squall lines. However, the TRMM signal should be validated for squall line rainfall. To increase the reliability of space-based rainfall measurements, TRMM based rainfall rate estimates were calibrated with rainfall measurements from a dense network of rain gauges.

Surface Runoff – Remote sensing has limited value in estimating surface runoff. The savanna of West Africa, however, is dotted with a large number of small reservoirs used to supply water for households, cattle, and small scale irrigation. Bathymetry of sixty reservoirs in Ghana's Upper- East Region produced a very regular correlation between surface area, as observable by satellites, and volumes. By using all-weather RADAR imagery and the measured surface/volume curves, surface runoff volumes can be monitored throughout the year. These indirect runoff measurements will help researchers to develop surface-runoff models for the Volta Basin.

MARTINE POOLMAN & NICK VAN DE GIESEN, Participation: Rhetoric and Reality. The Importance of Understanding Stakeholders, Based on a Case Study in Upper East Ghana, in: Water Resources Development, Vol. 22, No. 4, 561–573, December 2006

Based on the views of a number of stakeholders involved in the development of small reservoir systems in the Upper East Region of Ghana in West Africa, this paper examines the importance of understanding the stakeholders whom the international development community wants to include in its participatory approaches. The paper also aims to show that terms such as 'participation', 'participatory approach' and 'participatory planning' are often used in project proposals, but that in reality the extent to which stakeholders are actually able to participate in projects is limited. This limitation is often due to a lack of understanding by the project organization of the interests and views of the stakeholders, which are then not incorporated in the project process.

A stakeholder analysis could provide more insight in the interests, goals and views of all stakeholders involved in a project, as well as in the differences between the stakeholders. In the development of water resources, the long-term sustainability of a project's work is dependent on the manner in which relevant (often local) stakeholders continue the process after the official time of the project has ended. Thus, since the project is dependent on the involvement of relevant stakeholders, the formulation of adequate and appropriate forms of stakeholder engagement that will ensure information exchange and participation is essential. However, as the case study shows, such analyses were not always carried out, thus leading to a number of problems with project implementation and also with transplantation from one region, district or community to another.

J. Liebe, N. van de Giesen, M. Andreini, Estimation of small reservoir storage capacities in a semi-arid environment A case study in the Upper East Region of Ghana in: *Physics and Chemistry of the Earth* 30 (2005) 448–454

In semi-arid regions at the margins of the Sahel, large numbers of small reservoirs capture surface runoff during the rainy season, making water available during the dry season. For the local population, small reservoirs are important water sources which help them cope with droughts. The lack of knowledge of the number of existing reservoirs, their distribution, and their storage volumes hinders efficient water management and reservoir planning. The authors have developed a simple method that allows the estimation of reservoir storage volumes as a function of their surface areas. This function is based on an extensive bathymetrical survey that was conducted in the Upper East Region of Ghana. In combination with satellite imagery, this function can be used determine and monitor the storage volumes of large numbers of small reservoirs on a regional scale.