CPWF Project Report

Improved water and land management in the Ethiopian highlands and its impact on downstream stakeholders dependent on the Blue Nile

Project Number 19

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UNESCO-CWR

Program Preface:

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

The CPWF conducts action-oriented research in nine river basins in Africa, Asia and Latin America, focusing on crop water productivity, fisheries and aquatic ecosystems, community arrangements for sharing water, integrated river basin management, and institutions and policies for successful implementation of developments in the water-food-environment nexus.

Project Preface:

Improved water and land management in the Ethiopian highlands and its impact on downstream stakeholders dependent on the Blue Nile – short title Upstream-Downstream in Blue Nile **River** project is one of the projects in the Nile Basin supported by the CPWF. It was implemented during from 2007 to 2009 through a partnership of 8 institutions. The Blue Nile is the major tributary of the Nile River, contributing about 62% of the Nile flow at Aswan. About two thirds of the area of this densely populated basin is in the highlands and hence receives fairly high levels of annual rainfall of 800 to 2,200 mm. However, the rainfall is erratic in terms of both spatial and temporal distribution with prolonged dry spells and drought often leading to crop failures. Currently, water resources are only marginally exploited in the upper basin but are much more developed in the downstream reaches. The population, located in the downstream part of the Blue Nile, is dependent on the river water for supplementary irrigation and energy production. Canal and reservoir siltation is a major problem, adding the burdens of poor riparian farmers. This project was envisaged to improve the scientific understanding of the land and water resources of the basin, and hypothesized that with increased scientific knowledge of the hydrological, watershed, and institutional processes of the Blue Nile in Ethiopia (Abbay), constraints to up-scaling adaptable best practices and promising technologies (technical, socio-economic, institutional) could be overcome, which will result in significant positive impacts for both upstream and downstream communities and state.

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Acronyms

AAU	Addis Ababa University
AGNPS	Agricultural Non-Point Source Pollution
AHD	Aswan High Dam
ANN	Artificial Neural Network
ANN	Artificial Neural Network
ANOVA	analysis of variance (ANOVA)
ARARI	Amhara Regional Agricultural Research Institute
ARIs	Agricultural Research Institutes
AWM	Agricultural Water Management
BBF	Broad Bed and Furrow
BBM	Broad Bed Maker
BCM	Billion Cubic Meters
BDU	Bahir Dar University
BNB	Blue Nile Basin
BoARD	Bureau of Agriculture and Rural Development
CGIAR	Consultative Group on International Agricultural Research
CPWF	Challenge Program on Water and Food
CSA	Central Statistics Authority
CU	Cornell University
CVM	Contingent Valuation Method
CVM	Contingent Valuation Method
ENS	Efficiency criteria of Nash and Sutcliff coefficient
ENSAP	Eastern Nile Subsidiary Action Program
ENTRO	Eastern Nile Technical Regional Office
EP	Environmental Protection
EPA/EPLAUA	Environmental Protection Authority
EPE	Environmental Policy of Ethiopia
EPLUA	Environmental Protection and Land Use Administration
FAO	Food and Agriculture Organization
FSS	Forum for Social Studies
GIS	Geographic Information System
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit
GWh	Gigawatt Hours
HEC-ResSim	Hydraulic Research Station - Reservoir Simulation
HRUs	hydrologic response units
IE	Irrigation Efficiency
ILRI	International Livestock Research Institute
IPG	International Public Good
IWMI	International Water Management Institute
JMP	Joint Multipurpose Program

LAUP	Land Administration and Use Policy
LH-OAT	Latin Hypercube One-factor-At-a-Time
LULA	Land Use and Land Administration Policy
MCA	Multi criteria Analysis
mha	million hectares
MoARD	Ministry of Agriculture and Rural Development
MoWR	Ministry of Water Resources
MUSLE	Modified Universal Soil Loss Equation
MW	Megawatt
MWTP	mean willingness to pay
N	Nitrogen
NARS	National agricultural research systems
NBI	Nile Basin Initiatives
NGOs	Non-Governmental Organizations
OC	Organic Carbon
OIU	Omdurman Islamic University
OpenMI	Open Model Interface
PAs	Peasant Associations
PES	payments for environmental service
PET	Potential Evapotranspiration
RMSE	root mean square error
SCE	shuffled complex evolution
SCRP	Soil Conservation Research Project
SEI	Stockholm Environment Institute
SSI	Small-Scale Irrigation
SWAT	Soil and Water Assessment Tool
SWAT-CN	Soil and Water Assessment Tool - Curve Number Based
SWAT-WB	Soil and Water Assessment Tool - Water Balance Based
SWC	Soil and Water Conservation
tha	thousand hectares
UNESCO-CWR	UNESCO Chair on Water Resources
USDA	United States Department of Agriculture
USDA-SCS	United States Department of Agriculture-Soil Conservation Service
USDA-SWAT	United States Department of Agriculture-SWAT
USLE	Universal Soil Loss Equation
RUSLE	Revised Universal Soil Loss Equation
WaSiM- ETH	Artificial Neural Network and Distributed Hydrological Model
WDP	Water Delivery Performance
WEAP	Water Evaluation and Planning
WEAP	Water Evaluation And Planning
WRMP	Water Resources Management Policy
WSG	Watershed Management Guideline

WSM	Watershed Management
WTC	Willingness to Compensate
WTP	Willingness to Pay

PROJECT HIGHLIGHTS

The project entitled "Improved water and land management in the Ethiopian highlands and its impact on downstream stakeholders dependent on the Blue Nile – short title Upstream-Downstream in Blue Nile River" project addresses numerous water-related challenges. These include land degradation; inadequate knowledge and information on climate, hydrology, water use, water governance and policies; low productivity of crop and livestock and yet high rainfall in the Ethiopian highland; significant consequences of upstream downstream interactions related to water availability, water quality and sediment; poor interactions and data exchange of upstream downstream institutions and researchers; and an overall need for improved understanding of the systems through scientific research. The project was supported by Challenge Program on Water and Food and implemented by 8 institutions from the CGIAR centers, ARIs and NARS of Blue Nile basin. Many useful results were generated and the following are the major highlights:

This study began by conducting an inventory and summary of past water and land work. Extensive maps and database, describing the basin biophysical, social and institutional characteristics, were developed for Blue Nile that were based on primary and secondary data. These are made available in digital and hard form. Although numerous data existed in the basin countries, no mechanism existed for data sharing, which constrained integrated research across national and disciplinary boundaries.

Given limitation of data and spatial coverage, this project, through hydrological process understanding and adaptive models contributed to expanded regional hydrological information, provided mechanisms of estimating runoff in the ungauged areas and developed improved mechanisms of extending or generating data at gauged stations.

The popular USDA-SWAT watershed model was modified for the Blue Nile. A version of SWAT-WB greatly improved the ability to predict stream flow and sediment and nutrient loadings in tropical watersheds with monsoonal climates. Understanding hydrology, runoff and erosion and where the runoff occurs is critical in designing effective rain water management practices and in reducing soil erosion from the landscape. Field and modeling studies carried out under this project have shown that the runoff processes are unique. Unlike the traditional engineering wisdom, runoff being uniform over hillsides, runoff is spatially heterogeneous.

Spatial analysis revealed that most rainfall and runoff generation of the Blue Nile occurs at the Southern end of the basin and decreases both in North and West directions, with most runoff is produced in the lower-lying areas in the landscape. Land use of these areas is usually grazing. Modification to these areas will greatly affect water quality and quantity. Runoff generating areas should receive prioritization for implementing watershed management practices.

Extreme land degradation occurs in the Ethiopian Highlands and this result in significant sediment transport and accumulation in hydraulic infrastructure (e.g. dams, irrigation canals) in the downstream areas. Control of landscape and gulley erosion through integrated watershed management practice can effectively reduce the sediment problem, improve soil-carbon sequestration and contribute to sustainability of agricultural productivity in the basin.

Agricultural Water Management (AWM) technologies in rainfed systems largely make best use of the green water while improving the quantity and quality of water downstream. Converting non-beneficial water to productive use would improve *productivity and resilience. A significant part of the Ethiopian highland in Blue Nile (about 28,000km^2) is constrained due to drainage problem. Draining Vertisoils enhances early crop cover, minimizes erosion and opens opportunity for double cropping. Improved water productivity through intensification of systems is key for attaining increased productivity both in the upstream and downstream users. Integrating optimum levels of soil fertility, water use and improved seed enhances agricultural productivity. Improved integrated management practice resulted in productivity gains in the range of 18 to 124%.*

In addition, a unique socio-economic dataset from a representative sample of 1517 households from 29 Peasant Associations (Kebeles) in four regions of Ethiopia was collected to measure impact of AWM technologies. The poverty impacts of AWMT were assessed using standard poverty analysis techniques to explore whether those with access to AWMT have relatively higher consumption expenditure per adult equivalent compared to those without access. Findings indicated that the estimated average treatment effect on per capita income was significant and amounted to USD 82. Moreover, there was 22% less poverty incidence among users of AWMTs compared to non-users. The poverty impact of AWMT was also found to differ by technology type.

Upstream water resource development that increases blue water flow regulation can create win-win scenarios with significant economic and social benefits for both Ethiopia and Sudan. To take full advantage of the water resources of the Blue Nile basin, a single system management perspective, with water demand priorities was identified to maximize the overall benefits for both Ethiopia and Sudan. Current, intermediate and long term scenarios of irrigation and hydropower development were modeled to inform decisions. If Ethiopia were to develop all the hydropower and irrigation in the Blue Nile, the effect on the overall water balance would be 2.5 Bm^3 with the reduction between the national border and Khartoum. If Sudan realizes all its potential, the water balance effect would be 8.7 Bm^3. An aggregate effect would be an 11.2 Bm^3 flow reduction passing Khartoum compared to the present day.

Policy and institutions across local to basin scales are not well established and do not take into account downstream and upstream needs. Cooperation between upstream and downstream users is key to successful water management (e.g. dam operation; cost and benefit sharing, payments for environmental service [PES], and demand management). Institutional arrangements must be built across different scales (nested from local to international) that improve trust, facilitate the exchange of information and enable effective monitoring. Policy measures that involve stakeholders at grass root level during formulation create ownership and are much easier to enforce. New approaches of resources management such as PES are a useful means to enhance incentive-based land & water management, policy- enforcement and serves as an entry point for benefit sharing. Nevertheless, establishment of such options requires time investments from numerous stakeholders and co-financing from governments and/or donors.

EXECUTIVE SUMMARY

This publication, of the Challenge Program for Water and Food (CPWF), supports global efforts of the international community to increase productivity of water use in agriculture, for reducing poverty, promoting economic growth and environmental sustainability through improved management of water resources.

The Blue Nile (Abbay) is the major tributary of the Nile, contributing about 60% of Nile flow, and is home to millions of poor people. Nevertheless, natural resources are rapidly degrading due to poor land and water management. Knowledge related to water and land management, the linkage of livelihood and ecosystem services to water and land and governance mechanisms are limited and insufficient.

The primary objective of the Upstream-Downstream Blue Nile project was to increase understanding of land and water to enhance food security and improve sustainability of livelihoods of poor rural people in the Ethiopian highlands of the Blue Nile through better management and use of water and land, with minimal negative downstream impacts within Ethiopia and across international borders in Sudan. The study was designed to make contribution in designing action programs for improving livelihoods of poor communities in upstream while minimizing downstream impacts, to generate knowledge on upstream-downstream interaction, to enhance the effectiveness of interventions, and to increase agricultural water productivity while minimizing degradation.

Six major outputs were produced by the project.

One, a broad understanding of the basin was achieved through synthesizing existing knowledge and applying tools such as GIS and database development to characterize the basin and identify major water, land and livestock management constraints and opportunities, as well as impacts of current and future water and land management interventions within the catchment and in the downstream.

Two, existing and newly developed/adapted tools and methods related to hydrological process were used to understand rainfall-runoff, water distribution and availability in the basin. Extensive secondary and primary data were used in the analysis of the system. New models such as modified SWAT (SWAT-WB) were developed and used to enhance understanding of land – water interactions. (Common models developed in temperate climates need to be modified to predict the location of runoff producing areas in the watershed.)

Three, erosion-sediment-interventions were analyzed at different spatial scales ranging from micro watershed to basin level in a nested fashion to understand the severity of the problems from local to transboundary scale. Besides a better scientific understanding of the cause-effect relationships in erosion and sediment, interventions related to soil and water conservation, watershed management and related innovations such as payment for environmental services were considered and their impacts synthesized. Our particular findings show that extreme degradation occurs in Ethiopian Highland; and sediment yield predictions at Sudanese border ranges from 88 to 110Million ton/year. Collaboration of upstream and downstream stakeholders and managing the water resources at the watershed level followed by sustainable WSM measures could reduce soil erosion and Blue Nile river sediment yield.

Four, the Blue Nile farming system in the Ethiopian highland is mapped and presented, including evaluation of the impacts of water management technologies. About ten major farming systems dominate the highland. The productivity of these systems are affected by rainfall distribution, problems due to land degradation related soil fertility, input supply such as seed and fertilizers, water logging and other institutional factors. Models such as CropWat and AquaCrop were used to understand the productivity gaps that can be addressed. It was shown that the current crop productivity on average is at about 1/3 of the potential. As particular findings and conclusions, it was shown that AWM technologies in rain fed systems largely make best use of the green water (i.e., the fraction of rainfall that is stored in the soil and available for the growth of plants) while improving the quantity and quality of water downstream. Converting non-beneficial water to productive use would improve agricultural productivity and resilience. For example, draining Vertisoils enhances early crop cover, minimizes erosion and opens opportunity for double cropping. Improved water productivity through intensification of systems is key for attaining increased productivity both in the upstream and downstream users. While combining the interventions of soil fertility, seed and AWM technologies are providing highest result, specific impacts of AWM technologies and their impacts on poverty reduction were also analyzed.

Five, in addition to the rainfed agriculture system, the existing and future water uses in hydropower and irrigation were analyzed. Scenarios of existing uses based on inventory of these uses and the future development scenarios taking medium and long-term demands in meeting the development plans of Ethiopia and Sudan were studied. The implications of these scenarios and particularly the impacts on future water availability were analyzed using models such as WEAP, HEC-ResSim and Mike Basin. A peculiar conclusion related to this is that upstream water resource development, that increases flow regulation, can create win-win scenarios with significant economic and social benefits for both Ethiopia and Sudan. To take full advantage of the water resources of the Blue Nile basin, it needs to be managed as a single system, with water demand priorities established to maximize the overall benefits for both Ethiopia and Sudan.

Six, the policy and institutions that exist in the basin to govern water and land were analyzed and presented. Institutions at watershed, basin, national and transboundary levels are analyzed. The major findings were that policy and institutions across local to basin are not well established and do not take in to account downstream and upstream needs. Cooperation between upstream and downstream is key to success. Institutional arrangements must be built across different scales (nested from local to international) that increase trust, facilitate the exchange of information and enable effective monitoring required for successful water resources management (e.g. dam operation; cost and benefit sharing, PES, demand management etc...). Policy measures that involve stakeholders, at grass root level during formulation, are much easier to enforce. PES is a means to enhance incentive-based land & water management policy- enforcement and an entry point for benefit sharing. A full-fledged farmers' financed PES scheme may not be feasible (at least in the short-term). Therefore options for user & state co-financing must be sought.

Key findings include:

Despite the availability of numerous data in the basin countries, there are no mechanism existed for data sharing, which constrained integrated research across national and disciplinary boundaries.

The major runoff generating area of the Blue Nile was identified to be the Southern end of the basin. Runoff decreases both in North and West directions. In a landscape, most runoff is produced in the lower lying areas of the landscape. The dominant land use of these areas is grazing. Modification to these areas greatly affects water quality and quantity. Control of landscape and gulley erosion through integrated watershed management practice can effectively reduce the sediment problem, improve soil-carbon sequestration and contribute to sustainability of agricultural productivity in the basin

Numerous models and methods are used for understanding the Nile in general and Blue Nile in particular. The existing knowledge is compiled in Awulachew et al (2008). Reviewing these existing methods and tools will help researchers to avoid duplication of efforts.

The popular USDA-SWAT watershed model was modified for the Blue Nile and developed as SWAT-WB, which greatly improved the ability to predict stream flow and sediment and nutrient loadings in tropical watersheds with monsoonal climates. Understanding hydrology, runoff and erosion and where the runoff occurs is critical in designing effective rain water management practices and in reducing soil erosion from the landscape. In addition to standard SWAT and SWAT-WB, a number of models such as Artificial Neural Network (ANN), Distributed Hydrological Model (WaSiM- ETH), and Genetic Algorithms were used to effectively extend flow records, generate missing data and estimate flows at ungauged rivers.

About 28,000km^2 cultivated area in Blue Nile is constrained due to vertisol drainage problem. Draining Vertisoils enhances agricultural productivity. Furthermore, agricultural productivity is heavily constrained due to lack of intensification that utilizes optimum combination of water management, fertilizer and seed. As a result productivity is low and agriculture is pushed to marginal areas such as steep slopes and led to extreme degradation.

The incidence, depth and severity of poverty is shown to be significantly lower among AWM technology users than non-users. AWM technology users are 22% less poor compared to non-users.

Multi-reservoir and multi-purpose optimization of reservoir operation rule curve was developed for Lake Tana. The result showed that not all predicted development demands around Lake Tana can be meet using the planned water control infrastructures, and deficits in irrigation will occur. Operators of the system should compensate by adjusting the he area of irrigation to the optimum water allocation, particularly for three months (February, March and April) according to the rule curve.

The existing level of water control infrastructure in Ethiopia is very low and the management of existing infrastructure and water in the Sudan is inefficient. If Ethiopia develops all the hydropower and irrigation in the Blue Nile, the effect on the overall water balance is 2.5 Bm^3 and the reduction between the national border and Khartoum. If Sudan realizes all the potential, is 8.7 Bm^3. An aggregate effect would be an 11.2 Bm^3 flow reduction passing Khartoum compared to the present day.

There is no effective transboundary institution in the Blue Nile, except for Nile Basin Initiative affiliated Eastern Nile Subsidiary Action Program (ENSAP). Policy and institutions across local to basin scales are not well established and do not take in to account downstream and upstream needs. Cooperation between upstream and downstream is key to successful water management (e.g. dam operation; cost and benefit sharing, payments for environmental service [PES], and demand management).

New approaches of resources management such as PES are a useful means to enhance incentive-based land & water management, policy- enforcement and serves as an entry point for benefit sharing. PES was experimented in Ethiopian highland and it was found that farmers were willing to pay and willing to be compensated within a watershed, in a limited scope. Nevertheless, establishment of such options requires investments from numerous stakeholders and co-financing from governments and/or donors.

In addition, the project provided significant capacity building endeavors for research partners, NGOs, community leaders and policy makers, through collaboration with local institutions and universities to facilitate student research, stakeholder consultation, facilitation and engagement of stakeholders in dialogues on resource management issues and innovative approaches, as well as generating knowledge that can be used by planners and policy makers. As a particular example, 45 M.Sc. students linked with the project obtained funding, supervision and completed their thesis. 5 workshops conducted in Ethiopia and Sudan, and a number of papers are presented during these workshops and other national and international forums. The results of the findings are currently under compilation to be published in four chapters of a Nile Book in collaboration with other completing CPWF projects. Readers are invited to read this book.

Policy recommendations:

- Investment is needed to upgrade the data measuring networks and to improve spatial coverage of gauged hydrological and meteorological data.
- Data sharing between upstream and downstream countries need to improve in order to enhance knowledge and understanding on the Blue Nile water as well as enhance upstream downstream collaborations in water resources development.
- Runoff generating areas should receive prioritization for implementation of watershed management practices. Furthermore, better land and water management through improved tillage practice and synchronized cropping with onset of rains will control erosion and sediment
- Prioritize modeling analysis using a water balance approach instead of curve number to provide improved results for rainfall-runoff predictions. Hydrologist and planners should adopt and customize models to suit relevant socio-economic, bio-physical and climatic conditions.
- Operation of Lake Tana with the emerging dams upstream of the Lake to meet various demands, existing traditional navigation and the new intra-basin transfer for hydropower generation of the Tana Beles requires cautious operation to ascertain equity among various uses. Multi-reservoir and multi-purpose optimization of reservoir operation rule curve, which has been developed for Lake Tana, can be used to identify optimum use of the available water resources. Dam operators should be acquainted with such systems for efficient of operation of water control structures. Current capacity is limited and thus relevant capacity needs to be developed.
- Collaboration of upstream and downstream stakeholders and managing the water resources at the watersheds followed by sustainable WSM measures will lead to reduced soil erosion and Blue Nile river sediment yield, leading to significant reduction of costs of maintenance of dams and hydraulic infrastructures.
- AWM technologies in rain fed systems largely make best use of the green water while improving the quantity and quality of water downstream. These technologies are essential to upgrade rainfed system in Ethiopian highlands. Existing coverage is limited and policy makers and donors should out scale such interventions through increased investments

- Draining Vertisoils of the cultivated areas are not provided sufficient attention, and water logging is one of the major system loss of available water. Vertisol management enhances early crop cover, minimizes erosion, opens opportunity for double cropping and increase water availability for productive use both on site and offsite downstream. Investment is required to undertake relevant research and foster adoption of relevant technologies.

- Improved water productivity should be achieved through intensification of systems, through more crop per year, access to irrigation water, selection of high yielding varieties etc, increase the productivity of both upstream and downstream uses. Optimum levels of soil fertility, water use and improved seed enhances agricultural productivity by up to two to three fold over existing productivity.

- Flow regulation in Ethiopian Highland should be improved. Upstream water resource development, that increases flow regulation can create win-win scenarios with significant economic and social benefits for both Ethiopia and Sudan.

- Managing the Blue Nile waters as a single system with established demand priorities can maximize the overall benefits for both Ethiopia and Sudan. Policy makers across the international boundaries should work to establish effective institutions for governance and management of the Nile Waters

- PES is one of new mechanisms for benefit sharing for farming communty or water sharing countries. Although the mechanism has not been used in the Blue Nile Basin context, the project has shown PES has stakeholder interest and may work. Farmers are willing to pay and be compensated, yet the amount of their payment is not adequate and thus options for state co-financing are needed and should be encouraged.

INTRODUCTION

More than 70% of people in Africa live in rural areas with livelihoods dependent on land and water. In most African countries, agriculture is the main component of the economy. There is strong need for integrated water resources management to alleviate poverty and food insecurity with a broad based, integrated approach that coordinates the activities of people dependent on a common resource-base to achieve resource-use efficiency, equity and sustainability.

In the Nile Basin, water from the Ethiopian highlands, particularly from the Blue Nile (known as Abbay in Ethiopia), has historically benefited downstream people in Sudan and Egypt in different ways – enabling agriculture, livestock, industry and electrical power. However, such benefits are now threatened due to dramatic changes in upstream land, water and livestock management practices. High population pressure, lack of alternative livelihood opportunities and the slow pace of rural development are inducing deforestation, overgrazing, land degradation and declining agricultural productivity. Increased land degradation resulting from poor agricultural practices and erosion means more siltation and associated problems of water quality along the course of the river. High sediment loads can reduce power generation capacity, interfere with irrigation, contribute to flood risk and affect clean water supplies.

Poor water and land management upstream severely affects runoff characteristics and the quality of water reaching downstream users. For example, reservoirs and irrigation conveyance structures in Sudan suffer from siltation as a result of high sediment loads from Ethiopia. The result is a downward spiral of poverty and food insecurity for millions of people both within the upper catchment and downstream across international borders. Over the past 30 years, per capita food production in Ethiopia has declined from 280 kg to about 160 kg per year and at present, more than half of the country's population is food insecure. In the drought of 2002/3, over 14 million people required assistance to survive and even in normal years some 5 million people now require food aid. It is widely recognized that improved water management in the Ethiopian highlands will considerably alleviate the impacts of natural catastrophes such as droughts and reduce resource-use conflicts among stakeholders.

Given this background, this research project addressed the hypothesis that with increased scientific knowledge of the hydrological, watershed, and institutional processes of the Blue Nile in Ethiopia (Abbay), constraints of up-scaling adaptable best practices and promising technologies (technical, socio-economic, institutional) can be overcome, and significant positive impacts for both upstream and downstream communities and states be attained. The detailed research questions investigated were as follows:

1: What are the successful interventions that help improve productivity and reverse degradation?

- Which kinds of water, land and livestock interventions would have the greatest benefits upstream?
- Under what specific biophysical and social conditions are they sustainable and sufficient to reverse the negative environmental trends, poverty and food insecurity in the highlands?

2: What are the impacts downstream?

- If widely applied, what effect would the above interventions have on the supply of water and silt downstream?

- What would be the associated benefits for downstream users, in terms of reduced reservoir sedimentation?

3: What are the opportunities and constraints of enhancing rural livelihoods and food security?

- What technical, socio-economic and institutional constraints and opportunities exist for strategic and spatial allocation of water among different uses and sectors in the Blue Nile?

- How best can the exchange of technical, institutional and policy innovations be promoted at all scales in the Blue Nile?

This project was supported by the CPWF and implemented by 8 collaborating institutions from international, national agricultural research systems (NARS) and universities. This report summarizes the major study components and the key findings of the project as it has been undertaken during the implementation period of 2007 to 2009.

The report is organized in the following manner. First the objectives of the project are presented. Then section one describes results of scoping study, database, characterizations and different maps of Blue Nile Basin produced. Section two summarized the hydrological process in the various parts of the basin; followed by section three dealing with the adaptation of watershed management models to Nile conditions and associated analysis of impacts from interventions. Both section two and three cover the issues starting from micro watershed to basin level in a nested fashion of analysis. Section four focuses on agricultural system and productivity by analyzing the farming systems in Ethiopian Highland and impacts of interventions. Section five concentrates on modeling the current and future water demand and allocation options and provides the implications of these on water availability. Section six summarized the policy and institutional analysis that helps to understand the existing conditions and policy and institutional innovations required to uptake interventions. Sections 2 to 6 follow similar structures of introduction, methods & tools and results. The remaining sections of the report focus on CPWF proforma, the international public goods, recommendations and references associated to the project.

PROJECT OBJECTIVES

The study has been designed to achieve the following specific objectives:

1. Identify major water, land and livestock management constraints and opportunities in the Abbay catchment, as well as impacts of current and future water, land and livestock management interventions within the catchment and downstream.

2. Adapt and apply existing hydrological, watershed, and economic models that can be used to estimate such impacts both basin-wide and locally in selected communities, including their costs and benefits, and identify 'best-bet' interventions.

3. Create a better overview of 'best-bet' management practices and interventions, and the hydrological and socio-economic conditions for up-scaling them. These will include practices and interventions for improved land and water management (including some previous tried), and measures for assessing their impacts on poverty and rates of land degradation. The economic component will further seek to identify policies, institutional arrangements (including property rights to land and water and transboundary issues), and investment strategies required to scale up identified practices and water management options, and assess implications for equity, poverty reduction and long-term food security.

4. Build capacity of research partners, NGOs, community leaders and policy makers, through collaboration with local institutions and universities to facilitate student research, stakeholder consultation, facilitation and engagement of stakeholders in dialogues on resource management issues and innovative approaches, as well as generating knowledge for planners and policy maker

In order to address the above research questions and objectives the research project, the study was conducted in various components and the results are summarized and organized in the following major undertakings and outputs for the purpose of this report.

a) Scoping studies, database, characterizations and maps of Blue Nile Basin (BNB)

b) Hydrological Process in BNB

c) Adaptation of watershed management model and analysis of impacts of interventions in BNB

d) Agricultural systems and productivity of BNB

e) Development of water demand and water allocation models in BNB

f) Policy and institutional analysis of BNB

This report therefore discusses these 6 components describing the various methods used, the results generated, discussions and conclusions in some details. The seventh component related to capacity building, dissemination and consolidation of outputs of CP19 is presented in the proforma part of the reporting to the CPWF.

SCOPING STUDY, DATABASE, CHARACTERIZATIONS AND MAPS OF BLUE NILE BASIN

Key messages

- *This study made an inventory of past works and extracted relevant materials. A review of the literature, on hydrology, watershed management and sediment, policy and institutions in the Nile Basin revealed that many studies exist concerning this basin and several hydrology models have been developed.*
- *Numerous data existed in the basin countries, but no mechanism existed for data sharing which constrains integrated research and basin wide analysis.*
- *Under this study, extensive maps and database were developed for Blue Nile based on primary and secondary data. These data were made available to researchers and other users*
- *Improvement of gauging stations and data network in terms of both spatial distribution and station numbers is essential. Current instrumentation is influenced by accessibility, not providing good distribution. Therefore, new investment is needed to improve network of data collection, sharing including application and use of modern technologies such as remote sensing*

1.1 Introduction

As the objective of the project was broad, a system characterization of the basin was needed to produce maps, basin information and serve as reference to various components of the project. The scoping study therefore, was a background review of existing knowledge about the Blue Nile Basin. Pertinent literature was collected as reference. In addition, relevant project data related to basin physiographic, meteorological, hydrological, agricultural, sediment data were compiled from public sources for the development of a pertinent database and for use in analysis. This section focuses on the review of the project set-up with stakeholder at inception phase, literature review, development of geospatial based information system, and derived results such as database and maps.

1.2 Methods

During the scoping study, the project background, context, and relevance were established using input of stakeholders during the inception workshop and helped to enhance the project proposal. During the inception workshop, through inviting key stakeholders and resource persons, the major crop, land and livestock problems and constraints were identified and used as a basis for further investigation. Literature reviews focused on watershed modeling, water allocation modeling, hydrological studies, water resources planning, water use information such as irrigation, policy and institutions. Field visits were made in parallel with inception workshop for Ethiopian highland part. The field visit in the Sudan was conducted in the latter period during the implementation of the project. Based on identified criteria, and expert judgment, specific sites were chosen for detail investigations. The development of the geospatial database for the Blue Nile was started with the acquisition of different datasets. Datasets were acquired from relevant institutions in Ethiopia and Sudan. The datasets then populated to the geospatial database developed specifically for the project, as Blue Nile Database. A Geographic Information System (GIS) was used to capture, analyze and present various spatial data and produce maps at various levels.

1.3 Results and discussions

1.3.1 Inception workshop and site visits

The workshop was held at the shore of Lake Tana, the source of Blue Nile (Abbay) at Bahir Dar University Main Campus, Ethiopia. Twenty-seven participants form 14 institutions of Ethiopia and Sudan as well as international organizations attended. The major focuses of the workshop included: clarification of the content of the project, develop detailed plan of activities for the project, discuss activities and roles for each of the principal investigators (PIs) and participants, brainstorming major water and land / watershed management issues, and field visits of candidate sites.

Criteria were developed for the selection of sites considering the scope of the project. The selection criteria that were used to represent a diversity of land use systems such as poorly vegetated, moderate and well vegetated; degree of land degradation; production systems (mixed crop-livestock, irrigated, pastoral, forested); agro-ecology; physiographic; access/accessibility to markets; population density; watersheds with and without interventions; location; data availability including calibration and validation; potential users; accessibility; and size of watershed (range of sizes). In order to apply these criteria, Multi Criteria Analysis (MCA), a matrix based evaluation or expert judgment could be utilized. Parallel to this, a number of sites were recommended and with a guiding decision that various sites for study components of hydrology, sediment, etc were selected in a nested fashion such that the individual studies could lead to understanding basin wide issues and upstream downstream consequences. During the implementation, most of the recommended sites and additional sites in the BNB have been used.

1.3.2 Literature review results

The literature gathered during the first year of the project was summarized in the following reports:

1) A Review of Hydrology, Sediment and Water Resource Use in the Blue Nile Basin by Awulachew, S. B. et al (2008b) published as IWMI Working Paper 131 in 2008. This publication provides a comprehensive literature reviews; identifies types, sources and provides geo-referencing of data in the basin; compiles information of hydrology, sediment and water resources and its uses. It also provides review of applicable models for watershed and water allocation simulation, research methods, past studies and published materials related to Blue Nile. Extensive references materials and previous studies are also gathered.

2) Institutional Settings and Livelihood Strategies in the Blue Nile Basin: Implications for Upstream/Downstream Linkages by Haileslassie, A. et al (2008), published as IWMI Working Paper 132 in 2008. Through rapid assessment of exiting literature and documents, the report synthesizes existing knowledge, gaps on policies and institutions and identifies key research issues that need in-depth study as part of the CP19-Upstream-Downstream Research. It provides overview of the range of key livelihoods and production systems in the Blue Nile Basin (BNB) and highlights their relative dependence on, and vulnerability to, water resources and water-related ecosystem services. Inventory of current water and land related policies and institutions in the BNB, their organizational arrangements, dynamics, linkages and key policy premises including the major problems in institutional arrangements and policy gaps are provided.

1.3.3 Database, characterizations and maps of Blue Nile Basin

The result of the analysis from the different geospatial datasets in the database were used to characterize the basin and the sub basins as well as selected watersheds and micro-watersheds. The characteristics were then produced in a form of maps.

The Blue Nile basin is sub divided into 18 major sub basins namely, Lower Blue Nile, Upper Blue Nile, Dinder, Rahad, Tana, Beshelo, Beles, Dabus, Diddessa, Jemma, Muger, Guder, Fincha, Anger, Wenbera, South Gojam, North Gojam and Welaka, see Awulachew et al. (2008) for details. Each sub basin was characterized and mapped for different attributes. The attributes include topography, climatic conditions (such as rainfall, temperature, evapotranspiration), hydrology, land use/ land cover, soil, geology, etc. The socio-economic aspect was also captured in administrative regions of the countries and their population.

Maps were produced for the basin, sub basin, selected watersheds and micro-watersheds. Figure 1 splits the Blue Nile in to Ethiopia and Sudan parts, based on digital elevation model and watershed divides, taking in to account national boundaries. The Ethiopia part of Blue Nile, also called Abbay Basin in Ethiopia, is subdivided into 16 sub basins see also Figure 2. The Sudan part is divided in to 4 sub-basins, where Dinder and Rhad are common to both.

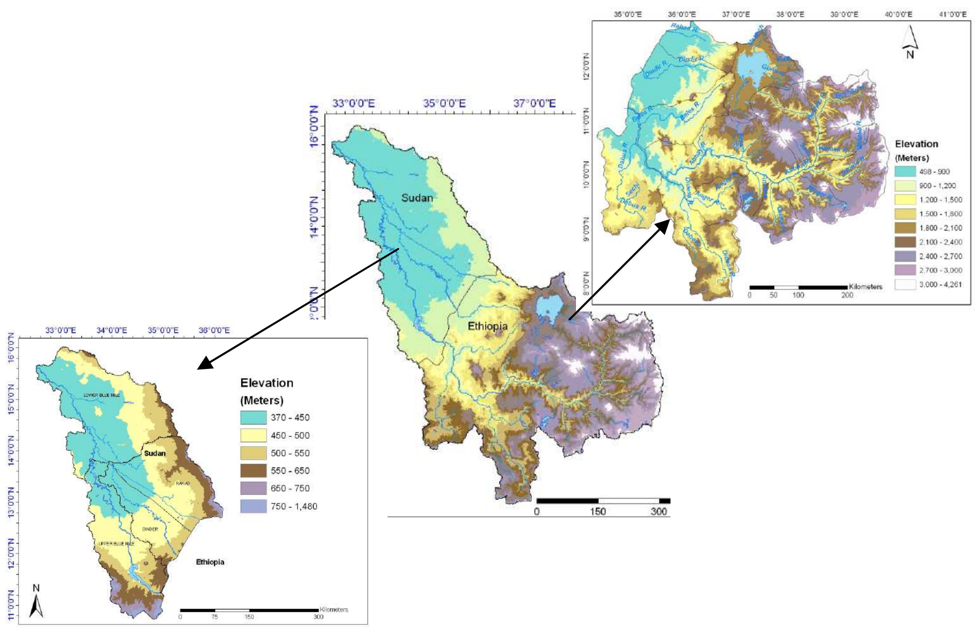


Figure 1: Topography of the Blue Nile Basin

The topography of the Blue Nile divides the basin in to two main features, the rugged topography, mountainous areas in the Ethiopian highlands and the flat topography in the lowlands in the Sudan. The altitude in the Blue Nile ranges from 344 meter above sea level (masl) at the downstream end at Khartoum to 4261 masl in the Upper Blue Nile in the Ethiopian highlands. Rainfall ranges between 126 mm and 2200 mm per year in the basin. The mean annual temperature ranges from 5^{o}C to 30^{o}C. Potential

Evapotranspiration (PET) based on evaporation pan measurements ranges between 1056 mm and 2292 mm per year.

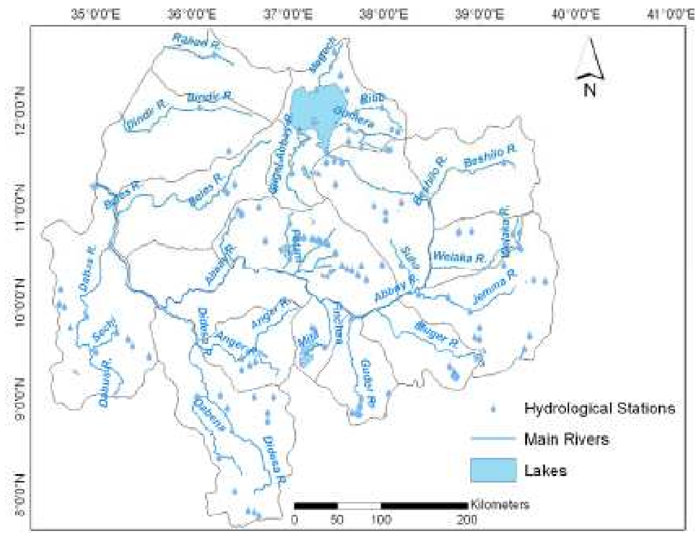


Figure 2 : The 16 sub basins in Abbay basin

The Ethiopian part of Blue Nile covers an area of approximately 199,812 sq km. The country's largest freshwater lake, Lake Tana, the source of the Blue Nile (Abbay) river is located to the north of the basin. The Abbay basin accounts for a major share of the country's irrigation (815,581 ha) and hydropower (78,820 GWH/yr) potential. The basin has an average annual run-off estimated to 54.8 BCM (Awulachew et. al. 2008). The topography of the Abbay basin signifies two distinct features; the highlands, rugged mountainous areas in the center and eastern part of the basin and the lowlands in the western part of the basin. The altitude in the basin ranges from 498 masl in the lowlands up to 4261 masl in the highlands.

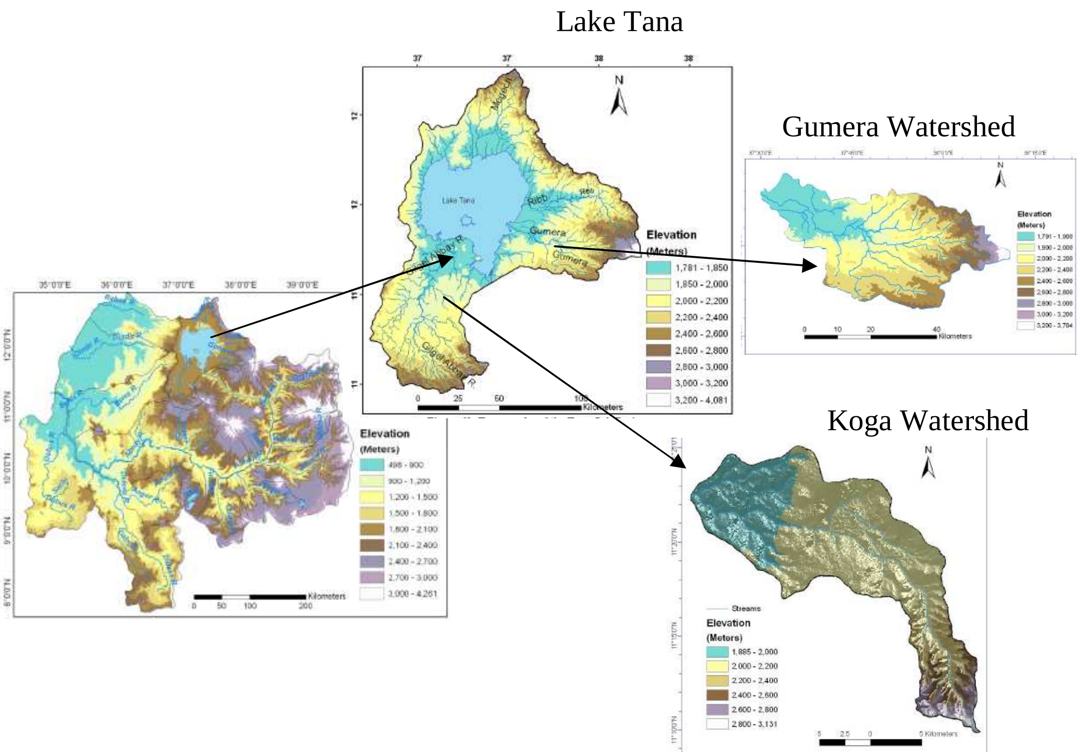


Figure 3: Lake Tana Sub basin and selected sub watersheds

Figure 3 shows two watersheds with in a Lake Tana sub-basin as an example of GIS mapping. In a similar way any watershed within the BNB can be generated. Comprehensive maps and details were provided in the Blue Nile Atlas, prepared under this project. Reference and this result can be found under Denekew and Awulachew (2009)

Similarly, data related to meteorological, hydrological, soil, geological, land use and socio-economic information were collected for the basin and mapped. These are also provided in the reports generated under this study and included in Awulachew et al (2008), Hailesellassie et al (2008), Denekew and Awulachew (2009)

1.4 Conclusions

This part of the study documented the available hydrological and social data and information for the BNB. The data included the various characteristics and attributes of the basin such as topography, basin and sub-basin boundaries, climatic conditions, hydrology, land use/ land cover, soil and other related properties of the basin and its sub basins. The characterization of the basin and its sub basin were compiled in a form of Geospatial Atlas and also used as an input for the production system mapping and for modeling water availability and other parts of the research.

HYDROLOGICAL PROCESS

Key messages

- *Maximum rainfall and runoff generation of the Blue Nile occurs at the Southern end of the basin and decreases both in North and West directions*
- *Most runoff is produced in the lower lying areas in the landscape. Land use of these areas is usually grazing. Modification to these areas will greatly affect water quality and quantity*
- *Runoff generating areas should be prioritized for implementing watershed management practices*
- *Models developed in temperate climates need to be modified to better predict the location of runoff producing areas in the watershed. Generalized application of models may not provide accurate results.*
- Multi-reservoir and multi-purpose optimization of reservoir operation were developed for Lake Tana and revealed that not all predicted development demands were being met using the planned water control infrastructures. Deficits in irrigation water will occur, mainly for three months (February, March and April). Such a temporal shortage can be compensated by adjusting the area of irrigation to the optimum water allocation.

1.5 Introduction

This section describes the characteristics of the climatic behavior, rainfall characteristics and runoff process across various spatial scales in the BNB. Attempts were made to explain the rainfall runoff relationships, factors shaping this process at small watershed to the basin level and to quantify the water resources at various spatial scales. Models used for rainfall runoff in the basin were reviewed, the appropriateness and limitations of existing models were described and results of newly derived models and approaches presented.

1.6 Methods

1.6.1 Approach

The data from various stations used to describe spatial variability of rainfall and runoff were compiled as discussed in previous section and thus are not repeated here. The analysis of hydrological process were undertaken by considering processes at various spatial extents, ranging from the micro watershed, sub-watersheds, sub-basin and basin wide analysis. Separate analyses were carried out at reservoir sites to understand the factors controlling the reservoirs and the water balance components.

Table 1 provides the summary of the spatial scale and methods used for the various levels.

Table 1: Various models developed/adapted for BNB at various spatial levels

Spatial Scale	Methods and models used	
1) Micro watershed		
Anjeni	Simple water balance model using SWAT-WB model to simulate the saturation excess flow was applied	Legesse (2009)
Andit Tid[1]	Simple conceptual model	Ashagire (2009)
Maybar[1]	Simple conceptual model	Bayabil (2009)
Combined micro watersheds	Combination and aggregation of watersheds using SWAT-WB	Easton et al (2010)
2) Watershed		
Gumera	Standard SWAT and SWAT-WB	Tenaw (2009), White et al (2010)
Rib	Extreme flow analysis using statistics	Gelaw (2008)
3) Sub-basins		
Lake Tana	Generation of flow at ungauged basins, water use optimization using Artificial Neural Network, HEC-Res, WASIM-ETH and multi-objective optimization model	Saliha et al (2009a, b,c)
16 Sub-basins	Flow analysis and sediment using standard SWAT, SWAT-WB,	Fetene (2009), Easton et al (2010)
4) Basin		
Upper Blue Nile	Flow analysis and sediment simulations using Standard SWAT and Standard SWAT with Open MI	Fetene (2009), Easton et al (2010), Betrie et al (2009)
Blue Nile	Standard SWAT with Open MI, and WEAP	Betrie et al (2009), McCartney et al (2009)
5) Special study		
Rosaries reservoir	Rosaries' water balance	Bashar and Moustafa (2009)
Planned dams in Blue Nile	Water balances of emerging reservoirs	Elala G. (2009)

1.6.2 Micro Watersheds hydrological process methods

The rainfall-runoff model of the Anjeni micro watershed was developed to test the validity of the assumptions concerning runoff processes at a small scale. To assess the variability in the water table across the watershed, thirty piezometers were installed in four transects to represent the variability in soil depth and slope and hillslope location. A simple water balance model was developed and tested earlier by Collick et al (2009) was used to predict the stream flow for four small watersheds (<500 ha) in the Blue Nile. This same model is used here by Legesse et al. (2009). The performance of the model was evaluated using three different techniques: coefficient of determination (R^2), Efficiency criteria of Nash and Sutcliff coefficient (ENS), and root mean square error (RMSE).

[1] These micro watersheds are outside the BNB, but found in the neighboring basins. Their data which has been collected by the Soil Conservation Research Project (SCRP) provides invaluable database to establish basic relationship of rainfall run-off process and hence sued in this study

In addition, Easton et al (2010) and White et al (2010) used the new water balance version of SWAT (SWAT-WB) to predict flow. The SWAT –WB model (White et al., 2010) was adopted from the SWAT model to capture processes controlling saturation excess overland flow by incorporating a physically based landscape water balance, and was developed for Ethiopian monsoonal climates. The study of Ashagre et al (2009) adopted the conceptual model based on the work of Steenhuis et al. (2009) and presented by Collick et al (2009) in the Andit-Tid watershed. It used similar principles as Anjeni, but used directly measured runoff and rain gauge data. The model assumed that rainfall in excess of field capacity on hill slopes becomes recharge and routed down through interflow or base flow while the bottom flat lands, which drain the upslope areas, easily saturate to produce saturation excess runoff.

Bayabel et al (2009) used similar model on Maybar watershed to characterize subsurface flow and ground water table fluctuations in response to rainfall causing saturation excess runoff, the basic principle of variable source area hydrology. Twenty-nine piezometers were installed in 2008 and water table measurements were taken during the main rainy season. The developed model attempted to efficiently simulate the location of saturated runoff generating areas and predict river discharge. This work had direct benefits for realistic planning of watershed interventions. Furthermore, the study assessed the changes in soil physical and chemical properties of the study area between 1986 and 2008 (not dealt with here).

1.6.3 Watershed, sub-basin and basin hydrology methods

Tenaw and Awulachew (2009) used a standard SWAT model and Easton et al (2010) applied the modified SWAT model for Ethiopian highland to analyze the rainfall-runoff process and to generate runoff at various scales in the upper BNB. Gelaw et al (2008) analyzed the Ribb watershed using GIS and analyzed the meteorological and hydrological data for characterizing the flooding regime and extents of damage in the watershed.

At the sub-basin level, Saliha et al (2009a) study compared Artificial Neural Network and Distributed Hydrological Model (WaSiM- ETH) for predicting daily runoff over five small to medium sized sub-catchments in the Blue-Nile River basin. Daily rainfall and temperature time series data in the input layer and daily runoff time series data in the output layer of Recurrent Neural Net with hidden layer feedback architecture was formed. The neural networks capability of modeling a complex rainfall-runoff relationship was observed. As most of the watersheds in the basin are ungauaged, Saliha et al (2009b) used a Kohonen neural network and WaSiM-ETH to estimate flow in the ungauged basin. A Kohonen neural network as used to delineate hydrological homogeneous region and WaSiM-ETH to generate daily flow. 25 sub-catchments of the Blue Nile River basin, Ethiopia, were grouped in to five hydrological homogenous groups. WaSiM has been calibrated using automatic nonlinear parameter estimation method PEST coupled with shuffled complex evolution (SCE) algorithm and validated for data series not involved during calibration to check the performance the model. In the coupled program, the Kohonen neural network assigned the ungauged catchment into one of the five hydrological homogenous groups. Each homogeneous group has its own full set of optimized WaSiM-ETH parameters, which was derived from simultaneous calibration, and validation of gauged rivers in the respective homogeneous group. The coupled program will transfer the whole set of optimized WaSiM parameters from the homogeneous group (which the ungauged river belongs to) to the ungauged river.WaSiM calculated the daily flow of the ungauged river.

The two sets of approaches, discussed above, developed by Easton et al (2010) and Saliha et al (2009a, b, c) provided for a means of estimating runoff in the BNB using various techniques. In addition, Fetene et al (2009) and Betrie et al (2009) provided alternative aggregated modeling using SWAT and SWAT combined with open MI software to analyze the runoff. Both have also used the models to predict sediment at the outlet of the basin. Furthermore, the latter used to understand the morphodynamics of the BNB and suspended sediment downstream of Rosaries reservoir, and will be discussed in section 3.

1.6.4 Multi-Reservoir Operations

In addition to flow generation, multi-reservoir system operation rules for planned and existing reservoir systems in ungauged catchments were developed by combining artificial intelligence, a watershed model, a reservoir simulation model and an optimization model, Saliha et al (2009a, 2009b). This was a special application of the various models to see the impacts and seek optimal management of available water at sub-basin level. Further discussion will be provided latter in section 5 in the context of upstream down-stream using an integrated model such as WEAP. A small program using Perl, which prepared the template file from HEC-5A control file, and MatLab programming languages were written to couple the simulation model (HEC-5A in our case) with single objective optimization algorithm (CMA-ES). The coupled models were used to represent reservoirs in Lake Tana sub-basin, which are either under construction or their final design reports were submitted and approved by the Ethiopian Ministry of Water Resources, including the Koga reservoir (completed only canals are under construction), Ribb reservoir (under construction), Megech reservoir (site clearing to begin construction), Gumera reservoir (final design report), Tana-Belles basin transfer for hydropower production (under construction) and Tis-Abbay I and II (existing hydropower stations). The coupled model was multi-dimensional able to handle up to 65 (5 reservoirs * 13 target reservoir levels) dimensions for all reservoirs considered in the case study area. It was also capable of handling multi-criteria optimization problems among different water users like irrigation water supply versus energy production, and navigation versus hydropower energy production by introducing different weights.

Finally we used a water balance computation for years 1985, 1995 & 2005 for Roseries reservoir, Bashir and Moustafa (2009). Available bathymetric surveys of the reservoirs and pertinent data determined the selection of these years. The analysis examined if changes and trends in the components of the water balance occurred during the last 25 years. The results of this part is discussed in section 3.

1.7 Results and Discussion

The following provide highlights of results based on outputs outlined in previous sections. Readers are advised to refer to the corresponding reports or papers for details.

1.7.1 Micro watersheds

In the Anjeni micro watershed where flow is dominated by saturation excess runoff rather than by infiltration excess runoff, the new water balance version of the popular SWAT model was utilized to predict daily flow with a coefficient of determination (R^2) of 0.92 and Nash-Sutcliffe coefficient (ENS) of 0.91. Daily simulations using a semi-distributed water balance model for Andit Tid showed an R^2 of 0.78, ENS of 0.78, and Root Mean Square Error (RMSE) of 2.37. For the simple water balance model at Mybar values of coefficient of determination of 0.76, 0.81 and 0.94 were obtained for the daily, weekly and monthly time steps, respectively. Similarly, ENS values of 0.68, 0.80, and 0.92 were obtained for the daily, weekly and monthly time steps, respectively.

Examination of the piezometer data and direct measurement of runoff at the micro watersheds indicated that infiltration excess runoff from upslope areas of the watershed is almost nonexistent. Test plots located at the lower slope produced high runoff amounts compared to those located on steeper slopes. This provides new insights about the effect of slope on runoff generation that is in contrast to the common belief that steeper slopes generate more runoff. Water table measurements confirmed that flat lands near the stream remained saturated during most of the rainy season. These areas receive both flow from upland area and direct rainfall and as a result they become runoff source areas during most of the rainfall season. The simplicity and scalability of the model hold promise for use in un-gauged catchments. For more details, see Legesse et al. (2009), Ashagire et al. (2009), Bayabil et al (2009) and Easton et al (2010)..

1.7.2 Watershed, sub-basin and basin levels

At the watershed level (Gumera) we compared the modeling results of a standard SWAT model (Tenaw et al., 2009) and modified SWAT-WB model (White et al., 2010). The standard SWAT model for Gumera watershed provided calibration resulted in ENS of 0.76, R^2 of 0.87, and mean deviation (D) of 3.29 %, at a monthly time step (Figure 4). Similarly the validation results also show good agreement between measured and simulated values, with ENS of 0.72, R^2 of 0.82 and D of -5.4%.

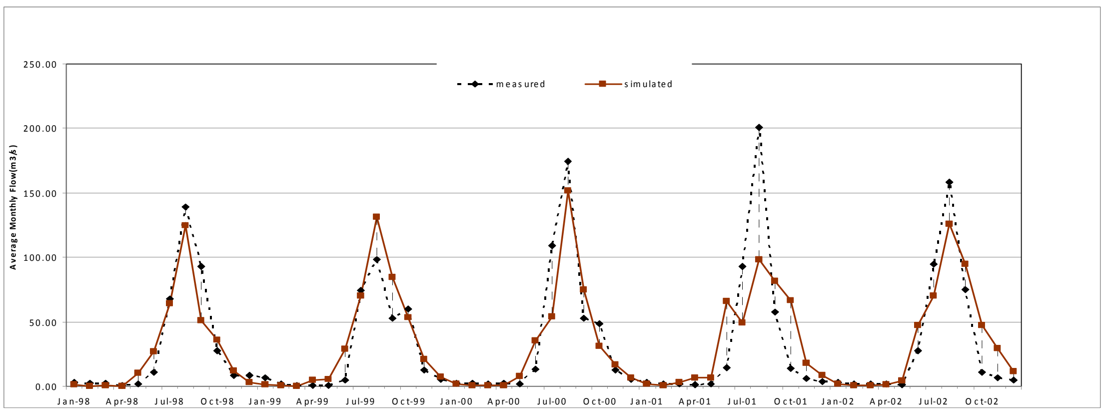


Figure 4: Calibration results of average monthly measured and simulated flow at Gumera gauge

The model results obtained with SWAT-WB indicate that a complex watershed model can be run with adequate results for predicting peak flows in both the monsoonal climate of Ethiopia and in more typical US climates such as New York State at a daily time step if the curve number approach, in the standard SWAT (SWAT-CN), is replaced. Following calibration, SWAT-WB returned more accurate results for the Gumera basin than the standard. SWAT-WB returned daily ENS and R^2 values of 0.74 and 0.77, respectively, while the calibrated standard SWAT-CN returned a ENS of 0.61 and R^2 of 0.70 on a daily basis. When compared to SWAT-CN, SWAT-WB returns ENS values 15% higher for the calibration period and 25% higher for the validation period. Figure 5 shows the results from the daily simulations.

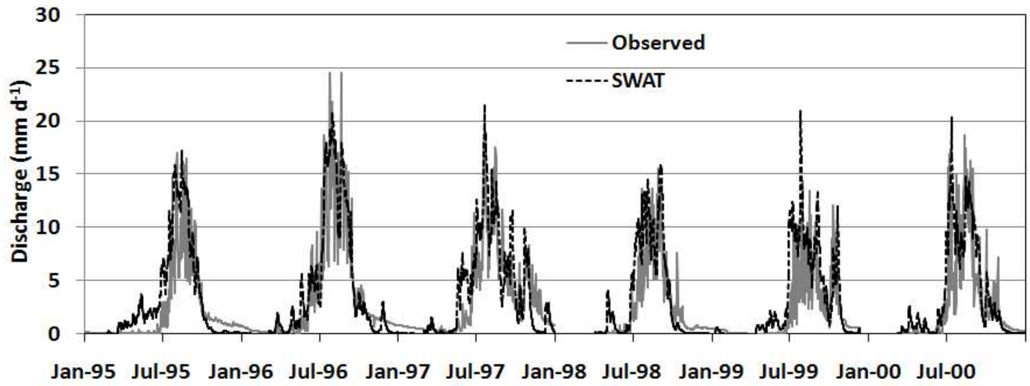


Figure 5: Daily observed and predicted discharge from the Gumera sub-basin.

Easton et al. (2010) used SWAT-WB to model the BNB at several scales from the level of the micro watershed to the entire upper BNB. In order to understand the integrated watershed responses, runoff from saturated areas and subsurface flow from the watershed were summed at the watershed outlet to predict stream flow. The graphical comparison of the modeled and measured stream flow at the Sudan border is shown in Figure 6. The model was able to capture the dynamics of most events. Both base flow and storm flow were correctly predicted with a slight over prediction of peak flows and a slight under prediction of low flows, however, all statistical evaluation criterion indicated that the model predicted well. In fact, all calibrated sub-basins predicted stream flow at the outlet with reasonably accuracy (Table 2). Model predictions showed good accuracy ENS ranged from 0.57-0.92 with measured data across all sites except Kessie, where the water budget could not be closed; however, the timing of flow was well captured. The error at Kessie appears to be due to under estimated precipitation at the nearby gauges, as measured flow was nearly 15% higher than precipitation. Nevertheless, the prediction is within 25% of the measured data. Normalized discharge across the sub-basins shows a large gradient, from 210 mm at Jemma to 563 mm at Anjeni. For the basin as a whole, approximately 25% of precipitation exits the BNB at the border with Sudan.

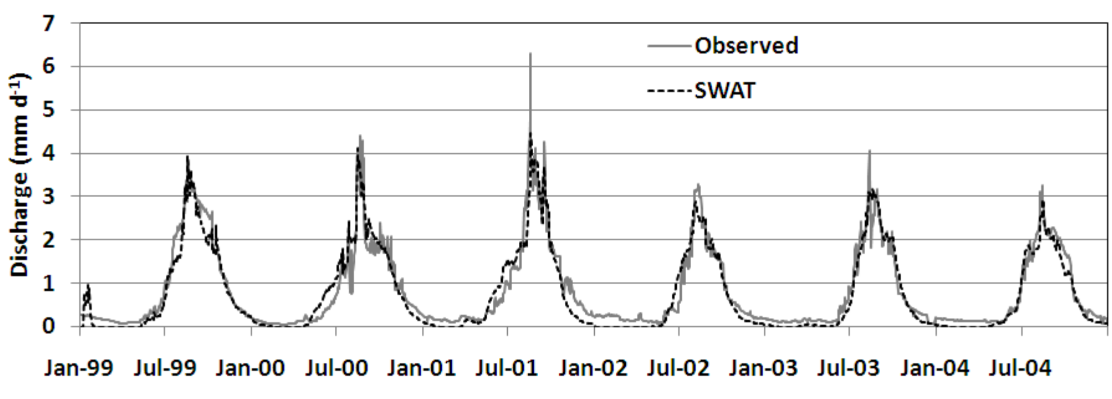


Figure 6: Daily observed and predicted discharge at the Sudan border

Table 2: Calibrated sub-basins for SWAT-WB, drainage area, model efficiency, and predicted flows

Subbasin	Area (km^2)	R^2	ENS	Mean Annual Discharge (Mm^3)	Normalized (mm)	Direct Runoff (mm)	Ground Water (mm)
Anjeni	4.8	0.76	0.84	0.40	563	44	453
Gumera	1,286	0.83	0.81	501	390	22	316
Ribb	1,295	0.74	0.77	495	382	25	306
North Marawi	1,658	0.78	0.75	646	390	27	274
Jemma	5,429	0.91	0.92	1142	210	4	197
Angar	4,674	0.87	0.79	1779	381	21	341
Kessie	65,385	0.73	0.53	19237	294	19	329
Border	174,000	0.92	0.87	56021	322	13	272

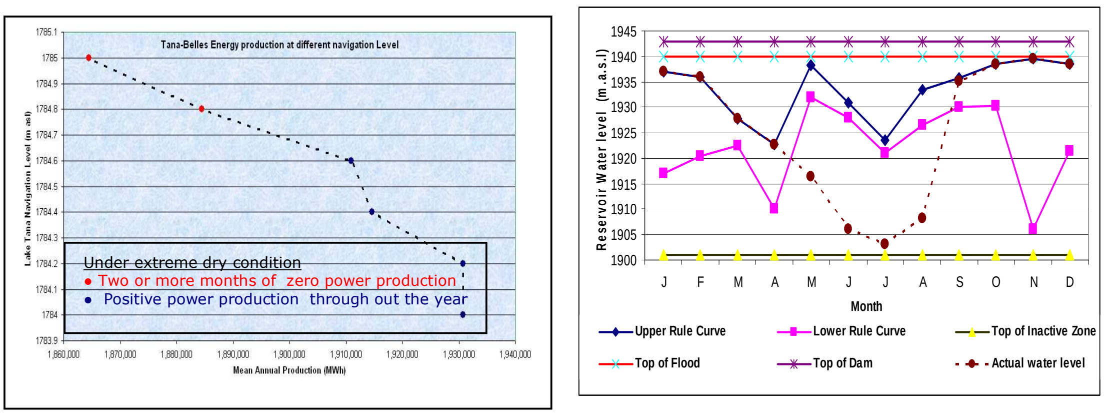
Runoff and stream flow are highly variable both temporally (over the course of a year) and spatially (across the Ethiopian Blue Nile basin) (Table 2, Fig. 5). Daily watershed outlet discharge during the monsoonal season at Gumera is nearly an order of magnitude larger than at the border (after normalizing flow) (Figs. 5 and 6). Discharges (in $Mm^3\ y^{-1}$) intuitively increase with drainage area, but precipitation also has a large impact on overall sub-basin discharge. For instance Both Jemma and Angar are approximately the same size (Jemma is actually slightly bigger) yet discharge from Angar is nearly 40% higher, a result of the higher precipitation in the southwestern area of the basin. Temporally, outlet discharges typically peaked in August of the small and medium sized basins and slightly latter for Kessie and the border, being simply a result of the lag time for lateral flows to travel the greater distances. Due to the monsoonal nature of the basin, there is a very low level of base flow in all tributaries, and in fact, some dry up completely during the dry season, which the model reliably predicts, which is important when considering the impacts of intervention measures to augment flow.

Runoff losses predicted by the model varied across the basin as well, and were generally well corroborated by runoff estimates from base flow separation of the stream flow hydrograph. Predicted runoff losses (averaged across the entire sub basin) varied from as low as 4 mm y^{-1} in the Jemma sub-basin to as high as 44 mm y^{-1} in Anjeni. Of course, small areas of the sub basins produce significantly higher runoff losses and others significantly less.

1.7.3 Special Application of Hydrological Process Studies- Multi-Reservoir Operations

The integrated reservoir simulation and optimization (HEC5A-CMAES) model was demonstrated by considering the existing supply and use situation and future development scenarios affecting water resources in the case study sub-basin. The competing water sectors considered were irrigation, municipal water supply, environment and hydropower production. Thus, objective function was set to minimize the sum of reservoir and lake release deficits and to maximize irrigation and hydropower generation in the same order of importance. In addition, we assessed the impact of navigation level of Lake Tana on Tana-Belles hydropower production or vice versa by varying the levels of the lake which are kept for navigation purpose from 1784.0 m a.s.l with an increment of 20 cm till 1785.0 m a.s.l. Figure 7a depicts twenty years mean annual Tana-Belles hydropower production with the proposed four upstream reservoirs in place at different navigation levels. A reduction in hydropower production becomes necessary when the navigation level is greater than 1784.6 m asl. There are even some zero monthly power productions under extreme dry season when the navigation level is greater than or equal to 1784.8 m asl.

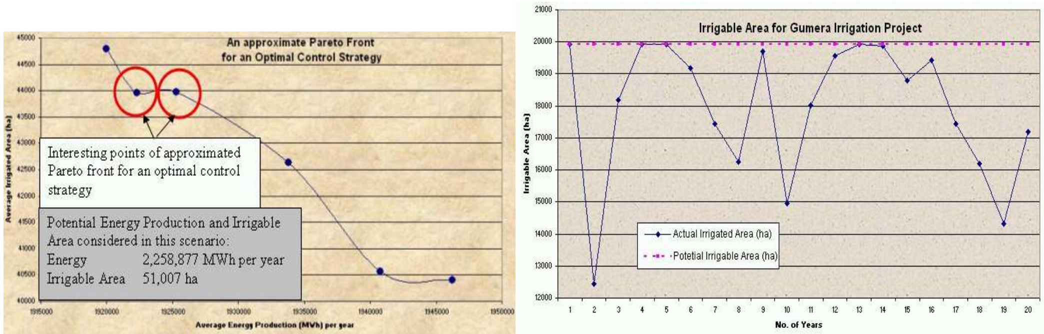
The integrated model provides reasonable operation rule curve for single and multi purpose reservoir. Conditions of minimum downstream release for environment, minimum downstream requirement for the waterfall and public water supply for Gondor city were satisfied in all model outputs. Figure 7b shows sample monthly water level of Ribb irrigation reservoir for 1987. There is a continuous decrease in reservoir level from January till end of June and an increase in reservoir level from July till end of December. All demands will be satisfied as long as the current water level in the reservoir is on and above the upper rule curve. First priority demand and a fraction of less priority demand will be satisfied when the current water level is between upper and lower rule curves. Only the highest priority demand (environmental flow) will be satisfied when the water level is between the lower rule curve and top of inactive zone. Accordingly as per figure 7b rule curves, all demands (i.e., irrigation and environmental flow) were satisfied from September till end of April and only environmental flow were satisfied from May till end of August when there is no irrigation demand in these months.



a) b)

Figure 7: a) Tana-Belles mean annual power production at different navigation levels (with four upstream reservoirs in place). b) Sample simulated water level for 1987, upper and lower rule curve for Ribb irrigation reservoir

Under the multi-purpose multi-reservoir operation scenario, deficits arise in irrigation water supply (consequently reduction in Irrigated area) for some months. Figure 8a depicts twenty year mean irrigated area (ha) and average annual energy production (MWh) for four upstream reservoirs for irrigation and Tana-Belles hydropower station which were optimized simultaneously with different weights (increasing priority level) given to hydropower production. Each blue points on the figure represents 65 coordinates (5 reservoirs * 13 monthly target level) of the optimized rule curve. Figure 8b is the actual and potential irrigated area on a number of years for Gumera Irrigation Project after multi-objective multi-reservoirs operations. In all cases, the Lake Tana water level under Multi-objective and Multi-Reservoirs Operation is well above the dead storage level (1784 m a.s.l).



a) b)

Figure 8**:** a) Twenty years average Irrigated land (ha) and average annual energy production (MWh) under different energy priority level. b) Actual Irrigated Area on a number of years for Gumera Irrigation Project

1.8 Conclusions

Understanding hydrological process of a basin as diverse as the BNB is an essential prerequisite to understand the water resources and to ultimately design water management strategies for water access and improve water use in agriculture and other sectors. The results of various studies of this project, as briefly demonstrated above provided a wide range of tools and methods of analysis to explain such process. It was also possible to show that various accuracy levels can be obtained depending on the applicability of a given model such as SWAT-CN and SWAT-WB and other rigorous modeling works. Direct use of models developed elsewhere for other hydro-meteorological, climatic and physical conditions cannot provide accurate simulation results. Therefore, efforts are needed to adopt models to improve applicability.

A multi basin analysis of water resources in the Blue Nile Basin was conducted to determine the relative importance of runoff sources in order to better manage water resources and effectively control erosion and sediment losses. Using the SWAT-WB model we were able to quantify the relative contributions from the various areas of the BNB with good accuracy, particularly at a daily time step. The analysis showed that not all subbasins contribute flow or runoff equally. In fact, there is large variation in average flow and runoff across the watershed. Within any one watershed, the model indicates that there are areas that produce significantly more runoff and areas that produce almost no runoff, which, of course has implications for the management of these areas. This model could be helpful to identify areas of a basin that are susceptible to erosive or other contaminant losses, due to high runoff production. These areas should be targeted for management intervention to improve water quality.

In general water balance models have been found to work in nearly all climates, therefore incorporation of these procedures into SWAT as SWAT-WB provides a more robust model and is potentially applicable in watersheds (such as in Ethiopia) where it has been determined that runoff generation is driven by saturation excess processes. Perhaps more importantly, the new SWAT-WB model improves the prediction of runoff at daily, monthly and annual levels and provides the estimates of runoff at any spatial location.

The SWAT-WB model can assist water resource and agricultural planners, designers and managers with a tool to better manage water resources in Ethiopian highland and to potentially mitigate impacts on water availability in downstream countries. Application of reservoir models provide an understanding of the adequacy of planned or constructed infrastructure and reservoirs for supply of various water uses. Specifically, the integrated model (HEC5A-CMAES) analyzed existing development situation in the BNB and four future water resources development scenarios. The competing water demand exerted by irrigation, municipal water supply development, and environment flows, and hydropower production were examined. The coupled model provided reasonable operation rule curve for single and multipurpose reservoir. In all scenarios considered, the Lake Tana water level is well above the dead storage level. Under multi-purpose and multi-reservoir operation scenario, deficits in irrigation water supply occur mainly for three months (February, March and April), which can be compensated by adjusting the area of irrigation to the optimum water allocation.

ADAPTATION OF WATERSHED MANAGEMENT MODELS AND ANALYSIS OF IMPACT OF INTERVENTIONS

Key Messages

- *Extreme land and water degradation occurs in the Ethiopian Highlands. The main sources of sediment are landscape-, gully- and channel-erosion or deposited sediment. A small percentage of the land produces most of the erosion.*
- *Determining runoff source areas in a watershed can help targeting interventions and better land and water management and synchronized cropping with onset of rains will control sediment erosion*
- *Sediment yield is variable and predictions at Ethiopia-Sudanese boarder ranges 88-110Mt/year, which is equivalent to 1/2 mm over the whole Blue Nile. However since erosion occurs on a small portion of the landscape locally, the effect can be disastrous for specific geographic areas of agricultural activity*
- *If gully erosion is controlled with an efficiency of 90%, it is possible to save 495 tons/km^2/yr (experimental evidence). Modeled interventions such as grass strips can reduce sediment yield by 50% to 70%*
- *The benefit of preventing soil erosion are many such as preserving land productivity, prolonging life of reservoir through reducing deposition of sediment in reservoirs and improving soil carbon sequestration*
- *Collaboration of upstream and downstream stakeholders to manage water resources in the watershed with sustainable WSM measures can lead to reduced soil erosion and Blue Nile river sediment yield*

1.9 Introduction

High population pressure, improper land-use planning, over-dependency on agriculture as a livelihood and extreme dependence on natural resources are inducing deforestation, overgrazing, expansion of agriculture to marginal lands and steep slopes, declining agricultural productivity and degradation of the environment. Poor agricultural and other land use practices affect runoff characteristics and result in increased erosion and siltation and reduced water quality in the BNB (see also Awulachew et al 2008a). According to EHRS (1984), it is estimated that over 1.9 billion tons of soil are lost from the highlands of Ethiopia annually. Erosion from the land surface takes place in the form of sheet erosion, rill and inter rill erosion, or gully erosion part of which is delivered to rivers. This, together with in stream bed and bank erosion of rivers constitutes the sediment load in the river (Awulachew et al 2008b). According to Hydrosult et al (2006), the Ethiopian plateau is the main source of the sediment in the Blue Nile system. The main area of sheet erosion is within the Ethiopian Highlands. Some sheet erosion occurs within Sudan, mainly on and around the rock hills, which have become devoid of vegetative cover. Most of this is deposited on the foot slope and does not enter the drainage system. Those streams reaching the river however during the rainy season can carry high sediment concentrations.

The eroded and transported sediment from Ethiopian Highlands ultimately reaches Sudan, causing significant loss of the reservoir, and reduced conveyance capacity in the irrigation canals. Furthermore, the effect of sediment is transmitted to Aswan High Dam (AHD) as suspended sediment. As a result, our study of erosion, sedimentation and understanding the impacts of interventions, concentrated on the Ethiopian Highlands and as far as Roseries reservoir, which is found at the boarder of Ethiopia and the Sudan. Modeling sediment can help understanding the basin wide issues in terms critical factors controlling erosion and associated sediment transport. However, sediment modeling on a daily or weekly basis in Ethiopia has generally not been very successful, because the underlying hydrologic model(s) did not predict runoff well (e.g., Agricultural Non-Point Source Pollution (AGNPS) model (Haregeweyn and Yohannes, 2003 and Mohammed et al., 2004), and WEPP (Zeleke, 2000)). Many have tried various approaches with limited degree of success because of ineffective ability to link erosion and sediment transport to hydrological process. This project therefore used an in depth analysis of various landscape sediment sources to understand the erosion-sediment transport relationship in the various watersheds in the basin.

1.10 Methods

1.10.1 Schematization of the BNB for Sediment Modeling

In order to understand from erosion process in micro watershed to basin level, and propose intervention measures to reduce erosion and sedimentation,the BNB was divided as nested system from micro watershed to basin level; where a given watershed included a number of micro watersheds (e.g. Anjeni, Andit Tid on Fig. 9) and a number of watersheds (e.g. Koga and Gumera on Fig. 9) build sub-basins (eg Tana sub-basin) and finally number of sub-basins provide the basin.

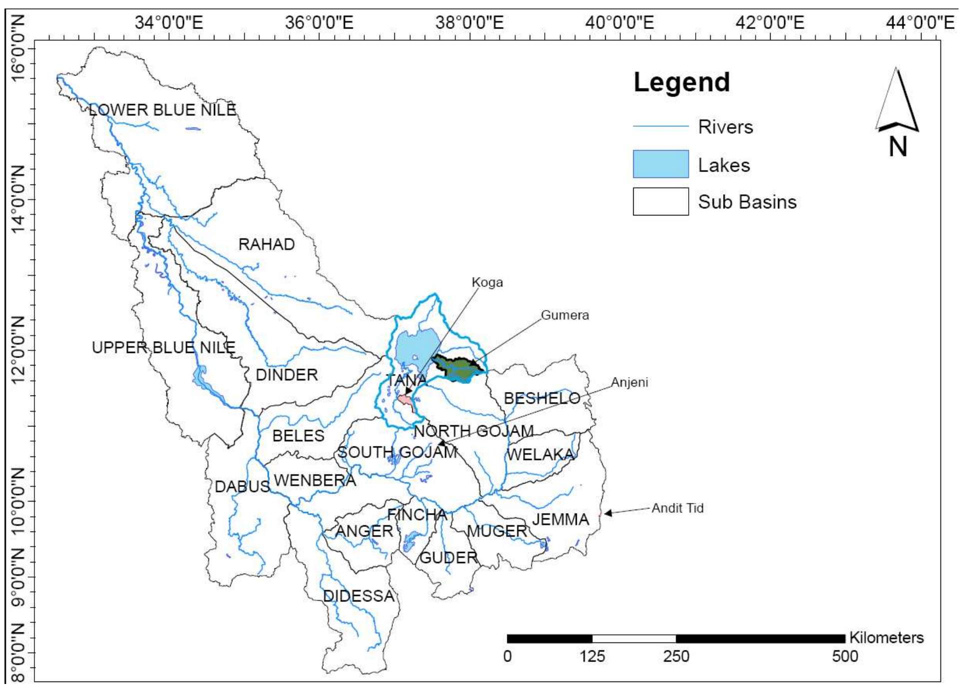


Figure 9: Idealized schematization of Blue Nile for Erosion and Sediment Analysis

Similar to the rainfall run-off study, intensive primary and secondary data were collected from stations such as Anjeni, Maybar and Andit Tid; watershed sites of Koga and other small dam sites; sub-basin data at previously existing gauging stations on tributary rivers and main stream of Blue Nile; and at Abbay outlet with Roseries as a system sink for sediment. As most of the sediments are generated in Ethiopian Highlands, the in-depth study and modeling focused largely in the highland area, but time series bathymetry and reservoir capacity curves at Roseries provided information about the consequences of erosion and sediment.

1.10.2 Micro watersheds and experimental stations

Since the establishment of the micro-watersheds by the Soil Conservation Research Project (SCRP) in 1981, high resolution data on climate, hydrology, and suspended sediment, from both river and test plots, have been collected and an expansive database was established that serves as a data source to carry out hydrological, soil erosion, and conservation research. The Anjeni, Andit Tid and Maybar stations fall under this category.

For better understanding of hydrologic and erosion process in the watersheds, during the study of the micro-watersheds, soil infiltration rates were measured at different locations throughout the watershed using a 30-cm diameter single-ring infiltrometer. Piezometers were installed at different parts of the watershed in transects to observe subsurface water depth as reflecting the fluctuations during rainfall events in the upslope and lower slope areas. Those data in conjunction with field observation, stream sediment trend analysis and discussion with the community of the micro-watersheds helped to develop simplified models to predict erosion.

Long-term upslope erosion predictions based on Hurni (1985) who adapted the empirical Universal Soil Loss Equation (USLE) for Ethiopian conditions to predict annual soil losses are considered reasonable. However, these models do not include erosion due to concentrated flow channels and gullies, hence they fail to predict erosion accurately at the field or plot scale. In the early days of such efforts, software tools such as SWAT were not available, and USLE equations were used with cumbersome modeling efforts. The models such as Curve Number based SWAT (SWAT-CN) were used widely in many parts of the world. Our work here constitute both use of SWAT-CN and a water balance based SWAT (SWAT-WB). As stated earlier, the latter was specifically developed for the BNB. The main difference between SWAT-CN and SWAT-WB is that runoff is explicitly attributable to source areas according to a wetness index distribution that shows the degree of wetness, rather than by land use and soil infiltration properties as in SWAT-CN. Soil properties that control saturation-excess runoff generation (saturated conductivity, soil depth) affect runoff distribution in SWAT-WB since they are included in the wetness index. Landscape erosion in SWAT is computed using the Modified Universal Soil Loss Equation (MUSLE). MUSLE determines sediment yield using a runoff factor that estimates the energy that governs the transport of eroded sediment in surface flow. Thus the sediment delivery ratio is incorporated into the equation and does not need to be specified separately. Thus the improved runoff estimates can somewhat overcome the inherent limitation of using MUSLE. By utilizing better hydrologic models, our prediction of runoff and thus identifying sediment source areas provided much more realistic results.

In the Andit Tid micro-watershed, a simple water balance model was developed and employed as a starting point for further sediment modeling in the watershed. In the Anjeni watershed a physically based modified SWAT model, SWAT-WB (White et al., 2010)], was as well applied to simulate the rainfall/runoff and erosion process. In the Maybar watershed, the spatial and temporal variation of chemical and physical soil properties were assessed after the implementation of soil conservation structures in the watershed. Theoretical consideration and detail discussions on the types of model equations used for this study related to erosion modeling are provided in detail in Easton et al (2009). We examined plot level runoff-soil loss relationships, stream sediment loss trends and erosion modeling.

1.10.3 Watersheds and small dam sites

Several studies have been carried out in the Debre Mewi watershed (508 ha). Tigist (2009) and Anteneh (2009) studied gully formation. Zegeye et al (2009) measured upland erosion in a sub catchment and found that the USLE on the average could predict the catchment wide observed erosion. Similarly, the Revised USLE (RUSLE) in combination with remotely sensed data and GIS assessed the overall erosion potential of the Debre Mewi watershed.

In the Gumera watershed, we used SWAT-CN model (at the time when SWAT WB was not readily available) to predict erosion risk and sediment yield, see Tenaw (2009). In order to identify the most important or sensitive model parameters before calibration, model sensitivity analysis was carried out using a built-in SWAT sensitivity analysis tool that uses the Latin Hypercube One-factor-At-a-Time (LH-OAT) (Van Griensven, 2005). Manual calibration procedure was used and the model calibrated and validated using suspended sediment data measured at a gauging station covering about 90 % of the total watershed. Percent difference between simulated and observed data (D), Correlation coefficient (R^2) and Nash and Sutcliffe simulation efficiency (E_{ns}) (Nash and Suttcliffe 1970) were used to evaluate the model's performance during calibration and validation processes. The ultimate objective of Gumera watershed modeling by Tenaw was to identify critical erosion risk areas, propose interventions and ultimately evaluate the impacts of the interventions.

Similarly, further studies were carried out using GIS based SWAT modeling, erosion source area identification, and sediment deposition characteristics at other watersheds. Specific studies to understand the behavior of sediment deposition in small reservoirs were undertaken at Koga watershed and reservoir, Gomit Micro Dam, Zana Watershed, Dana Watershed and Tebi watershed. The methods used for the dam sites were simple analysis of bathymetric information and that examined the impacts of erosion, sediment transport, yield and depositions at the dams sites.

1.10.4 Sub-basin and Basin Levels

In order to predict sediment at various outlets of the basin that include sub-basins and basin outlets, we used integrated modeling of the entire Blue Nile using SWAT-CN method as discussed in Fetene and Awulachew (2008). Betrie et al (2009) used SWAT to model soil erosion in the upper catchments of the Blue Nile over the Ethiopian Plateau. In the latter, the SWAT output forms the input sediment load for a one dimension morphological model known as SOBEK . The two models were integrated using the principles of the Open Model Interface (OpenMI) at the Ethiopia-Sudan border. The sediment accumulation at a given reservoir or lake represents the yield of land degradation, erosion, sediment transport and ultimate yield at that particular point. We considered the Roseries reservoir as a sink of sediment coming from the entire Ethiopian highland. Of course not all sediment is deposited in the reservoir, since some fraction of suspended sediment can also pass downstream. Through the work of Bashir et al (2009), we assessed sediment accumulation as well as the rate of sedimentation in the Roseires Reservoir. The basis for the study is the previous bathymetric surveys carried out on the reservoir in the years 1976, 1981, 1985, 1992, 2005 and 2007. Analysis and comparative studies were carried out between the different surveys to quantify the amount of sediment deposited as well the rate at which sedimentation took place. The design storage capacity of 1967 for the different reservoir levels was taken as a baseline. The sediment accumulation rates for the different bathymetric surveys were obtained as the difference between baseline capacity and the computed capacity at the respective levels during the specific survey. Detail discussions of these methods are beyond the scope of this report and readers can refer to the indicated references.

1.10.5 Interventions

Two aspects related to control of erosion and impacts of interventions are considered in detail based on Zegeye et al (2009), Awulachew & Tenaw (2008a).

Gully formation and upland erosion were studied in the Debre-Mewi Watershed in the Gilgil Abbay Basin south of Lake Tana. The historic rate of gully development was assessed through the AGERTIM method (Assessment of gully erosion rates through interviews and measurements, Nyssen et al., 2006) and by interpretation of air photos and satellite images. Gully hydrological processes were investigated by installing a weir to measure runoff. In addition to the weir, 24 piezometers (ranging in depth up to 6 m) were installed in the gully bottom as well as the gully's contributing area. The runoff and water depths were recorded manually during several storm events. Throughout the contributing area of the gully, soil bulk density was estimated and infiltration tests were performed. On July 1 and October 1, 2008, the volume and surface area of the entire gully system were estimated through measurements of width, depth and length of gully profiles. Upland erosion was assessed as well. Fifteen representative fields were selected according to slope positions. Soil samples were collected in three typical slope positions in four locations of each field for determining the moisture content. Additionally, farmers' perceptions about soil loss and soil conservation were gathered by interviewing 80 farm households from the four surrounding villages and by holding focus group discussions with groups of watershed community members.

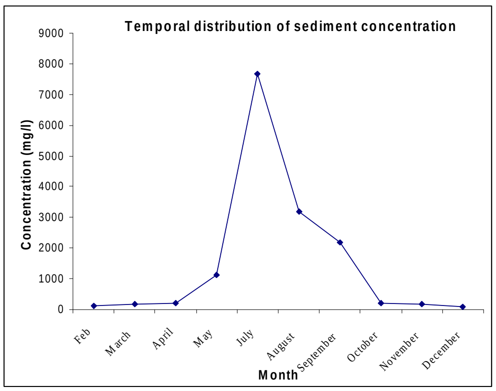
With regards to observation of impact of intervention on sediment yield, the model adopted by Tenaw and Awulachew (2009) was used. The SWAT model, once it had been validated and the results were considered acceptable, was parameterized to the conditions of interest (e.g., to evaluate impact of land use change, management and conservation practices). After detailed analysis of the problems and benefits of the existing physical conservation practices in the watershed, we tested the model with alternative scenario analysis of vegetation filter strip (buffer) with varying width to reduce sediment production from critical sub watersheds. The critical watersheds were identified based on running the model and identifying the watersheds exceeding the tolerable rate of 11 ton/ha/year. In evaluating the impact of filter strips, three management scenarios were considered and simulated: Base case (no filter strip); filter strip 5 m wide on all HRUs (hydrologic response units) in selected sub watersheds; and filter strips 10 m wide on all HRUs in selected sub watersheds.

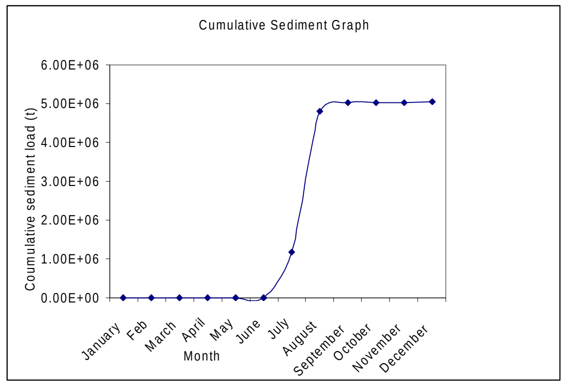
1.11 Results and Discussion

1.11.1 Temporal Distribution of Sediment and Data

Examination of the sediment stations available from the Hydrological Department of the Ministry of Water Resources (MoWR) in Ethiopia shows that there are a total of 45 stations in the Abbay Basin. However, most of these have only very sporadic measurements. Most of the available sediment data is related to periods during which stage-discharge relationships were developed for flow gauging stations or when revisions to such relationships were made. Continuous monitoring of sediment has not been undertaken at any of the stations, except at experimental ones. A consolidated list of stations with data records for the Abbay is provided in Awulachew et al (2008b).

Preliminary analysis shows that sediment peaks during the rainy season, particularly in the month of July and almost no sediment is measured in the streams in the dry season. The annual sediment concentration (sediment weight per volume of water) measured in mg/l shows sediment load distribution is concentrated in June to September, with the highest peak is in July, while the rainfall and runoff peaks occur in August. Figure 10 is a typical case of Blue Nile tributaries, in the case the long-term monthly average sediment concentration of Ribb River at Addis Zemen. The river is a medium sized watershed tributary, with drainage area 1592 km^2 draining to Lake Tana.





a) b)

Figure 10: a) Typical monthly sediment concentration, and b) cumulative sediment load over time at Ribb at Addis Zemen station, a tributary of the Blue Nile

The important implication is that sediment-rating curve established only on flow volume or river stage cannot provide accurate estimation of sediment yield. Sediment delivery varies not only according to the rainfall and runoff volume but also according to onset of rainfall, land use and land cover.

1.11.2 Micro watersheds and experimental stations

For the Anjeni analysis the input data consists of the fluxes for the three source areas simulated by the water balance model describe in Section 2. There are three calibration parameters, one for each source area, that determine its contribution to the sediment load at the outlet of the watershed. The calibrated parameters were then used to predict to sediment concentrations for the 1991- 1993. The best-fit data (Figure 11) show that the interflow and base flow have an order of magnitude lower sediment concentration than the surface runoff from the degraded areas. Model results for the entire record are shown in Figure 12 for the calibration and Figure 13 for the validation periods.

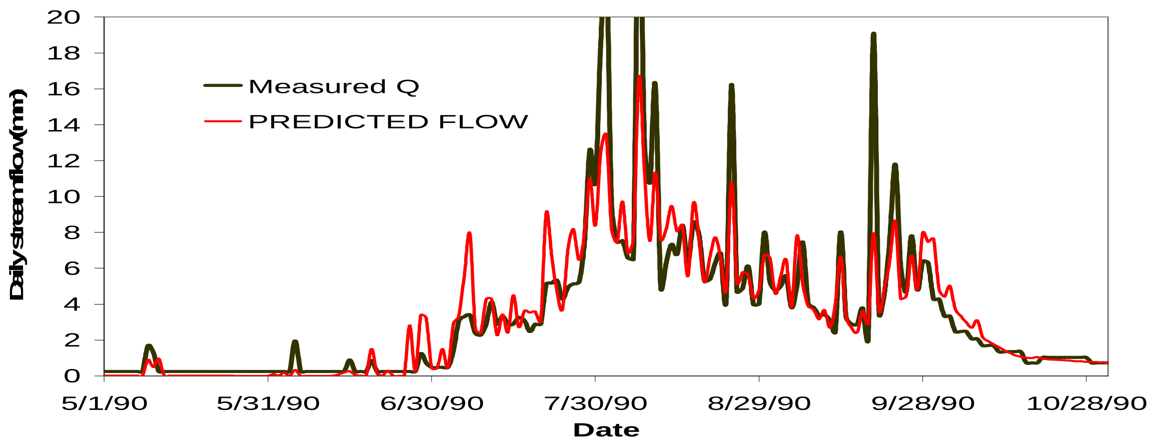


Figure 11: Calibrated and observed stream flow for Anjeni Watershed

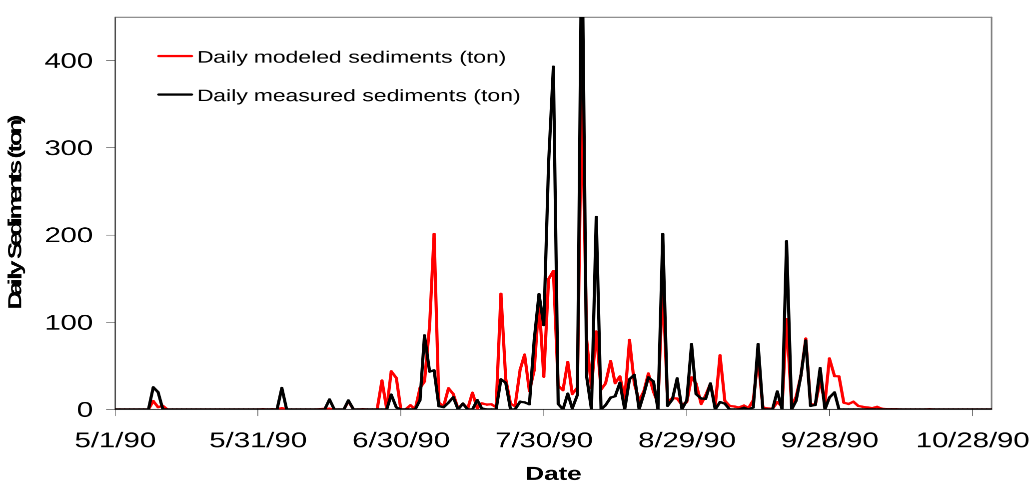


Figure 12: Predicted and observed sediments load for the Anjeni Watershed during the calibration period

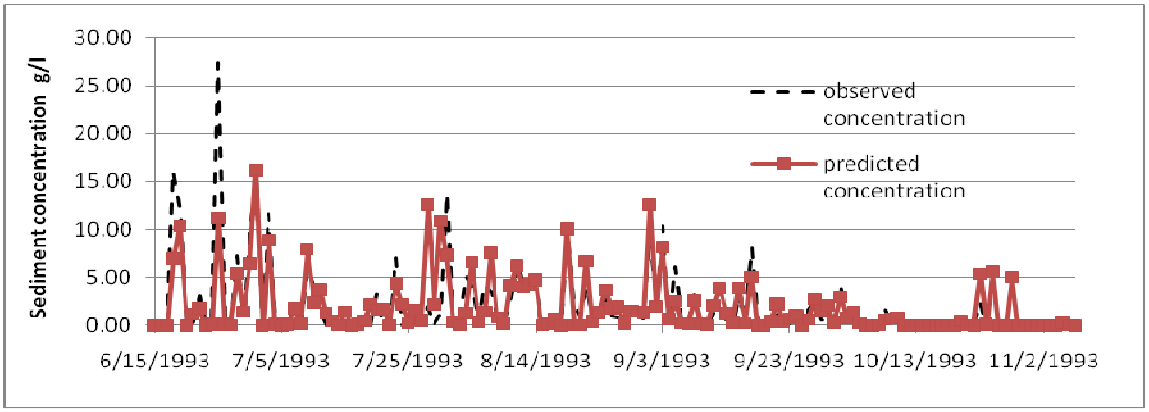


Figure 13: Predicted and observed sediments concentration for the Anjeni Watershed during the validation period

At Andit Tid, four years of daily measured data were used to model the erosive losses. Two simple models, which relate soil transport capacity of surface runoff mechanisms, were developed and used to simulate stream sediment load. The simple empirical relationships used to simulate soil loss were:

$$Sl = 0.3 \times Q_{or}^3 + Q_{st}^2 \qquad \text{(a)}$$

$$Sl = 18.5 \times Q_{or} + 0.2 \times Q_{st} \qquad \text{(b)}$$

where Sl is stream sediment load in tons, Q_{or} is surface runoff from rock outcropping/degraded areas in mm, and Q_{st} is surface runoff from saturated areas in mm. Trend correlation coefficient, R^2, values of 0.5 and 0.6 were found between measured and modeled daily sediment loads using Eqs. a and b, respectively (Figs. 14a and b). These R^2 values for the daily data from both equations indicate that these models reasonably predicted soil loss trends (Figure 15).

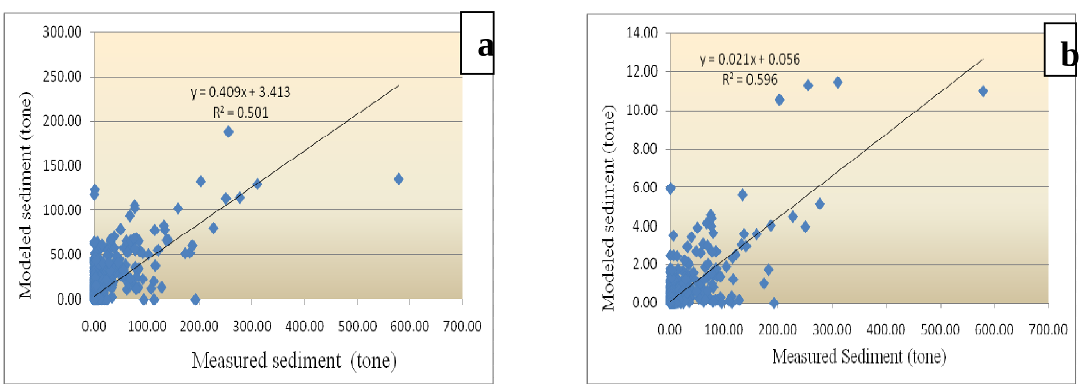


Figure 14: Trend correlation coefficient of measured and modeled sediment load using equations (a) and (b).

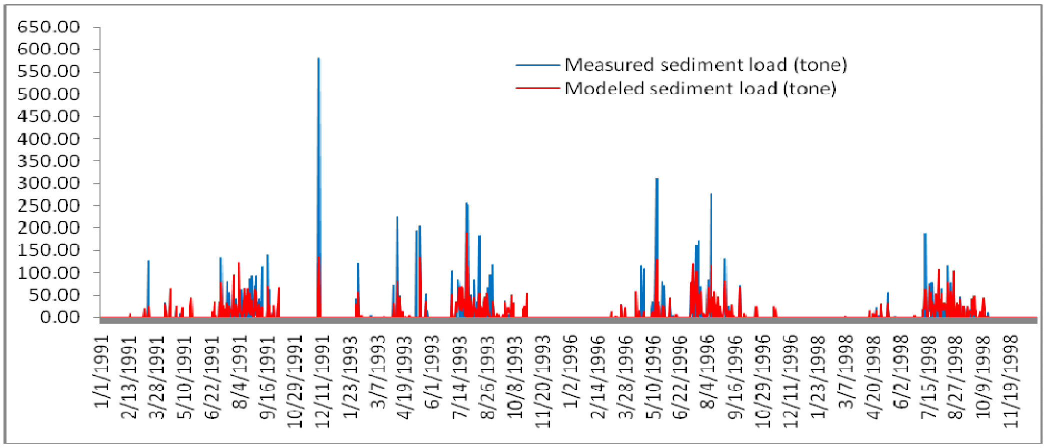


Figure 15: Measured and modeled sediment load

The simple erosion model in Andit Tid clearly indicated that surface runoff and soil loss are related. The erosion model revealed that the lower degraded and saturated areas of the watershed are the main runoff source areas and should be the focus during water quality and land management activities.

1.11.3 Watershed and Small Dam Sites

The erosion predictions at Gumera watershed showed good agreement between calibrated monthly sediment and measured sediment yield with ENS of 0.74, R^2 of 0.85, and D of -14.2% (Figure 16). Validation results also showed good agreement between measured and simulated values, with ENS of 0.62, R^2 of 0.79, and D of -16.9%.

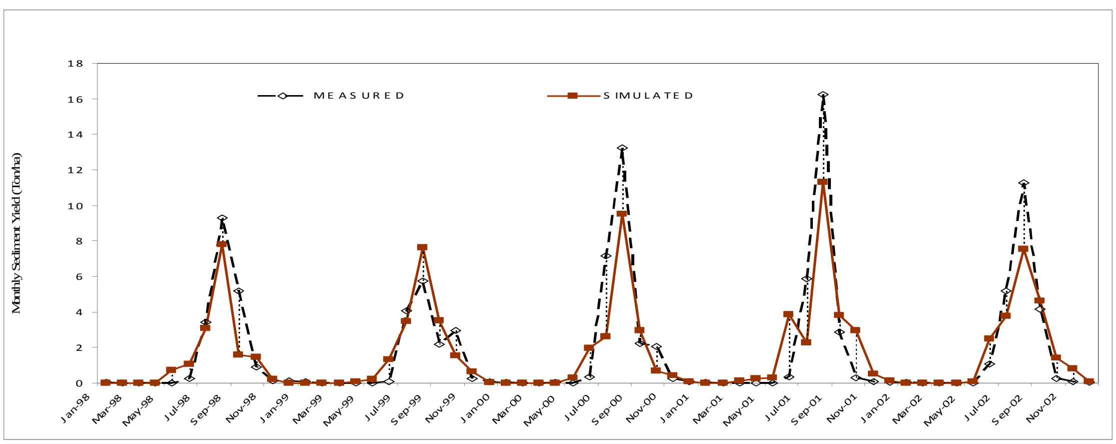


Figure 16: Calibration results of monthly measured *(--♦--)*and simulated *(–■–)* sediment yield at Gumera gauge

Spatial pattern of sediment source

The spatial distribution of annual sediment generation for the Gumara River watershed shows that 18 out of 29 sub-watersheds produce average annual sediment yields ranging from 11-22 ton/ha/yr, while most of the low land and wetland areas in the north west region produce 0-10 ton/ha/yr (Figure 17)

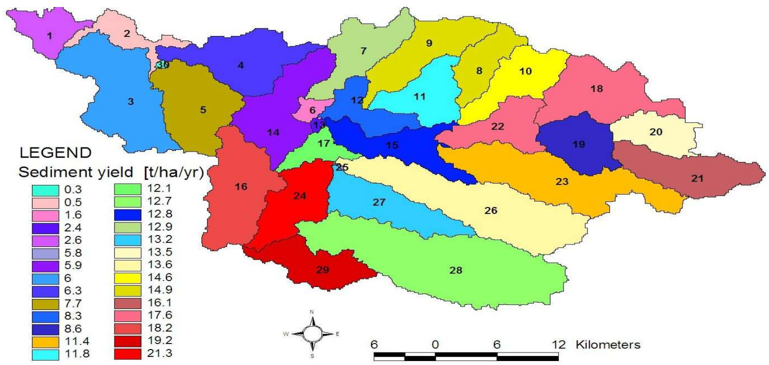


Figure 17: Spatial distribution of average annual sediment yield by sub-watershed (t/ha/yr) simulated using SWAT. Numbers (1-29) are sub-watershed numbers in Gumera watershed

In fact, the previous sub-section demonstrates that erosion such as at the flat areas where saturation flow predominates, gully based erosion is the most dominant. While it is possible to correlate watershed and climatic parameters on the hillsides, erosion behavior in the low lands is controlled by other parameters such as degree of saturation and moisture, which cannot easily be included in the SWAT-CN model.

1.11.4 Sub-basin and Basin Level

After completing calibration of runoff, Fetene (2009) calibrated the SWAT model for sediment by comparing monthly model simulated sediment yield against monthly measured sediment yields at Gilgel Abbay, Ribb and the main Abbay near Kessie. The sediment discharge curve was derived and by using this curve, monthly data for the site of calibration was generated. Table 3 provides the results of calibration and validation. To minimize the discrepancy, the discharge sediment curve was derived as wet season and dry season curve separately, where data exists. bIn absence of data, it is possible to generalize the model work for other similar sub basins with similar HRU from these calibration and validation results and sites.

Table 3: SWAT model calibration and validation statistics for monthly sediment yield comparison at selected sites

Watersheds		Simulation Period	Monthly Average efficiency	
			R^2	E_{NS}
Addis Zemen	Calibration	1992-1994	0.89	0.88
	Validation	1997-2000	0.81	0.75
Gilgel Abbay	Calibration	1992-1994	0.71	0.66
	Validation	1997-2000	0.71	0.65
Kessie	Calibration	1992-1994	0.86	0.85
	Validation	1997-2000	0.82	0.77

Based on basin wide analysis, the Guder, North Gojam and Jemma are the highest sediment yielding sub basins, respectively and cover 13%, 11% and 10% respectively of the whole Blue Nile basin in Ethiopia. The amount of soil erosion or sediment yield that occurs in given watershed is related to five factors: the rainfall and runoff, the soil erodibility, the slope length and steepness, the cropping and management of the soil, and any support practices that are implemented to prevent erosion. The land use/cover of the three highest sediment yielding sub basins are dominated by crop agriculture covering 95.66%, 95.41% and 93.89% respectively and this is a key factor for erosion in these sub basins

Similarly, the results of Betire et al (2009) was based on data from El Diem station in Sudan, upstream of Roseries. SWAT sediment out flow calibrated for the period 1981 to 1986, while 1980 was used for warming the model. The validation was made for the period of 1990 to 1996. The ENS was found to be 0.72 and 0.66 for results of SWAT daily sediment calibration and validation, respectively. The SOBEK results also showed a good fit of the simulated river flows at Roseires and Sennar reservoirs, both for calibration and validation. The results of the integrated modeling system showed 86 million tonnes/year of sediment load from the Upper Blue Nile in the Roseires Reservoir. The spatial variability of soil erosion computed with SWAT showed more erosion over the northeastern part of the Upper Blue Nile, followed by the northern part, and the result is similar to Fetene et al (2009), discussed in previous paragraph. The sediment load values are also similar to that of Fetene 88 Million tones/year and that of BCEOM (1998), 91 Million tones/year. The overall exercise indicated that the integrated modeling is a promising approach to understand soil erosion, sediment transport, and sediment deposition in the Blue Nile Basin. Modeling helps to improve the understanding of the upstream-downstream interdependencies, for better land and water management at basin scale.

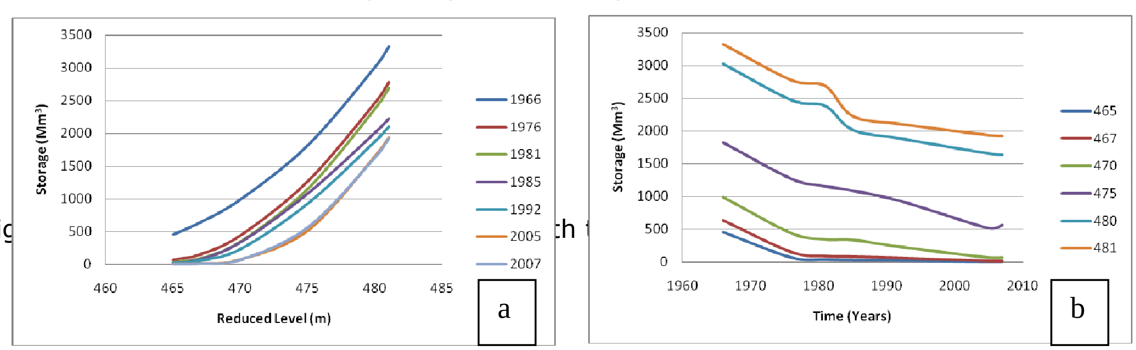
The variations of the reservoir storage capacity and silt contents with elevations calculated from the bathymetric surveys of the years, 1976, 1981, 1985, 1992, 2005 and 2007, according to Bashir et al (2009) are shown in Table 4.

Table 4: Storage capacity of Rosaries Reservoir

Reduce Level	1966 (Mm^3)	1976 (Mm^3)	1981 (Mm^3)	1985 (Mm^3)	1992 (Mm^3)	2005 (Mm^3)	2007 (Mm^3)
465	454	68	36	26	23	4.5	6.21
467	638	152	91	80	60	13.71	13.98
470	992	444	350	342	235	72.46	72.38
475	1821	1271	1156	1088	932	517.46	566.85
480	3024	2474	2384	2020	1886	1658.38	1637.56
481	3329	2778	2689	2227	2104	1934.73	1920.89

Table 4 shows the decrease in the storage capacities with time at all reduce levels/bed elevation. Figures 18a and b show the variation of storage with reduce level in the specific survey years and the variation of the same with time at specific reduce level. It can be seen that after forty one years of operation (1966-2007), the total capacity of the reservoir will be reduced to 1920.89 million cubic meters and 13.84 million cubic meters have been lost in the last two years (2005 – 2007).

Fig



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1.11.5 Erosion and Sediment Interventions

In the micro watersheds, such as Anjeni, farmers in the watershed started constructing terraces in 1984. Analysis showed that the rate of gully formation after 1982 increases from 301 tons/yr (during the time when there are no terraces in the watershed) to 550 tons/yr (during the time when the farmers are practicing terraces). Construction of terraces encourages infiltration, which reduces erosion from the terraces, but increase subsurface flow, and hence accumulation of water in the low lying areas, which might increase erosive losses (via gullies) from those areas. As water infiltrates, there is the chance for the occurrence of soil piping. Indeed, observations in the watershed showed the occurrence of soil piping. Soil piping is a major cause of channel head extension, riling and gulling in landscapes and piping as a major cause of gulling. In addition to this, gully formation may occur due to the under-cutting of banks of gullies by a high velocity runoff.

The impact of filter strips were simulated with three management scenarios, as discussed in the methods section. With implementation of vegetation strips, an average annual sediment yields can be reduced by 58 % to 62 % with 5m filter strip and 74.2 to 74.4 % with 10m filter strips (Table 5 and Figure 19)

Table 5: Average annual change in sediment yield due to implementation of vegetation (filter strips) of varying widths in selected critical Sub Watersheds.

Selected critical Sub Watersheds	Average Annual Sediment Yield t/ha/yr) (1996-2005)			Percent Reduction in Sediment Yield	
	Base Case (no filter strip)	Field Strip or Buffer (5m wide)	Field Strip or Buffer (10m wide	Field Strip or Buffer (5m wide)	Field Strip or Buffer (10m wide)
11	11.800	4.5	3.03	-62	-74
16	18.200	7.6	4.68	-58	-74
17	12.100	4.6	3.11	-62	-74
22	17.600	6.8	4.54	-61	-74
24	21.300	8.2	5.48	-62	-74
28	12.700	4.9	3.28	-61	-74
29	19.200	7.4	4.95	-61	-74

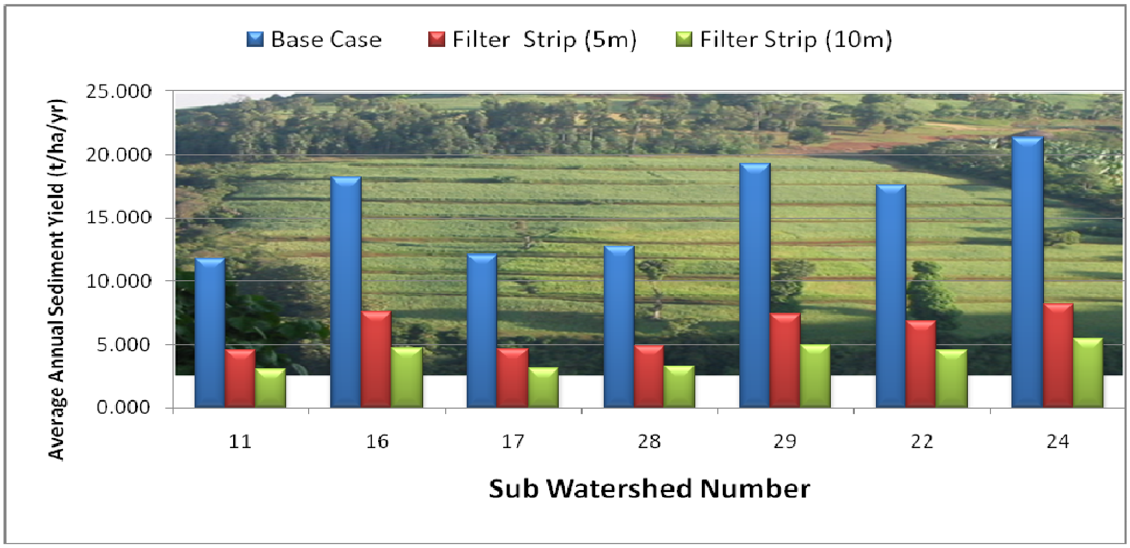


Figure 19**:** Reduction in sediment yield (t/ha/y) due to implementation of different width of filter strips as compared to the base case

1.12 Conclusions

Erosion, sediment transport and sedimentation are critical problems in the Blue Nile Basin. Currently erosion, sediment transport and sedimentation are causing considerable loss of soil, and deposition in rivers and reservoirs, and can cause irreversible levels of soil degradation, loss of livelihoods. Additional impacts include significant cost in downstream areas for canal and reservoir dredging and new investment required for heightening of reservoirs to sustain reservoir capacity.

The BNB, while providing significant flow, also yields heavy sediment loads. The analysis of data at various stations showed that seasonal sediment distribution is highly variable, and that the highest sediment concentration occurs in July, when most of the land is cultivated using traditional practices that lead to significant loss of soil and nutrients from agricultural fields in the form of erosion and sediment. The consequence is rapid accumulation and losses of capacity of small reservoirs built for agricultural or other water supplies and rapid filling of the dead storage of large reservoirs and natural and man-made lakes. This section also demonstrated the usefulness of modeling tools such as SWAT to model a complex and data scarce basin. Through modeling of the Gumera watershed and the whole of Blue Nile, we showed that runoff and sediment can be simulated with reasonable accuracy using varying models. This also indicates that sediment and yield data can be generated for ungauged basins. In addition using the bathymetric survey results of Roseries, it was possible to show the extent of sediment yield and the massive sediment volume at the outlet of Blue Nile from Ethiopian highland.

As demonstrated by the vegetative filters, the impact of soil and water conservation interventions can be quantified and the results suggest that vegetative filters can provide a significant reduction in sediment load to the upper Blue Nile. Application of the vegetative filter and other soil and water conservation interventions throughout the basin could help to reverse land degradation and improve the livelihoods of the people upstream, and at the same time reduce the cost[2] of operation and maintenance of hydraulic infrastructure and other sedimentation damage downstream. In order to target the critical areas requiring interventions, the GIS supported maps are useful and the identified high erosion risk areas dictate immediate interventions areas.

[2] Unofficial data describes that 70% of the cost of operation and maintenance in the Blue Nile part of Sudan is spend on sediment related and canal maintenance

AGRICULTURAL PRODUCTIVITY AND IMPACT OF AWM TECHNOLOGIES

Key Messages

- *Agricultural water management (AWM) technologies in rain fed systems largely make best use of the green water while improving the quantity and quality of water downstream*
- *Converting non-beneficial water such as evaporation to productive use such as evapotranspiration would improve productivity and resilience*
- *Draining Vertisoils enhances early crop cover, minimizes erosion and opens opportunity for double cropping*
- *Intensification of systems is not the case in Blue Nile.Improved water productivity through intensification of systems is key for attaining increased productivity both in the upstream and downstream users*
- *Improved water and soil management saves water, improves productivity and sustains biodiversity. The current level of land use and degradation in Blue Nile is not sustainable*
- *Integration of optimum levels of soil fertility, water use and improved seed enhances agricultural productivity. However, such interventions are not adequately accessible in Blue Nile*
- *Impact of AWM technologies used in supplementary irrigation is significant in poverty reduction compared to pure rainfed system*

1.13 Introduction

The Blue Nile was characterized based on topographic, sub-basins/watersheds, hydro-meteorological, systems etc. as discussed in section 1. This section extends the characterization with respect to farming/production systems of the Ethiopian highland part of the BNB and deals with analysis and discussion of the major productivity constraints including the water management, and other biophysical constraints. It also deals with identification of the type of agricultural water management, soil fertility and seed improvement interventions that are under use and potentially usable for upgrading rainfed production systems. The impacts of agricultural water management (AWM) were examined in selected parts of the Ethiopian highland parts of the basin.

1.14 Methods

The farming systems of the basin have been classified into homogenous units based on the Basin Master Plan Study (BCEOM, 1998), major livelihood activity, soil types, agro-ecology, major types of crops grown and cultivation practices. The productivity of the farming systems were analyzed under the prevailing farming practices based on the district level CSA reports (CSA, 2005). Potential agricultural water management and other complementary technologies suitable for the areas were identified based on a survey conducted earlier in the country (Loulseged *et al*., 2009) and literature review.

The possible influences of the technological interventions on both the upstream and downstream water and land users have been analyzed. The water productivity of sequentially grown maize and potato under rainfed and supplementary irrigation in the maize based farming system was estimated using the FAO AquaCrop (Raes et al., 2009) model assuming varying soil fertility scenarios. We have assessed the type of technologies used to produce the inventory list.

Impacts of the AWM technologies on poverty reduction were assessed by undertaking household consumption survey from the rainfed and irrigated areas, with a unique dataset from a representative sample of 1517 households from 29 Peasant Associations. Poverty impacts related to incidence, depth and severity of poverty were analyzed. The poverty impacts were assessed using standard poverty analysis techniques (Foster et al., 1984) to explore whether those with access to AWMT have relatively higher consumption expenditure per adult equivalent compared to those without access. For details on methodology, see Awulachew et al (2008c).

1.15 Results and Discussion

1.15.1 The farming systems

The farming systems in the upper part of the Blue Nile basin has been categorized into the mixed crop-livestock farming of the highlands and the pastoral-agro-pastoral of the lowlands. These were sub divided to make nine distinct subsystems (Figure 20) although only four of them cover about 70% of the basin. The cereal based crop cultivation, livestock, coffee and other tree and root crops complex together with enset (*Ensete ventricosum*) constitute the mixed crop-livestock farming system. The cereal-based crop cultivation system was further subdivided to form three sub-systems including (1) a single cropping per annum (2) double cropping per annum and (3) shifting cultivation subsystems.

1.15.2 Productivity of the farming systems

Leptosols, Nitisols and Vertisols cover the major part of the basin. The productivity of these soils is constrained by their shallow depth, acidity and water logging, respectively. Under the prevailing management regime, the average crop productivity of the farming systems is less than one-ton ha^{-1} with a minimum of just over 0.7-ton ha^{-1} and a maximum of 1.2-ton ha^{-1}, for the enset-root crops complex and the barley based single cropping systems, respectively (CSA 2005). The productivity of the crops grown in the basin is lower than their respective national average and their potentials.

Among the major impediments to productivity are: (1) Soil erosion and land degradation that reduce the nutrient and water storage capacity of the soil; (2) Frequent draughts aggravated by unreliable rainfall; (3) Soil acidity and waterlogging in the areas receiving sufficient rainfall; (4) Lack of technologies such as improved crop varieties and fertilizers farm implements; (5) Poor soil fertility management – as the traditional practices are diminishing and the adoption of the modern technologies such as fertilizers and lime are sluggish and (6) Livestock disease particularly trypanosomiasis in the western part and feed shortage, especially in the eastern part of the basin.

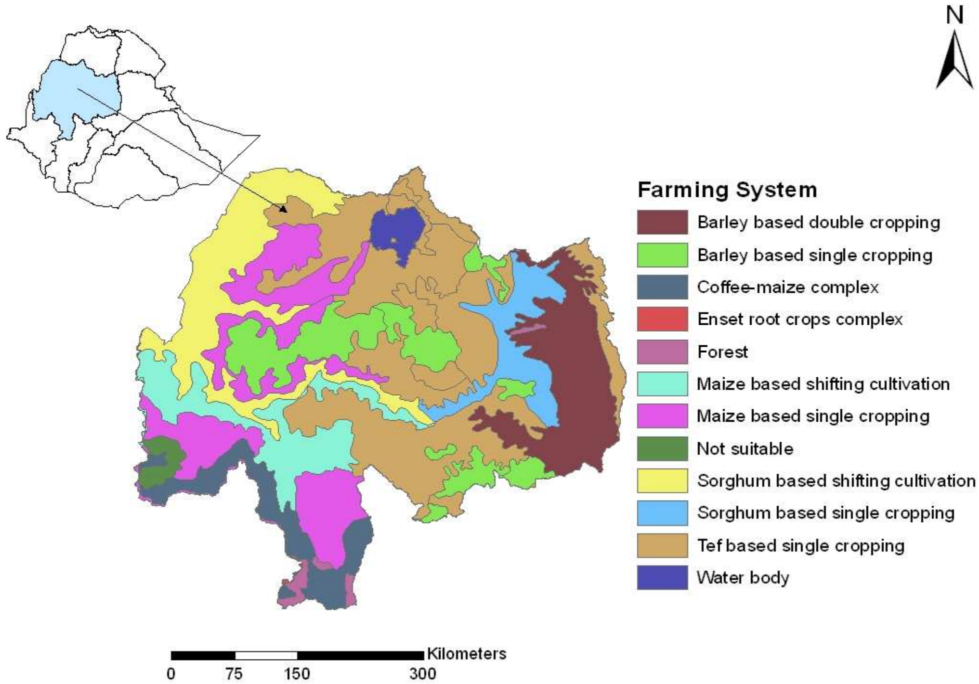


Figure 20: Distribution of the farming systems in the Abbay basin

1.15.3 Impact of the potential interventions

The relative severity of the constraints varies from one farming system to another. Consequently, interventions should also vary based on the priority problems. In-situ water conservation techniques can enhance the productivity of crops in the moisture deficit areas or seasons. Research conducted in semi-arid areas in Ethiopia, including the Abbay Basin, indicate that the use of tie-ridges increased grain yield of maize, sorghum, wheat and mung beans by 50% to over 100% as compared to the traditional practice of planting on flat beds (Kidane *et al*., 1999). Other rain-water harvesting techniques such as run-off farming, flood spreading, in-situ water harvesting (ridges, micro basins, etc.) and roof water harvesting (Alem, 1999), and more recently ponds and development of shallow wells are common in the basin. The harvested rainwater can be used as supplementary irrigation to bridge the prolonged dry spells during the main season or as full irrigation of high value crops grown on small plots during the dry seasons. Complementary to the water harvesting, integrated watershed management is necessary to avoid siltation of the storage structures, encourage recharging of the shallow wells and to ensure sustainability. Loulseged et al (2008) provide comprehensive list of inventory of the agricultural water management technologies practiced in and around the basin.

Only few farmers in the basin and the country at large have been practicing traditional small-scale irrigation (SSI) from springs, rivers and other water sources for generations. Using such practices can ensure significant stability and increase crop yield without much investment and with less technical support. Crop yield under SSI was at least 30% higher than under rainfed conditions, with much higher benefit in higher potential areas and in farms where external inputs (fertilizer, improved seeds and pesticides) are accessible. A significant yield increase was reported for drought sensitive crops like maize, which could completely fail if the dry spell coincides with the most drought sensitive stage of the crop. In the four major farming systems alone, over 41,000 ha can be developed by SSI using different sources of water ranging from rainwater harvesting to river diversions (BCEOM, 1998). The widespread use of SSI to exploit the potential requires extensive promotion work among a range of stakeholders.

It is also important to note SSI development and intensification have significant benefit for rural women example through enabling women to increase their cash incomes, diversify family nutrition and food. The issue of access to improved land and water by women, including those who are household heads are critical in ascertaining equity, and should be a priority. On the other hand in both male and female headed households, AWM is likely to increase the burden of labor on women, as use of AWM technologies is a labour intensive form of agriculture. From a gender point of view, SSI can therefore also have negative impacts on women (if men capture an unfair share of farm profits, or if women's labour burden increases without adequate compensation).

Waterlogged Vertisols cover about 2.6 million ha in the basin. Traditionally, most crops grown on these soils are planted towards the end of the rainy season to grow on residual moisture (Abate et al, 1988). This significantly reduces the length of effective growing period and water productivity since much of the water is lost due to evaporation. Several studies have shown that surface drainage allows early sowing, enabling the full utilization of the growing period, and thereby enhancing crop water productivity on these soils. Besides, the early-established surface cover may reduce soil erosion (El-Swaify *et al.* 1985; Abate et al, 1988; Astatke and Kelemu 1993; Teklu et al., 2004; Teklu *et al*. 2006) leading to ecological sustainability. Among the various surface drainage alternatives, broad bed and furrow (BBF) which is constructed by broad bed maker (BBM) significantly increased productivity of several crops grown on Vertisols in Ethiopian highlands. The advantage of this technology can be augmented by harvesting the excess water to use during the dry season as supplementary or full irrigation of the subsequent crops. This allows multiple cropping per year on a piece of land, leading to higher land use intensity.

Integrating AWM practices with complementary technologies such as improved crop varieties, fertilizers and pest control practices can augment benefits. For example, the use of improved seeds, fertilizers and other crop management practices significantly increased the productivity of maize grown in and around the basin (Chimdo et al, 2001) (Table 6).

Table 6: Effect of management practices on productivity of maize

Location	Variety	Improved practice	Traditional practice	% increment
Jimma	local	37.3	28.4	32
	UCB	46.1	25.9	78
	Beletech	39.8	26.3	51
	BH_140	45.9	26.4	74
	BH-660	57.6	25.8	124
	kuleni	46.2	26.5	75
Adet	BH-540	48.96	29.3	67
	kuleni	81.8	50.6	61
Pawe	BH-530	81.7	41.7	96
	BH-140	76.7	41.7	84
Bako	BH-140	34.2	29	18
	Beletech	38.2	29	32

Source: Chimdo et al, 2001

Most part of the basin, especially areas dominated by the cereal-based farming systems lack sufficient fertility due to the long history of cultivation without attention to sustainable land resources management. Studies demonstrated that application of organic or inorganic fertilizers together with other complementary management practices could enhance both grain and biomass productivity of various cereals grown in the basin. For instance, Edwards et al (2007) reported that the productivity of barley and wheat grown in Tekeze sub basin increased from just over 1 ton ha^{-1} to about 2.5 tons ha^{-1} due to the use of compost (Figure 21). The same study indicated that the use of compost and mineral fertilizers increased the productivity of maize from about 1.7-ton ha^{-1} under the traditional management to 3.7 and 2.8 tons ha^{-1}, respectively.

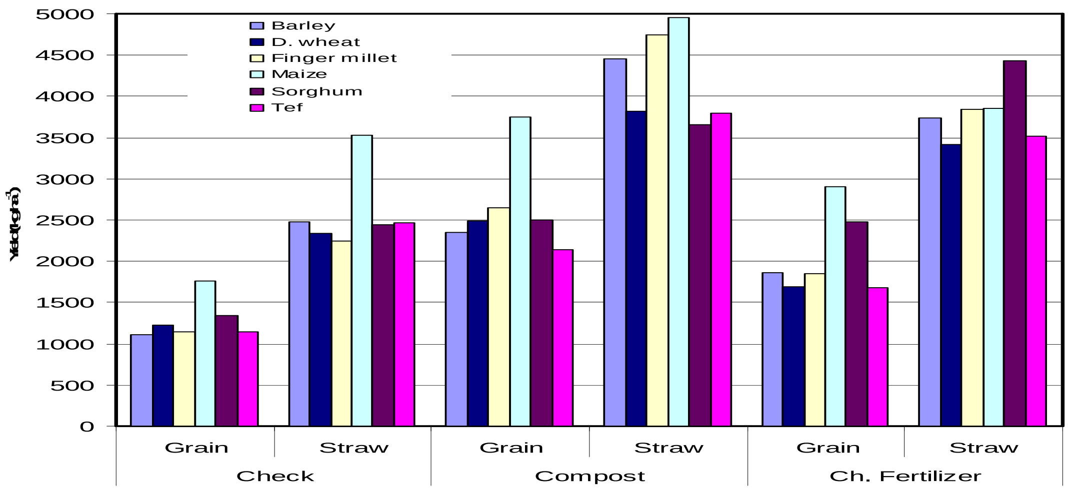


Figure 21: Effect of organic and inorganic soil fertility maintenance on grain yield of major cereals grown in Tekeze basin

Source: Edwards, et al., 2007

Modeling the productivity of maize and potato grown in the maize-based farming system using the FAO AquaCrop model under varying soil fertility levels (poor, near optimal and none limiting) revealed that enhancing soil fertility tremendously increases grain and biomass productivity under the prevailing climatic conditions and use of improved seed. For instance, grain yield of maize increased from 2.5-ton ha^{-1} under poor to 6.4 and 9.2-ton ha^{-1} with near optimal and non-limiting soil fertility conditions, respectively (Figure 22). Correspondingly, soil evaporation decreased from 446 mm to 285 and 204 mm, while transpiration increased from 146 to 268 and 355 mm increasing the grain water productivity by 48% and 54%, respectively, due to the near optimal and non-limiting soil fertility conditions (Figure 23).

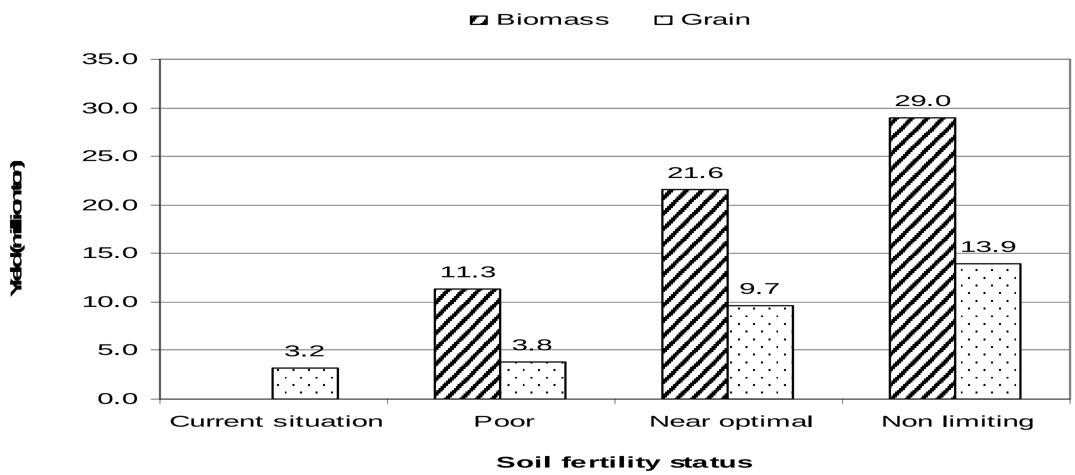


Figure 22: Effect of soil fertility status on productivity of maize

The model predicts about 593 mm of the seasonal rainfall to be lost from the system as runoff or unproductive evaporation, which can be used to grow second crop on a fraction or the whole area depending on the type of crop, irrigation efficiency and labor availability. For example, if planted in about 10 days after the maize harvested in October, about 4, 8 and 10-ton ha^{-1} (dry weight) of potato can be obtained under poor, near optimal and non-limiting soil fertility conditions, respectively, with corresponding Net Irrigation Requirement (NIR) of 414, 452 and 480 mm. Assuming 65% Irrigation Efficiency (IE), growing potato under near optimal and well-fertilized conditions, correspondingly require about 696 and 739 mm of irrigation, which is about 17 and 25% higher than the available excess water. Therefore, either the land area to be planted to potato should be reduced or other less water-consuming high value crops be considered. Reducing the irrigated land area to a fraction of the rainfed crop would also save water for livestock or domestic uses. Another option is to improve the irrigation efficiency to about 80%, which allows growing potato on the same area of land as maize with the excess water without any deficit.

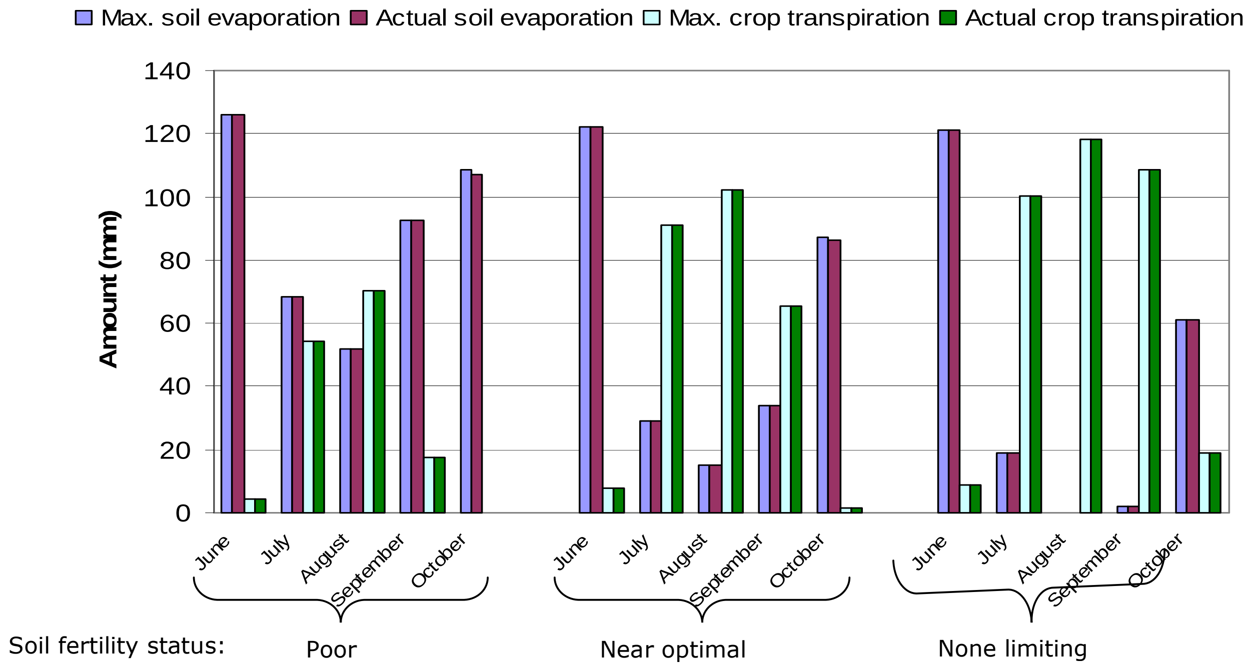


Figure 23: Effect of soil fertility status on the water balance of maize field

1.15.4 AWM Impacts

Our results show significant poverty reductions as a result of AWM technology use. Average treatment effect on per capita income was significant and amounted to USD 82. This also shows about 22% less poverty would result among users compared to non-users of AWM technologies. The magnitude of poverty reduction is technology specific. Deep wells, river diversions and micro dams are associated with 50, 32 and 25% reductions respectively in poverty levels compared to the purely rainfed system. The use of modern water withdrawal technologies (treadle pumps and motorized pumps) was also found to be strongly related to lower poverty. The use of motorized pumps was associated with more than a 50% reduction in poverty incidence. Similarly, households using gravity irrigation had significantly lower poverty levels than those using manual (cans) applications because of scale benefits. These results suggest that the promotion of modern water withdrawal and application technologies can enhance poverty reduction. We found that the poverty differences between users and non-users were statistically significant. Furthermore, from the poverty severity indices, we have found that AWM technologies were not only effectively poverty-reducing but also equity-enhancing, see also Hagos et al (2010) and Awulachew et al (2008c)

While poverty analysis techniques do not have in-built mechanisms of creating comparable groups, and hence could lead to attribution bias, our results from the propensity score matching, indicated that the average treatment effect of using AWM technologies is significant and has led to an income increase of, on average, USD 82/household.

While access to AWM technologies is correlated with reduced poverty, our study also indicated that there is a host of factors that can enhance this impact. The most important determinants include asset holdings, educational attainment, underutilization of family labor and poor access to services and markets. To enhance the contribution of AWM technologies to poverty reduction, there is, hence, a need to: 1) build assets; 2) develop human resources; and 3) improve the functioning of labor markets and access to markets (input or output markets). These actions could provide entry points for policy interventions to complement improved access to AWM technologies in Ethiopia.

1.16 Conclusions

Abbay basin (Ethiopian Highland) encompasses an array of contrasting agro-ecological settings with varying potentials and constraints. This resulted in evolution of varying livelihood strategies and contrasting farming and agro-pastoral systems. Crop, water, soil management technologies and other complementary technological options should be tailored to exploit the potentials of the respective systems. A synergy can be achieved from an integrated use of the technologies to enhance land and water productivity, reduce degradation and improve the quality and quantity of water left for other production and environmental services. The success of such efforts rests on the continued generation and adaptation of technologies, building the implementing capacity of the farming communities and strengthening the extension services while ensuring adequate and timely supply of the necessary inputs such as improved seeds and fertilizers as well as functioning market outlet for agricultural products.

Numerous technologies have been developed and tested on research stations or farmers fields in isolation or in integration with a significant yield increase. Most of the suitable technologies suggested in the project promote the beneficial use of green water to achieve food security and poverty reduction. The integrated watershed management interventions, which are complementary and augment the benefits of the crop, water and soil management technologies in the upstream, is believed to result in increased infiltration and catchment water storage, reduced runoff, improved ecosystem functioning and a better human health and habitation. The envisaged effects on the downstream include flow regulation with reduced peak flow and increased base flow, reduced sedimentation and a better water quality. However, the widespread use of the proven technologies is yet to be materialized, waiting for concerted effort by all stakeholders.

DEVELOPMENT OF WATER DEMAND AND ALLOCATION MODELS

Key Messages

- *Upstream water resource development, that increases flow regulation can create win-win scenarios with significant economic and social benefits for both Ethiopia and Sudan.*
- *To take full advantage of the water resources of the Blue Nile, the basin needs to be managed as a single system, with water demand priorities established to maximize the overall benefits for both Ethiopia and Sudan.*

1.17 Introduction

Egypt, and to a lesser extent Sudan, are almost wholly dependent on water that originates from the Nile with significant irrigation in both countries (Waterbury, 2002). In contrast, Ethiopia has developed less than 5% of the irrigable land in the basin and less than 3% of the hydropower potential (Block *et al*., 2007). Currently, the Ethiopian and Sudanese governments are developing plans and programs to increase both irrigation and hydropower, with the aim of increasing food security, reducing poverty and driving socio-economic development. This section focuses on the likely consequences of these developments for downstream flows. Computer models were used and different development scenarios investigated. Results can be used by decision makers to enhance planning and may assist with negotiations on water development within the basin.

1.18 Methods

Both Ethiopia and Sudan, plan to increase development of the Blue Nile water resources significantly in the near future. Data for both existing and future schemes were obtained from the basin master plans as well as scheme feasibility studies, where available. The sources of these materials include BCEOM (1998), Awulachew et al (2008b), ENTRO (2007), and McCartney et al (2009).

The Stockholm Environment Institute (SEI) Water Evaluation and Planning (WEAP) model was used to model and analyze the demands. The WEAP model performs a mass balance of flow sequentially down a river system, making allowances for abstractions/water use and inflows. The elements that comprise the water demand-supply system and their spatial relationship are characterized within the model. The system is represented in terms of its various water sources (e.g., surface water, groundwater and water reuse elements); withdrawal, transmission, reservoirs, and wastewater treatment facilities, and water demands (i.e. user-defined sectors, but typically comprising industry, mines, irrigation and domestic supply) (SEI, 2007; Yates *et al*., 2005).

In this section, we report the WEAP modeling results. However, other models including Mike Basin and HEC-ResSim for Ethiopia part of the basin were used by Wubet & Awulachew (2009). For the Sudanese part of the basin, HEC-ResSim was also used to simulate the consequences of development scenarios by Ibrahim et al (2009).

Typically the WEAP model is first configured to simulate a “baseline” year, for which the water availability and demands can be confidently determined. It is then used to simulate alternative scenarios to assess the impact of different development and management options. The model optimizes water use in the catchment using an iterative Linear Programming algorithm, the objective of which is to maximize the water delivered to demand sites, according to a set of user-defined priorities. When water is limited, the algorithm is formulated to progressively restrict water allocation to those demand sites given the lowest priority.

In this study, the model was set-up to simulate four scenarios: i) the natural situation with no abstractions, ii) the current situation (2008), iii) medium-term future demand (i.e. approximately 2015) and iv) long-term future demand (i.e. after approximately 2025). Clearly, the future scenarios reflect only an approximate timeline for water resources development in the catchment. In reality, development is dependent on many external factors and so it is impossible to predict exactly when many planned schemes will actually be implemented. As they stand, the medium and long-term future scenarios represent plausible development trajectories. The scenarios provide a useful basis for discussion and planning of likely future development.

Time series of monthly naturalized flow data for the period 1960-1992, obtained from the Abbay Basin Master Plan (BCEOM, 1998), and modified slightly based on more recent feasibility studies (ENTRO, 2007) were used as input data. Because in the future scenarios time is needed to fill the larger reservoirs, particularly those located on the main stem of the Nile a five-year "warm-up" period was introduced and all comparisons were made for the 27 years 1966-1992.

1.19 Results and Discussion

Existing and planned development in the basin is summarized in Figure 24 and also in Table 7 for the two major uses, irrigation and hydropower.

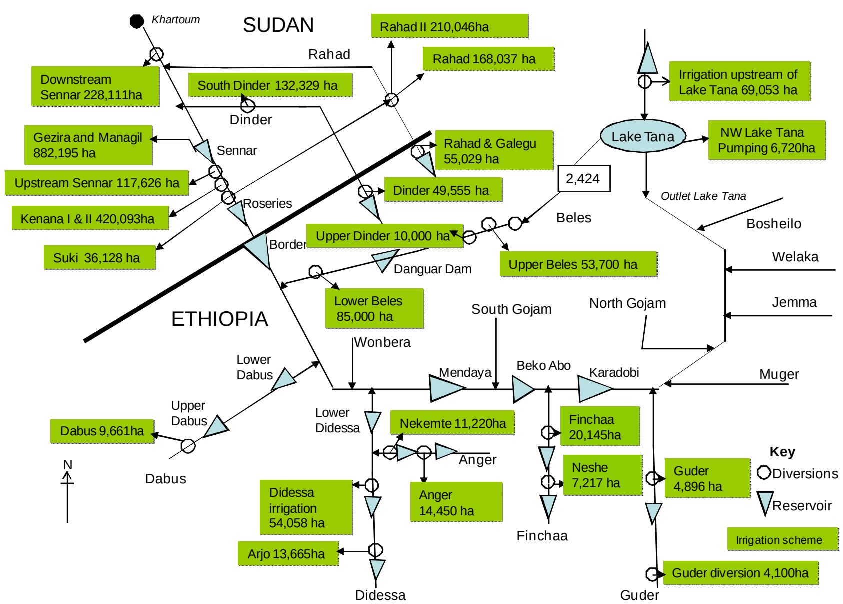


Figure 24: Schematic of the model configuration for the 2025 scenario (see McCartney et a, 2009)

Table 7: Existing and planned irrigation and hydropower schemes in the BNB

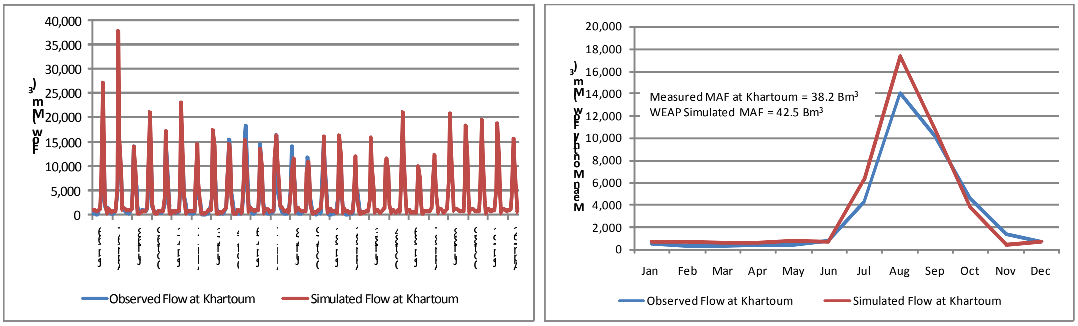
Interventions	Current		Medium term		Long term	
	Ethiopia	Sudan	Ethiopia	Sudan	Ethiopia	Sudan
Irrigation command area (ha)	10,000	1,305,000	210,000	2,126,000	451,000	2,190,000
Hydropower (MW)	218	295	2,194	295	6,426	295

The WEAP model was configured to simulate these three development scenarios and in addition, a natural flow condition was simulated. Figure 25 illustrates the WEAP configuration for the long-term development scenario both in Ethiopia and the Sudan.

Figure 25: The WEAP modeling set up of long-term scenario in the BNB

Figure 26 shows the simulated and observed flows at the Ethiopia-Sudan border and at Khartoum for the current situation. These results indicate that the WEAP simulation is reasonably accurate. At Khartoum, observed data (obtained from the Global Data Runoff Centre) were only available for the period 1966-1982. Over this period the percentage error in the simulated mean annual flow was 12.8%. Because of current abstractions, primarily for irrigation in Sudan, the flow at Khartoum is estimated to be approximately 7.7 Bm^3y^{-1} less than would have occurred naturally over this period (i.e. 42.5 Bm^3y^{-1} rather than 50.2 Bm^3y^{-1}). At the border, there are two flow-gauging stations. One is operated by the government of Ethiopia and just a few kilometers downstream another is operated by the government of Sudan. Possibly because of differences in periods of missing data, observed flows at these two stations differ and there is a 13% difference in mean annual flow over the period 1966-1992; 50.2 Bm^3 measured by Ethiopia and 43.6 Bm^3 measured by Sudan. Without detailed analyses, it is not possible to know which of the two flow series is the more accurate. The WEAP model simulation falls exactly half-way between the two with a mean annual discharge of 46.9 Bm^3.

a)



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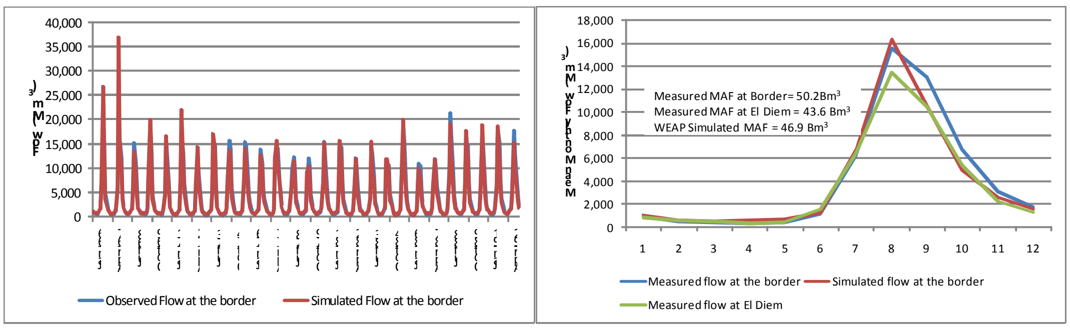

Figure 26: Simulated and observed flow series and mean monthly flows for the Blue Nile (current situation) at: a) Khartoum and b) the Ethiopia-Sudan border

Currently irrigation water demand in Sudan greatly exceeds that in Ethiopia. Total irrigation demand in Sudan is currently estimated to average 8.45 Bm^3y^{-1}. This compares to an average of just 0.26 Bm^3y^{-1} in Ethiopia. With the planned irrigation development, demand is estimated to increase to 13.39 Bm^3y^{-1} and 3.65 Bm^3y^{-1} in the medium term future scenario and to 13.83 and 5.13 Bm^3y^{-1} in the long-term future scenario in Sudan and Ethiopia respectively (Table 8). If all planned dams are constructed total reservoir storage in Ethiopia is estimated to increase to 70 Bm^3 (i.e. 1.5 times mean annual flow at the border) in the medium term and to 167 Bm^3 (i.e. 3.6 times mean annual flow at the border) in the long-term.

Hydropower generated in Ethiopia, from the Tis Abbay and Finchaa power stations, is currently estimated to be 1,383 $GWhy^{-1}$. With the construction of the Tana Beles transfer, the Karadobi dam and other smaller schemes this is estimated to increase to 12,908 $GWhy^{-1}$ in the medium term. With Border, Mendaya and Mabil on line, as well as additional smaller schemes, electricity production could increase to 31,297 $GWhy^{-1}$ in the long-term. A significant proportion of the additional electricity produced is likely to be sold to Sudan and possibly other countries in the Nile Basin. Hydropower generated in Sudan is currently estimated to be just over 1,000 $GWhy^{-1}$, but there are no publicly available data to confirm this estimate. Because of the additional head and increased storage, the raising of the Roseries dam will result in a very small increase to 1,134 $GWhy^{-1}$ in the medium-term and to 1,205 $GWhy^{-1}$ in the long-term future. The increase in the long-term future is due to entirely to more regular flows as a consequence of increased regulation upstream in Ethiopia.

Table 8: Comparison of current and future irrigation demand and hydropower production in the Ethiopian and Sudanese parts of the Blue Nile

	Current		**Medium term**		**Long term**	
	Ethiopia	**Sudan**	**Ethiopia**	**Sudan**	**Ethiopia**	**Sudan**
Total storage (Mm^3)	11,578	3,370$^+$	70,244	10,770	167,079	10,770
Formal irrigation						
area (ha)	<10,000	1,305,000	210,00	2,126,000	461,000	2,190,000
water demand (Bm^3y^{-1})	0.26	8.45	3.65	13.39	5.13	13.83
Hydropower						
Installed capacity (MW)	218	295	2,194	295	6,426	295
Production ($Gwhy^{-1}$)	1,383	1,029	12,908	1,134	31,297	1,205

$^+$ Allowance made for sedimentation of both the Roseries and Sennar reservoirs

Comparison of the mean monthly flows at Khartoum for the simulated natural condition, current situation and the medium and long-term future scenarios indicates that the mean annual runoff is progressively reduced because of greater upstream abstractions. Wet season flows are reduced significantly but flows in the months January to May are increased because of flow regulation (Figure 27a; Table 8). Under natural conditions, 73% of the river flow occurs in the wet season months (July – September). In the medium and long-term future scenarios this is reduced to 58% and 35% respectively.

At the Ethiopia-Sudan border, the current situation is almost identical to the natural condition so this not shown. Mean annual flow is reduced from 47.0 Bm^3 to 44.8 Bm^3 and 44.4 Bm^3 in the medium and long-term future scenarios respectively. Similar to Khartoum there is a significant reduction in wet season flows, but significant increases in dry season flows as consequence of flow regulation (Figure 27b; Table 9). Under natural conditions, 72% of the river flow occurs in the wet season but this decreases to 61% and 35% in the medium and long-term future scenarios respectively. Interestingly the total decrease in border flow in the long-term scenario is less than might be expected given the increased irrigation demand in Ethiopia. The reason is partly that less water is diverted from the Tana to the Beles catchment and more flow is routed down the main stem of Blue Nile. Shortfalls in meeting irrigation demand in Ethiopia also increase.

a) b)

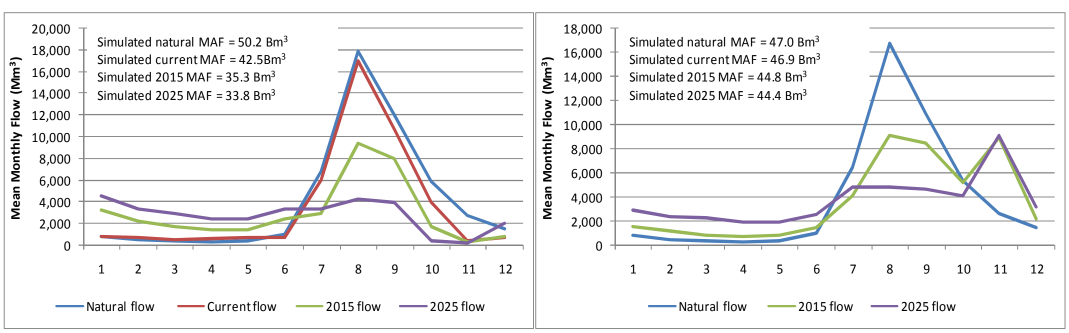

Figure 27: Comparison of simulated mean monthly flow derived for natural, current, medium and long-term future scenarios at: a) Khartoum and b) the Ethiopia-Sudan border

Table 9: Simulated mean monthly flow (Mm^3) (1966-1992) at the Ethiopia-Sudan border and Khartoum for natural, current, medium and long-term future scenarios

	Natural		**Current**		**Medium term**		**Long term**	
	Border	Khartoum	Border	Khartoum	Border	Khartoum	Border	Khartoum
Jan	840.8	841.9	937.8	781.9	1,604.9	3,245.3	2,896.0	4,599.6
Feb	467.0	467.0	577.1	688.7	1,178.0	2,215.8	2,320.1	3,385.4
Mar	373.0	373.0	467.8	536.0	887.2	1,655.3	2,213.6	3003.8
Apr	306.5	306.6	526.3	620.0	769.3	1,372.6	1,875.6	2,490.6
May	388.1	388.2	657.5	719.9	819.4	1,369.5	1,905.7	2,472.8
Jun	994.8	1,000.1	1,244.4	649.9	1,517.0	2,393.3	2,476.2	3,392.6
Jul	6,436.0	6,803.8	6,595.7	5,921.5	4,127.1	2,877.6	4,820.2	3,404.5
Aug	16,710.9	17,898.2	16,338.0	16,983.1	9,098.1	9,434.4	4,821.1	4,333.9
Sep	10,885.0	12,047.2	10,550.0	10,661.0	8,445.0	7,987.7	4,665.6	3,967.1
Oct	5,381.5	5,886.5	4,944.9	3,882.6	5,207.0	1,684.4	4,093.9	461.9
Nov	2,685.5	2,734.3	2,518.0	384.9	8,877.6	262.5	9,141.4	250.8
Dec	1,483.9	1,485.8	1,518.0	701.6	2,255.5	759.8	3,127.2	2072.9
Total	46,952.9	50,232.3	46,875.4	42,531	44,785.9	35,294	44,356.8	33,835.8

	Natural		**Current**		**Medium term**		**Long term**	
	Border	Khartoum	Border	Khartoum	Border	Khartoum	Border	Khartoum
Jan	840.8	841.9	937.8	781.9	1,604.90	3,245.30	2,896.00	4,599.60
Feb	467	467	577.1	688.7	1,178.00	2,215.80	2,320.10	3,385.40
Mar	373	373	467.8	536	887.2	1,655.30	2,213.60	3003.8
Apr	306.5	306.6	526.3	620	769.3	1,372.60	1,875.60	2,490.60
May	388.1	388.2	657.5	719.9	819.4	1,369.50	1,905.70	2,472.80
Jun	994.8	1,000.10	1,244.40	649.9	1,517.00	2,393.30	2,476.20	3,392.60
Jul	6,436.00	6,803.80	6,595.70	5,921.50	4,127.10	2,877.60	4,820.20	3,404.50
Aug	16,710.90	17,898.20	16,338.00	16,983.10	9,098.10	9,434.40	4,821.10	4,333.90
Sep	10,885.00	12,047.20	10,550.00	10,661.00	8,445.00	7,987.70	4,665.60	3,967.10
Oct	5,381.50	5,886.50	4,944.90	3,882.60	5,207.00	1,684.40	4,093.90	461.9
Nov	2,685.50	2,734.30	2,518.00	384.9	8,877.60	262.5	9,141.40	250.8
Dec	1,483.90	1,485.80	1,518.00	701.6	2,255.50	759.8	3,127.20	2072.9
Total	46,952.90	50,232.30	46,875.40	42,531	44,785.90	35,294	44,356.80	33,835.80

A key issue not considered in the current model simulations was the transient stages of reservoir filling. All reservoirs were initiated with water levels between full and top of the dead storage and of course the 5-year warm-up period was also introduced. Given the large cumulative volume of the planned reservoirs in Ethiopia, it is essential that reservoir filling is managed in such a way that adverse downstream impacts be minimized.

1.20 Conclusions

Development scenarios were compiled from the various documents and project plans. Current large-scale irrigation development in Ethiopia is minimal (only about 10,000ha). In comparison Sudan's development (1,305,000 ha) is considerable. The area increment in the long term for Ethiopia's irrigation development is 441,000ha and while that of Sudan is 885,000ha, size double to Ethiopia's development plan. However, the Ethiopia's development demand may also increase if some of the criteria for estimating the potential are modified; see BCEOM (1998) on the methods used to estimate the technical and economically feasible potentials. For hydropower, there is no envisaged development in the Sudan but, significant plans and opportunities exist on the Ethiopian side.

The WEAP model was configured to simulate the impacts of water resource development in the Blue Nile basin. The results presented were preliminary and based on many assumptions. Lack of flow and water demand and use data, particularly from Sudan, make it very difficult to validate the model for the current situation. Where possible to verify the data, the model results were reasonable. Nevertheless, the current results must be treated with caution. In future, it is hoped that the model can be refined using improved estimates of irrigation water demand and better estimates of dates at which schemes will become operational.

It is useful to note that, if Ethiopia develops all the hydropower and irrigation, the effect on the overall water balance is 2.5 Bm^3 and the reduction between the border and Khartoum, if Sudan realizes all the potential, is 8.7 Bm^3, with an aggregate effect of 11.2 Bm^3 flow reduction passing Khartoum compared to the present day water balance. For all scenarios the model was run as a single system, making no allowance for the fact that Ethiopia and Sudan are separate countries. Hence, water demands in Sudan were given the same priority as those in Ethiopia and water was released from reservoirs in Ethiopia to meet downstream demands in Sudan. This assumes a high level of cooperation between the two states over management of the river water resources. Currently the riparian countries of the Nile have agreed, through the Nile Basin Initiative, to collaborate in the development of water resources for sustainable socio-economic growth. It is to be hoped that the level of cooperation required for managing the water resources in the most effective and equitable manner will be developed in the near future.

POLICY AND INSTITUTIONAL ANALYSIS

Key Messages

- *Policies and institutions across local to basin are not well established and do not take into account downstream and upstream needs.*
- *Institutional arrangements must advanced across different scales (nested from local to international) that built trust, facilitate the exchange of information and enable effective monitoring required for successful water resources management (e.g. dam operation; cost and benefit sharing, PES, demand management etc...)*
- *Policy measures that involve stakeholders, at grass root level during formulation, are much easier to enforce or be respected.*
- *PES is a means to enhance incentive-based land & water management policy-enforcement & an entry point for benefit sharing.*
- *A farmer financed PES scheme may not be financially feasible (at least in the short-term) given an inability to pay. Therefore options for user & state co-financing should be sought.*

1.21 Introduction

Agriculture provides the major livelihood security in the Blue Nile basin. There are diverse production systems which are affected by spatio-temporal water distribution and associated land availability. For example, over 95% of the food producing sector in upstream areas (i.e. Ethiopia) is based on rain fed agriculture (i.e., green water management). In the downstream areas (i.e. in the Sudan), the Blue Nile provides water for major irrigation development (blue water management). In production term: 65% of cotton, 70% of wheat 32% of sorghum, 15% of groundnut, and 20% of vegetable production in Sudan come from Gezira irrigation schemes (Haileslassie et al., 2009).

Agriculture is a nested hierarchy of systems ranging from plots through farms and watersheds to the basin. For such a hierarchy, operating within the same hydrological boundary (i.e. Blue Nile Basin) water flows create intra- and inter- system linkages. Because of these linkages, changes in one part of a basin affect water availability and associated livelihoods and ecosystem services in other parts. Threats to these 'co-dependent livelihoods' arise from the new drivers of change: population growth and food demand; agricultural intensification; environmental degradation and water scarcity (Haileslassie et al., 2008). Consequently, several questions need explanation: How do these drivers of change relate to unsustainable water management? To what degree are communities vulnerable to disruptions of water delivery and water-related ecosystem services? What will be the role of policy and institutions in the envisaged population and environment nexus?

There is evidence suggesting that natural ecosystem services are severely threatened in the Blue Nile basin. For example, both erosion and localized sedimentation are major threats in upstream areas (Ethiopia), whilst sedimentation is a major challenge in downstream areas (e.g. Sudan). In Ethiopia, both on-site and off-site impacts of erosion are widely recognized. On-site, there is severe nutrient depletion, and farmers have very low capacity to replenish the lost nutrients using fertilizers. For example, the application of 16-28 kg of fertilizer ha^{-1} yr^{-1} which is currently applied in upstream areas does not match with the magnitude of nutrients depleted under cereals system (79 kg N ha^{-1} yr^{-1} in Amhara and (99 kg N ha^{-1} yr^{-1}) in Oromiya regions. Yield loss and low productivity of grain and animal feed are all observed impacts of erosion. Soil erosion has strong implications not only to the above-mentioned provision of ecosystem services (e.g., food, fiber, fuel), but also on the status of green water productivity in upstream areas in general (Haileslassie et al., 2005).

The off-site impacts of soil erosion on communities' livelihoods mainly occur in downstream areas, despite observations of high local redistribution of sediments (i.e., sedimentation in wetlands, farmlands and water bodies amongst upstream landscapes). At the basin scale, sedimentation has become a major factor in the design and operation of structures in Sudan. The cost of silt removal from canals and irrigation infrastructure takes as high as 50% of a schemes' management cost. This has strong implications for water conveyance efficiencies in the downstream areas. With a limited amount of river water and increased demand in both upstream and downstream regions on one hand, and unsustainable land and water management on the other, one can hypothesize that water shortages will become more widespread and frequent and the resultant tensions over water allocation will worsen in the future.

To meet the livelihood demands of the community, future increases in agricultural production will have to be realized by intensification, which obviously takes improved management of land and water into account. In view of these new features, it is important to explore if the current institution and policy setup responds to improved land and water management needs and to examine on how institution and policies can help achieving livelihood demands in both upstream downstream regions. Therefore, the overarching objectives of policy and institutional study were:

i) To describe the institutions and policies at different scale in the basin, their mandates and gaps related to land and water utilization and management;
ii) To explore determinants of adoption and intensity of different land and water management practices in the study area and institutional and policy strategies for up-scaling of improved land and water management technologies;
iii) To identify mechanisms for basin and local level upstream/downstream community cooperation through benefit sharing, by taking payment for environmental services as an example.

1.22 Methodology and Analytical Framework

The policy and institutional studies of this project were developed in recognition of the fact that every intervention is implemented in a unique context of biophysical factors and institutions and policies. Therefore, the institutional analysis component of the project examined the role of institutions and related support services in promoting or discouraging improved land, livestock and water management within the sub-basin and communities downstream. Understandings of the socioeconomic, institutional and policy issues complemented research efforts in the other components of the project.

To achieve these aims the policy and institutional analysis used a phased approach:

i) The first phase dealt with stakeholder analysis and rapid appraisals. This was undertaken with the intent of identifying broader livelihood sources and their relative dependence on water resources; current water and land utilization methods and how these relate to water availability and scarcity; existing organizational structures and their impact on land and water management. As part of the stakeholder analysis, the study also identified key research questions to precede to detailed study scales.

ii) In-depth study at three scales followed a nested approach. The local or community scale analysis focused on research questions such as: how current institution and policy arrangements respond to marginal land and water management interventions; what are the determinants of improved lands and water management practices, and what are the up-scaling strategies? What are prospects of payment for environmental services? At the sub-basin (regional) scale, in-depth analysis examined research question that addresses existing and envisaged policies and institutions accounting for downstream and upstream linkages.

1.22.1 Community and watershed scale studies

Based on the appraisal (first phase) results, Gumera and Koga watersheds (Tana sub-basin (Eastern part of the Blue Nile)), were selected as study sites. The two rivers draining Koga and Gumera watersheds originate from Mount Wezem and Mount Guna respectively. Koga and Gumera watersheds exhibit an elevation range of 3200-1890 meter above sea level (masl) and 1782-3704 masl respectively. In this, community scale study, a multi-stage sampling technique was used: in the first stage, Koga and Gumera watersheds were objectively selected. The rationale behind is that, in both watersheds, irrigation schemes are under development and at the same time, the upstream of those watersheds are degrading. It is frequently suggested that higher rate of erosion in upstream and sedimentation in downstream of Blue Nile are major triggers of poor water uses efficiencies and conflict in the basin. Thus, mechanisms for improving regulating ecosystem services were sought. We selected the two watersheds as a model and learning sites representing diverse landscape with rain fed and irrigation based production systems in the Blue Nile Basin.

After identification of the watersheds, in the second stage, Peasant Associations (PAs, the smallest administrative units in Ethiopia) were selected using random sampling procedure. In the third stage, from the lists of the farm households in each PA, sample farm households representing upstream and downstream community, were selected randomly. From each PA, 25 sample households were selected comprising a total of 325 sample farm households operating on 1155 plots. In March 2008, we administered a structured and pre-tested questionnaire to collect all necessary data on different land and water management techniques, adoption by farmers and hypothesized explanatory variables (Alemayehu et al., 2008).

Prospects of payment for environmental services (PES): To asses upstream and downstream communities' willingness to pay (WTP)/ willingness to compensate (WTC) for investment for restoration of environmental services, we applied a Contingent Valuation Method (CVM). CVM can estimate the value that a person places on a good that has no market price. Many applications of the CVM deal with public goods such as measuring willingness to pay for environmental services and in policy formulation and for evaluating investments (Alberini and Cropper, 2000). In this study, we used the double-bounded dichotomous-choice format to illicit users' WTC/WTP. A dichotomous choice payment question asks the respondent if she/he would pay B_i (initial bid amount) to obtain the good. There are only two possible responses to a dichotomous choice payment question: 'yes' and 'no'. Then following the response, follow up bids are presented (B_i^d and B_i^u, where $B_i^d \leq B_i \leq B_i^u$) depending on the response to the initial bid. The bid value (B_i) is varied across respondents. The dichotomous choice approach does not observe WTC/WTP directly: at best, we can infer that the respondent's WTC/WTP amount was greater than the bid value or less than the bid amount, and form broad intervals around the respondent's WTC/WTP amount. Mean WTC/WTP were estimated statistically from the data of responses obtained from respondents (Alemayehu et al., 2008)

Determinants of adoption of improved land and water management technology To explore determinants of adoption and intensity of different land and water management practices in the study area and institutional and policy strategies for up scaling of improved land and water management technologies, the household datasets were analyzed using Logit, Tobit and truncated regression models. The linear probability, the logistic function (Logit), and the normal density function (probit) models are regularly used in analyzing adoption (e.g. Feder et al., 1985). These models use binary variable as a dependant variable. However, this approach may not capture intensity of adoption. In response to those shortcomings, the use of Tobit estimation method, where the dependant variable is continuous (e.g. proportion of the area covered under different soil and water conservation (SWC) technology) with a zero lower limit, is becoming customary. The tobit model imposes a structure that is often too restrictive: the variables affecting the probability of adoption equally determine the level of adoption (intensity) and, moreover, with the same sign. This is not a realistic assumption.

Logit and Probit models produce identical results with small samples. Nevertheless, Logit has an advantage over Probit in that it follows less complicated calculation procedures. For this study we used Logit due to its simplicity and the fact that, unlike Probit, it captures the dynamic aspects of adoption of technologies (Bett, 2004). Therefore, Logit, Tobit and truncated regression models were all employed to analyze both the adoption decision and intensity of improved land and water management technology in the study watersheds respectively. The results are reported for comparison.

1.22.2 Sub-basin and international scale studies

Institution and policy framework and gaps: At the sub-basin (regional) scale, in depth analysis examined existing and envisaged policies and institutions accounting for downstream and upstream linkages. Research also examined if the current institution and policy framework created an enabling environment for integrated water resources development, and reviewed the major environmental problems, their causes, their costs and potential policy responses. The focus of this study is the Tana Beles sub-basin in Northwestern Ethiopia. The Tana-Beles basin is important sub-basin of the Blue Nile and is located in the Amhara and Benshangul Gumuz Regional States in Ethiopia. A combination of different approaches was used to gather the data need for this study. Firstly, literature survey was conducted. Next, focus group discussions and key informant interviews were held in the two regional states (Amhara and Benishangul Gumuz Regions) at three scales: (1) regional state officials (e.g. bureaus of agriculture and rural development, water resources development, environmental protection and land use administration, agricultural research systems), (2) the lower government administrative units, and (3) community members from informal institutions, like water users association. For better insight, the land and water management activities and degree of land degradation were also observed during the filed visits.

We used the institutional analysis framework reported in Bandaragoda (2000); Krister et al., (2009). Institution in this study was defined as established rules, norms, practices and organizations that provide a structure to human actions related to water management. Notably, the established organizations are to be considered, here, as a subset of institutions. The Bandaragoda (2000) framework presents the overall institutional framework in three broad categories: policies, laws and administration, all of which are related in some way to water resources management (Bandaragoda, 2000). Using these data sets and analytical framework, we explored the institutional performance of the basin by identifying the missing key policy elements and policy instruments. We also developed a list of essential organizational design criteria (e.g. Bandaragoda 2000) and compared these against the current state of organizations dealing with land and water management. Each level of analysis involved different physical dynamics, stakeholders, policy and institutions, and, therefore, options for policy interventions. Where relevant, it also explored interactions between these levels (Mapedza et al ., 2009 and Mapedza et al., 2008)

1.23 Results and Discussion

Institution and policy framework and gaps: A number of institutions are involved in land and water management in upstream and downstream regions of the Blue Nile Basin, but have conflicting roles and responsibilities and poor inter-sectoral and inter-regional linkages and collaboration. Discussion with officials at regional level indicates also that the organizations involved in land and water were marked by frequent restructuring and re-organization over the last few years and the process seems to be going on. While adjusting organizational responsibilities and redesigning organizational structures may be called for, in the light of the changes and development needs of the country, the frequent restructuring process has certainly produced uncertainties, made capacity building difficult.

Table 10 summarizes important land and water management policy elements that are reflected/not reflected in the documents of selected land and water management policies: Water Resources Management Policy/ Regulation/ Guideline; Environmental Policy of Ethiopia; Watershed Management Guideline and Land Use and Land Administration Policy. Important policy elements such as climate change /water resources demand management; role of educational activities; research and investigations are not clear/uncertain noted in the policy documents (Table 10). A critical constraint against effective and common river basin management was that institutions and policy frameworks do not distinguish between upstream or downstream users (e.g. the 1929 Egypt and the colonial power and later in latter, in 1959, the Sudan and Egypt Nile water use agreements, (Table 10)). This holds true also at sub basin and watershed scales.

At the regional level (i.e. Ethiopia,) important issues are conflict between boundaries of river basins and those of political units (nations, regions, districts, etc). The administrative boundaries pose potential constraint in management of small watershed that fall partly within two districts or farmers association (Hagos et al., 2009). This calls for establishing viable and acceptable institutional mechanisms for shared management of water resources in the river basin and watershed.

In terms of policy instruments, particular concerns exist in overall tendency to focus on command-and-control type policy instruments than incentive mechanisms (e.g. PES) for improved land and water management (Hagos et al., 2009 (Table 11)). In this respect one of the important features that the upstream and downstream regions policy setup share is a lack of well-established cost recovery mechanisms, lack of water valuation and inclination towards supply augmentation rather than demand management (Table 10). This encourages overuse of water and poor management of water resources structures.

Table 10: Essential elements of water and land management policies in the Ethiopian Blue Nile Basin (summarized from discussions with experts and also review of respective organizations' policy)

Element	WRMP	EPE	LULA	WSG
General intent of the policy/law	✓	✓	✓	✓
Jurisdiction – spatial and administrative scales	✓	✓	✓	✓
Responsibility (establishes or enables commitment)	✓	✓	✓	✓
Specific goals and objectives	X	X	X	X
Duty of care (Ethical, legal responsibility, attitude, responsibility or commitment)	✓	✓	✓	✓
Hierarchy of responsibilities ('rights and obligations' of hierarchies)	X	✓	✓	✓
Institutional changes (statements of an intended course of action/ needed reform or legal change)	✓	✓	✓	✓
Climate change scenarios/demand management	X	X	X	X
Upstream-down stream linkages (e.g. watershed level)	X	X	✓	✓
Role of educational activities	X	X	X	X
Research and investigation	X	X	X	X
Community participation	✓	✓	✓	✓
Green and blue water /land use planning	X	X	✓	X
Financing	✓	X	X	X
Enforcement/regulation (SE vs. TPE)	X	✓	✓	X
Mechanisms for dispute resolution	X	X	✓	X

Codes: WRMP is for Water Resources Management Policy/ Regulation/ Guideline; EPE is for Environmental Policy of Ethiopia; WSG is for Watershed Management Guideline; LULA is for Land Use and Land Administration Policy; **X** is for not clear/uncertain, ✓ is for clearly reflected

Moreover, lacks of effective cost recovery mechanisms (Hagos et al., 2009) often inhibit the ability of organizations to sustain themselves and fulfill their mandates. This implies that strategies developed assume that there is plenty of water potential to tap but no demand management (Table 10). Economic water scarcity is considered as a greater challenge than physical water scarcity. Climate change and its impact on water resources and the needs of community in the upstream/downstream regions are hardly taken into account in the development of these strategies. Although public programmers such as for Food for Work (FFW);Cash for Work CFW and Productive Safety Net Program (PSNP) are major policy instrument mentioned in watershed management guide lines. Their role in water management, environmental and land use and land administration policy is not reflected. Most often those programmers are criticized for creation of dependency syndrome. But if well managed, can be a good source of cheaper labor for land and water management activities. Therefore, policy options that address these gaps must be promoted (e.g. improved management of rainwater through public program, valuation of water, well-established cost recovery mechanisms and improved water productivity) in the basin in general.

Table 11: Typology of policy instruments in environmental management in Ethiopian Blue Nile Basin

Policy instrument	WSG	LULA	WRMP	EPE	Responsible
Information and education	✓	X	X	✓	
Regulations/standards		✓	X	✓	EPA/EPLAUA
Incentive-based					
Subsidies	X	✓	X	✓	EPA/EPLAUA
Taxes	X	X	X	X	
Charges/penalties	X	✓	✓	✓	
Certification (property rights)	X	✓	X	X	
Cost and benefit sharing	X	X	✓	X	MoWR
Cost Recovery	X	X	✓	X	MoWR
Public programs (PSNP, FFW, CFW)	✓	X	X	X	MoARD/ BoARD
Conflict resolution	✓	✓	X	X	EPLAUA/social courts

Codes: IWSM is for Integrated Watershed Management; LAUP is for Land Administration and Use Policy; WRMP is for Water Resources Management Policy/ Regulation/ Guideline; EP is for Environmental Protection policy/guideline; **X** is for not clear/uncertain, ✓ is for clearly reflected. FFW is for Food for Work; CFW is for Cash for Work; and PSNP is for Productive Safety Net Program

Determinants of adoption of improved land and water management technology: Details of description of the variables used in the analytical models and model results for determinants of intensity of adoption are reported by Gebreselassie et al., (2008).Table 12 presents the results of logistic regression model: variables that affect farmers' decision for the adoption of improved land and water management technologies.

Farm households in upstream are less likely to make investment decisions than those in the downstream. The odds-ratio of adoption of the downstream households is 0.55 times compared to households in upstream. The model also indicated that land tenure security has increased the odds of adoption significantly (Table 12). Farmers with registered plots were more likely to adopt the conservation investments than farmers with the nonregistered plots. With one unit increases in the land registration, the odds of a farmer decision to use land and water management practices increased by 5.8 times. As suggested in number of empirical studies (e.g. Gebremedhin and Swinton, 2003), security of tenure is a critical variable determining incentives to conserve land quality. A secured land tenure right reinforces private incentives to make long-term investments in soil conservation. Security of tenure is also claimed to lengthen the planning horizon or lower the effective discount rate. The significant and positive relation of land registration and farmers decision to adopt improved land and water management was consistent with those arguments. Moreover, owner-operated plots are more likely to be conserved than sharecropped in or out land and plots that are acquired recently are less likely to be conserved.

Farmers are not passive observers of changes in their farm land. Example of such reaction to change in their farm land could be intensification of agricultural practices as population increase and correspondingly farm sizes diminish (Boserup, 1965). The decision for those changes, however, requires farmers' perception about the impacts of changes (e.g. erosion) in their farm. Farmers who perceived that their farm plots are affected by erosion are more likely to adopt conservation technologies.

Conservation activity is mainly labor intensive, requiring mainly male labor. This study results show that households with more female adults are less likely to apply conservation measures: i.e. significant and negative relation between adoption of improved land and water management and higher number of female household members over the age of 16. This implies conservation requires mainly male labor or the existing cultural taboo against females. The number of assistances from traditional labor exchange system (wonfel) negatively influences adoption decision implying that the traditional labor exchange is usually done in productive than conservation works. This may need policy action to create incentive for such local institutions to be involved in conservation activities.

The significant and negative relations of distance to output markets with adoption decision of the sample farm households substantiate the fact that households allot their labor to non-conservation activities as the return from agriculture might not be significantly higher compared to engagement in non-farm employment. This holds true even if the distance to output market increases. Many more factors such as plot characteristics: plot area, slope, soil type, and fertility have significant effect on adoption decisions. Plot area has relatively the most vivid effect on the odds of a farmer decision to adopt land and water management techniques: with one unit increase in the area of plot, the odds of a farmer decision to use land and water management practices increased 2.2 times. The most commonly adopted physical soil and water conservation practices in the area, stone bund and soil bund, occupy space and this reduce the actual area under crops. Thus farmers with larger plot area are more likely to adopt given the technological requirement for space. This contradicts with Pender and Gebremedhin (2007), who suggested that population pressure and small farm sizes contribute to adoption of more intensive practices. Slope of the land increases the adoption decision implying that flat land is less likely to be targeted for conservation. Highly fertile land is less likely to be conserved than less fertile land. Moreover, plots with moderate depth are more likely to be targeted for conservation than shallow soil. Shiferaw and Holden (1998) also noted the importance of technology-specific attributes and land quality differentials in shaping conservation decisions. Therefore, the findings of this study substantiate these findings.

Factors that determine the decision to adopt improved land and water management technologies may not necessarily determine the intensity of use. The results of truncated regression models, depicted on Table 12b, may support this idea.

The degree of intensification is a good indicator for the scale of adoption. Therefore, those variables that explain both adoption and intensification can give better ideas where policy and institutions related to improved land and water management should focus to increase adoption and intensification. From the model, we realized that some factors can influence both farmers' decision of and intensity of adoption. Plot area, tenure status, walking distance to output markets and location dummies significantly influenced both the probability of adoption and intensity. Owner-operated plots and plot area have positive and significant effect on the probability of adoption and intensity. This clearly shows the preference of farmers to invest more and more on their own plots than on rented in or out plots. As opposed to the results on binary model, however, distance to output markets positively affects the intensification decision. This implies that plots that are located farther away form the output markets are more intensively conserved. Moreover, the location dummies, i.e., upstream and downstream watersheds, were found to be significant at 5 percent significance level in the tobit model. However, the variable was not significant in the truncated model. This implies that, contrary to our expectations, farmers in upstream invest less on soil and water conservation.

Female and male adults respectively affect negatively and positively conservation intensity confirming that conservation is mainly male activity. Households with more female adults have less intensity that than households with male adults. Walking distance to nursery site and all weather roads respectively affect negatively and positively conservation intensity implying that distance to nursery site negatively affects the intensity decisions while distance to all weather roads positively, although at 10 percent level of significance in the truncated model, affects the conservation intensity. Walking distance to output markets and all weather roads increases the intensity of conservation implying that in remote communities the intensity becomes higher because engagement in non-farm employment is lower. People engage more in conservation activities. Plot level characteristics such as soil type and distance of plots from homestead affect conservation intensity. Plots with black soils and plot distance, unexpectedly, positively influences conservation intensity.

In summery in spite of decades of efforts to improve land and water management in the Blue Nile Basin, achievements are low. Farmers' conservation decision and intensity of use of improved land and water management are influenced by many policy and institutional factors (Table 12b). Some of these factors are related to access to resources while some others are related to policy incentives (e.g. access to market, PES) and appropriateness of technology (e.g. lack of niche-evel technology that fits small land sizes). Most of these determinants are reflections of policy and institutional gaps presented in preceding sections. The question is whether these policy and institutional issues are possible to be met only at regional level (i.e. upstream or downstream).

The agrarian-based livelihood in the basin is operating within the same hydrological boundary. This also means policy measures that respond to local needs (e.g. poverty alleviation in upstream) may center change in resources use (e.g. intensification), including considerations of equity and gender. Use upstream has impacts on the downstream users. Therefore while addressing local and regional level policy and institutional issues, mechanisms for basin level cooperation must be sought (e.g. virtual water trade to improve market access of farmers, PES, benefit sharing, and etc.).

Table 12a. Probability of adopting conservation technologies

Dependent variable: conserved99 (yes=1 no=0)	**β (Exp(β))**	**Robust Std. Err.**	**P>|z|**
Upstream watershed (reference downstream)	0.551 (-0.594)	0.131	0.013***
Plot distance walking time in minutes (*pdistance*)	1.000 (0.0002)	0.004	0.957
Plot area in ha (*areaha*)	2.272 (0.820)	0.309	0.000***
Total cultivated area in ha (*landareaha*)	1.159 (1.147)	0.170	0.317
Tenure of the plot 1= owner operated (reference= sharecropped in or out)	0.606 (0.500)	0.156	0.053**
Years since acquired the plot (*acquireyr*)	0.994 (-0.005)	0.013	0.707
Land registration (*registered= 1 0= otherwise*)	0.801 (0.588)	0.398	0.008***
Slope of the plot (1= *flat slope, reference not flat land*)	0.376 (-0.977)	0.084	0.000***
Black soil type (reference sandy soil)	0.831 (-0184)	0.285	0.592
Red soil type (reference sandy soil)	1.019 (0.019)	0.338	0.953
Highly fertile (*reference infertile*)	0.623 (-0.471)	0.180	0.104*
Moderate fertility (*reference infertile*)	0.729 (-0.315)	0.201	0.253
Medium soil depth (reference shallow soil)	1.517 (0.417)	0.327	0.053**
Deep soil (reference shallow)	1.360 (0.308)	0.305	0.170
Tropical livestock unit (*tlu*)	1.040 (0.040)	0.046	0.370
Walking distance to output market (*wokoutmart*)	0.994 (-0.005)	0.001	0.003***
Walking distance all weather road (wokweterod)	1.002 (0.002)	0.001	0.133
Walking distance to Extension office (*wokdaoffice*)	1.001 (0.001)	0.003	0.637
Walking distance to nursery site (*woknersit*)	0.572 (0.0009)	0.002	0.679
Obtained credit (1= yes, 0= otherwise)	0.927 (-0.072)	0.169	0.682
Got assistance from Debo (1= yes, 0= otherwise)	1.167 (1.155)	0.246	0.462
Got assistance from Wonfel (1= yes, 0= otherwise)	0.572 (-0.557)	0.131	0.015***
Female household head (reference male-headed)	0.741 (-0.297)	0.300	0.461
Age of the household head (*agehh*)	0.986 (-0.013)	0.008	0.139
Female household members over 16 (*ageover16_f*)	0.623 (-0.472)	0.100	0.003***
Male household members over 16 (*ageover16_m*)	1.125 (0.118)	0.137	0.332
Education level of household head (*eduhh*)	0.971 (-0.029)	0.061	0.645
Land affected by erosion (1= yes, 0= otherwise)	1.771 (0.571)	0.355	0.004***
Value of fixed asset (birr) (*valuefixeda*)	1.001 (0.006)	0.001	0.217
Non-farm income (birr) (*nonfrmincome*)	1.000 (0.0004)	0.0004	0.347
Constant	10.28	27.251	0.706
	Number of obs = 1155		
	Wald $chi^2(30)$ = 108.92		
	Prob > chi^2 = 0.0000		
	Log -likelihood = -672.44		
	Pseudo R^2 = 0.134		

Table 12b. Intensity of the use of conservation technologies

Dependent variable: sizeswc99	**Tobit**			**Truncated**		
Explanatory variables	**Coef.**	**Std. Err.**	**P>t**	**Coef.**	**Std. Err.**	**P>z**
Upstream watershed (reference downstream)	-20.36	9.43	0.031**	-85.22	55.23	0.123
Plot distance walking time in minutes (*pdistance*)	0.433	0.220	0.050**	2.027	1.227	0.099*
Plot area in ha (*areaha*)	11.999	4.931	0.015***	67.766	30.16	0.025**
Total cultivated area in ha (*landareaha*)	-0.708	5.353	0.895	-2.685	31.074	0.931
Tenure of the plot 1= owner operated (reference= sharecropped in or out)	21.702	11.06	0.050**	143.66	72.07	0.048**
Years since acquired the plot (*acquireyr*)	0.323	0.464	0.486	-0.466	2.572	0.856
Land registration (*registered= 1 0= otherwise*)	-3.187	8.242	0.699	-20.30	44.82	0.651
Slope of the plot (1= *flat slope, reference not flat land*)	-7.841	7.345	0.286	-43.94	44.82	0.651
Black soil type (reference sandy soil)	33.453	13.125	0.011**	180.67	91.54	0.048**
Red soil type (reference sandy soil)	15.855	12.702	0.212	82.18	83.61	0.326
Highly fertile (*reference infertile*)	6.236	11.492	0.587	11.33	63.08	0.857
Moderate fertility (*reference infertile*)	1.252	10.736	0.907	-23.98	59.48	0.687
Medium soil depth (reference shallow soil)	15.065	8.572	0.079*	74.71	50.98	0.143
Deep soil (reference shallow)	-2.885	9.185	0.753	-14.17	57.38	0.805
Tropical livestock unit (*tlu*)	0.795	1.583	0.963	2.20	8.10	0.786
Walking distance to output market (*wokoutmart*)	0.298	0.0816	0.000***	1.55	0.584	0.08***
Walking distance all weather road (wokweterod)	-0.119	0.078	0.124	0.794	0.494	0.108*
Walking distance to Extension office (*wokdaoffice*)	0.104	0.180	0.563	0.576	0.884	0.515
Walking distance to nursery site (*woknersit*)	-0.247	0.075	0.001***	-1.17	0.506	0.020**
Obtained credit (1= yes, 0= otherwise)	1.087	6.613	0.865	24.49	38.76	0.528
Got assistance from Debo (1= yes, 0= otherwise)	-0.167	7.765	0.983	32.51	45.38	0.474
Got assistance from Wonfel (1= yes, 0= otherwise)	-3.715	7.914	0.639	-37.46	46.72	0.423
Female household head (reference male-headed)	16.886	16.613	0.311	42.87	84.71	0.613
Age of the household head (*agehh*)	1.024	0.356	0.004***	5.05	2.17	0.02**
Female household members over 16 (*ageover16_f*)	-11.241	5.362	0.037**	-50.58	29.19	0.083*
Male household members over 16 (*ageover16_m*)	15.762	4.168	0.000***	69.83	25.65	0.006***
Education level of household head (*eduhh*)	-1.798	2.012	0.372	-6.41	12.79	0.616
Land affected by erosion (1= yes, 0= otherwise)	6.776	8.029	0.399	22.31	49.64	0.646
Value of fixed asset (birr) (*valuefixeda*)	0.0433	0.039	0.272	0.284	0.247	0.251
Non-farm income (birr) (*nonfrmincome*)	0.003	0.016	0.819	0.001	0.104	0.987

Constant	-673.60	929.94	0.469	197.11	5121.12	0.969
	Number of obs	= 462		Number of obs	= 461	
	LR chi2(30)	= 117.96		Wald chi^2(30)	=	
	Prob > chi^2	= 0.0000		18.463		
	Log likelihood	= -2559.61	Pseudo R^2	Prob > chi^2	= 0.9511	
	= 0.022			Log likelihood	= -2364.16	

Note: *, ** and *** are levels of significance at 10, 5 and 1 percent, respectively. The figures in the parentheses are expected values of βs. *, **, *** are levels of significance at 10, 5 and 1 percent, respectively. **Notes**: Codes for dependent variable: use conservation technology: yes=1 no=0. The figures in the parentheses are expected values of βs. If βi is positive, E(βi) > 1, which means that the odds of change in the dependent variable are increased when the ith independent variable increases by one unit. If βi is negative, E(βi) < 1 which means that the odds are decreased. If βi= 0, E(βi) =1 which leaves the odds unchanged. The absolute values of E(β)) indicate the factor by which the odds change.

Prospects of payment for environmental services (PES): The findings from PES study substantiate the hypothesis of PES as being a potential instrument for conflict resolution between upstream and downstream users and sustainable uses of land and water resources. Farmers were more willing to pay in labor than in cash (Table 13 and 14). Overall (for both upstream and downstream) about 64.9% of the samples were willing to pay in cash (Table 13) and the downstream farmer households showed a stronger willingness compared with their fellow farmers in the upstream. Accordingly, 75% of the downstream farm households were willing to contribute in cash for improved land and water management practices. These differences between upstream and downstream can be accounted for by the discrepancy of benefits that can be generated from such intervention (e.g. direct benefits from irrigation schemes, reduced flood damages, etc) and also from the differences in resources holding between the two groups. In general the findings of farmers' willingness to pay in cash differ with Pawlos (2002), who reported insignificant farmers WTP in cash. We argue that Pawlos (2002) observation could be a bit generalization as farmers' willingness to pay in cash depend on the envisaged returns from investment and farmers' financial capacity to invest. Interestingly, farmers' willingness to pay in labor was two fold higher compared to their willingness to pay in cash. This implies that farmers are willing to invest in improved environmental services but obstructed by low level of income. Here, the major point of concern is also whether this farmers' contribution (either in cash or in labor) could cover the financial demand required for investment and maintenance of conservation structure and if this is not the case what can be the policy and institutional options to fill these gaps?

Table 12: Sample farmers WTP in cash (for number of respondents) and labor units (Koga and Gumera watersheds, Blue Nile basin, Ethiopia)

Attributes	Upstream		Downstream		Total	
	Willing	Non-willing	Willing	Non-willing	Willing	Non-willing
WTP (in cash; number of respondents)	99	76	112	38	211	114
WTP (labor PD $month^{-1}$)	169	6	147	3	316	9

WTP is for willingness to pay; PD is for person days (i.e. number of adult person to be involved in land and water management activities)

As indicated in Table-14, the average labor contributions for upstream and downstream farmers were 3.3 and 3.9 person-days per month ($PDmonth^{-1}$) respectively. Whereas the average cash contribution of the upstream and downstream farmers were 10.4 and 13.1 Ethiopian Birr (ETB $month^{-1}$) respectively. Values of MWTP fails far short of covering the investment and maintenance cost for improved land and water management. The MoWR (2002) reported an estimated watershed management cost of 9216 ETB (760 US$$ha^{-1}$). Taking mean current land holding per household and inflation since the time of estimate into account, a farm household may require about 13,104 ETB (1,365 US$) to implement improved land and water management on his plots. In general, the results suggest that the general public in the two watersheds are willing to pay for cost of activities to restore the regulating ecosystem services. PES may be able to bring about a win-win scenario in upstream and downstream water use in watersheds and larger scale river basin. Nevertheless, the low magnitude of farmers' bid (Table 13 and Table 14) can be challenges for its realization. Thus a user-financed PES scheme may not be feasible in short term either at local and basin scales. Alternatively, a PES paid by the users with government support could be a viable strategy. Modalities of government support could include association with investments in irrigation infrastructure, and links to global target of increasing soil carbon through land rehabilitation and tree plantations.

Table 13: Estimated mean WTP in cash and labor units (Koga and Gumera watersheds, Blue Nile basin, Ethiopia)

Mean WTP	N	Mean value	C-I (95%)		P > t
MWTP ETB month^{-1} (upstream)	175	10.4	8.2	12.6	0.0029
MWTP in ETB month^{-1} (downstream)	150	13.1	11.8	14.5	
MWTP (in labor PD month^{-1} (upstream)	175	3.3	3.15	3.40	0.0000
MWTP (in labor PD month^{-1} (downstream)	150	3.9	3.69	4.01	

MWTP is for mean willingness to pay; ETB is for Ethiopian currency which is 1US$ is equivalent to 9.6 ETB; PD is for person day

OUTCOMES AND IMPACTS

During the project implementation, the Impact Pathway and Outcome Logic Model was developed. The proforma provided in the table below summarizes the main impact pathways of the project

OUTCOMES AND IMPACTS PROFORMA

Table 14: **Summary Description of the Project's Main Impact Pathways**

Actor or actors who have changed at least partly due to project activities	What is their change in practice? i.e., what are they now doing differently?	What are the changes in knowledge, attitude and skills that helped bring this change about?	What were the project strategies that contributed to the change? What research outputs were involved (if any)?	Please quantify the change(s) as far as possible
Basin Institution (ENTRO and NBI)	Proactively engaging researchers to present results. Request for data, analyzed results and publications. Request to advice and seek resources persons related to project results	K: knowledge transfer in modelling S: skill transfers/ sharing in communication A: Realization of the benefit of collaborations	Joint planning, co-publication, joint meetings; sharing data, tools and methodologies	Basin institutions provided their published material and data to the project. Project implementers presented 3 papers in the basin and 2 papers in the national forum. The result of water demand modeling is requested to be shared for comparison with their consultancy result. About 5 face to face consultations on watershed management, database and information development, knowledge sharing, decision support system are conducted
National Ministries such as water and	Uptake research results to strategy and	K: increased understanding of improved practice of water	Provide good evidence on practices; establish mechanisms of	Provided consultations for irrigation capacity building.

agriculture	policy. Consult researchers for prioritizing high impact interventions. Provide data, published materials to researchers. Developed by law for WUA	and land management A: realizing the importance of sharing their data for research and scientific work	providing policy synthesis and recommendations; dissemination mechanisms; Stakeholders dialogue; Policy recommendations	Used materials as an input to Capacity Building and 5 years development plan. Invited in 3 workshops and shared knowledge and findings
Universities and research partners	Working in teams: sharing data, developing models, joint field work and visits, joint supervision of students, exchange of knowledge, joint publications	K: New modeling knowledge; S: New skills of comparing and integrating models; transfer of skills in shaping research results to outputs; A: No blanket approach in modeling and the need for adaptation realized; the benefits of institutional collaboration beyond the national boundaries for understanding impacts broadly	Joint planning, co-publication, joint meetings; co development and increased knowledge on current water and land use practices; Enhanced research and implementation capacity; Analytical tools and methodologies	Over 30 joint publications as working papers, journal articles, book chapters, proceeding are published or under publication. 5 workshops and joint meetings taken place. 4 joint field visits/work conducted. A number of models for WSM, WAM and Rainfall runoff are used. Over 20 M.Sc./M.A. students jointly supervised
Donors	More consultations to get inputs for interventions. More interest to focus on Ethiopian highland in water management.	A: Donors get an opportunity to focus more on high impact interventions than balanket approaches.	Lobbying donors and sharing generated knowledge	Donors invited to attend in 3 workshops and attended. The CPWF Bile Phase II focuses on Ethiopian highland for greater poverty impact and lesson learning.

	Willingness to identify future intervention sites matching research sites			Funded ENTRO project is obtaining continuous consultation on interventions in its intervention sites

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?
Uptake of research results in strategies: This will provide best bet interventions in water management, land rehabilitation, agricultural productivity leading to high benefit to productivity gains, food security and ecosystem services

Working in a team: collaborations for research will be sustainable and will provide high impact in institutional partnership in upstream-downstream countries to work together effectively, reduce conflict and mistrust so that useful interventions could be put in place effectively for the ultimate beneficiaries.

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.

Continuity of research is essential so that more piloting and demonstration can be put in place, further insights of the impacts of the outputs can be studied and partnerships be maintained. Measures are in place and one of the most important is the Nile Basin Development Challenge focuses on Rain Water Management strategies in Ethiopian Highland (Blue Nile) and undertake more in-depth research on strategies, targeting, institutional and policy innovation and analyzing consequences on basin wide. These provides exact fit as a follow up to enhance realization of the potential.

What would you do differently next time to better achieve outcomes (i.e. changes in stakeholder knowledge, attitudes, skills and practice)?
Undertake in depth problem and gap analysis to identify measures and changes needed in KAS and practice before even designing the research problem or research project.

Engage relevant stakeholder during the problem and gap analysis to effectively engage throughout the proposal development, research implementation and uptake phases.

Develop effective tools and methods for monitoring and evaluation of the impact pathways are realistic and leading to the desired outcomes.

INTERNATIONAL PUBLIC GOODS

The International Public Good (IPG) developed as a result of this project include: published material, developed tools, methods and approaches, adapted software and database.

1.24 SWAT-WB: an Improved Model for Ethiopian Highland:

Soil and Water Assessment Tool (SWAT) is a basin-scale model designed to simulate hydrologic processes, nutrient cycling, and sediment transport throughout a watershed. Catchment area varies widely throughout the peer-reviewed literature, with SWAT being used on watersheds as small as 0.15 km^2 and as large as 491,700 km^2. In many cases, SWAT is widely applied throughout the world with little adaptation research. To improve SWAT performance in areas dominated by saturation-excess runoff processes, a new runoff routine was added to SWAT. A daily soil water balance was used to determine the saturation deficit of each hydrologic response unit (HRU) in SWAT, which was then used, instead of the Curve Number method, to determine daily runoff volume. This is an improvement on the existing method and provides improved result over the existing one. The theoretical documentation was adapted from the SWAT-WB article available from the SWAT-WB website and is meant to provide a brief overview of the changes made to the original version of SWAT. The official SWAT-WB paper should be referred to for a full discussion of the model and its successful application in two test watersheds in the Blue Nile. The SWAT-WB is documented as IPG and complete reference is provided under http://soilandwater.bee.cornell.edu/research/ swatwb/swatwb.html. For a full description of the original SWAT program please refer to either the official SWAT website (www.brc.tamus.edu/swat).

Hence, the popular USDA-SWAT watershed model was modified for the Blue Nile, greatly improving the ability to predict stream flow and sediment and nutrient loadings in tropical watersheds with monsoonal climates.

1.25 Configuration of Software and Models for Blue Nile

- The Stockholm Environment Institute (SEI) developed Water Evaluation and Planning (WEAP) model is configured for Blue Nile River Basin as integrated model of Ethiopia and Sudan. The WEAP model is capable to perform a mass balance of flow sequentially down a river system, making allowance for abstractions and inflows. In this section we report the WEAP modeling results. The model was set-up to simulate four scenarios: i) the natural situation with no abstractions, ii) the current situation (2008), iii) medium-term future demand (i.e. approximately 2015) and iv) long-term future demand (i.e. after approximately 2025). In the configuration, time series of monthly naturalized flow data for the period 1960- 2007 are compiled from various sources. Hence, this configuration is an IPG that serves researchers and development actors to advance further understanding of the BNB.

- Similarly, other models including Mike Basin and HEC-Res for Ethiopia part of the basin. For the Sudan part of the basin HEC-Res is also configured to simulate the consequences of development scenarios.

- In addition, at the sub-basin level, Artificial Neural Network (ANN) and Distributed Hydrological Model (WaSiM- ETH) for predicting daily runoff over five small to medium sized sub-catchments in the Blue-Nile River basin are used to understand daily rainfall-runoff processes. The neural networks capability of modeling a complex rainfall-runoff relationship has been observed which advances the ANN applicability in developing countries, limited data and ungaguged basin situations.

1.26 Experimenting Payment for Environmental Service (PES) and Identifying Determinants of Adopting AWM Interventions

Payment for Environmental Services, Benefit Sharing, and Determinants of Adopting Technologies are relatively new concepts, where there are no clarity how and when they are applicable in the river basins. To asses upstream and downstream communities' willingness to pay for environmental services, contingent valuation method (CVM) was applied in the Blue Nile to test the method and experiment the usefulness of the approach. Our study substantiated the hypothesis of PES as a potential instrument for conflict resolution between upstream and downstream users and sustainable uses of land and water resources. The experiment provided methods and approaches how to implement PES study in developing countries and poor farming communities. In addition determinants of adaption of AWM technologies were investigated and the most important ones were prioritized. These can serve as IPG for adapting the approaches or using the results to implement action projects in various parts of the world.

1.27 Data Sets, Maps and Information

A number of data sets and maps are prepared that can contribute to IPG related to Blue Nile Basin. These include Blue Nile Atlas covering over 250 maps and figures, digital elevation model, delineated sub basins, spatial information covering climate and hydrology, soil, land use, population, farming system, existing and planned development sites, water use information, etc.

PARTNERSHIP ACHIEVEMENTS

New partnerships between institutions of upstream downstream countries such as Omdurman Islamic University – UNESCO Chair on Water resources, Hydraulic Research Station, Addis Ababa and Bahir Dar Universities, Forum for Social Studies, Amhara Regional Agricultural Research Institute including global Institutions such as IWMI and ILRI as well as ARI such as Cornell University have been established. The major achievement was that the various institutions worked together tackling the challenge of disconnect between upstream and downstream, visited the basin together, worked together and co-published results. The usually difficult data sharing between countries has been tackled through researcher to researcher sharing.

There has been very good participation of stakeholders during field data collection and appreciation of the problems and interest in uptakes of project findings. The clear evidence is that the papers presented to the Ethiopia Nile forum have been requested to be submitted to the Khartoum Nile wide forum that the project results are accepted as useful input to the Nile discourse and establishing long-term partnership for CPWF projects. Two other project related results were also presented in the Khartoum forum. There have been very good support in providing relevant documents, such as from Eastern Nile Technical Regional Office (ENTRO) and other country and provincial offices in Ethiopia and Sudan. There has been strong willingness that the project uses the Amhara Institute of Agricultural Research, ENTRO, African Development Bank, Gazira Irrigation Scheme, GTZ, etc sites for the purpose of evaluation of impacts of watershed interventions, water allocation modelling and policy and institutional studies.

Furthermore, many local institutions such as the Amhara Bureau of water in Ethiopia, the Sustainable Water harvesting and Institutional strengthening, the GTZ watershed management project, Ministry of Water Resources of Ethiopia and Ministry of Water Resources and Irrigation in the Sudan have provided us with useful data and documents relevant to the project.

Experts from Egypt, Sudan and Ethiopia coming from various institutions, to which the project has relevance have been invited to the dissemination workshop and participated actively. These expertise retain contact with the project and useful network to develop similar projects and initiatives in future.

RECOMMENDATIONS

The following are major recommendations for research, extension, policy makers, academia and development organizations

- Crop livestock systems are the most important livelihood means for people in Blue Nile basin. However, agricultural productivity is showing considerable gap. Interventions that are showing promising results at experimental plot level need to be scaled up to improve productivity. Identifying biophysical, technical, institutional and policy constraints as well as investment in their improvement are important.

- Low productivity of agriculture, poor cultivation practices combined with overpopulation are the major causes of degradation of land and water resources. The resulting consequences are loss of agricultural land, increased flooding, deposition of sediment in natural lakes and reservoirs and canals. The cost of loss of storage or agriculture as a result is significant. It is recommended to enhance collaboration of upstream and downstream stakeholders in managing the water resources at the watershed areas through sustainable WSM measures are needed and such measures will lead to reduced soil erosion and Blue Nile river sediment yield.

- Further research in the Blue Nile related to water and land resources management, agriculture should first critically review existing knowledge. There are numerous, models, data and results already developed. Using the existing knowledge in the Blue Nile can speed up investment.

- Researchers and other users are advised to make use of the extensive maps, database, model adoption on primary and secondary data collected and generated by the project.

- For future monitoring and adequate distribution of data network, improvement of gauging stations and data network in terms of both spatial distribution and station numbers are essential. Current level of instrumentation is determined by accessibility and does not provide adequate distribution of instrumentation. Therefore, new investment is needed to improve network of data collection, sharing including application and use of modern technologies such as remote sensing

- Most runoff is produced in the lower lying areas in the landscape. Land use of these areas is usually grazing. Modification to these areas such as overgrazing, deforestation, etc will greatly affect water quality and quantity. Runoff generating areas should receive prioritization for implementation of watershed management practices, and investors should pay attentions to such areas

- Models developed in temperate climates need to be modified to predict the location of runoff producing areas in the watershed. New tools such as SWAT-WB, customized WEAP for Blue Nile, etc have been available. It is important to build on these and further the results instead of re-inventing the same product. The SWAT-WB model result provided better runoff simulation, and thus predictions of sediment source areas are much more realistic

- Converting non-beneficial water, for example in cultivated vertisol through drainage and water harvesting, to productive use would improve productivity and resilience. Use of AWM technologies in rainfed systems, that largely use of the green water will upgrade rainfed systems in terms of productivity and affect the Blue Water insignificantly. Focusing in managing rain water can improve livelihood of poor people in Ethiopian highland significantly, thus NGOs and Governments are advised to provide adequate attention to such investments

- Ultimate optimization of productivity is possible through integration of optimum levels of soil fertility, water use and improved seeds. Thus integrated investment is essential to improve productivity per unit of land and water.

– Upstream water resource development, that increases flow regulation can create win-win scenarios with significant economic and social benefits for both Ethiopia and Sudan. Thus, it is advantageous that the two countries plus Egypt work together for increased benefit of all. However, to take full advantage of the water resources of the Blue Nile basin, it needs to be managed as a single system, with water demand priorities established to maximize the overall benefits for both Ethiopia and Sudan with due consideration to the needs to further downstream in Egypt.

– Policy and institutions across local to basin are not well established and does not take in to account downstream and upstream needs. Cooperation between upstream and downstream is essential and key to success. Institutional arrangements must built across different scales (nested from local to international) that increase trust, facilitate the exchange of information and enable effective monitoring required for successful water resources management

– Innovations such as PES are a means to enhance incentive-based land & water management policy- enforcement & an entry point for benefit sharing. A full-fledged farmers financed PES scheme may not be feasible (at least in the short-term). Therefore options for user & state co-financing must be sought.

– Further research is needed to identify crucial interventions for rain fall and water management at various spatial scales at farm, landscape and watershed levels that can be out scaled at basin wide to create broader productivity and wealth creation impact. Further research is also needed to evaluate and understand consequences in the upstream downstream context.

PUBLICATIONS

Table 15: *The following are key publications and products*

S. B. Awulachew, M. McCartney, Tammo S. Steenhuis and A. A. Ahmed, A Review of Hydrology, Sediment and Water Resource Use in the Blue Nile Basin, 87p. Working Paper 131, www.iwmi.cgiar.org/Publications/index.aspx

Haileslassie, A.; Hagos, F.; Mapedza, E.; Sadoff, C.; Awulachew, S. B.; Gebreselassie, S.; Peden, D, Institutional settings and livelihood strategies in the Blue Nile Basin: Implications for upstream/downstream linkages. Colombo, Sri Lanka: International Water Management Institute., 81p. WMI Working Paper 132, www.iwmi.cgiar.org/Publications/index.aspx

S.H. Alemayehu, S.B. Awulachew , Hans-B. Horlacher , J. Cullmann, Comaprision of ANNs and A Distributed Conceptual Hydrological Model (WaSim-ETH) for Predicting Daily Watershed Runoff WATERSHED RUNOFF, Journal of Hydrology , Under review

Tammo S. Steenhuis, Amy S. Collick, Zachary M. Easton1, Elias S. Leggesse, Haimonote K.Bayabil, Eric D. White, Seleshi B. Awulachew, Enyew Adgo, Abdassalam Abdalla Ahmed in J. Hydrological Process, Predicting Discharge and Erosion for the Abbay (Blue Nile) with a Simple Model, Journal of hydrological Process, Journal of Hydrological processes, 23, 3728–3737 (2009)

S.H. Alemayehu1, S.B. Awulachew , Hans-B. Horlacher, J. Cullmann, Estimation Of Daily Flow In Ungauged Catchment By Coupling Hydrological Model And Neural Networks: Case Study, Journal of Hydrologic Engineering , Under review

S.H. Alemayehu, N. Schütze, H.B. Horlacher, S.B. Awulachew, Optimization of Multiple Reservoir Releases Using an Evolutionary Strategy: Case Study Of Lake-Tana Sub-Basin, Ethiopia, International Journal of Water , Under review

Solomon Gebreselassie, Fitsum Hagos, Amare Haileslassie, Seleshi Bekele Awulachew, Don Peden Land Degradation & Development, Determinants of adoption of improved land and water management practices in the Blue Nile Basin: exploring strategies for out scaling of promising technologies by Solomon G/Sellassie, Journal of Land Degradation & Development, Under review

Teklu Erkossa , Seleshi B. Awulachew and Aster Denekew, Farming System Productivity Modeling: Maize and Potato in Ethiopian Blue Nile Basin, Agricultural Water Management, Under review

Collick AS, ZM. Easton, Tegenu Ashagrie, Biniam Biruk, Seifu Tilahun, Enyew Adgo, Seleshi B. Awulachew, Gete Zeleke and TS Steenhuis., A simple semi-distributed water balance model for the Ethiopian Highlands, Hydrological processes, Journal of Hydrological processes, 23, 3718–3727 2009

Liu, B.M., Collick, A.S., Zeleke, G., Adgo, E., Easton, Z.M. and T.S. Steenhuis. , Rainfall-Discharge Relationships for a Monsoonal Climate in the Ethiopian Highlands, Hydrological processes, Journal of Hydrological processes. 22, 1059–1067 (2008)

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APPENDICES

Abstracts of all key publications

i) Working papers

A review of hydrology, sediment and water resource use in the Blue Nile Basin. Colombo, Sri Lanka: International Water Management Institute. 86p. (IWMI Working Paper 131)

Awulachew, S. B.; McCartney, M.; Steenhuis, T. S; Ahmed, A. A. 2008.

Summary

The objective of this report is to undertake comprehensive literature review, broad analysis of Blue Nile water resources, identify and compile data and information in relation to hydrology, sediment and water uses in the context of CP19-Improved water and land management in the Ethiopian highlands and its impact on downstream stakeholders dependent on the Blue Nile project. In the document, section 1 provides context of the study through looking at water resources in Africa and the Nile Basin. It also provides general overview of the project – why it's being done, what the objectives are. Section 2 deals with the overview of Abbay-Blue-Nile basin characteristics, its climatic and hydrological data network, data coverage and availability of such information. It also reviews geology, soil and land-use, land cover based on secondary sources. Section 3 focuses on overview of the hydrology and water resources of the Blue Nile, description of flow in major tributaries – seasonal variation and trends over time and database and summaries of hydrological modeling in the Nile and Blue Nile. Section 4 focuses on erosion and sediment transport, data sources for sediment (including map – watershed, lakes/reservoirs and large catchments), overview of sediment in the major tributaries – seasonal variation and trends over time. Discussions on the levels of degradation and implication on the research project are also provided. Section 5 reviews the existing development and future potential with respect to major water use, i.e. irrigation and hydropower. Outline and justification of research method and models to be used in the study are included in the conclusion and recommendation part in section 6. List of reference materials are also listed, which are important resource material for the study.

***Institutional settings and livelihood strategies in the Blue Nile Basin: Implications forupstream/downstream linkages*.** Colombo, Sri Lanka: International Water Management Institute. 81p. (IWMI Working Paper 132)

Haileslassie, A.; Hagos, F.; Mapedza, E.; Sadoff, C.; Awulachew, S. B.; Gebreselassie, S.; Peden, D. 2008.

Summary

This report provides an overview of the range of key livelihoods and production systems in the Blue Nile Basin. It is highlighting their relative dependence on, and vulnerability to, water resources and water-related ecosystem services in the catchments. It also

elucidates current water and land related policies and institutions. The objective of this report is mainly to synthesize and summarize existing knowledge and gaps on institution and policy so as to guide the envisaged in-depth research. In this executive summary key messages and findings in major topics will be presented.

- *Agriculture as the major source of livelihoods in the Blue Nile Basin*: Livelihood security in the Blue Nile Basin is strongly dependent on spatiotemporal water distribution and land management practices. Over 95% of the food producing sector, in upstream areas, is based on rainfed agriculture. Conversely, in the downstream areas (in Sudan), **t**he Blue Nile provides major irrigation developments. Gazira irrigation scheme alone represents about 50% of the irrigated area in Sudan. In production terms: 65% of cotton, 70% of wheat 32% of sorghum, 15% of groundnut, and 20% of vegetable production in Sudan come from this scheme. In general, water as a renewable natural resource sector is of particular importance because of the relatively high proportion of livelihoods that it supports in the Blue Nile Basin.
- *Production systems as manifestation of livelihoods diversity*: Since agriculture is an asset and activities are required as a means of living in the basin, the different livelihoods in the basin are manifested through farming systems and its subsystems. Those include: small grain cereal-based mixed farming systems of the upstream areas of the Northern Highlands (1,500 to 3,000 meters above sea level (masl) in Ethiopia); maize-based perennial crops in the South (upstream area of the Didesa sub-basin in Ethiopia); and maize-sorghum complex in the western lowland valleys (Dabus and Beles, upstream of the Dinder and Rahad subbasins in Ethiopia). The maize-sorghum complex extends to Sudan where sorghum becomes a dominant crop (e.g., the rainfed semi-mechanized production and the irrigated sorghum production). Another dimension of the production systems, in the Blue Nile basin, is the pastoral and agropastoral systems in Sudan. The fact that the resource base, activities and the decision-making of farmers differ across production systems in the Nile basin implies the diversity in the challenges and opportunities for development.
- *Upstream/downstream linkages and prospects in land and water management:* Agriculture is a system hierarchy ranging from plots through farm watersheds through the production to a basin. For such a hierarchy operating with the same hydrological boundary (i.e., basin) water flows create intra- and inter-system linkages. Because of these linkages, changes in one part of a basin will affect water availability and attendant livelihoods and ecosystem health in other parts of the basin. Threats to these 'co-dependent livelihoods' arise from the new dimensions: population growth and food supply; poverty; agricultural intensification; environmental degradation; and water scarcity. The growing importance of land and water management arises from the pressure of ongoing population growth in the context of constrained availability of agricultural land. For example, in upstream areas of the Blue Nile, the area of cultivable land per person is less than 2 hectares (ha) with low crop yield. As a result, a major part of the upstream area falls under the food deficit zone. To meet the livelihood demands of the community, future increases in agricultural production will have to be realized by raising yields on existing cultivation areas, rather than by expanding the area under cultivation. Sustainable increases in production and ecosystem health can be also maintained if those increases in yield could be associated with soil and water conservation (SWC), hydropower development, and water supply and sanitation. This will, obviously, put blue and green water management as a key element of those development scenarios. A Number of pertinent initiatives are, currently, reported in Ethiopia: irrigation projects in Tana sub-basin (e.g., Koga, Gumera, Rib and Megech); Tan-Beles, Karadobi, Mendia

and Border hydropower projects; and a number of watershed management interventions (e.g., Koga, Jema, Rib and Gumera watersheds). In view of those new dimensions, it is important to explore the impacts of those interventions on the downstream areas and the role of institution and policies to harmonize and help achieve livelihood demands in both upstream and downstream regions.

- *Institutions and policy in the Blue Nile basin*: The organizational environment for land and water in the Nile Basin region is fairly well-defined. There are organizations with clear mandates, duties and responsibilities. The organizational settings have been organized in such a way that organizations that have to do with land and water, directly or indirectly, have been identified and given duties and responsibilities, by law, in order to execute their tasks appropriately. That said, however, there are important problems that have been identified in the organizational setting and some questions remain to be answered. Important policy gaps are identified as well. Some of the major problems pertinent to institutions in the Blue Nile Basin are: 1) disciplinary orientations rather than interdisciplinary orientations; 2) organizational instability; 3) inefficient organizational structure (due to understaffing, under equipping, lack of organizational units at the lowest possible levels like *Woredas*, and zones to cater to the needs of the sector); 4) lack of linkages and alliances between institutions; 5) problem of capacity (e.g., shortage of skilled manpower); inadequate office and workshop facilities; 6) limited funds/budget; 7) lack of effective cost recovery mechanisms; 8) lack of integrated information management systems; 9) insufficient public- NGO- private partnerships; 10) the focus of all these organizations is on surface water and groundwater, i.e. blue water; and 11) there is no transboundary organization.
- Considering the central importance of policy and institutional capacities to promote sustainable development has long been recognized. It is remarkable how little research has been done to understand how to support the new dimension of improved land and water management. In the Blue Nile, there are few case studies. We realized that institution and policy studies should apply rigorous comparative analysis and contextual case studies examining a representative range of success, failure, and intermediate cases. Research topics needing urgent attention are indicated in section 4, *Key Messages and the Way Forward*, of this report. In general, it can be emphasized that the livelihood base of the community and land and water resources in the Blue Nile Basin are threatened. Interventions in upstream areas that aimed at improving the livelihoods of the local community will have an impact on the downstream region. Bringing a win-win scenario by upscaling promising land and water management technologies needs appropriate policy and institutional support, e.g., policy and institutions that can address the upstream/downstream interactions. Therefore, in-depth studies that can, ultimately, lead to a pragmatic policy recommendation are required

ii) Journal Articles

Predicting discharge and sediment for the Abbay (Blue Nile) with a simple model

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HYDROLOGICAL PROCESSES *Hydrol. Process.* **23**, 3728–3737 (2009)

Abstract:

Models accurately representing the underlying hydrological processes and sediment dynamics in the Nile Basin are necessary for optimum use of water resources. Previous research in the Abbay (Blue Nile) has indicated that direct runoff is generated either from saturated areas at the lower portions of the hillslopes or from areas of exposed bedrock. Thus, models that are based on infiltration excess processes are not appropriate. Furthermore, many of these same models are developed for temperate climates and might not be suitable for monsoonal climates with distinct dry periods in the Nile Basin. The objective of this study is to develop simple hydrology and erosion models using saturation excess runoff principles and interflow processes appropriate for a monsoonal climate and a mountainous landscape. We developed a hydrology model using a water balance approach by dividing the landscape into variable saturated areas, exposed rock and hillslopes. Water balance models have been shown to simulate river flows well at intervals of 5 days or longer when the main runoff mechanism is saturation excess. The hydrology model was developed and coupled with an erosion model using available precipitation and potential evaporation data and a minimum of calibration parameters. This model was applied to the Blue Nile. The model predicts direct runoff from saturated areas and impermeable areas (such as bedrock outcrops) and subsurface flow from the remainder of the hillslopes. The ratio of direct runoff to total flow is used to predict the sediment concentration by assuming that only the direct runoff is responsible for the sediment load in the stream. There is reasonable agreement between the model predictions and the 10-day observed discharge and sediment concentration at the gauging station on Blue Nile upstream of Rosaries Dam at the Ethiopia–Sudan border.

KEY WORDS model; erosion; sedimentation; rainfall-runoff; monsoonal climate

A simple semi-distributed water balance model for the Ethiopian highlands

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HYDROLOGICAL PROCESSES *Hydrol. Process.* **23**, 3718–3727 (2009)

Abstract:

The discharge of the Nile River is highly dependent on the flow generated in the highlands of Ethiopia. However, little is known about the local (i.e. small scale) watershed hydrological response, due in part to a lack of long duration, continuous hydrological data. The goal of this paper was to develop a realistic, simple model that is useful as a tool for planning watershed management and conservation activities so that the effects of local interventions on stream flow can be predicted at a larger scale. The developed model is semi-distributed in that it divides the watershed into different regions that become hydrologically active given different amounts of effective cumulative rainfall after the start of the rainy season. A separate water balance is run for each of the hydrologic regions using rainfall and potential evaporation as the major inputs. Watershed parameters that were calibrated included the amount of water required before each region becomes hydrologically active, the fraction of soil water that becomes runoff and subsurface flow, and aquifer characteristics, Model validation indicated that daily discharge values were predicted reasonably well with Nash Sutcliffe values ranging from 0Ð56 to 0Ð78. Despite the large distance between the test watersheds, the input parameter values for the watershed characteristic were remarkably similar for the humid highlands, indicating that the model could be used to predict discharge in un-gauged basins in the region. As expected, the watershed in the semi-arid region behaved somewhat differently than the other three watersheds. Good quality precipitation data, even for short durations, were key to the effective modelling of runoff in the highland watersheds.

KEY WORDS rainfall runoff; Thornthwaite–Mather; Upper Nile Basin; Nile; monsoonal climate

11 additional articles are in pipeline

iii) Book Chapters

Chapter 19: Hydrological Water Availability, Trends and Allocation in the Blue Nile Basin (forthcoming book)

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Abstract

Rainfall varies significantly with altitude and is considerably greater in the Ethiopian highlands than on the plains of Sudan with in the Blue Nile River. The river is the principal tributary of the main Nile River providing 62% of the flow (reaching Aswan. The variation of flow is extreme, with unimodal peak. Similarly, sediment transport in the river is considerably varying. Any meaningful development centering water therefore requires considerable investment on water control and management to offset variability. Ethiopia currently utilizes very little of the Blue Nile waters. Sudan uses considerable volumes both for irrigation hydropower. However, there remains significant potential for additional exploitation and both Ethiopia and Sudan have plans to further develop the water resources of the river. In Ethiopia primary development is about 200,000ha & 815,000ha in long term and many hydropower plants. In Sudan, it is planned to develop 889,000ha of additional irrigation in long term and no hydropower. This chapter provides an overview of the basin characteristics, hydrology and hydrological variability of the Blue Nile, brief evaluation of the current and future status of water resource development and implications on water availability.

Key words: Abbay, Blue Nile, Variability, Sediment, Water Allocation, Water Use Potential

Four book chapters for Nile Book under preparation

iv) Workshop Proceedings

Best bet technologies for improving agricultural water management and system intensification in Ethiopia

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Abstract

A significant part of Ethiopia and its agricultural production is affected by prolonged dry spells, recurrent drought, land degradation and consequential low productivity, resulting in extreme poverty and highly vulnerable rural communities. In Ethiopia, both in-situ and ex-situ Agricultural Water Management (AWM) technologies are used. Among the in-situ soil and water conservation technologies, use of measures to reduce runoff and erosion, such as terracing, stone bunds and trash lines, are common. However, evaluation of thei[3]r use and impacts on crop production and productivity is difficult and not well established in Ethiopia. The ex-situ technologies include rain water harvesting technologies for supplementary or full irrigation – most commonly from ponds, river diversion, micro dams, and pumping from wells. This paper first lists the most widely used AWM technologies in Ethiopia and their possible combination with respect to water control, lifting, conveyance and field application. Nearly forty types of AWM technologies are used in Ethiopia. Second, the paper, based on key informant interviews, identifies most widely and successfully used technologies. Based on the second step, 6 categories of technologies related to water source/control that have been successful and are widely used by small holders identified. Finally the paper evaluates the poverty impacts of the various technologies based on extensive data that were collected from 1,500 households using these technologies and control households (non-users) in four major Ethiopian regions. The incidence, depth and severity of poverty is significantly lower among AWM technology users than non-users. AWM technology users are 22% less poor compared to non-users. Technologies with the highest impacts on poverty were deep wells, river diversion and micro dams, leading to poverty reductions of 50%, 32%, and 25% respectively. The difference is mostly attributed to the scale effect and increased system reliability.

Micro watershed to basin scale impacts of widespread adoption of watershed management interventions in the Blue Nile Basin

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Abstract

High population pressure, inappropriate agricultural policies, improper land-use planning, over-dependency on agriculture as a source of livelihoods and extreme dependence on natural resources are inducing deforestation, overgrazing, expansion of agriculture to

[3] Agricultural water management and poverty in Ethiopia

marginal lands and steep slopes, declining agricultural productivity and resource-use conflicts in many parts of the Blue Nile River Basin. Poor agricultural and other practices affect runoff characteristics and result in increased erosion and siltation and reduced water quality in the basin. The result is a downward spiral of poverty and food insecurity for millions of people both within the upper catchment and downstream across international borders. Quantification of erosion and sedimentation and evaluation of the impacts of interventions are difficult tasks. We studied rainfall-runoff and sediment-runoff relationships in the Gumera watershed, and calibrated the SWAT model for this watershed. The analysis shows that rainfall, runoff and sediment load are highly variable in both time and space. The amount of sediment in the river systems is strongly related to the onset of rainy season. The hydrographs show that the peak sediment concentration occurs first, followed by the peaks for rainfall and then runoff. Furthermore, the cumulative sediment load curve shows that most of the sediment enters the river in the first three months of the rainy season. The results show that both runoff and sedimentation can be reasonably simulated using the SWAT model(R^2=0.82 and 0.79, respectively). The study demonstrated, that by undertaking spatial analysis using topographic, soil and land use parameters with the SWAT model, that it is possible to identify the high sediment risk sub-watersheds. The modelling studies showed that use of vegetative filters with widthd of 5 and 10 m in high erosion risk watersheds reduced sediment yield by 52% and74% respectively.

Keywords: Erosion, Sedimentation, Rainfall-runoff, Degradation, Interventions, Blue Nile

Indicators of Environmental Degradation in the Blue Nile Basin: Exploring Prospects for Payment for Environmental Services.

Haileslassie, A, Fitsum Hagos and Seleshi Bekele Awulachew, Don Peden Solomon Gebreselassie, Fekahmed Negash, 2008.

Proceeding of Nile basin development forum. 16-19 November, Sudan Khartoum

Abstract

The Blue Nile Basin (Abbay in Ethiopia) covers wide range landscapes and climatic zones in Ethiopia and Sudan. Different agricultural production systems, in the basin, evolved in response to those diverse landscapes and climatic zones, and the attendant human decision dynamics that responds to changing livelihood opportunities. Many production systems studies recognized only mixed agriculture in the highlands and pastoralism in the lowland areas. Now it is widely recognized that several other factors such as land-use, vegetation cover, and different land and water management practices are important in defining production systems. These study approaches help to capture the diverse water and land related livelihoods of the farming communities in upstream and downstream parts of the basin and their impact on their respective environments. In this review, we follow a similar approach but focus at the basin scale to define and characterize major production systems and associated subsystems specifically: small grain cereals-based mixed crop-livestock and maize-sorghum-perennials systems and their associated subsystems. We then focus on water management practices in rainfed and irrigated systems. We also synthesized impacts of those production systems on the environment and upstream-downstream linkage using erosion, sedimentation, livestock and crop water productivity, soil nutrient balances as indicators. Evidences suggest that

natural ecosystem services (e.g. regulation services such as nutrient recycling and redistribution) are severely threatened in the Blue Nile basin. On-site and off-site effects of pedogenic processes like sediment removal, transportation, redistribution and attendant environmental impacts (e.g. nutrient balances and water productivity) are highly correlated with dominant farming practices and attendant anthropogenic interventions. Indicators such as water productivity and soil nutrient depletion and farmers' activities to replenish the lost nutrients are also strongly related to the degree of the farmers' resource endowments. In view of initiating the upstream community to invest more on land and water management, options for payment for environmental services (PES) must be sought and, interventions that enhance sustainable ecosystem management must use integrated approaches and farming system/subsystems as entry point.

Key words: *Production systems; environmental degradation; upstream downstream; Blue Nile basin; water productivity, payment for environmental services (PES)*

Application of a physically-based water balance model on four watersheds throughout the upper Nile basin in Ethiopia. In: Eds. W. Abtew and A. M. Melesse.

Collick, A.S., Easton, Z.M., Adgo, E., Awulachew, S.B., Zeleke Gete, and Steenhuis, T S. 2008. Proceedings of the 2008 workshop on the Nile Basin hydrology and ecology under extreme climatic conditions.

Abstract
Local hydrological knowledge is important because of the lack of long duration, continuous hydrological data at a small watershed scale and the extensive variability in rainfall and resulting runoff over the Ethiopian landscape. A better understanding of the local hydrological characteristics of different watersheds in the headwaters of the Nile River is of considerable importance because of the collective interest in the access to its water resources and the need to improve and augment development and management activities of these resources. A simple hydrological model for watersheds in varying locales at daily and weekly time scales was developed to gain insight into the hydrologic conditions of the larger Nile River basin. This model appears to be useful as a tool for planning watershed management and conservation activities. The water balance model was based on the Thornthwaite and Mather procedure, using rainfall and evaporation as major inputs, available water storage after the dry season and contributing area as partitioning factors within the watershed. Discharge data from three SRCP watersheds and one near Sekota were used for calibration of the storage coefficient. The Nash-Sutcliffe efficiencies along with other comparison statistics showed that model performed well compared to other water balances of the upper Nile Basin done with a monthly time step. The model was able to represent daily discharge values well. Despite the large distance between the test watersheds, the input parameter values were remarkable similar. Good quality data, even for short durations, were key to the effective modeling of runoff in the highland watersheds.

Key words: variable source area, simulation model, water balance,

The following abstracts are CP19 based workshop proceedings

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Blue Nile Basin Characterization And Geospatial Atlas

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The Blue Nile is the most important tributary river of the Nile. It provides 62% of the flow at Aswan. Information related to GIS layers and commonly available data are not easily accessible to researchers and practitioners, and repeated duplication of efforts has been observed to generate such information. The paper deals with the characterization of the Blue Nile Basin and its subbasins. The characterization generally looks into the topography, climatic conditions, hydrology and land use/cover, soil, and other related properties. The basin, as well as selected subbasins, watersheds, and micro-watersheds are considered and presented separately to help provide basic information at watershed to basin level, and lay the basis for other studies and researches. The basic information in this paper comes from the Blue Nile Geospatial Database, which has been developed for the upstream/downstream project. Several maps describing various aspects of spatial information of the basin, subbasins, selected watersheds and micro-watersheds based on the database are produced in the form of an atlas. It provides over 270 various maps and figures, and the digital information system can be accessible for various uses.

Impacts of Improving Water Management Of Smallholder Agriculture In The Upper Blue Nile Basin

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With its total area of about 200,000 square kilometers (km^2), which is 20% of the country's land mass, and accommodating 25% of the population, the Upper Blue Nile Basin (Abbay) is one of the most important river basins in Ethiopia. About 40% of agricultural products and 45% of the surface water of the country are contributed by this basin. However, the characteristic-intensive biophysical variation, rapid population growth, land degradation, climatic fluctuation and resultant low agricultural productivity and poverty are posing daunting challenges to sustainability of agricultural production systems in the basin. This calls for technological interventions that not only enhance productivity and livelihoods in the basin, but also bring about positive spillover effects on downstream water users. In this study, the farming systems in the basin have been stratified and characterized; and promising agricultural water management technologies, which may upgrade the productivity of smallholder rainfed agriculture while improving downstream water quality, have been identified. As a consequence, supplementary and full irrigation using rainwater and drainage of waterlogged soils are recognized as being among the promising agricultural water management technologies that can be easily

scaled-up in the basin. The magnitude of the impacts of these technologies on the productivity of the upstream farming systems and the concomitant effects on the downstream water flow and quality are under investigation, assuming an assortment of scenarios.

Simulation of water resource development and environmental flows in the Lake Tana subbasin

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Lake Tana is a natural reservoir for the Blue Nile River which has huge potential for hydropower and irrigation development. Water resource development is being encouraged by the government to stimulate economic growth and reduce poverty. In this study, the Water Evaluation And Planning (WEAP) model was used to simulate planned hydropower and irrigation development scenarios. Simulation of water demand and estimated downstream environmental flows was conducted for a 36-year period of varying flow and rainfall. Based on the simulation results, water availability for the different proposed irrigation and hydropower schemes was determined. The likely impact of future water resource development on water levels of the lake was assessed based on the simulation results of three development scenarios. The simulation results revealed that, if the full future development occurs, on average, 2,207 $GWhy^{-1}$ of power could be generated and 548 Mm^3y^{-1} of water could be supplied to irrigation schemes. However, the mean annual water level of the lake would be lowered by 0.33 meters (m) with a consequent decrease of 23 km^2 in the average surface area of the lake. Besides having adverse ecological impacts, this would also have significant implications for shipping and the livelihoods of many local people.

Water Balance Assessment of The Roseires Reservoir

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Roseires Reservoir on the Blue Nile River was completed in 1966 to serve the purposes of hydropower generation, irrigation and flood retention. During its lifetime, the reservoir suffered from serious sedimentation, to the limit that its present capacity is less than 2 cubic kilometers (km^3). Operation of the reservoir is maintained closely together with the Sennar Dam according to the operation policy. Operation of reservoirs depends on rules set for that purpose, which is based mainly on the water balance of the system among other factors. Such rules are rarely revised during the lifetime of the reservoirs. Roseires is not an exception. This paper presents an attempt to look closely at the different aspects of the operation and water balance parameters to gain an insight into the whole operation of the reservoir. In addition, an attempt is also made to find an accurate balance formula for the system, taking into account the part of the intervening catchment (14,578 km^2) that is totally ungauged. The flow from the Ethiopian Highlands is monitored at Eddeim Station. The mean annual rainfall in the area amounts to

approximately 700 mm. The daily evaporation rates were derived from monthly data available in the operation rules of the Blue Nile reservoirs. The change in reservoir storage (Δs), and surface area were computed from the bathymetric surveys conducted during 1985, 1992 and 2005. Water balance computations were carried out for 1985, 1995 and 2005, corresponding to the availability of data. The ten years bathymetric data survey intervals give enough time for changes in water balance to take place, if any. Daily and 10-day water balances were computed using Eddeim flow data as the only inflow to the reservoir for the whole year, and for the dry and rainy periods. It was found that outflow from the reservoir can be reproduced with an efficiency of 97% R^2, indicating that the contribution of the intervening catchment to the inflows is negligible.

Improving Water Management Practices in The Rahad Scheme

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This study aims to investigate and develop proper operational water management tools for the Rahad irrigation scheme. The Rahad project is considered as being among one of the schemes that could have a huge potential for expansion in the near future after the heightening of the Roseires Dam. The water supply sources for the Rahad scheme are the Blue Nile River and the Rahad seasonal river. The study explores options of augmenting the supply from the Rahad River during the wet season with the goal of minimizing sedimentation problems on the supply canals, reducing operation and maintenance costs associated with the Mena pumping station. Crop water requirements for the Rahad scheme were computed based on the historical cultivated areas of the different crops for the period 2000-2004. The Water Delivery Performance (WDP) Indicator for the scheme was evaluated. Frequency analysis and flow duration curves for the historical records of the Rahad seasonal stream were conducted in order to establish the yield of the Rahad River at different assurance levels. It is found that the yield from the Rahad seasonal river with 90% assurance level could be adequate to maintain an optimum performance of the irrigation system. Such proposed water management tools would improve the WDP by more than 25%. The dependence on the Rahad River during the wet season to meet the project irrigation water demands is anticipated to significantly minimize the maintenance and operation cost of diverting water from the Blue Nile.

Analysis of Water Use on A Large River Basin Using Mike Basin Model - A Case Study Of The Abbay River Basin, Ethiopia

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The purpose of this study is to simulate water allocation for major activities (existing and planned) in the Abbay Basin using up-to-date water allocation and simulation models. The model, MIKE BASIN, is used to gain an insight into the potential downstream consequences of the development of physical infrastructure and water abstraction in a number of different future development scenarios. Seventeen irrigation projects covering an area of 220,416 hectares (ha) of land have been selected from different gauged catchments of the subbasin in addition to 4,800 megawatt (MW) hydropower projects on the main stream of the study area (Ethiopian part of Blue Nile). From the analysis, the total water extracted for these irrigation projects was estimated to be 1.624 billion cubic meters (BCM) annually. A reduction in the border flow volume as a result of the implementation of these irrigation projects under the reservoir scenario is 3.04% of the estimated mean annual flow of **50.45** BCM. Similarly, from the analysis, the total power generated due to the development of the major hydropower projects on the main stream, having an installed capacity of 4,800 MW, is 18,432 gigawatt hours (GWh) per year. This implies, while these interventions provide significant opportunities with respect to interventions and energy generations, their impact on downstream water availability is minimal.

Application of The Water Evaluation And Planning (Weap) Model To Simulate Current And Future Water Demand In The Blue Nile

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The riparian countries of the Nile have agreed to collaborate in the development of its water resources for sustainable socioeconomic growth. Currently there is significant potential for expansion of hydropower and irrigation in the Blue Nile River in both Ethiopia and Sudan. However, the likely consequences of upstream development on downstream flows have not been fully assessed and the water resource implications of development in both countries are unclear. Against this background, the Water Evaluation And Planning (WEAP) model was used to provide an assessment of both the current situation and a future (2015) scenario. The future scenario incorporated new irrigation and hydropower schemes on the main stem of the Nile and its principal tributaries. Data for all existing and planned schemes were obtained from the basin master plans as well as from scheme feasibility studies. Water use was simulated over a 32-year period of varying rainfall and flow. Preliminary results indicate that currently irrigation demand in Sudan is approximately 8.5 Bm^3y^{-1} for 1.16 million hectares (mha). This compares to a total irrigation demand in Ethiopia of just 0.2 Bm^3y^{-1}. By 2015, with many existing schemes being extended in Sudan and new schemes being developed in both countries, irrigation demand is estimated to increase to 13.4 Bm^3y^{-1} for 2.13 mha in Sudan and 1.1 Bm^3y^{-1} for 210 thousand hectares (tha) in Ethiopia. The flow of the Blue Nile is estimated to decline from an average of 46.9 Bm^3y^{-1} to 44.8 Bm^3y^{-1} at the Ethiopia-Sudan border and from a current average of 43.2 Bm^3y^{-1} to 36.2 Bm^3y^{-1} at Khartoum (including evaporation from all reservoirs). Although total flows are reduced, greater regulation results in higher dry season flows at both locations.

Sediment Accumulation In Roseires Reservoir

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Sedimentation is a serious problem faced by natural and man-made reservoirs. It is a major problem which endangers and threatens the performance and sustainability of reservoirs. It reduces the effective flood control volume, presents hazards to navigation, changes water stage and groundwater conditions, affects operation of low-level outlet gates and valves, and reduces stability, water quality, and recreational benefits. Reservoirs are often threatened by loss of capacity due to sedimentation. While there being many causes of reservoir sedimentation watershed, sediment and river characteristics are among the main natural contributing factors. Other important factors are reservoir size, shape and reservoir operation strategy. Man-made activities also play a significant role particularly in land use patterns. This paper is an attempt to assess sediment accumulation as well as the rate of sedimentation in the Roseires Reservoir. The basis for the study is the previous bathymetric surveys carried out on the reservoir in the years 1976, 1981, 1985, 1992, 2005 and 2007. Analysis and comparative studies were carried out between the different surveys to quantify the amount of sediment deposited as well the rate at which sedimentation took place. The design storage capacity of 1967 for the different reservoir levels was taken as a baseline. The sediment accumulation rates for the different bathymetric surveys are obtained as the difference between baseline capacity and the computed capacity at the respective levels during the specific survey. It was found that sedimentation in the Roseires Reservoir resulted in the reduction of the reservoir capacity from design storage of 3.0 Bm^3 in 1966 to 1.9 Bm^3 in 2007, i.e., a loss of approximately 1.1 Bm^3 during 41 years of operation. The sedimentation rate varies with both time and levels in the reservoir.

Soil And Water Assessment Tool (Swat)-Based Runoff And Sediment Yield Modeling: A Case Of The Gumera Watershed In Lake Tana Subbasin

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Land degradation is a serious threat in the Gumera watershed which is reflected in the form of soil erosion. Erosion is a major watershed problem causing significant loss of soil fertility and productivity. Increased sediment loads that shorten the useful life of the reservoir, the lives of other water-related structures, and increase the cost of maintenance and sediment remediation are off-site impacts of erosion. To develop effective erosion control plans and to achieve reductions in sedimentation, it is important to quantify the sediment yield and identify areas that are vulnerable to erosion. In recent decades, several simulation models have been developed in order to estimate, quantify, enhance understanding of spatial and temporal variability of erosion, and identify areas which are high contributors of sediment at micro-watershed level and over large areas. We used SWAT (Soil and Water Assessment Tool) to predict sediment yield, runoff, identify spatial distribution of sediment, and to test the potential of watershed management interventions in reducing sediment load from ‘hot spot’ areas. The tool was calibrated and validated against measured flow and sediment data. Both, calibration and

validation results, showed a good match between measured and simulated flow and suspended sediment. The model prediction results indicated that about 72% of the Gumera watershed is erosion potential area with an average annual sediment load ranging from 11 to 22 tonnes/ha/yr exceeding tolerable soil loss rates in the study area. The model was applied to evaluate the potential of filter strips with various widths to reduce sediment production from critical micro-watersheds. The investigation revealed that implementing vegetation filter strips can reduce sediment yield by 58 to 74%.

Development Of Rainfall-Runoff-Sediment Discharge Relationship In The Blue Nile Basin

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The Blue Nile (Abbay) Basin lies in the western part of Ethiopia between 7^0 45'-12^0 45' N and 34^0 05'-39^0 45' E. The Blue Nile region is the main contributor to flood flows of the Nile, with a mean annual discharge of 48.5 km^3 (50 km^3). Soil erosion is a major problem in Ethiopia. Deforestation, overgrazing, and poor land management accelerated the rate of erosion. The SWAT was successfully calibrated and validated for measured streamflow at Bahir Dar near Kessie and at the border of Sudan for flow gauging stations, and for measured sediment yield at Gilgel Abbay, Addis Zemen and near Kessie gauging stations in the Blue Nile Basin. The model performance evaluation statistics (Nash–Sutcliffe model efficiency (E_{NS}) and coefficient of determination (r^2)) are in the acceptable range (r^2 in the range 0.71 to 0.91 and E_{NS} in the range 0.65 to 0.90). It was found that the Guder, N. Gojam and Jemma subbasins are the severely eroded areas with 34% of sediment yield of the Blue Nile coming from these subbasins. Similarly, the Dinder, Beshilo and Rahad subbasins only cover 7% of sediment yield of the basin. The annual average sediment yield is 4.26 t/ha/yr and the total is 91.3 million tonnes for the whole Blue Nile Basin in Ethiopia.

Modeling of Soil Erosion And Sediment Transport In The Blue Nile Basin Using The Open Model Interface Approach

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Rapid land use change due to intensive agricultural practices in the Ethiopian Highlands, results in increasing rates of soil erosion. This manifested in significant impacts downstream by reducing the storage capacity of reservoirs (e.g., Roseires, Sennar), and high desilting costs of irrigation canals. Therefore, this paper aims to provide a better understanding of the process at basin scale. The Soil and Water Assessment Tool (SWAT) was used to model soil erosion in the upper catchments of the Blue Nile over the Ethiopian Plateau. The SWAT output forms the input sediment load for SOBEK, a river morphology model. The two models integrated using the principles of the Open Model Interface (OpenMI) at the Ethiopia-Sudan border. The Nash-Sutcliffe coefficient was found to be 0.72 and 0.66 for results of SWAT daily sediment calibration and validation, respectively. The SOBEK results also show a good fit of the simulated river flows at Roseires and Sennar reservoirs, both for calibration and validation. The results of the integrated modeling system showed 86 million tonnes/year of sediment load from the Upper Blue Nile, while SOBEK computes on average 19 Mm^3/year of sediment deposition in the Roseires Reservoir. The spatial variability of soil erosion computed with SWAT showed more erosion over the northeastern part of the Upper Blue Nile, followed by the northern part. The overall exercise indicates that the integrated modeling is a promising approach to understand soil erosion, sediment transport, and sediment deposition in the Blue Nile Basin. This will improve the understanding of the upstream-downstream interdependencies, for better land and water management at basin scale.

Rainfall-Discharge Relationships For Monsoonal Climates

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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 during which soils dry out to a considerable depth. This has a distinct effect on runoff generation that is not captured by “the temperate climate” models. The scope of this tool is to develop a simple water balance method for predicting river discharge. Water balance models have been shown to better predict river discharge in regions with monsoonal climates than alternative methods based on the United States Department of Agriculture-Soil Conservation Service (USDA-SCS) curve number. The latter is an empirical-based model developed in the USA that does not apply to monsoonal climates with distinct dry and wet periods.

A Water Balance-Based Soil and Water Assessment Tool (Swat) For Improved Performance In The Ethiopian Highlands

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The Soil Water Assessment Tool (SWAT) is a watershed model widely used to predict water quantity and quality under varying land use and water use regimes. To determine the respective amounts of infiltration and surface runoff, SWAT uses the popular Curve Number (CN). While being appropriate for engineering design in temperate climates, the CN is less than ideal when used in monsoonal regions where rainfall is concentrated into distinct time periods. The CN methodology is based on the assumption that Hortonian flow is the driving force behind surface runoff production, a questionable assumption in many regions. In monsoonal climates water balance models generally capture the runoff generation processes and thus the flux water or transport of chemicals and sediments better than CN-based models. In order to use SWAT in monsoonal climates, the CN routine to predict runoff was replaced with a simple water balance routine in the code base. To compare this new water balance-based SWAT (SWAT-WB) to the original CN-based SWAT (SWAT-CN), several watersheds in the headwaters of the Abbay Blue Nile in Ethiopia were modeled at a daily time step. While long term, daily data is largely nonexistent for portions of the Abbay Blue Nile, data was available for one 1,270 km^2 subbasin of the Lake Tana watershed, northeast of Bahir Dar, Ethiopia, which was used to initialize both versions of SWAT. Prior to any calibration of the model, daily Nash-Sutcliffe model efficiencies improved from -0.05 to 0.39 for SWAT-CN and SWAT-WB, respectively. Following calibration of SWAT-WB, daily model efficiency improved to 0.73, indicating that SWAT can accurately model saturation-excess processes without using the Curve Number technique.

Assessment Of Hydrological Controls On Gully Formation And Upland Erosion Near Lake Tana, Northern Highlands Of Ethiopia

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For the past five decades, gully erosion has been the dominant degradation process in the Ethiopian Highlands. Gully erosion negatively affects soil resources, lowers soil fertility in inter-gully areas, reduces the pastureland available for livestock, and aggravates siltation of reservoirs. Assessing the location and rate of gully development and changes in the controlling factors (climate, soil, hydrology and land cover) of gully erosion will help explain the acceleration in land degradation that is faced. The study was performed in a gully system in the 800 ha Debre-Mewi Watershed south of Bahir Dar, Amhara region, Ethiopia. Analyses comprised monitoring gully development through profile measurements, air photograph interpretations, and semi-structured interview techniques. Gully hydrological processes were investigated based on measurements of gully runoff and water levels in 24 piezometers in the gully contributing area. Upland erosion was also assessed. The Debre-Mewi gully is still an actively eroding gully system. A comparison of the gully area estimated from a 0.5 m resolution QuickBird image with the current gully area, walked with a Garmin GPS, showed that the eroded gully area increased by 30% from 0.51 ha in 2005 to 0.735 ha in 2008. Based on measurements of several gully cross-sections, an approximate gully volume of 7,985 cubic meters (m^3)

and an average gully erosion rate of 24.8 t ha^{-1} a^{-1} could be estimated. Gully erosion rates accelerated since 1991 through the increased degradation of the vegetation cover and clearance of indigenous vegetation on the hillsides, leading to an increase of surface and subsurface runoff from the hillsides to the valley bottoms. Gully heads retreat into the hillslope through concentrated runoff during the rainy season, erodes existing soil pipes and cracks in the vicinity of the gully head and banks. Piping and tunneling facilitate the slumping of the gully wall and their retreat. The sediment produced from the collapsing walls is exported during heavy storm events. The loss of erosion due to gulley formation is many times that of upland erosion. We find that alteration of the runoff response due to reestablishing the natural vegetation on the hillside and improvement of existing farming practices will be most important to decelerate current erosion rates.

Assessment Of Hydrological And Landscape Controls On Gully Formation And Upland Erosion Near Lake Tana

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Gully formation and upland erosion were studied in the Debre-Mewi Watershed in the Gilgil Abbay Basin south of Lake Tana. Gully erosion rates were found to be equivalent to over 500 tonnes/ha/year for the 2008 rainy season when averaged over the contributing watershed. Upland erosion rates were twentyfold less. Gully formation is accelerated when the soils are saturated with water as indicated by water table readings above bottom of the gully. Similarly, upland erosion was accelerated when the fields were close to saturation during the occurrence of a rainfall event. Height of the water table is an important parameter determining the amount of erosion and should, therefore, be included in simulation models.

Lessons From Upstream Soil Conservation Measures To Mitigate Soil Erosion And Its Impact On Upstream And Downstream Users Of The Nile River

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A study was conducted to evaluate the effects of soil bunds stabilized with vetiver grass (V. zizanioides) and tree lucerne (C. palmensis) on selected soil physical and chemical properties, bund height, inter-terrace slope and barley (Hordeum vulgare L.) yield in Absela site, Banja Shikudad District, Awi administrative Zone of the Amhara National

Regional State (ANRS) located in the Blue Nile Basin. The experiment had five treatments that included non-conserved land (control), a 9-year old soil bund stabilized with tree lucerne, a 9-year old soil bund stabilized with vetiver grass, a 9-year old sole soil bund, and a 6-year old soil bund stabilized with tree lucerne. Data were analyzed using one-way analysis of variance (ANOVA) and mean values for the treatments were separated using the Duncan Multiple Range Test. Results of the experiment indicated that organic carbon (OC), total nitrogen (N), bulk density, infiltration rate, bund height, and inter-terrace slope are significantly ($p \leq 0.05$) affected by soil conservation measures. The non-conserved fields had significantly lower OC, total N, and infiltration rate; whereas higher bulk density as compared to the conserved fields with different conservation measures. However, no significant differences in bulk density were observed among the conservation methods. The field treated with 9-year old soil bund stabilized with tree lucerne or sole soil bund had significantly higher OC content than all other treatments. Fields having 6-year old soil bunds had lower OC and total N when compared to fields having 9-year old soil bunds irrespective of their method of stabilization. Fields with soil bunds stabilized with vetiver grass had the highest bund height and the lowest inter-terrace slope than fields with the remaining conservation measures. Barley grain and straw yields were significantly ($P \leq 0.05$) greater in both the soil accumulation and loss zones of the conserved fields than the non-conserved (control) ones. In the accumulation zone, fields with the 9-year old soil bund stabilized with tree lucerne and those with the 9-year old sole soil bund gave higher grain yields (1878.5 kg ha^{-1} and 1712.5 kg ha^{-1}, respectively) than fields having 9-year old soil bund stabilized with vetiver grass (1187 kg ha^{-1}) and 6-year old soil bund stabilized with tree lucerne (1284.25 kg ha^{-1}). When we compare the accumulation and the loss zones, the average grain yield obtained from the accumulation zones (averaged over all the treatments) was 29.8% higher than the average grain yield obtained from the loss zones. The causes of soil erosion in the region could be the rugged nature of the topography, high and erratic rainfall patterns, extensive deforestation, continuous cultivation and complete removal of crop residues from the field, overgrazing and free-grazing, improper farming practices and development efforts, overpopulation and poverty, socioeconomic problems, lack of awareness on the effect of erosion, and poor land use policy enforcement. From the study it was possible to conclude that soil bunds stabilized with vegetative measures (such as tree lucerne and vetiver) better held the soil in-situ and improve inter-terrace soil physical and chemical properties compared to the non-conserved fields. This suggests that by applying soil conservation measures upstream, the erosion rate will be minimized and the amount of silt entering streams and ultimately the Blue Nile River will be minimized. This, in turn, will significantly improve land productivity in the upstream areas and cut the huge costs of silt cleaning in the dams and irrigation canals of the downstream countries that use the Blue Nile River.

Assessment Of Local Land And Water Institutions In The Blue Nile And Their Impact On Environmental Management

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Land and water institutions play a vital role in managing and sustaining land and water resources as well as enhancing economic development and poverty alleviation efforts. While a lot has been done in terms of understanding the micro-determinants of farmers' decisions in land and water conservation, there is little attempt to understand the broad macro-institutional and organizational issues that influence land and water management decisions. The objective of the study was to assess institutional arrangements and challenges for improved land and water management in the Ethiopian part of the Blue Nile Basin (Tana and Beles subbasins). Focus group discussions and key informant interviews were held in Amhara and Benishangul Gumuz regions with important stakeholders such as the bureaus of Agriculture and Rural Development, Water Resources Development, Environmental Protection and Land Use Administration (EPLUA), National Agricultural Research Systems, and important NGOs, operating in the area of land and water management, and selected community members. As the major findings in this study, we outlined major land and water-related institutional arrangements that are currently in place and their design features, in order to identify those institutions related to superior performance. We highlighted major institutional and policy gaps and actions that are required to respond to emerging issues of environmental degradation, upstream/downstream linkages and climate change. Such analysis of institutions and their design features provides useful insights and contributes to the debate on institutional reform for improved land and water management in the Blue Nile Basin, in general. By doing so, it identifies the gaps in institutional arrangements and policies and potential remedies.

Benefit-Sharing Framework In Transboundary River Basins: The Case Of The Eastern Nile Subbasin

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In some parts of the world, including Africa, problems related to water scarcity and water stress (which is even worse) is evident. Currently, about one-third of the African population is experiencing water scarcity. For countries sharing transboundary rivers, the adoption of water governance in all their strategies is of paramount importance. For this to happen, cooperation among riparian states becomes indispensable. Cooperation can help in availing more water in the basin, reducing soil erosion, mitigating drought and ensuring food security. At present, there is more emphasis on the sharing of transboundary benefits rather than physical water per se. Whereas the former can bring about a zero-sum negotiation the latter can yield a positive sum outcome. The benefits that can be accrued through cooperation could be economic, environmental, social and political. The aim of this study is to highlight the concept of benefit sharing and benefit-sharing framework in general terms as well as in the context of the Eastern Nile Subbasin. By doing so, the study looks into some of the ongoing and planned Eastern Nile projects, with particular emphasis on the Joint Multipurpose Program (JMP), to test the degree of relevance of the issue of the benefit-sharing framework and to suggest the way forward. The findings of the study have indicated that benefit sharing in transboundary river basins is an outcome of a collaborative effort by the co-riparian states to reduce costs and increase outputs. It could also mean the management of shared waters more efficiently and effectively across all sectors, so-called sectoral optimization. The effects and impacts of joint investments in both upstream and downstream states can yield a bundle of benefits including, but not restricted to, flood control, reduction of sedimentation, availability of more water in the basin and hydropower production. These, in turn, can ensure food security, mitigate drought and avail renewable energy. For transboundary rivers such as the Nile, attempts should be made to identify the typologies of benefits, aspects of benefit sharing, scenarios of benefit sharing, and the optimization/maximization of benefits. With the better management of ecosystems cooperation can provide 'benefits to the river'; with cooperative management of shared rivers benefits can be accrued 'from the river' (e.g., increased food production and power); with the easing of tensions between riparian states costs 'because of the river' could be reduced; and with cooperation between riparian states leading to economic integration comes 'benefits beyond the river'. In terms of aspects of benefit sharing, issues related to benefit sharing for whom, by whom and because of who need to be addressed. Similarly, scenarios of benefit sharing should be considered as phases or time perspectives by anchoring short-term works of strengthening the hitherto existing riparian links, medium-term tracking and improvement of in-country and transborder institutional arrangements for resource use and cooperation, and long-term efforts on investment in basin-wide joint development and programs. Due to the prevalence of centuries of hydropolitical stalemates in the Nile Basin, costs 'because of the river' remained high. The lack of cooperation impeded many of the basin states to reap little or no benefits from the river. The establishment of the Nile Basin Initiative (NBI) in 1999 has been marked as a strong departure compared to its predecessors. The Eastern Nile Subsidiary Action Program (ENSAP) and with it the Eastern Nile Technical Regional Office (ENTRO) have identified a number of projects, of which JMP stands out as one of the most significant ones. It aims to undertake multipurpose and multi-country programs of activities encompassing watershed and environmental management; and enhanced agricultural production and renewable energy. When this project gets grounded, it could mitigate natural resources degradation, alleviate poverty and enhance agricultural production. There is a possibility for the three Eastern Nile countries to accrue transboundary benefits. As things stand now, the three Eastern Nile countries need to first and foremost identify the bundle of benefits that can be generated from the project and then agree on the mechanisms by which they can realize the 'equitable sharing of benefits'. They also need to formulate and sign a benefit-sharing treaty, develop a sound financial framework to realize the equitable sharing of benefits, costs and risks and the joint ownership of assets. Last but not least, the Eastern Nile countries should establish institutions that will manage benefit-sharing schemes and address issues such as mechanisms of delivering benefits.

Transboundary Water Governance Institutional Architecture: Reflections From Ethiopia And Sudan

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Transboundary water resource governance is premised on equitable water and water-related benefit sharing. Using the case of the Blue Nile (Ethiopia and Sudan), we explore the conceptual issues that need consideration in the crafting of cross-border cooperation within the water sector. First, drawing on global experiences with transboundary water management, we evaluate how upstream and downstream concerns are addressed by transboundary water management institutions. Second, we explore the kinds of institutional design and the issues which need to be considered to result in 'win-win' scenarios for both upstream and downstream users, as well as the mechanisms of benefit sharing negotiated amongst different stakeholders. Third, we examine ways of addressing equity and livelihoods in transboundary institutional arrangements. Finally,

we attempt to assess how transboundary institutions can address broader historical, political and economic issues and their implications for sustainable transboundary water governance. This paper raises key issues that need to be addressed in establishing transboundary governance institutions.

Prospect Of Payments For Environmental Services In The Blue Nile Basin: Example From Koga And Gumera Watersheds, Ethiopia

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In transboundary river basins, like the Blue Nile, conflicts over the use of water resources are growing and recent advances in sustainable resource management recognizes the need for approaches that coordinate activities of people dependent on a common resource-base to realize sustainability and equity. Payments for Environmental Services (PES) are a component of a new and more direct conservation paradigm and an emerging concept to finance conservation programs by fostering dialogue between upstream and downstream land users. Those kinds of approach are particularly useful if applied in basins where irrigation schemes are emerging and the service life of reservoir and irrigation canals, in downstream areas are threatened by the sediments moved from upstream region. Here we report the results of our study on the determinants of Willingness to Pay (WTP) and Willingness to Compensate (WTC) for improved land and water management practices in the Blue Nile Basin (Gumera and Koga watersheds). A total of 325 sample households were selected using a multi-stage sampling technique, and a structured and pre-tested questionnaire was used to collect data from the sample households. We applied Contingent Valuation Method (CVM) to elicit WTP using monetary and material payment vehicles. Our results showed that more households are willing to pay in labor than in cash. The mean WTP for improved land and water management was estimated at US$1.06 and US$1.3 months^{-1} household^{-1} for upstream and downstream farmers, respectively. Besides, 83.56% of the sample farm households showed WTC the upstream farmers in cash. However, the aggregate WTP falls far short of the estimated investment cost needed for ecosystem restoration. Among others, the number of livestock, size of arable land, access to education and credit by the sample farm households were identified to positively influence sample farmers' WTP for restoration of ecosystem services and downstream farmers' WTC for improved ecosystem regulation services. Therefore, institutions and policy measures that enhance environmental education, reduce poverty and foster stakeholders' cooperation must be promoted.