Improved Water and Land Management in the Ethiopian Highlands: Its Impact on Downstream Stakeholders Dependent on the Blue Nile

Intermediate Results Dissemination Workshop
February 5-6, 2009, Addis Ababa, Ethiopia

Organized by

IWMI Subregional Office for East Africa and Nile Basin, Addis Ababa, Ethiopia

Compiled by

Seleshi B. Awulachew, Teklu Erkossa, Vladimir Smakhtin and Ashra Fernando

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IWMI receives its principal funding from 58 governments, private foundations and international and regional organizations known as the Consultative Group on International Agricultural Research (CGIAR). Support is also given by the Governments of Ghana, Pakistan, South Africa, Sri Lanka and Thailand. The CGIAR Challenge Program on Water and Food (CPWF) supported the project, the workshop and the outputs reported here; IWMI together with International Livestock Research Institute (ILRI), Cornell University (CU), USA; the Omdurman Islamic University, UNESCO Chair in Water Resources (OIU, UNESCO-CWR), Sudan; Bahir Dar University, Addis Ababa University, Amhara Agricultural Research Institute, Forum for Social Studies, Ethiopia have implemented the project and the papers presented here.

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Please send inquiries and comments to: iwmi@cgiar.org

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Acknowledgements

This proceedings booklet and the attached CD contain the results of the workshop conducted during February 5- 6, 2009 and present findings from PN19 'Improved Water and Land Management in the Ethiopian Highlands and its Impact on Downstream Stakeholders Dependent on the Blue Nile (Upstream/ Downstream in Blue Nile)". The CGIAR Challenge Program on Water and Food (CPWF) supported the project, the workshop and the outputs reported here. The International Water Management Institute (IWMI) together with International Livestock Research Institute (ILRI), Cornell University (CU), USA, the Omdurman Islamic University, UNESCO Chair in Water Resources (OIU, UNESCO-CWR), Sudan, Bahir Dar University (BDU), Addis Ababa University (AAU), Amhara Regional Agricultural Research Institute (ARARI), Forum for Social Studies (FSS), Ethiopia, have implemented the project and were involved in the papers presented here. The authors of the papers and beneficiaries of the project would like to thank the support rendered to implement the project and conduct the workshop.

Project

The reports and papers included in this booklet and on the CD are part of the projects related to the Nile Basin supported by the CGIAR Challenge Program on Water and Food (CPWF).

Partners

About the CPWF

Water scarcity is one of the most pressing issues facing humanity today. The Challenge Program on Water and Food (CPWF), an initiative of the Consultative Group on International Agricultural Research (CGIAR), contributes to efforts of the inter-national community to ensure global diversions of water to agriculture are maintained at the level of the year 2000. It is a multiinstitutional research initiative that aims to increase water productivity for agriculture-that is, to change the way water is managed and used to meet international food security and poverty eradication goals-and to leave more water for other users and the environment.

The CPWF deals with complex agriculture-related systems, for which there are a growing number of stakeholders generating information. Its community-of-practice works in innovative ways to collate, unify, organize, extract, distill and share the ideas, information and knowledge to allow next-users to gain insights and deduce principles, concepts and cause-and-effect relationships from its research results. To help achieve this, the CPWF focuses on building multi-disciplinary north-south and south-south

partnerships, as demonstrated by the work produced in this special journal of Water Policy.

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Introduction

This proceeding provides the papers and discussion results of a two-day workshop that was organized at International Water Management Institute (IWMI) office in Addis Ababa during the period of February 6-8, 2009 in relation to CPWF Project 19 – Improved water and land management in the Ethiopian Highlands and its impact on downstream stakeholders dependent on the Blue Nile. Short title: Upstream Downstream (USDS) in the Nile. The project is being under implementation during the last one and half years in partnership with various institutions that include International Livestock Research Institute, Cornell University, Omdurman Islamic University-UNESCO Chair in Water Resources, Addis Ababa University, Bahir Dar University, Amhara Regional Agricultural Research Institute and Forum for Social Studies.

The main aims of the workshop had been:

- Bring together key stakeholders relevant to the project
- Present, debate and validate the intermediate results of the project
- Disseminate key results to wider audiences through workshop participating stakeholders
- Follow up on the progress of the project and plan remaining tasks of the project

The workshop focus themes were:

- General characterization of the Blue Nile Basin
- Watershed modeling and analysis
- Water demand and allocation modeling and simulation
- Policy and institutions of the water management in the Blue Nile basin

During the workshop, three opening and programmatic speeches, 27 technical papers and 10 posters were presented, being divided in 4 sessions. The papers were enriched by discussions and debate at the end of each session attended by over 60 participants from over 36 institutions. The program of the workshop as executed attached in Annex 1.

This proceeding is compiled based on mainly from the project output, but one additional input from Egypt. The proceeding is compiled as submitted by the authors and hence content and quality of the papers is the responsibility of respective author/s. The contents of discussion and associated documentations are compiled by session rapporteurs. This proceeding therefore includes the following session contents:
Session I - Opening
Session II - Water demand modeling
Session III- Watershed modeling
Session IV-Policy and institutions
Session V- Group discussion, plenary and closing

In addition to the above, the proceeding also contains the following soft copies on interactive CD:

- The above papers and reports

- The pdf version of all power point presentations
- All posters presented
- The Blue Nile atlas that includes over 270 figures and maps characterizing the Blue Nile
- 2 working papers related to IWMI WP131 and 132 focusing on Blue Nile characterization and policy and institutions respectively

We hope that this documentation provides significant knowledge base and wide information material who would like to pursue further studies, research and undertake development in the Nile Basin in general and Blue Nile in particular.

Seleshi Bekele Awulachew (PhD)
Project Leader

Session I: Opening and General

Opening address

Dr. Akissa Bahri

Dear Participants,
Dear Colleagues,

It is with great pleasure that I welcome you all on behalf of the International Water Management Institute and on my own behalf to this workshop on “Improved Water and Land Management in the Ethiopian Highlands and its Impact on Downstream Stakeholders Dependent on the Blue Nile”.

This two-day meeting is an “intermediate results dissemination workshop” of a collaborative research project sponsored by the CPWF that started in 2007 and should come to a closure by the end of 2009. It is implemented by the International Water Management Institute (IWMI), the International Livestock Research Institute (ILRI), Cornell University (CU), Bahir Dar University (BDU) and Addis Ababa University (AAU), the Forum for Social Studies (FSS), Amhara Agricultural Research Institute (ARARI), the Omdurman Islamic University (OIU)/UNESCO Chair in Water Resources, and the Hydraulic Research Station (HRS).

The aims of the workshop are fourfold:

1. To bring together key stakeholders relevant to the project
2. To present, debate and validate the intermediate results of the project
3. To disseminate key results to wider audiences through workshop participating stakeholders
4. To follow up on the progress of the project and plan remaining tasks of the project.

The International Water Management Institute, member of the CGIAR system, is the leading international scientific research organization on water, food and environment, with an overall mission “to improve the management of land and water resources for food, livelihoods and the environment”. In Africa, IWMI conducts research in three sub-regions; the Nile Basin and East Africa, West Africa and Southern Africa. Water scarcity, poverty, low productivity, health issues, water quality, endemic droughts and floods and transboundary conflicts in water management, along with land degradation are some of the critical issues Africa faces. IWMI works closely with Africa-wide sub–regional organizations and many national and agricultural research systems to study the land and water management challenges facing poor rural communities and to develop innovative approaches, tools and interventions that can improve food security, livelihoods, health and ecosystem services.

In IWMI new strategic plan, particular attention is given to managing the impacts of land degradation on water resources with the specific goal to reducing the negative impacts of inappropriate land management in catchments to enhance water quality and livelihoods.

This research project on “Upstream Downstream in the Nile” is meant to fill a knowledge gap regarding the run-off, sedimentation, erosion, hydrological, hydraulic and institutional processes in the Blue Nile watersheds. It aims at improving the understanding of these processes and to overcome constraints to up-scaling promising management practices and technologies within the watershed. The work includes hydrological and water allocation modeling, watershed management and policy and institutional studies at various levels. The specific activities of the project include *inter alia* micro-watershed and watershed level analysis of rainfall-runoff-sediment processes; analysis of sub-basin level impacts of water management interventions; evaluation of sediment management impacts on water infrastructure such as micro-dams; basin and transboundary level analysis of the impacts of upstream interventions on major reservoirs.

This project is contributing to the CPWF immediate objectives and themes. It focuses on seeking innovations in improved water management and aims to enable people to benefit from the improved management of land and water resources, namely improved productivity of water through better water management. The Blue Nile upper catchments are highly degraded area where many poor people live. The downstream riparian are also affected due to heavy erosion, sedimentation, poor water quality and similar impacts. It also strongly relates to the integrated management of the basin water, as the project helps to understand the overall water availability, current and future water allocations under the face of water scarcity. It is primarily focused on understanding the causes of degradation, impacts on water availability, impacts of these on livelihood, mechanisms of reversal of these degradation so that production systems can be made on sustainable natural resources base and ultimately the poor people benefit. Thus, it is a pro-poor focused and addressing sustainable natural resources management. It also helps future development interventions through evaluation of impacts of past investment in the watersheds and water management.

This project has also a strong capacity building component with a total of 18 M.Sc. and 1 Ph.D. students which have been supported by the project and whose work will be presented during this workshop.

Dear Participants, Dear Colleagues,

The program of the workshop includes various presentations on the three major components of the project: the “Water Allocation Modeling of the Blue Nile”, the “Watershed Modeling” and the “Policy and Institutions Component” and group discussions.

This workshop is a major milestone in the implementation of our research project. At the end of these 2-day workshop, we should have a better understanding of the progress made regarding the knowledge on current water and land management practices and understanding of best practices, the results obtained so far as to the modeling works for water allocation and watershed management and the remaining tasks that should lead to better natural resources management and to the improvement of the environmental conditions of the Blue Nile Basin.

On behalf of IWMI, I would like to thank you all for coming and look forward for a fruitful workshop.

Thank you

Dr. Kim Geheb

The CPWF is a network of research and development institutions, which provides support towards research for development in the field of water and food.
CP 19: Improved water and land management in the Ethiopian highlands and its impact on downstream stakeholders dependent on the Blue Nile, in short: Upstream Downstream (USDS) in the Nile is one of the projects supported by CPWF. In brief:

- The CPWF has been very proud to be associated with upstream downstream project, lead by IWMI, form its offices here in Addis Ababa.
- It congratulates the research team on progress made so far on this project, which we feel has a distinct and definite contribution to make towards the management of the Blue Nile Basin, and indeed the broader Nile system
- The CPWF notes the significant progress made with respect to the development of models that can estimate erosion rates and sediment loads and, indeed, the proposal of methods by which these can be remedied
- We believe that these and other supporting studies from the project can contribute to a dialogue on water allocation within this basin
- We draw attention to the very substantial partnerships that have enabled this project succeed, and take pride in have been a part of this

Thank you very much

Blue Nile Basin Characterization and Geospatial Atlas

Aster Denekew Yilma[1] and Seleshi Bekele Awulachew[1]

[1]*International Water Management Institute, Addis Ababa, Ethiopia*

Abstract

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.

(For details of the complete report, see the separate PDF file on the CD titled '*Blue Nile Characterization and Geospatial Atlas*').

Impacts of Improving Water Management of Smallholder Agriculture in the Upper Blue Nile Basin

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Abstract

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.

Introduction

Currently, Abbay is one of the least planned and managed sub-basins of the Nile. About two thirds of the area of this densely populated basin fall in the highlands and hence receive fairly high rainfall of 800 to 2,200 mm per year. However, the rainfall is erratic in terms of both spatial and temporal distribution, with dry spells that significantly reduce crop yields and sometimes lead to total crop failure. The impacts of droughts on the people and their livestock in the area can sometimes be catastrophic. The population located in the downstream part of the Blue Nile, is entirely dependent on the river water for supplementary irrigation. Canal and reservoir siltation is a major problem exacerbating socio-economic burdens on poor riparian farmers together with the seasonality of the river flow. Solutions lie in improving agricultural practices and conserving water at all levels by all stakeholders: both within Ethiopia and downstream communities. Particularly, there is a paramount need for integrated agricultural water management to overcome the effects of water shortage in small scale agriculture, alleviate poverty and food insecurity; and avert the negative impacts of climate change in this part of the basin through improving rainfed system. As a component of the water demand assessment, identification of appropriate agricultural water management interventions, analysis of impacts on productivity and poverty alleviation as well as hydrology need to be carried out. This study therefore focuses on various indigenous and research based agricultural water management technological interventions suitable for small holder farmers in the Abbay basin, and attempts to quantify their impacts on productivity of the small holders agricultural as well as the overall livelihood of the farming communities. Therefore the overall objectives are to:

- Characterize the upper BNSB and establish ‘homogenous’ units of agricultural production Systems ;
- Identify agricultural water management technologies for upgrading the rainfed systems;
- Evaluate the impact of selected agricultural water management technologies on agricultural productivity, water availability and hydrology;
- Develop methodologies and decision support tools for improved agricultural water management in the basin.

Methodology

Location and biophysical settings

The Blue Nile basin covers an area of 311,548 km^2 (Hydrosult et al 2006b). It provides 62% of the flow reaching Aswan (World Bank, 2006). The river and its tributaries drain a large proportion of the central, western and south-western highlands of Ethiopia before dropping to the plains of Sudan. The confluence of the Blue Nile and the White Nile is at Khartoum. The basin is characterized by highly rugged topography and considerable variation of altitude ranging from about 350m at Khartoum to over 4250m a.m.s.l. (meter above sea level) in the Ethiopian highlands. The main stay of the economy in the upper part of the basin is rainfed small scale mixed agriculture. Although the total annual rainfall the area receives is relatively good, due to its unfavorable temporal and spatial distribution, agriculture is prone to moisture stress. Besides, the poor water and land management in the region exacerbates land degradation leading to low agricultural productivity and perpetuating poverty.

Abbay river basin is one of the three sub-basins of the upper Blue Nile in Ethiopia (Fig. 1). Situated in the north-central and western parts of the country it forms a generally rectangular shape that extends for about 400 km from north to south and about 550 km from east to west. It is characterized by a high bio-physical variation, such as terrain (Fig. 2) and soil (Fig. 3). The intensively changing train which leads to varying agro-ecology within short distances does not only hamper agricultural development planning and mechanization, but also exacerbates the rate of land degradation. Corresponding to the variation in landscape and other soil forming factors such as climate and vegetation, the soils of the basin are also highly variable. However, only four soil types, Nitisols, Leptosols, Luvisols and Vertisols cover over 80% of the area. Apparently, these soils have various productivity limiting characteristics such as acidity, depth and permeability (Table 1).

Table 1 Area coverage of the major soil types in the basin and their corresponding limitations

Soil type	**Area (km^2)**	**% of the area**	**Limiting factors**
Nitosols	86,665	39.08	Acidity
Leptosols	52,529	23.68	Depth
Luvisols	31,494	14.20	
Vertisols	26,735	12.05	Permeability
Cambisols	11,234	5.07	
Alisols	9,238	4.17	
Phaeozems	2,707	1.22	
Fluvisols	1,188	0.54	

The basin covers a total area of 199,812 km^2 and has an average annual discharge of about 49.4 Billion Cubic Meter, measured at Sudan border (BCM). Extending over three regional states of Ethiopia including Amhara, Oromia and Benshangul Gumuz, it is the most important basin in the country by most criteria as it contributes about 45% of the countries surface water resources, accommodates 25% of the population, 20% of the landmass, 40% of the nations agricultural product and most of the hydropower and a significant portion of irrigation potential of the country (http://www.mowr.gov.et/index.php?pagenum=3.1). Originating from the centre of its own catchments around Lake Tana in the north, it develops its course in a clockwise spiral, collecting its tributaries all along its nearly 1,000 km length from its source, to the south of Lake Tana up until the Ethio-Sudan border (MoWR Master Plan: Abbay, 1999). Dabus and Didessa rivers that spring in western Ethiopia are the largest tributaries accounting for about 10 % and 8.5% of the total flow at the border, respectively.

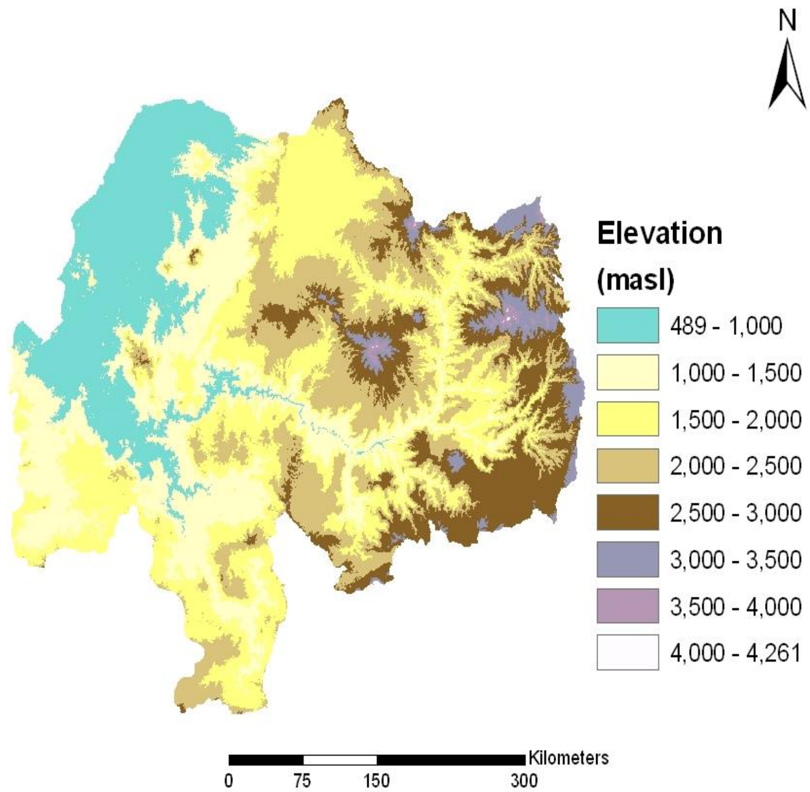

Figure 1: Elevation map of Abbay basin

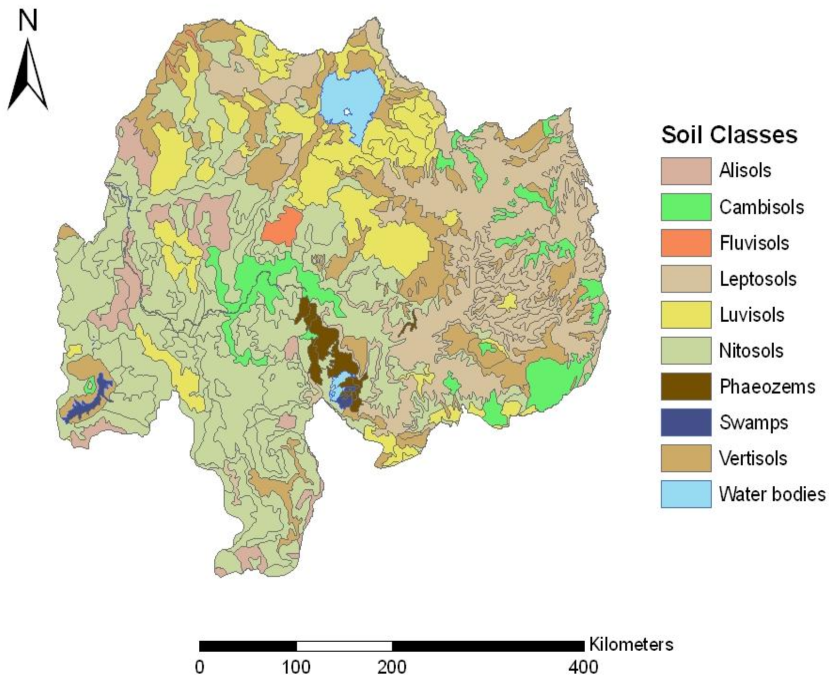

Figure 2: The major soil types of the Abbay river basin

Land use systems and agricultural water management

Although quite diverse land use systems are common, rainfed based agricultural land use dominates the basin. Over 80% of the populations in the basin drive their livelihood mainly from small scale rainfed agriculture. Because of hazardous land use and poor land and water management systems, high population pressure, land degradation, small land holding and highly variable climate, agricultural productivity in the basin is increasingly challenged. High population pressure, lack of alternative livelihood opportunities and slow pace of rural development are inducing deforestation, overgrazing, land degradation and declining agricultural productivity.

Poor water and land management in the upstream part of the basin reduces both potential runoff yields and the quality of water flowing downstream. The result is a vicious cycle of poverty and food insecurity for over 14 million poverty-stricken people in the uplands, and for millions of downstream users. It is widely recognized that improved water management in the Abbay catchments is key to improving both upstream and downstream livelihoods. Better water and land management will help increase water availability and alleviate the impacts of natural catastrophes such as droughts and reduce conflicts among stakeholders dependent on the Nile.

Methodology

Stratification and characterization

The farming system of the basin has been classified into homogenous units based on the Basin Master Plan Study (BCEOM, 1998). The approaches of Westphal (1974; 1975) were adopted. Accordingly, the major farming systems of the basin were described, but additional subsystems have been identified based on the major types of crops grown, vegetation, altitudinal variation, and cultivation practices. Also, the soil types of the farming systems were identified based on the basin master plan soil data (Figure 1) and the farming system data (Figure 2) using ArcGIS. The productivity of the farming systems under the current management systems have been determined based on district level CSA reports (CSA, 2007). Potential agricultural water management technologies suitable for the areas within the basin were identified based on a survey report conducted earlier in the country (Makonnen et al., 2009).

Data capturing and analytical tools

We used AquaCrop (FAO, 2009) and using SWAT to analyze the impacts of the technologies on water consumption, crop production, runoff, water balance and land degradation in the basin. Data on climatic parameters, crop characteristics, soils and land managements were collected from secondary information and were analyzed under various assumptions and scenarios.

Preliminary Results

The farming systems

The determinant factors that compel farmers to decide for one farming system or another could be a matter of further investigation. Apparently, environmental factors such as soil and climate play a vital role, while socio-economic factors including access to market for inputs and outputs, and exposure to productive technologies are also essential.

Broadly, the farming systems in the basin can be categorized into the mixed farming of the highlands and pastoral/agro-pastoralism of the lowlands. However, about nine distinct farming systems have been identified in the basin (Figure 4) although only four of them cover about 70% of the area (Figure 5). The cereal based crop cultivation, coffee and other tree crops complex together with enset and other root crops complex constitute the mixed farming system. Covering the largest portion of the area (over 90%), the cereal based crop cultivation can be further sub divided into the single cropping, double cropping and shifting cultivation sub systems, which cover about 60%, 10% and 20 % of the area. A smaller section of the area is under the double cropping cereal cultivation, which represents a system where two rainfed cropping seasons per annum is possible.

While tef, maize and sorghum account for about 50% of the single cropping system, barley dominates the double cropping system. Shifting cultivation systems which are practiced in the western and southern lowlands of the basin are persistently diminishing.

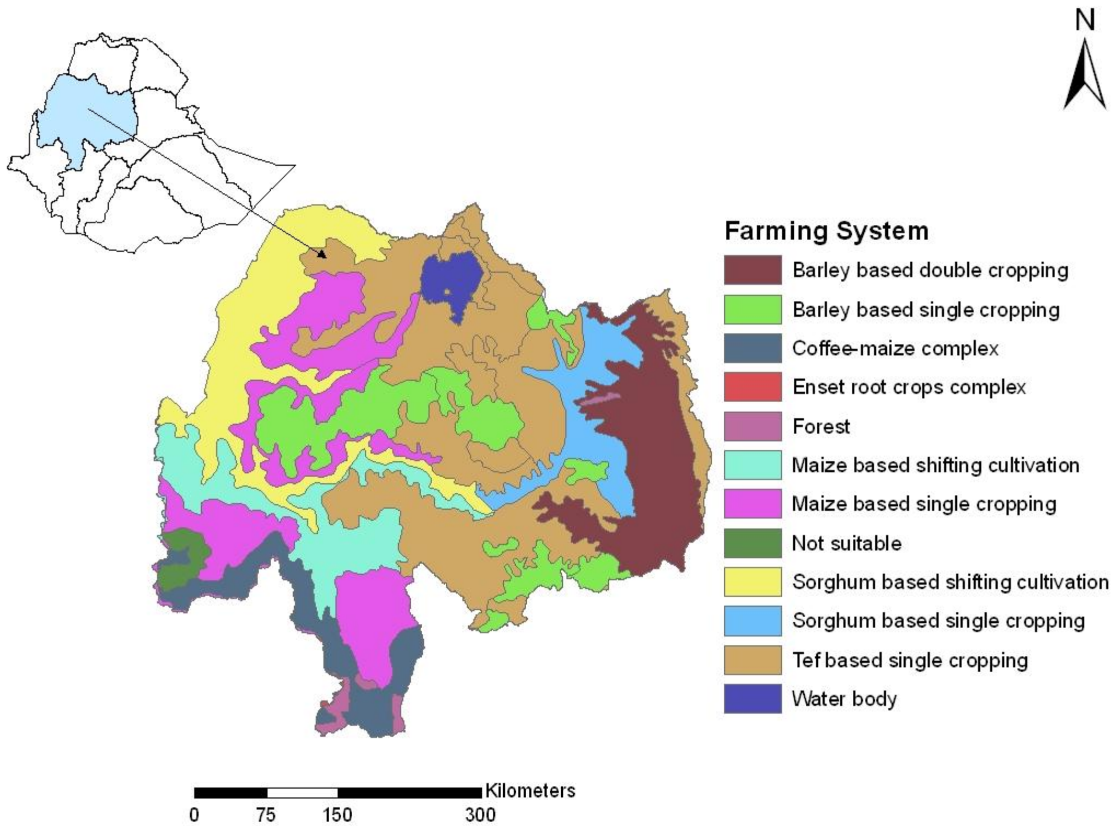

Figure 3: The major farming system of the basin

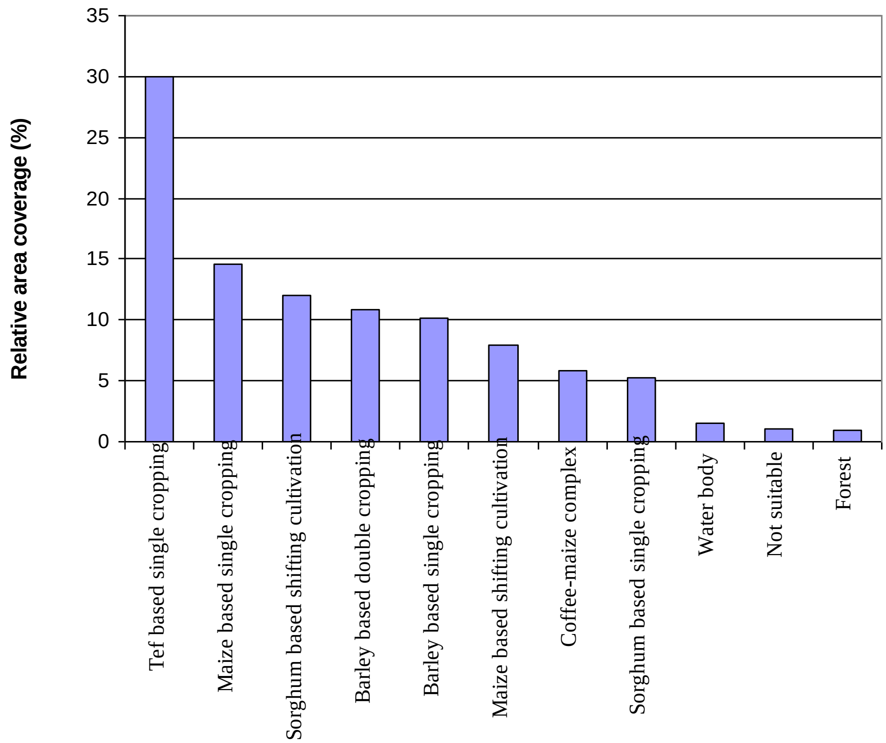

Figure 4: Relative area coverage of the farming systems

Characteristics of the farming systems

Cereal based-single cropping

Covering the largest part of the basin (62%), these farming systems encompass the cultivation of the major cereals grown in the basin including, tef, maize, sorghum and barley. The main characteristic of these systems is the production of crops from seeds, only once a year during the main rainy season. The production system can focus on production of either small grains such as wheat and tef or large grains such as maize and sorghum.

The small grain cereals

The production of small seeded cereals such as tef, barley and wheat dominates this system, but a large variety of other grains such as finger millet, maize, sorghum, pulses, oil seeds and spices are also grown. The topography of the area where this farming system prevails varies from almost flat and undulating type in the central and western parts to steep slope and mountainous in the northern and eastern parts with very scarce vegetation covers. The areas within this farming system mostly receive adequate rainfall during the cropping season. Leptosols and Vertisols dominate the tef based single cropping and barley based double cropping farming systems areas (Table 2). Among the major potentials of this farming system for agricultural development is the availability of vast area of land suitable for mechanized farming (BCEOM, 1998). Besides, a substantial part of the irrigation potential of the country including small scale irrigation (Table 3) fall within this farming system. Consequently, developing small, medium and large-scale irrigation schemes with suitable crop and water management systems is believed to significantly enhance productivity of the system and improve the livelihood of the communities. In this regard, low cost agricultural water management technologies which can be constructed and managed by the local communities can play a vital role, at least in the short term.

The large grain cereals

Dominated by the maize based system in the south western and sorghum based system in the north eastern parts of the basin (Fig. 2), the large grain cereal cultivation system covers about 20% of the basin. While maize and sorghum are the dominant crops, a large number of other crops like tef, wheat, barley, finger millet, pulses and oil crops are also widely grown. The maize areas have generally gentle to flat slopes as opposed to the sorghum areas which are characterized by rough, steep slopes and mountainous regions that are largely devoid of vegetation cover. Nitisols followed by leptosols dominate both the maize based and sorghum based systems, with a higher extent of leptosols in the latter. In contrast to the maize area, which receives ample and dependable rainfall, the sorghum areas get erratic and unreliable rainfall.

Similar to that of the small grain farming systems, not many farmers use the right type and quantity of fertilizers and improved seeds. The use of manure is established in maize areas, but often restricted to backyard farms. Crop rotation in maize areas of the western part involves legumes, but in the sorghum areas, the rotation is among the cereals. Land degradation and unreliability and shortage of rainfall are serious threats of the sorghum part (BCEOM, 1998). Thus, improving the rainfed agriculture through provision of efficient extension services and inputs, and implementation of suitable agricultural water management technologies, is believed to significantly enhance the level of production and productivity.

Table 2 The soil types in the dominant farming systems of the basin

Soil type	Tef based single cropping		Maize based single cropping		Sorghum based shifting cultivation		Barley based double cropping	
	Area (km^2)	% of the area	Area (km2)	% of the area	Area (km2)	% of the area	Area (km2)	% of the area
Alisols	266	0.10	11498	8.68	5901	8.28		
Cambisols	7701	2.85	4362	3.29	4414	6.20	5211	9.48
Leptosols	140369	51.91	15856	11.97	15263	21.43	42575	77.42
Luvisols	51367	19.00	10998	8.30	6024	8.46	641	1.17
Nitisols	38731	14.32	77099	58.22	34986	49.12	759	1.38
Vertisols	28032	10.37	8838	6.67	4254	5.97	5807	10.56
Total	270393	100.00	131888	99.59	70841	99.45	54993	100.00

Barley based-double cropping

A bimodal rainfall with the small rain resuming in January or February and extending to end of May; and the main rain starting in mid July and extending to mid September characterize the farming system. Although crops can be produced twice a year using the small and the main rains, both are not reliable due to climatic and edaphic factors. The onset and secession of the rainfall is highly variable that planning of agricultural activities is difficult. Besides, shallow soils (Letptosols) with limited water storage capacity cover over 70% of the area (Table 2). On the other hand, Vertisols, which have impeded drainage, are the second largest soil type covering over 10% of the area. Barley, wheat, tef and some pulses are widely grown in the farming system. The use of fertilizers and improved seeds is minimal, may be due to the unreliable rainfall, the subsistence nature of the farmers and highly degraded soils.

Despite the limitations, productivity can be enhanced with proper use of improved technologies. For example, moisture conservation measures and use of short duration crop varieties can improve the productivity of the crops during two rains on the letptosoil areas. On the other hand, enhanced drainage and harvesting of the excess water for supplementary or full irrigation, together with complementary technologies can significantly boost the productivity of the Vertisols.

Current productivity and limitations of the farming systems

Current productivity

Understandably, the livelihood strategy of the farmers in the basin is focused on production of food grains such as cereals, pulses and oilseeds, primarily for household consumption (CSA, 2005). Unfortunately, the productivity of the farming systems regardless of the crop types is miserably low (Table 3) (CSA, 2007). Evidently, the large grain crops gave the highest average yield across the farming system which is comparable to the national average, although that of Sorghum is slightly depressed. The overall grain productivity of the farming systems in the basin is less than 1ton per hectare. As the average land holding in the basin is less than 1 hectare per house hold, with the average household size of about seven, the level of crop productivity depicts the abject poverty in which the communities are entangled.

Table 3 Average crop productivity of the farming systems (100kg/ha) during the man cropping season (CSA 2007)

Farming system	Tef	Barley	Wheat	Maize	Sorghum	Finger Millet	Faba bean	Field pea	Average
Tef based single cropping	8.24	9.21	10.4	16.8	9.18	4.98	10.33	6.83	9.5
Maize based single cropping	7.28	6.25	7.13	22.04	12.92	9.89	6.81	4.18	9.56
Sorghum based shifting cultivation	7.26	4.89	6.46	20.68	10.93	6.53	6.13	2.66	8.18
Barley based double cropping	7.31	9.47	9.9	8.23	8.86	1.6	10.3	6.91	7.82
Barley based single cropping	8.97	14.81	12.23	18.05	12.88	10.97	12.06	8.78	12.34
Maize based shifting cultivation	5.77	5.18	6.53	20.38	13.72	6.86	5.17	3.69	8.41
Sorghum based single cropping	8.66	10.28	11.62	14.01	11.96	9.59	11.87	9.09	10.89
Coffee-maize complex	8.21	7.36	8.05	22.05	14.72	9.08	7.77	5.52	10.35
Average	7.71	8.43	9.04	17.78	11.90	7.44	8.79	5.96	9.63

Reasons for low productivity

The poor and declining performance of agriculture can be attributed to many interrelated factors including high population pressure, soil erosion and land degradation, unreliable rainfall, low water storage capacity of the soils and the catchments, crop pests and diseases, soil acidity, water logging, shortage of farm land, lack of improved technologies such as: improved varieties, soil fertility management (fertilizers, liming), water management (irrigation and drainage), soil and water conservation as well as farmers traditions. This calls for a comprehensive external intervention in terms of policy, institutions as well as technologies. The following session briefly deals with some priority technological interventions necessary to overcome the daunting challenges of productivity and sustainability prevailing in the basin.

Possible technological interventions and onsite and offsite impacts

Possible interventions technologies

In order to overcome the constraints and ensure enhanced and sustained crop production in the basin, integrated technological interventions is necessary. A range of technologies including improved crop verities and species, appropriate land use, improved land and water management practices etc. should be used in integration to benefit from their synergetic effects. The use of suitable agricultural water management technologies such as, water harvesting, supplementary and full irrigation using different water sources, drainage of water logged soils, which can also be supplemented with harvesting of the excess water to be used as supplementary or full irrigation may increase and stabilize the productivity of the rainfed agriculture with a possibility of growing during the dry seasons, which increases the land use intensity. Although a multitude of technologies can be considered, the most suitable and sustainable ones are those that can be constructed and managed by the local community with minor technical support. Identification of such technologies could be achieved through the involvement of the stakeholders including the farmers in the selection of site specific technologies. In line with this, some suitable agricultural water management technologies have been identified for scaling up in the basin and its environs through participation of the farming communities and other stakeholders (Table 4).

Traditional small scale irrigation from spring, river and other water sources has been practiced in Ethiopia since generations, but only by few farmers. Although a significant yield increase and productivity stability could be ensured without much investment and with less technical support. However, the widespread application was not sufficiently encouraged until recently. According to the Abbay basin master plan study document, a large area of land (over 41, 000 ha) can be developed by small scale irrigation using different sources of water ranging from rainwater harvesting to river diversions in the four major farming systems. On the other hand, a much larger area of land covered with vertisols (over 46000 km^2) (Table 5) can be developed by draining the excess water during the rainy season, and harvesting the drained water, which can be used for supplementary or full irrigation.

Rainwater water harvesting is when the precipitation is collected from a small/large surface area (catchments) and directed through channels to a storage facility or to a nearby field or retained at the site itself (in-situ). The rainwater harvesting techniques most commonly practiced in Ethiopia are run-off irrigation (run-off farming), flood spreading (spate irrigation), in-situ water harvesting (ridges, micro basins, etc.) and roof water harvesting (Getachew Alem, 1999), and more recently are ponds. The harvested water can be used for irrigation of crops, pastures and trees, and for livestock consumption. Among the goals of rainwater harvesting are increasing productivity of rainfed agriculture, minimizing the risk of crop failure in drought prone areas, combating desertification by tree planting, and supplying drinking water for human and animals (Finkel and Finkel 1986). In order to ensure sustainability by avoiding siltation, watershed management with reforestation and other erosion control measures are necessary. Improved watershed management encourages recharging of the groundwater which may enhance the possibility of shallow well exploitation. Because of their higher quality and availability during the dry season due to reduced evaporation loss, shallow wells can be used for prolonged period of time for crops, livestock and domestic consumption.

Table 4 Some promising agricultural water management technologies practiced in the sub basin and its environs

Technology	Description/merits
Small scale irrigation from springs and rivers	• Can be built by farmers • High level of ownership • Better operation and maintenance • Make structures permanent + enhance capacity
Shallow well development	• Provides reliable water- with continued recharge • Good water quality • Should be associated with catchments treatment • Terraces and trenches can allow recharge • Multiple uses including domestic water supply
Rain water harvesting	• Surface and sub-surface storage • Trapezoidal ponds found most suitable- with evaporation mitigation measures • Can be managed at household level
Surface drainage of Vertisols	• Use Broad bed and Furrows (BBF) • Constructed by Broad bed maker (BBM) designed and constructed at ICRISAT in (El-Swaify et al., 1985). • Introduced by ILCA and was modified to fit to the smallholder system • Recommended for successful cropping on Vertisols • BBM is drawn by a pair of oxen • It allows early planting and double cropping with/without supplementary irrigation • Yield increase of up to 200-300% reported

Source: Makonnen et al., 2009

A significant area of land in the basin is covered by the vertisols, which are characterized by very slow internal drainage with infiltration rates between 2.5 and 6.0 cm day^{-1} due to high clay content (Teklu et al., 2004), which leads to water logging, as a result of which early planting is not possible. Traditionally, many Vertisol crops are planted towards the end of the rainy season after the water is lost mainly to evaporation, to grow on residual moisture (Abate Tedla et al, 1988), which does not only significantly reduce the length of effective growing period, but also water productivity as much of the water is lost due to evaporation. However, several studies have shown that surface drainage allows early sowing enabling the full utilization of the potentially available growing period. Besides, the early-established surface cover may reduce soil erosion (El-Swaify *et al.* 1985; Abate Tedla et al, 1988; Astatke, A. and Kelemu, F. 1993; Teklu et al., 2004; Teklu *et al*. 2006) leading to ecological sustainability. Among the various alternatives, surface drainage technology, known as broad bed and furrow (BBF) constructed by broad bed maker (BBM) which was developed at ICRISAT in India (El-Swaify et al. 1985) and was later modified to fit to the smallholder system in Ethiopia (Astatke, A. and Kelemu, F. 1993) has been popularized in the major Vertisol areas of the country. The advantage of this technology can be amplified by harvesting the excess water, which can be used later on as supplementary or full irrigation of the subsequent crops, allowing multiple cropping per year on a piece of land leading to a better land use intensity.

Table 5 Estimated suitable area for small scale irrigation (ha) and surface drainage in the dominant farming systems

Farming system	Small scale irrigation (ha)	Surface drainage (km^2)
Tef based single cropping	27,480	28,000
Maize based single cropping	8,025	8,800
Sorghum based shifting cultivation	725	4,000
Barley based double cropping	4,850	5,800
Total	41,080	46,600

Possible impact of the technologies

The envisaged impacts of the selected agricultural water management technologies to be implemented in the upper part of the Blue Nile sub basin could be economical and environmental. The impacts are expected be revealed both in the upstream and downstream parts (Table 6). The technologies can potentially allow double or triple cropping in the upstream part of the basin, contributing to the food security and poverty reduction effort of the communities. Besides, the integrated watershed management interventions coupled with the technologies is believed to result in increased infiltration, reduced runoff, improved ecosystem functioning and a better human health and habitation. The concomitant effect on the downstream part could be flow regulation, with reduced peak flow and increased base flow; reduced sedimentation and a better water quality due to soil conservation at the upstream part; and increased surface runoff caused by surface drainage of the Vertisols since the water that was otherwise would have been lost as evaporation would contribute the surface flow.

Table 6 Possible impacts of the technologies

Technology	**Expected Impacts**	
	Upstream	Downstream
Shallow well + WSM	1. Reduced surface runoff and erosion 2. Double cropping possible 3. Increased crop productivity	1. Increased sub flow 2. Reduced peak flow 3. Improved water quality
RWH + WSM	1. Reduced surface runoff and erosion 2. Double cropping possible 3. Increased crop productivity	1. Increased sub flow 2. Reduced peak flow 3. Improved water quality
Surface drainage of Vertisols (BBF) + (WH)	1. Reduced evaporation 2. Increased ETc 3. Double cropping possible 4. Increased crop productivity	1. Increased runoff

WSM= watershed management; WH = water harvesting; BBF = Broad bed and furrows

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Session II: Water Demand Modeling

Simulation of Water Resource Development and Environmental Flows in the Lake Tana Subbasin

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Abstract

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.

Key words: Ethiopia, Lake Tana, water level, lake surface area, water resources development, modeling, and water demand

Introduction

The Tana-Beles area has been identified as an economic 'growth corridor' by the government of Ethiopia and the World Bank. The intention is to stimulate economic growth and reduce poverty through the development of hydropower and a number of irrigation schemes (MoFED 2006). However, the likely environmental implications of these developments and specifically the impact on lake water-levels have not been fully evaluated. An evaluation is crucial because the lake is important to the livelihoods of many people in a number of different ways including domestic water supply, fisheries, grazing and water for livestock, as well as reeds for boat construction. In addition, the lake is important for water transport and as a tourist destination.

This paper describes the use of the Water Evaluation And Planning (WEAP) model to investigate scenarios of future water resource development in the Lake Tana catchment. The model was used to investigate both the reliability of water availability for the planned schemes and their impact on lake water levels and consequently, lake surface area. For each scenario, the implications of maintaining environmental flows downstream of the lake to the Tis Issat Falls (a major tourist attraction) were also ascertained.

The Lake Tana subbasin

Lake Tana occupies a shallow depression (mean depth 9 m and maximum depth 14 m) in Ethiopian plateau located at an altitude of 1786 masl (Figure 1). It is the largest freshwater lake in Ethiopia with catchment area of 15,321 km^2 at its outlet.

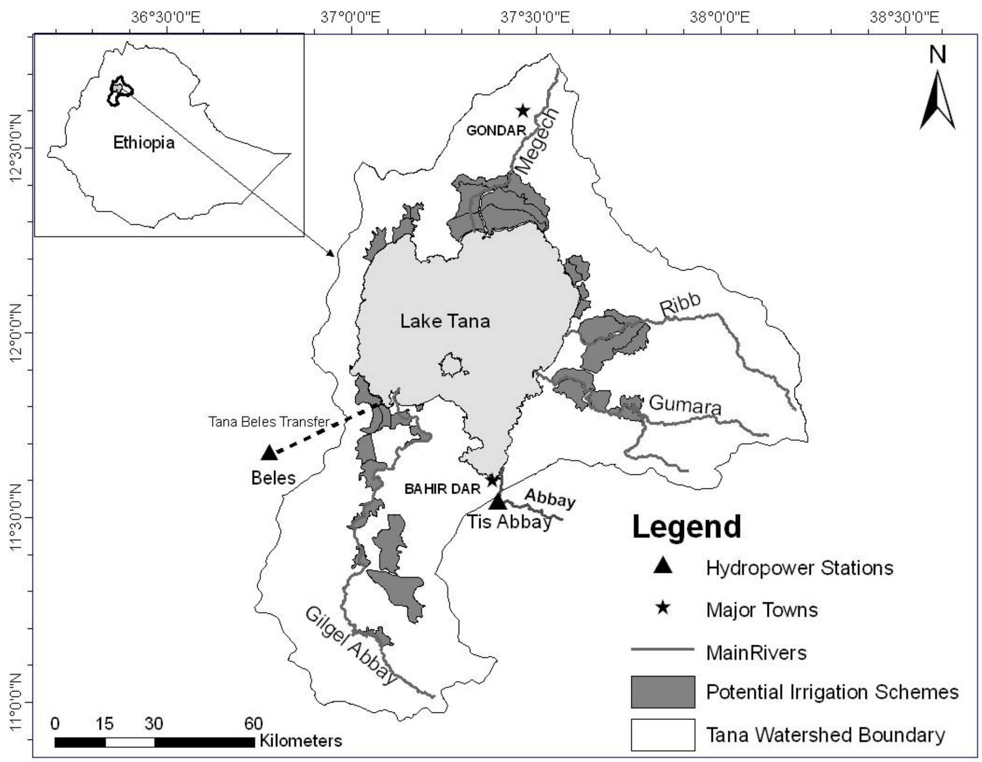


Figure 1: Location map of Lake Tana catchment showing catchment area, major inflowing rivers and planned irrigation and hydropower sites as well as Bahir Dar and Gondar towns (inset map shows location in Ethiopia)

Natural characteristics

The climate of Lake Tana region is 'tropical highland monsoon' with a single rainy season between June and September. The mean annual rainfall over the catchment is 1,326 mm, with slightly more rain falling in the south and south-east than in the north of the catchment (SMEC 2008). Average annual evaporation over the lake surface is approximately 1,675 mm (SMEC 2008).

Although the lake is fed by more than 40 rivers and streams, 93% of the water comes from just four major rivers: Gilgel Abbay, Ribb, Gumara and Megech (Fig. 1). A recent study on the lake's hydrology estimated the mean annual inflow to the lake to be 158 m^3s^{-1} (i.e. 4,986 Mm^3y^{-1}). Moreover, the mean annual outflow is estimated to be 119 m^3s^{-1} (i.e. 3,753 Mm^3y^{-1}) (SMEC 2008). Under natural conditions, discharge from the lake is closely linked to rainfall and there is considerable seasonal and inter-annual variability (Kebede et al. 2006). Naturally, the annual water level fluctuations varied between 1785.75 and 1786.36 masl. Analyses of mean annual water levels reveals longer wet and dry cycles of approximately 6-7 years, during which mean annual water-levels rise and fall respectively.

The Dembiya, Fogera and Kunzila plains form extensive wetlands in the north, east and southwest, respectively of the lake during the rainy season. As a result of the high heterogeneity in habitats, the lake and surrounding riparian areas support high biodiversity and are listed in the top 250 lake regions of global importance for biodiversity. About a quarter of the 65 fish species found in the lake are endemic. The lake contains eighteen species of barbus fish (i.e. of the *Cyprinidae* family) and the only extended cyprinid species flock in Africa (Eshete 2003). A three day survey in March 1996 indentified 217 bird species and the lake is estimated to hold a minimum of 20,000 water birds (EWLNHS 1996). In some places, close to the lake shore there is extensive growth of papyrus (*Cyprus papyrus*). The littoral zone (depth 0-4 m) of the lake, which comprises water-logged swamps, the shallow lake margins and the mouths of rivers feeding the lake, is relatively small, covering about 10 % of the total surface area (Eshete 2003).

Current socio-economic situation

The total population in the lake catchment was estimated to be in excess of 3 million in 2007 (CSA 2003). The largest city on the lake shore, Bahir Dar, has a population of over 200,000 and at least 15,000 people are believed to live on the 37 islands in the lake. The majority of the population lives in rural areas and their livelihoods are mainly dependent on rainfed agriculture. Recession cropping, mainly for maize and rice, is carried out in the wetlands adjacent to the lake shore.

Lake Tana is an important source of fish both for the people immediately around the lake and elsewhere in the country. Though the current fish production of Lake Tana is only about 1,000 tons per year, the potential for production is estimated to be 13,000 tons per annum (Berhanu et al. 2001).

The Lake Tana region is endowed with historical cultural and natural heritages which have high tourist attractions. Consequently, the area is an important tourist destination in the country. It is estimated that close to 30,000 people (both domestic and foreign) visit the area each year (EPLAUA 2006).

Outflow from Lake Tana is regulated by the Chara Chara weir. This was constructed in 1996 to regulate flow for a hydropower stations located at Tis Abbay, 35km downstream.

Prior to construction of the weir, the Tis Abbay I power station (capacity 11.4 MW) relied entirely on diversion of the natural flow of the river immediately upstream of the Tis Issat Falls.

The Chara Chara weir regulates water storage in Lake Tana over a 3 m range of water levels from 1784 masl to 1787 masl. The active storage of the lake between these levels is about 9,100 Mm^3, which represents approximately 2.4 times the average annual outflow. The regulation for power production has modified the natural lake-level regime, resulting in reduced seasonal but greater inter-annual variability (Fig. 2). The lowest level ever recorded was in June, 2003. This was a drought year in much of Ethiopia and hydropower production was constrained in many places. In an attempt to maintain electricity supplies production at Tis Abay was maximized and as result lake levels declined sharply (Gebre et al. 2007). As a consequence of the low lake levels in 2003, navigation ceased for approximately four months (i.e. when lake levels dropped below 1785 masl, the minimum level at which ships can currently operate), large areas of papyrus reed were destroyed, there was significant encroachment of agriculture on the exposed lake bed and there was a decrease in fisheries production (EPLAUA 2004).

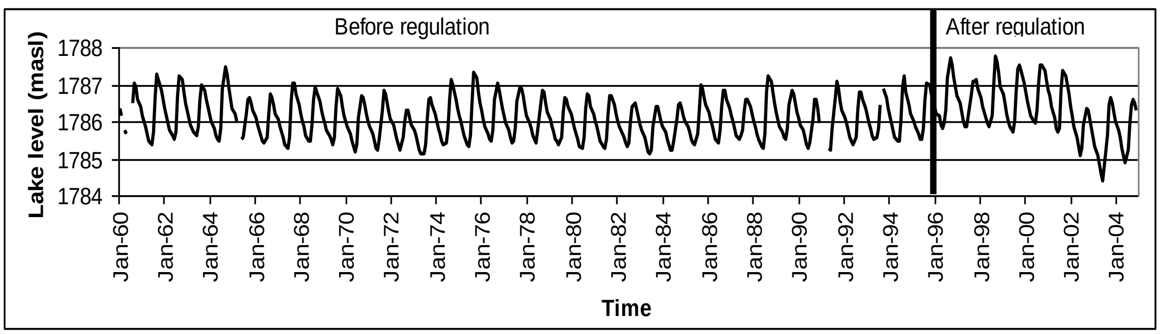


Figure 2: Water level fluctuations of Lake Tana before and after regulation (Source: plotted using data provided by the Ministry of Water Resources)

Planned irrigation and hydropower schemes

These days, Lake Tana region is at the centre of Ethiopia's plans for water resource development owing to its huge water resource potential. Consequently, a number of schemes are under development and planned for the future (Fig. 1). Construction of the Tana-Beles project is close to completion (August 2009). This scheme involves the transfer of water from Lake Tana to the Beles River via a 12 km long, 7.1 m diameter tunnel (Salini and Mid-day 2006). The aim of the inter-basin transfer is to generate hydropower by exploiting the 311 m elevation difference between the lake and the Beles River. A power station, with generating capacity of 460MW, is being built on the upper Beles River. This will enable far more electricity to be generated than is currently produced in the Tis Abbay power stations. Approximately 2,985 Mm^3 will be diverted through the tunnel each year to generate 2,310 GWh of electricity (SMEC 2008). Both the Tis Abbay power stations will be moth-balled and only used in emergencies.

As well as the hydropower development, a number of irrigation schemes (up to approximately 60,000 ha) are planned on the main rivers flowing into Lake Tana (Table 2). Of these only the Koga irrigation project (6,000 ha) is currently under construction. However, for several of the other schemes detailed feasibility studies have been undertaken and planning is at an advanced stage. It is anticipated that construction of several of the dams and irrigation schemes will commence in the near future.

Table 2: Planned irrigation development in the Lake Tana catchment (source: BCEOM 1998; Mott MacDonald 2004; WWDSE and ICT 2008; WWDSE and TAHAL 2008a, b)

Irrigation scheme	**Irrigable area (ha)**	**Estimated annual gross water demand Mm^3)[+]**	**Large dam storage (Mm^3)**	**Stage of development**
Gilgel Abbay	12,852	104 – 142	563	Feasibility studies ongoing
Gumara A	14,000	115	59.7	Feasibility studies completed
Ribb	19,925	172 – 220	233.7	Feasibility studies completed
Megech	7,300	63 – 98	181.9	Feasibility studies completed
Koga	6000	62	78.5	Under construction
NE Lake	5745	50 – 62	Withdrawals from the	Pre-feasibility studies completed
NW Lake	6720	54	Withdrawals from the	Identification
SW Lake	5132	42	Withdrawals from the	Identification

Note: + demands estimated though crop water modeling and presented in feasibility study reports. Where a range of demands is presented this reflects alternative cropping patterns.

Methodology

To simulate the future water demand in Lake Tana region along with the environmental flows the water allocation component of WEAP model was used. WEAP was developed by the Stockholm Environment Institute (SEI) in Boston and provides an integrated approach to simulating water systems associated with development (SEI, 2007). A detailed description of the model can be found in SEI (2007) and Yates et al. (2005).

WEAP configuration to the Lake Tana sub-basin

The modeling of the Lake Tana catchment with WEAP encompassed the major tributaries to the lake, upstream of the proposed dams (i.e. flows that will be affected by the future construction of dams), estimates of flows downstream of the proposed dams and total inflows on other rivers (i.e. flows that will be unaffected by the future development) as well as Lake Tana itself. Lake Tana was simulated as a reservoir (Fig. 3). In addition, because environmental flow requirements downstream of the Chara Chara weir are influenced by flows in the unregulated Andassa River (catchment area 683 km^2), which joins it approximately 17 km downstream of the weir, flows in this river were also incorporated in the model. The model was configured to run on a monthly-time step.

As primary input to WEAP, the inflow series at the planned dam sites were obtained from the relevant feasibility studies for the period 1960-2004. Where necessary, inflow data were augmented using area-weighted estimates from the nearest available flow gauging station. To simulate the current situation, the Tis Abbay hydropower plants were included as a demand node on the Abbay River, downstream of the lake. To estimate the diversions to the power stations the turbine discharge data from 1964-2006 were obtained from EEPCO.

Each development scenario was run for the 36 years (i.e. 1960-1995). This period was selected both because data are available and it represents a wide range of hydrological variability. Furthermore, it represents years before construction of the Chara Chara weir and so the impact of each development scenario could be compared with the natural water-level regime of the lake.

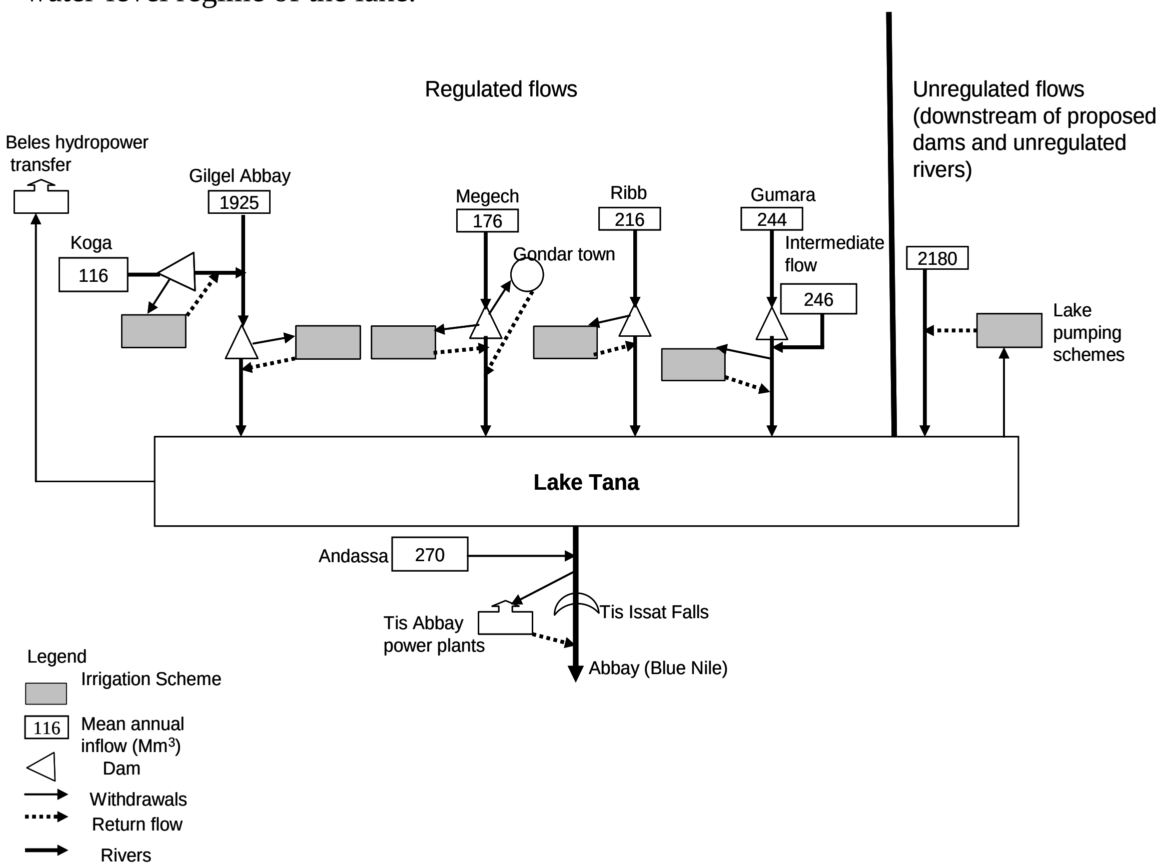


Figure 3: Schematic of existing and planned development schemes in the Lake Tana sub-basin as simulated in WEAP

Summary of irrigation and hydropower development scenarios

The data underpinning the various scenarios were obtained mainly from the Abbay River Basin Integrated Development Mater Plan and the feasibility studies conducted for each of the planned schemes. These indicate how the water demand for both irrigation and hydropower is likely to change in the catchment in the future. Four scenarios were developed based on the current stage of scheme development and hence the likelihood of full implementation (Table 3). Water demands for the irrigation schemes were entered into WEAP as monthly time series of net demands (i.e. gross demand minus the estimated return flows).

For the proposed new dams no operating rule curves are currently available. Consequently, no operating rules were incorporated within the WEAP model. This meant that the reservoirs were not drawn down to attenuate wet season floods and no restrictions were applied on abstractions as the reservoirs emptied. The one exception was Lake Tana itself where the operating rule was derived from the calibration process. In this case parameters were set using the pattern of operation in recent years. Thus, restrictions on draw-down were applied to reduce abstractions as lake levels dropped below 1786 masl and to ensure levels did not drop lower than the current physical minimum of 1784 masl.

Since it provides the highest economic returns hydropower production was designated a higher priority than irrigation. With the exception of the water demand for the city of Gondar, which in future will be abstracted from the Megech River, the water demand for domestic, municipal and industrial use, were not considered. This is because their impact on the water resources of the lake, both now and in the future, is insignificant (SMEC 2008). For each scenario the WEAP model was used to predict: i) the impacts on both lake water-levels and lake area for each month over the 36 years simulated and ii) the unmet demand for hydropower and each irrigation scheme.

Table 3: Summary of development scenarios (Source: BCEOM 1998; EEPCO database and SMEC 2008)

Scenario	**Hydropower developed**	**Irrigation schemes developed**	**Total mean annual water demand (Mm^3)+**
Baseline (BS)	Tis Abbay I and II	-	3,469
Ongoing development (ODS)	Tana Beles transfer	Koga	3,047
Likely future development (LDS)	Tana Beles transfer	Koga, Megech, Ribb, Gumara and Gilgel Abbay	3,621
Full potential development (FDS)	Tana Beles transfer	Koga, Megech, Ribb, Gumara, Gilgel Abbay and 3 schemes pumping directly from the lake	3,768

Note: + water demand has been calculated using the highest crop water estimates for each of the irrigation schemes.

An environmental impact assessment was conducted for the Tana Beles transfer scheme. To maintain the ecosystem of the upper reaches of the Abbay River this recommends an average annual release from Chara Chara of 17 m^3s^{-1} (536 Mm^3) with an absolute minimum of 10 m^3s^{-1} (Salini and Mid-day 2006). This environmental flow requirement, hereafter referred to as the minimum maintenance flow (MMF), was included in all the scenarios. Moreover, the proposed minimum instream flows downstream of each of the proposed dams (as identified in the feasibility studies) were also included in each scenario.

Recently, a more detailed evaluation of the environmental flow requirements needed to maintain the ecosystem of the Tis Issat Falls has been conducted (McCartney et al. 2008). This study allowed for the natural seasonal and inter-annual variability of flow and estimated environmental flow requirements on a monthly time-step for the period 1960-2004. The study found that to maintain the basic ecological functioning of the reach containing the Falls, variable flows are necessary, with an average annual allocation of 864 Mm^3 (i.e. 64% more than previously estimated) (McCartney et al. 2008). To ascertain the effect of the variable environmental flow (VEF) requirement, over and above the minimum maintenance flow, each scenario was run again with the variable environmental flow included. All environmental flows were given higher priority than the hydropower production.

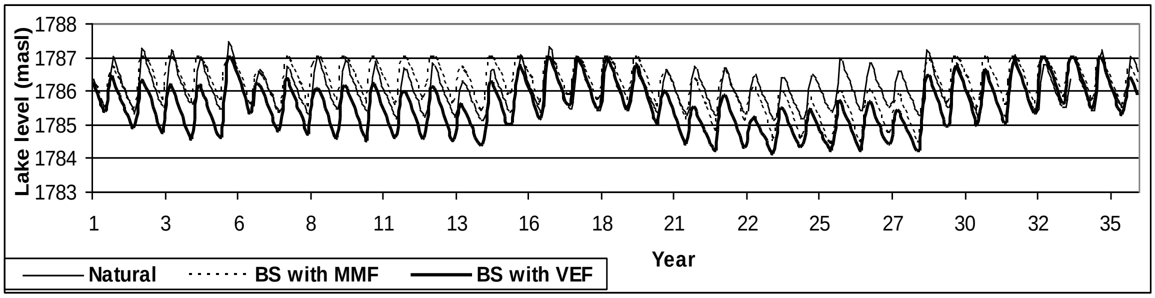
Results

Figure 4 presents a comparison of the time series of simulated lake levels for all scenarios with the natural condition, both with the downstream MMF and the VEF included. Table 4 summarizes the results of each scenario both with the MMF and VEF. The results indicate the decline in mean annual lake levels, and consequently lake area, as the water resource development in the catchment increases. This is manifested particularly by the increasing periods of time when lake levels are below 1785 masl, the minimum required for ships to navigate on the lake. Even without the VEF releases, in the full potential development scenario, water-levels exceed 1785 masl just 78.0% of the time (Table 4) and in some years hardly exceed this level in any months (Fig. 4d). This would have a very significant impact on shipping in the lake.

As would be expected, the greatest impact of the water resource development occurs during dry cycles in particular years 8-14 and most significantly from years 20- 28 of the simulation. During these periods, even without variable environmental flow releases, lake water levels are, depending on the development scenario, up to 0.82 m and 1.76 m lower than natural levels in the dry and wet season, respectively (Fig. 4).

The VEF requirements exacerbate the drop in lake water-levels in all scenarios. For the full development scenario the water level exceeds 1785 masl just 60% of the time and the mean lake area is reduced from 3,080 km^2 to 3,023 km^2 (Table 4). Furthermore, the amount of power produced and the amount of water diverted to irrigation are reduced by between 1% and 3% for hydropower and 2% to 5% for irrigation, depending on the scenario.

a)


Lake level (masl)
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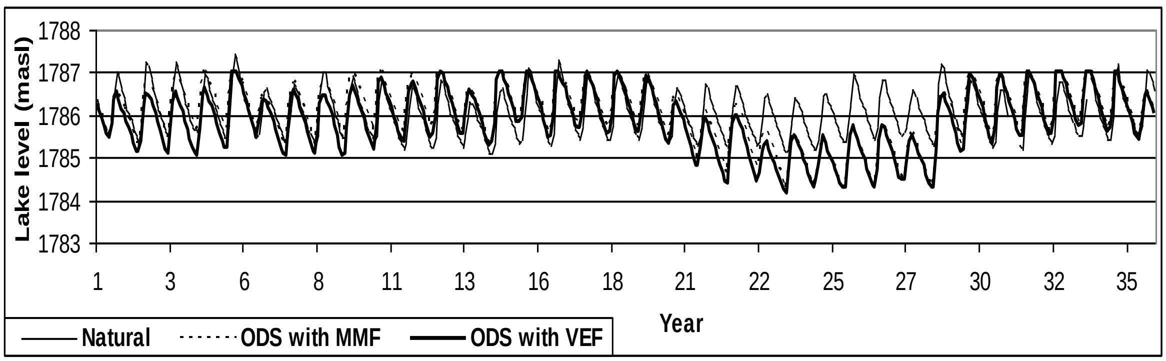
Year
Natural
BS with MMF
BS with VEF

b)


Lake level (masl)
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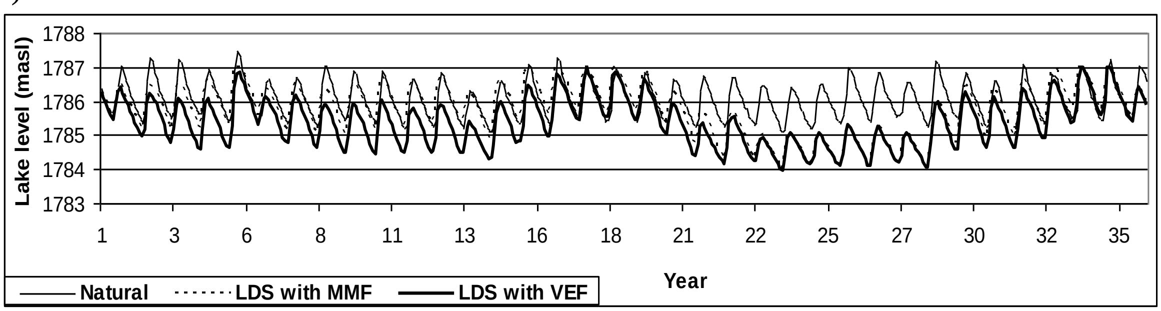
Year
Natural
ODS with MMF
ODS with VEF

c)


Lake level (masl)
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Year
Natural
LDS with MMF
LDS with VEF

d)

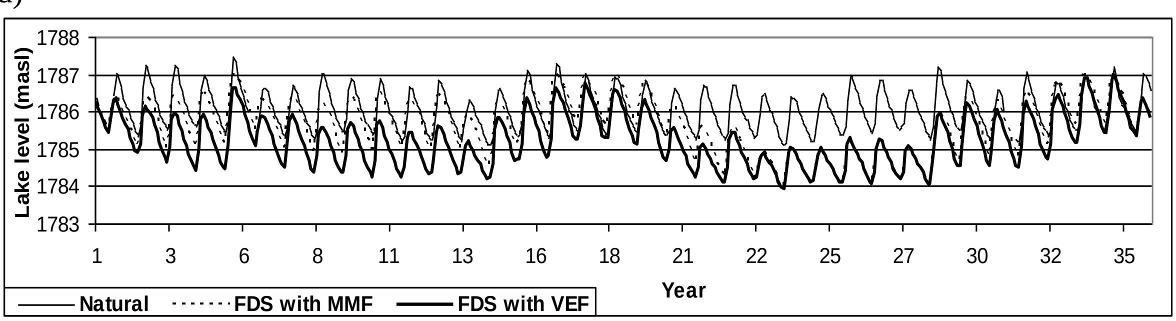
Lake level (masl)
1788
1787
1786
1785
1784
1783
1 3 6 8 11 13 16 18 21 22 25 27 30 32 35
Year
Natural
FDS with MMF
FDS with VEF

Figure 4: Comparison of simulated and natural (observed) lake levels over 36 years with, for each scenario, MMF and VEF. Scenarios are: 4a) baseline scenario (BS), 4b) ongoing development scenario (ODS), 4c) likely future development scenario (LDS) and 4d) full potential development scenario (FDS).

Table 4: Summary of simulation results for each scenario with minimum maintenance flow and variable environmental flows

Scenario	**MMF**					**VEF**				
	Mean water levels (masl)	**Mean lake area (km^2)**	**Mean power generated $GWhy^{-1}$**	**Mean irrigation Water Supplied Mm^3y^{-1}**	**% time that mean water level exceeds 1785 masl+**	**Mean water levels(masl)**	**Mean lake area (km^2)**	**Mean power generated $GWhy^{-1}$**	**Mean irrigation water supplied Mm^3y^{-1}**	**% time mean water level exceeds 1785 masl**
Natural	1786.05	3080	15.7*	0.0	100.0	1786.05	3080	15.7*	0.0	100.0
BS	1786.11++	3084++	356.7	0.0	93.5	1785.55	3045	332.8	0.0	75.2
ODS	1786.01	3077	2247.0	55.2	90.1	1785.86	3067	2225.1	53.9	88.7
LDS	1785.72	3057	2207.1	548.3	81.0	1785.39	3034	2177.8	537.0	66.4
FDS	1785.61	3049	2197.6	676.9	78.0	1785.24	3023	2134.2	644.2	59.7

Note: + 1785 masl is the minimum level required for shipping
* hydropower produced by Tis Abay I power station by diverting unregulated flow
++ increase in average lake water level and lake area occurred as a consequence of regulation which slightly increased dry season water level and area

Table 5 presents the average annual shortfall (as a percentage of the annual demand) for both irrigation and hydropower in each of the scenarios with both the MMF and the VEF. As would be expected, shortfalls occur mainly in dry years. In the model hydropower was given higher priority than irrigation, so shortfalls in hydropower production are less than in irrigation. Nevertheless, shortfalls in hydropower significantly increase as the irrigation development in the basin increases. Hence, even without allowing for the VEF average annual hydropower production declines from 2,247.0 GWh to 2,207.1 GWh and 2197.1 GWh if all the planned and all the possible irrigation schemes are developed respectively (Table 4). If the VEF is included unmet hydropower and irrigation demands both increase significantly (Table 5).

Table 5: Unmet demands for irrigation and hydropower in each scenario with minimum maintenance flow and variable environmental flows

Scenarios	Irrigation				Hydropower			
	MMF		VEF		MMF		VEF	
	Unmet demand %	Maximum unmet demand % (year)	Unmet demand %	Maximum unmet demand %(year)	Unmet demand %	Maximum unmet demand %(year)	Unmet demand %	Maximum unmet demand %(year)
BS	0.0	0.0	0.0	0.0	0.6	8.1(29)	7.3	41.4(24)
ODS	10.4	83.9(25)	12.5	90.2(25)	2.6	22.4(26)	3.5	33.3(24)
LDS	13.8	70.9(26)	15.6	72.9(24)	4.3	34.9(24)	5.6	36.5(24)
FDS	13.5	71.0(26)	17.7	72.6(24)	4.7	34.9(24)	7.5	38.8(24)

Discussion and conclusion

The analyses conducted in this study quantify some of the possible impacts arising from future development of the water resources of the Lake Tana catchment. The modeling results indicate that the water level of Lake Tana will be influenced by upstream development on the inflowing rivers, the diversion to the Beles catchment and the release of flow downstream of the Chara Chara weir. As would be expected, the effects on lake levels will be more pronounced during dry periods. In the past, the water level of the lake was controlled more by rainfall variation than by human activities (Kebede et al. 2006). In future, as a result of infrastructure development, anthropogenic activities will be the major control.

A recent assessment of Lake Tana and its associated wetlands identified a number of human induced ecological threats, including siltation, over fishing, recession agriculture and water level disturbance due to water withdrawals (EPLAUA 2006). In the absence of careful management all these threats are likely to be aggravated by the planned future development.

Approximately 3,400 Mm^3y^{-1} of water will be diverted for hydropower and irrigation schemes if the likely future development scenario in the Lake Tana sub-basin is implemented. Consequently, the mean annual water level will be lowered by 0.33 m and there will be prolonged periods, of several years, during which water levels will be much lower than they would be naturally. Due to this the average surface area of the lake will decrease by 23 km^2 (i.e. 2,300 ha). This is likely to have significant impacts on the ecology of the lake, particularly the littoral zone and in the wetlands around the shoreline. The desiccation of currently wet areas will certainly cause the loss of aquatic vegetation, including papyrus reeds. As a result the breeding habitat for aquatic fauna, including fish is likely to be reduced. This could have a significant impact on the productivity of the lake fisheries.

In 2003, farmers extended crop production onto about 562 ha of Lake Tana bed following the lower levels (EPLAUA 2004). This indicates that lower water levels will almost certainly result in people moving both cultivation and grazing onto the dried lake bed. This would exacerbate adverse impacts on near-shore vegetation and could greatly increase sedimentation in the lake.

Lower water-levels, particularly in the dry season, will have a negative impact not only on the ecology of the lake but on navigation. As a consequence of lower water levels in 2003, Lake Tana Transport Enterprise lost about 4 million Ethiopian birr (i.e. approximately US$ 400,000) because the ships could not sail (Dagne, personal communication). Due to the fact that the livelihoods of many people are dependent on shipping, strategies need to be developed to mitigate these impacts. These could include modification of ports as well as the ships themselves to enable them to operate at lower water-levels.

The WEAP simulations show the water availability for both irrigation and hydropower in each scenario. The results indicate that as demands rise in future, shortfalls in water supply will increase during dry periods. Very careful consideration needs to be given to the economic implications of reduced reliability of supply particularly for hydropower production in the Beles, resulting from increasing irrigation in the Lake Tana catchment.

In this study consideration was given only to the possible changes arising from future water resource development in the Lake Tana catchment. However, the water resources of the Lake Tana catchment are highly vulnerable to changes in rainfall and temperature. In a study of possible impacts of climate change on the hydrology of the Gilgel Abbay River, it was estimated that by 2080 mean annual runoff into the lake could be reduced by approximately 3% with much greater reduction in some years (Shaka 2008). However, this estimate makes no allowance for increased irrigation demand as a consequence of lower rainfall and higher temperatures. It is also probable that climate change will affect the temporal distribution of runoff (Deksyos and Abebe, 2006; Shaka, 2008) and this could also affect both water availability and irrigation demand. Hence, much more detailed studies of the possible impacts of climate change, including economic and livelihood implications, need to be undertaken.

The simulation results indicate that the allowance for VEF over the Tis Issat Falls reduces the availability of water for both hydropower and irrigation and causes increased drawdown of the lake. In the full development scenario the VEF reduce the average lake levels by an additional 0.37 m and the average surface area of the lake by an additional 26 km^2 (i.e. 2,600 ha). This is over and above the reductions resulting from the MMF and will almost certainly further exacerbate the adverse environmental and social impacts arising from drawdown of the lake. Therefore, a potential trade-off exists between the lake ecosystem and the ecosystem of the upper Abbay River and the Falls. Since the livelihoods and well being of many people are directly dependent on the ecological character of both ecosystems, very careful consideration needs to be given to determining how the water is best utilized. This requires much more detailed analyses of both the environmental and social consequences of water allocation patterns.

Acknowledgements

We are grateful to the CGIAR Challenge Program on Water and Food, project number 36: 'Improved planning of large dam operation' and Addis Ababa University, Science Faculty for research grant to Tadesse Alemayehu. The authors are also grateful to the Federal Ministry of Water Resources, the Ethiopian Electric Power Corporation and the National Meteorological Agency for the provision of data.

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Water Balance Assessment of the Roseires Reservoir

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Abstract

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.

Introduction

The Nile River, which is shared between (10) countries, is the primary source of Sudan water. The Blue Nile sub system in this respect accounts for 76% of the total irrigated agriculture on the three Nile tributaries (Atbara, White Nile and Blue Nile). A major characteristic of the Blue Nile discharges is the remarkable seasonality of its flow. More than 80% of the river discharge flows during the flood months, (June – October). Two Dams were built across the river (Sennar, 1925 and Roseires, 1966) to partially control the flows. The two dams serve about 2.7 million feddan of the Sudan irrigated area, as well as more than 40% of the total hydropower generation of the country.

The Roseires dam, which spans the Blue Nile 630 km upstream of Khartoum, is a 1000 m long and 68 m high concrete dam with the crest at 482.2 m. The dam was completed in 1966 to be used for irrigation water supply and hydropower. The dam contains 5 deep sluices and a

gated spillway, consisting of 7 units, with a maximum discharge capacity at level 480 m of 16500 m3/s. The hydro-electrical potential amounts to 212 MW.
The volume of the reservoir was originally 3.0 milliard m3 at a level of 480 m with a surface area of 290 Km2 extending over a length of 75 Km. The storage capacity has considerably been affected by siltation and is now about 30 percent less. The recent capacity is estimated to be about 2.1 milliard m3. A special operation strategy, maintaining low reservoir level and high flow velocities during the passage of the flood, is applied to reduce the siltation.
The main inflow to the reservoir is monitored at eddeim station 102 km south-east of Roseires dam on the Ethiopian/Sudanese border. This allows for an intervening catchment of 14,578 Km2 which is totally ungauged. As well the rainfall over the reservoir lake is monitored at Damazin stations. The significance of the contribution of the intervening catchment and the direct rainfall over the reservoir is alleged to be negligible.
Operation of reservoirs depends on rules set for that purpose, which is mainly based on water balance of the system among other factors. Such rules are rarely revised during the life time of the reservoirs and Roseires is not an exception.
This study is an attempt to closely look at the different aspects of the operation and water balance parameters to have an inside about the whole operation of the reservoir. In addition, to attempt finding accurate balance formula for the system, bearing in mind the part of the intervening catchments and the direct rainfall over the reservoir.

The Study area

Roseires Dam was completed in 1966 with an initial capacity of 3.024 Km3 at level 480 m level. The main objective to supply irrigation demands as first priority, and hydropower generation comes secondly. During its lifetime, the reservoir suffered from serious sedimentation to the limit that, its present capacity is less than 2.0 Km3.Operation of the dam is maintained closely with Sennar dam, according to the operating policy. Discharge in Roseires dam through gates (deep sluices and spillways) is computed by the dam operation engineer using flow charts prepared from a physical model before dam construction in 1965.

The deep sluices with sill levels of 435.5m amsl are used to pass the main volume of the flood, and to flush the sediment as much as possible. The deep sluices are always closed in low flow seasons to reduce the possibility of cavitations damage on the downstream apron at low tail water levels. The spillways with sills at 463.7m amsl are used to pass the peak of major floods and also, if necessary, to augment the downstream flows in the low flow season to provide the releases required for irrigation and other down stream water utilizations. At the extremities of the concrete section on each bank provision has been made for gravity supplies for future irrigation canals. On the west bank the head works would supply a future scheme in the Kenana area and on the east bank; supplies could be made for a future irrigation scheme in the Rahad, Dinder or Rosaries areas.

When the existing Rosaries dam was constructed provision was made for the future construction of a power station with seven generating units. In 1971 three units, each with a name plate rating of 30 MW were installed. The other four units were installed and commissioned later in January 1979. These sets have turbines similar in size to those of the first three units, but the generator name plate rating has been increased to 40 MW.
According to the design, the maximum retention level of the reservoir is 480.0m amsl.; however a study in 1973 (Sir Alexander Gibb & Partners, 1973.) came to the conclusion that the reservoir could probably be filled to 481m each year for a limited number of years without

incurring an unacceptable degree of risk. Nevertheless the operating range of the reservoir is kept between 467m and 480m.The live storage volume between these two levels is about 2386 million m^3, which is released for use downstream between November and June. The reservoir is held at the lower level through the flood season to minimize sediment deposition and is filled to 480m on the falling flood when the sediment load is much lower. A recent bathymetric survey has indicated that since the dam was built some 1.408 milliard $m^3$of the sediment has been deposited in the reservoir (HRS 2006), this definitely will affect the storage characteristics of the reservoir.

The design of the present dam made provision for a subsequent increase in height of ten meters. The limitation on the extent of the heightening was dictated by the necessity to avoid creating adverse effects in Ethiopia. The foundations and first few meters of buttress deepening required for the ultimate height were provided for in the initial construction and the sections of the concrete dam adjoining the earth dam were built to the ultimate profile. Dam heightening will be accompanied with extension in earth embankment bringing the total length of the dam to about 25km. Figure (1) shows the location of the reservoir together with the eddeim station. Figure (2) shows the longitudinal profile along the Blue Nile.

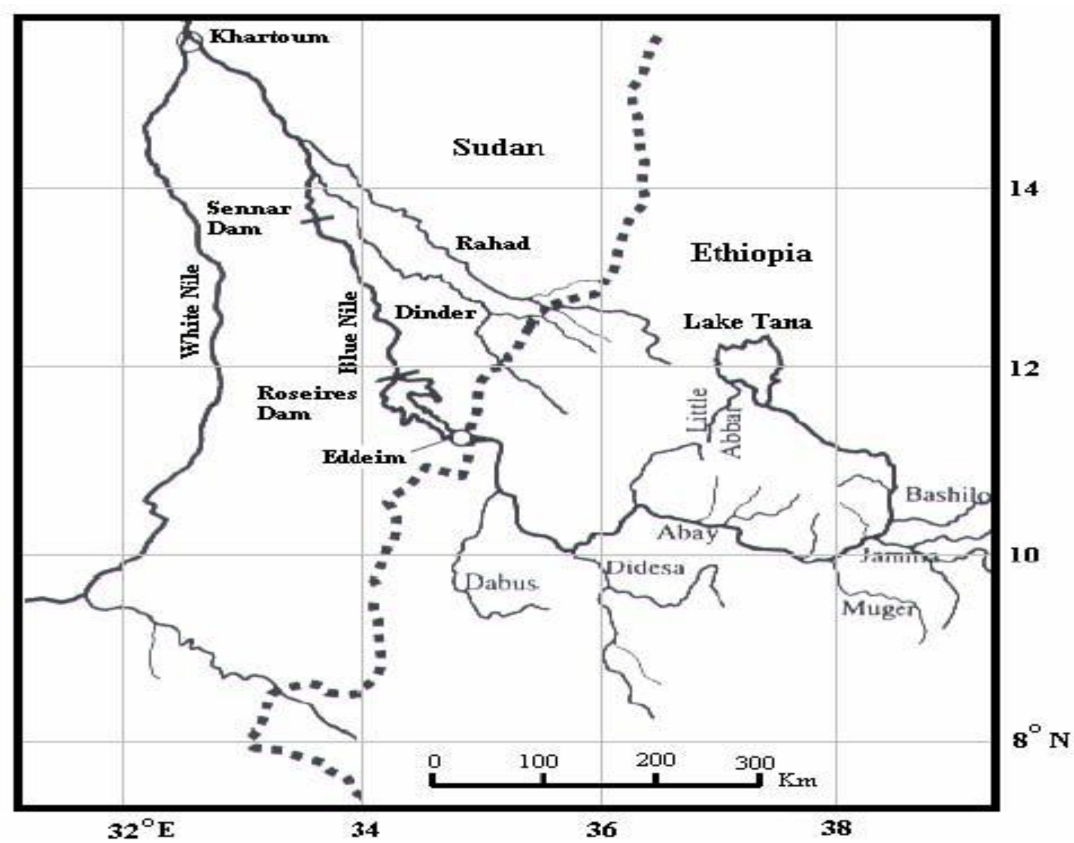

Figure 1: The Location of Roseires Dam and the Eddeim station within the Blue Nile in Ethiopia and Sudan

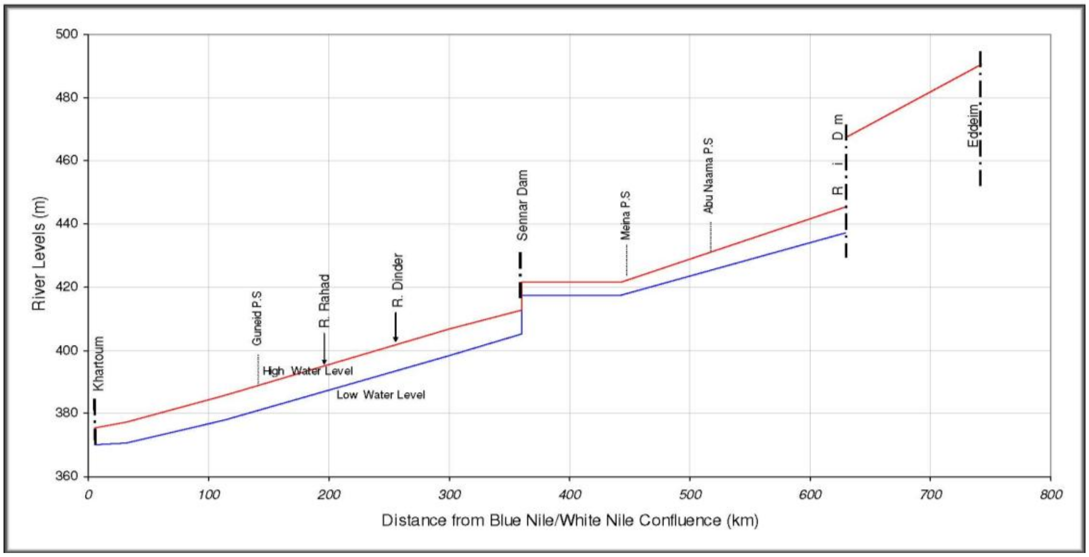

Figure 2: Longitudinal Profile of the Blue Nile

The data

The data required for this study comprises flow data at eddeim, the dam releases, rainfall data, evaporation data, reservoir characteristics and operation rules. These data is collected from the Nile Waters Directorate (NWD) of the MoIWR and Hydrological Year Books published by NWD.

The historical records of daily flows and water levels at Ed Deim and Roseires measuring stations were available from 1965 to 2007. Table (1) shows the availability of the collected data.

Table 1 The gauging sites under study

Gauging Site	Date of Erection	Latitude X°Y´N	Longitude X°Y´ E	Gauge Zero (m)	Data Type	Period Covered
Eddeim	1966	11 14	34 59	481.2	H, Q	1966-2007
U/S Roseires	1966	-	-	3.0	H	1966-2007
D/S Roseires	1966	11 50	34 23	3.0	H, Q	1966-2007

Evaporation data is available from Table (2) of the Blue Nile Waters Study, Volume 3. In this table the annual average Penman-evaporation is given in mm/day for the hydrological years 1962/63 to 1972/73. The project area was divided in five climatic zones of which the Roseires dam lies in the Southern Zone. The average annual evaporation for this Zone varies from 5.7 to 6.3 in the considered period.

More recent climate data including values up to 1990 are available from database of CROPWAT of the Food and Agriculture Organization of the United Nations (FAO). Climate data is taken from the Damazin station which is located close to the Roseires dam. This data base provides long term average values for e.g. rainfall and evapotranspiration for each month. From this data base the monthly distribution of annual evapotranspiration can be obtained.

For consideration of the evaporation from the reservoir the evapotranspiration needs to be reduced to the evaporation by application of the formula ET0 = Kp * E0. The factor Kp can be obtained from Table 5 of the FAO Irrigation and Drainage Paper No. 56 - Crop Evapotranspiration.

Table 2 Reservoir evaporation values of Roseires reservoir

Month	Mean daily evapo-transpiration	Kp	Mean monthly evaporation *)	Mean monthly evaporation	Mean monthly rainfall	Mean monthly net evaporation	Percent
	mm/day		mm/day	mm/month	mm/month	mm/month	%
January	5.43	0.70	6.98	216.4	0.0	216.4	12.9
February	6.04	0.70	7.77	217.4	0.0	217.4	13.0
March	6.67	0.70	8.58	265.8	1.0	264.8	15.8
April	6.89	0.70	8.86	265.8	19.0	246.8	14.7
May	6.70	0.70	8.61	267.0	40.0	227.0	13.5
June	5.75	0.75	6.90	207.0	119.0	88.0	5.2
July	4.37	0.85	4.63	143.4	181.0	-37.6	-2.2
August	4.09	0.85	4.33	134.2	203.0	-68.8	-4.1
September	4.48	0.85	4.74	142.3	129.0	13.3	0.8
October	4.85	0.80	5.46	169.1	41.0	128.1	7.6
November	5.09	0.80	5.73	171.8	3.0	168.8	10.1
December	5.34	0.70	6.87	212.8	0.0	212.8	12.7
Total/Average	5.48		6.62	2,413.3		1,677.3	100.0

*) attanuation factor of 0.9 to adjust values to those of the southern zone in table 2.5 of the Blue Nile Waters Study

Methods

Water balance computation was done for years 1985, 1995 & 2005. The selection of these years was due to the facts that during these years bathymetric surveys were done in the reservoir. It can be seen from the selection that the interval is ten years which gives good time for changes in water balance to take place and a period of 20 years can be covered.

During the period January to May, the gates are completely closed and water passes through power turbines only. The discharge through the turbines was used to be monitored by gauges, erected on the penstock of the turbines. However, since 1980's, those gauges were out of order and the discharge was then computed indirectly from the amount of generated energy.

The calculations of the inflow-outflow water balance were carried out to illustrate the relationship between the annual flows of the upstream and downstream measuring stations within each system, taking into account the inter-flows, local abstractions and other related factors.

This has clearly showed the deviations that might have occurred throughout these systems over the years.

The water balance equation of the Blue Nile at Roseires Reservoir can be written as:

$$QEd + Runoff = QRos + losses + \Delta s$$

Where

QEd = Discharge from Ed Deim

QRos = Release from Roseires

Runoff = Runoff from catchment between Ed Deim and Roseires

Losses = evaporation and seepage losses if any

Δs = change of storage content of Roseires reservoir

Results and Discussion

The application of water balance on daily basis was performed. The results for the three years namely (1985, 1995 and 2005) are given respectively in figure (3) to figure (5).

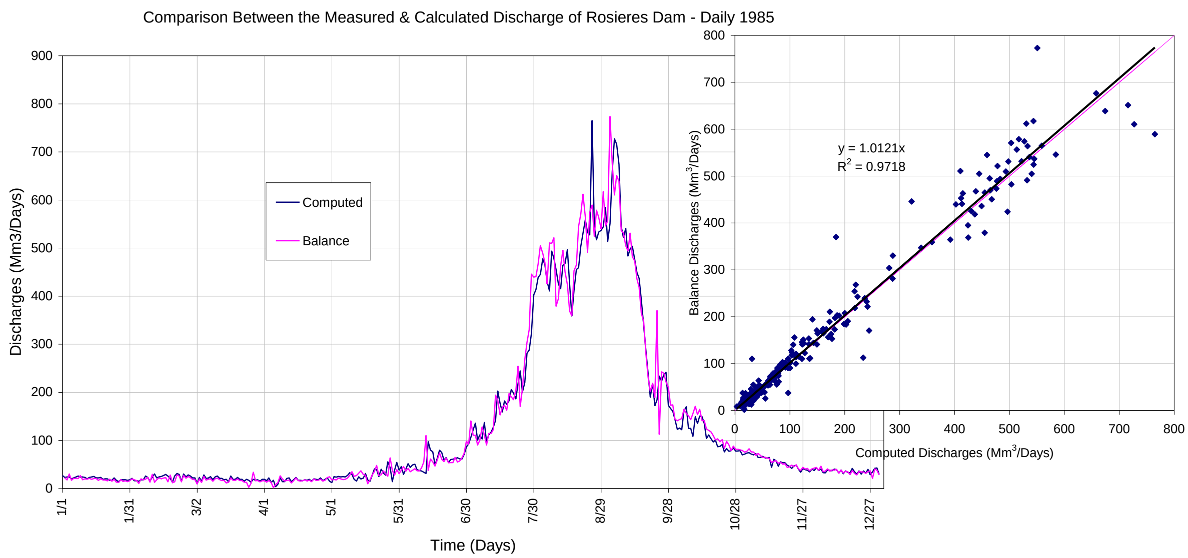

Figure 3: Comparison between the Computed & Balance Calculated Discharge of Rosieres Dam - Daily 1985

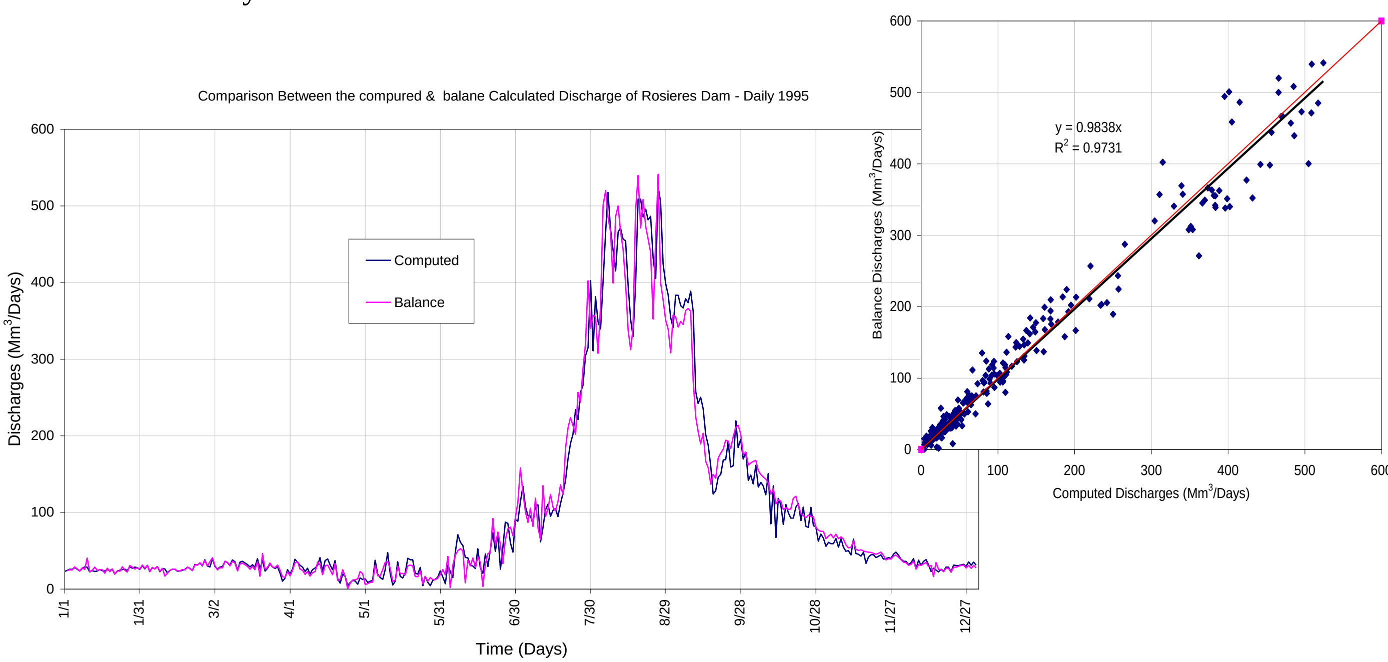

Figure 4: Comparison between the Computed & Balance Calculated Discharge of Rosieres Dam – Daily 1995

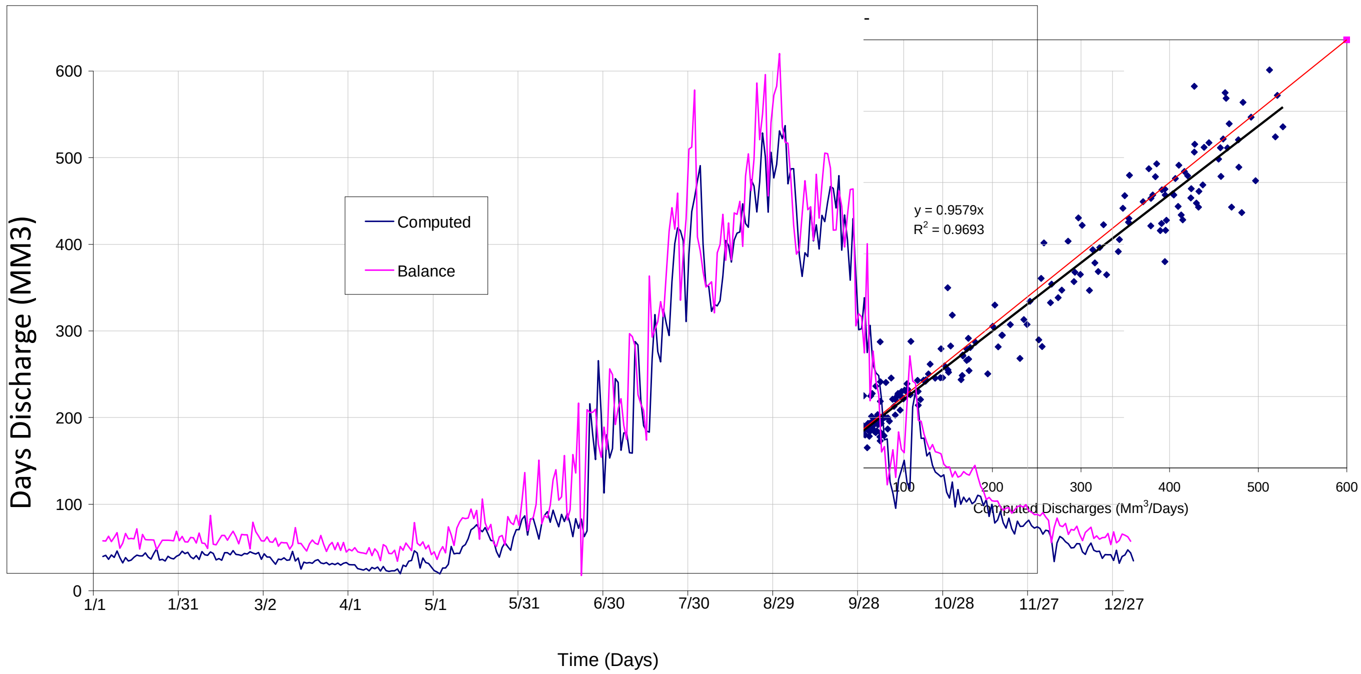

Figure 5: Comparison between the Computed & Balance Calculated Discharge of Roseires Dam - Daily 2005

The over all performance of the water balance on daily basis is relatively high which accounts for 97% of the initial variance. It should be noted that the calculation of water balance does not take into consideration the contributions of the intervening catchment and direct rainfall over the reservoir. This indicates that these contributions are insignificant.

10-Days water balance at Ed Deim Station (Back Routing):

The water balance is performed at 10 days time step at Ed Deim station.

Ed Deim station was chosen because of its stable river section (deep gorge) at the site. Although discharge measurements using cable at Ed Deim was ceased since1972, the recorded flow by staff gauge is believed to be reliable up to date.

As the balance of the river and the reservoir is greatly affect by season, in this work two periods were considered. These are:

- Flood period from 1st June to 31 November (with rain fall),
- Dry period from 1st December to 31 May (without rain fall).

Dry Period (December – May):

During the low flow period, December to May, usually, the dam gates are completely closed and flow is entirely through the power turbines. Leakage through spillways and deep sluices is negligible, which means validation of dam releases during low flow period, is actually validation of the discharge through power station. The discharge through the turbines is computed from the power equation P=γQH, knowing the power P, head H and efficiency γ, the discharge Q is calculated.

The water balance results for years 1985, 1995 and 2005 were obtained for the dry season of ten days interval and compared with the observed discharge at Ed Deim. The results are shown in figure (6) to figure (8).

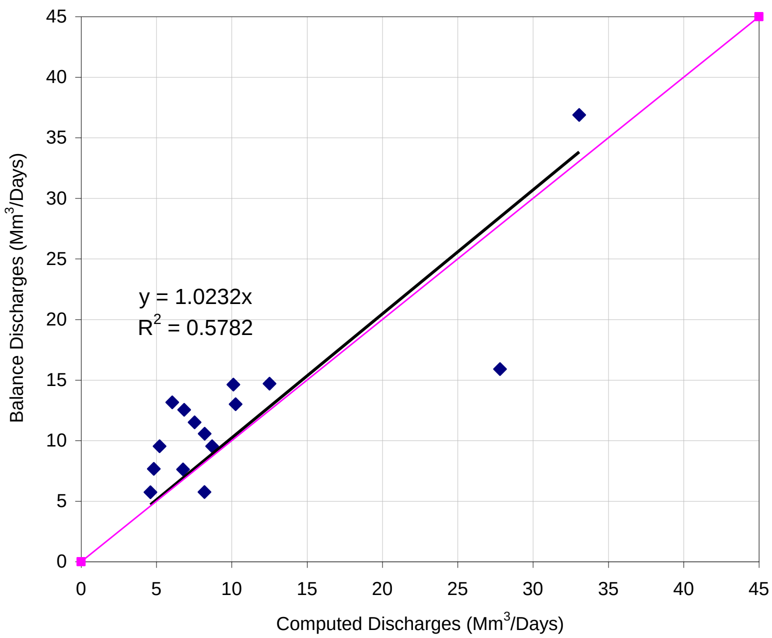

Figure 6: Relationships between the Computed and Observed Discharge at Ed Deim Station - Dry (Jan-May 1985)

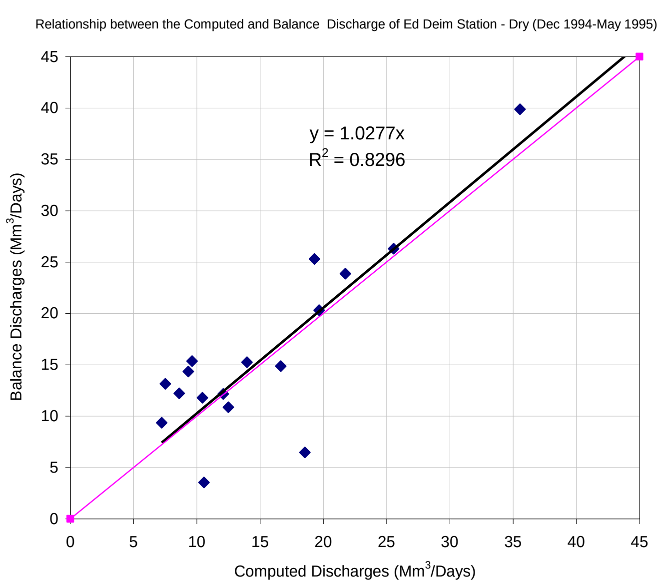

Figure 7: Relationship between the Computed and Observed Discharge at Ed Deim Station - Dry (Dec 1994-May 1995)

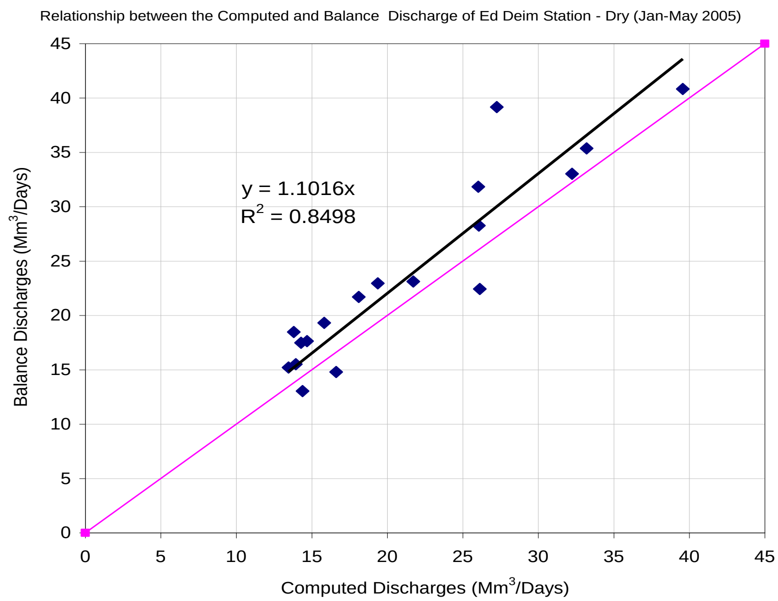

Figure 8: Relationships between the Computed and Balance Discharge at Ed Deim Station - Dry (Dec 2004-May 2005)

Flood Period (June – November):

The water balance for the wet season was also done for Ed Diem station. The results are shown in figure 9 to figure 11 respectively for the three years 1985, 1995 and 2005.

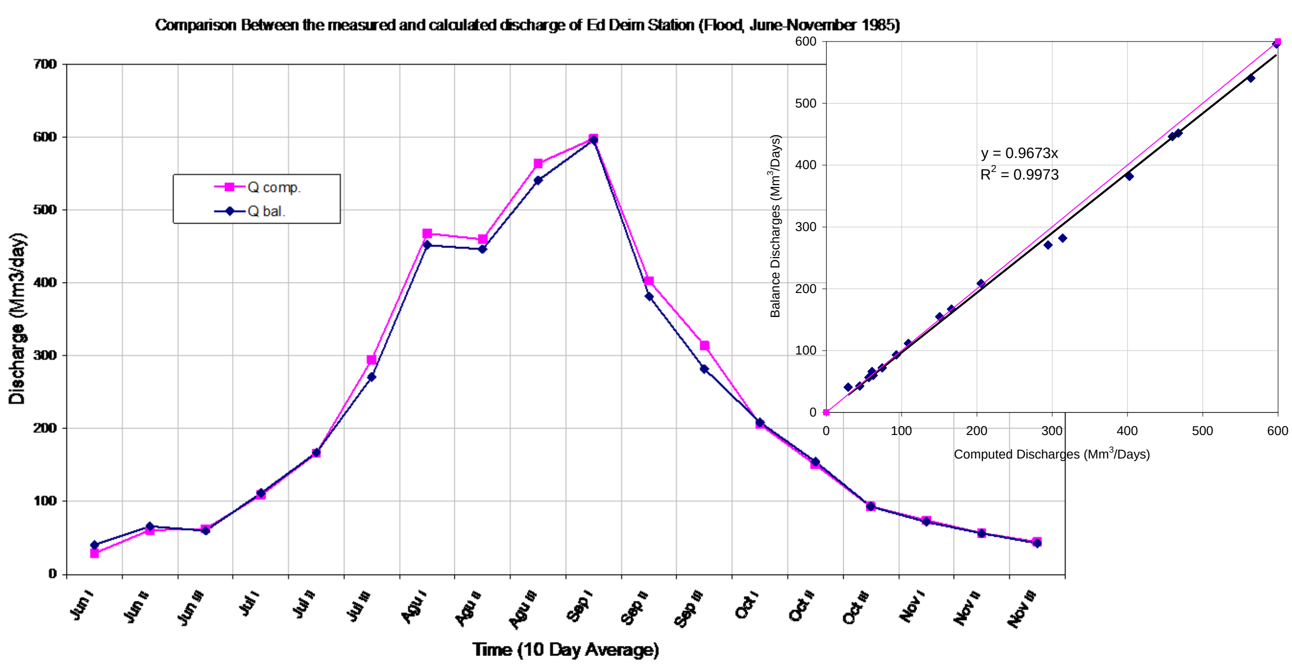

Figure 9: Comparisons between the Computed & Balance Calculated Discharge at Ed Deim Station - Flood (June-November 1985)

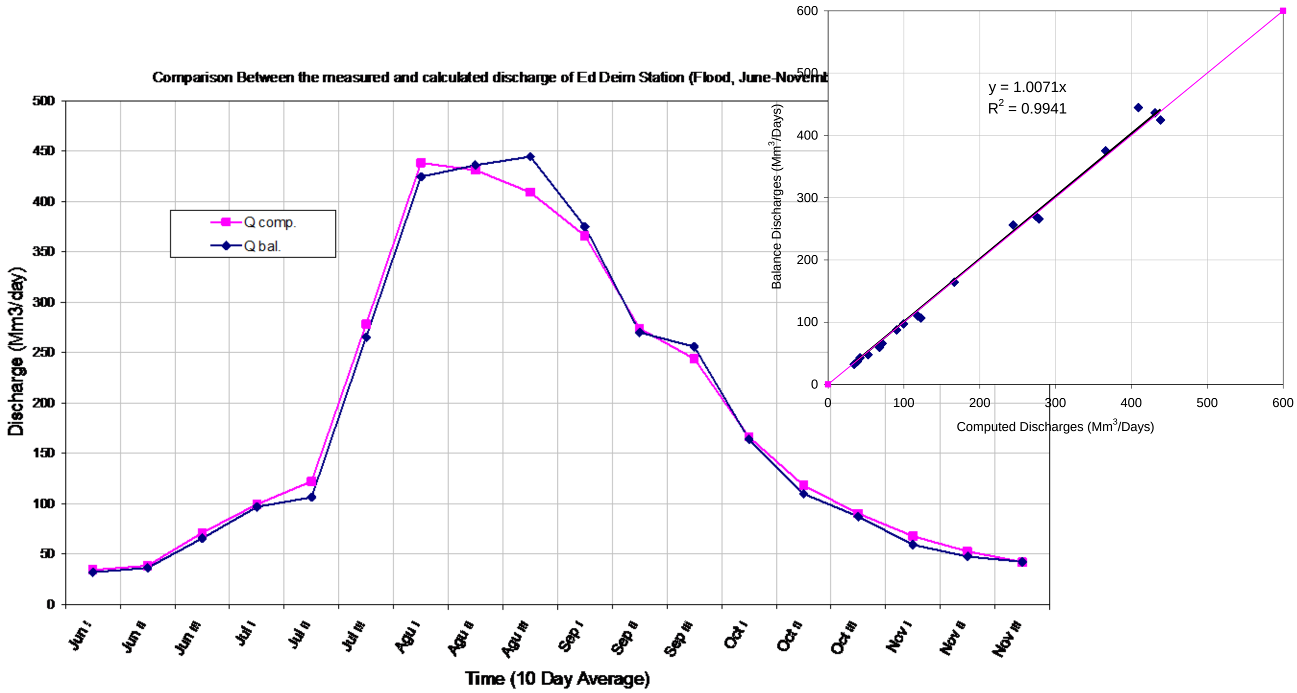

Figure 10: Comparisons between the Computed & Balance Calculated Discharge at Ed Deim Station - Flood (June-November 1995**)**

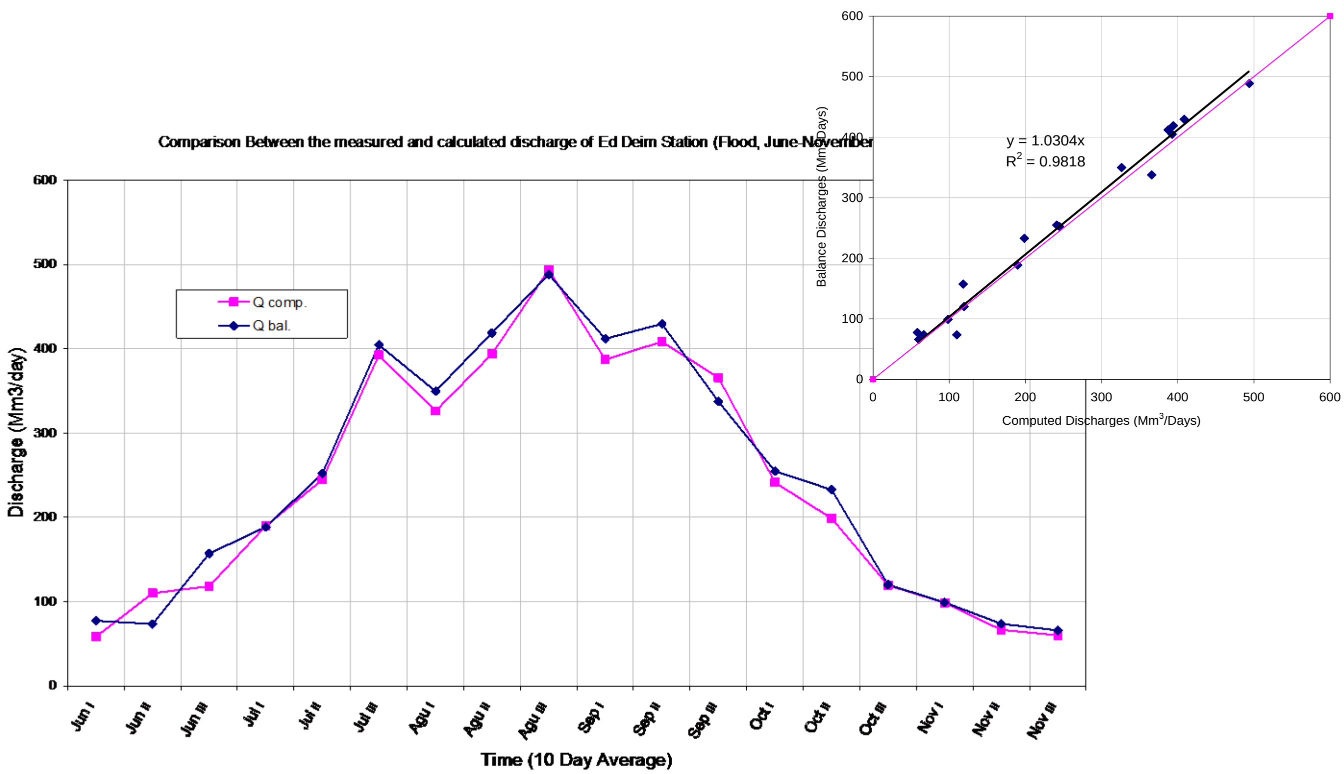

Figure 11: Comparison between the Computed & Balance Calculated Discharge at Ed Deim Station - Flood (June-November 2005)

Daily water balance at Ed Deim – Dry Period (December – May):
The water balance for daily basis for the dry season in Ed Diem was performed the results are shown in figure 12 to figure 14.

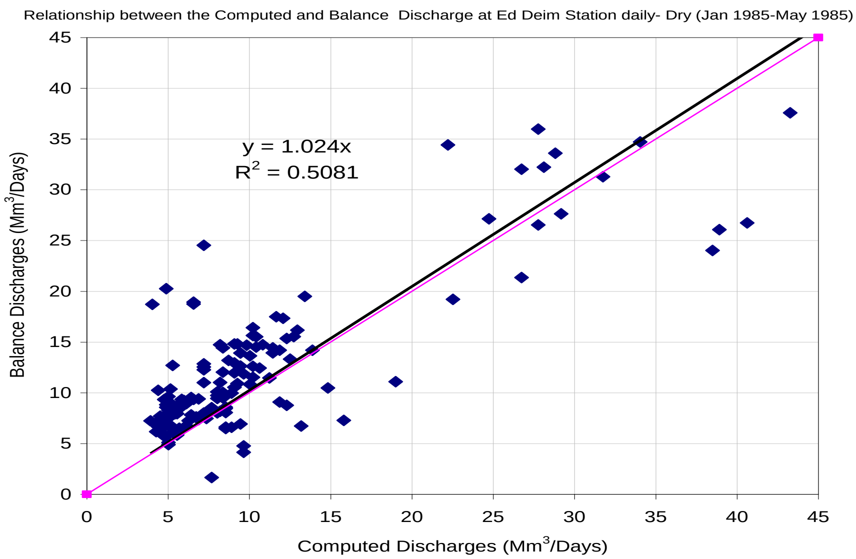

Figure 12: Comparison between the Computed & Balance Calculated daily Discharge at Ed Diem –Dry (Jan 1985 – May 1985)

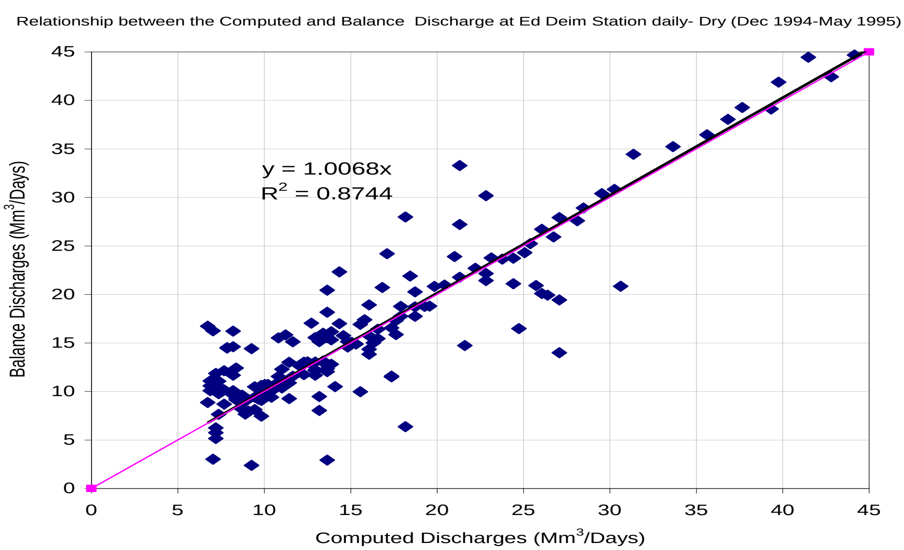

Figure 13: Comparison between the Computed & Balance Calculated daily Discharge at Ed Diem –Dry (Dec 1994 – May 1995)

It is observed that the balance discharge for 1985 is always higher than the computed discharge. The error in the water balance in this period is not systematic compared with water level downstream Roseires dam. These errors in the balance calculated discharge occurred due to the storage as shown in figure 12. It is observed that the result of the balance in 1995 is almost symmetric expect for the period after 20 April as shown in figure 13

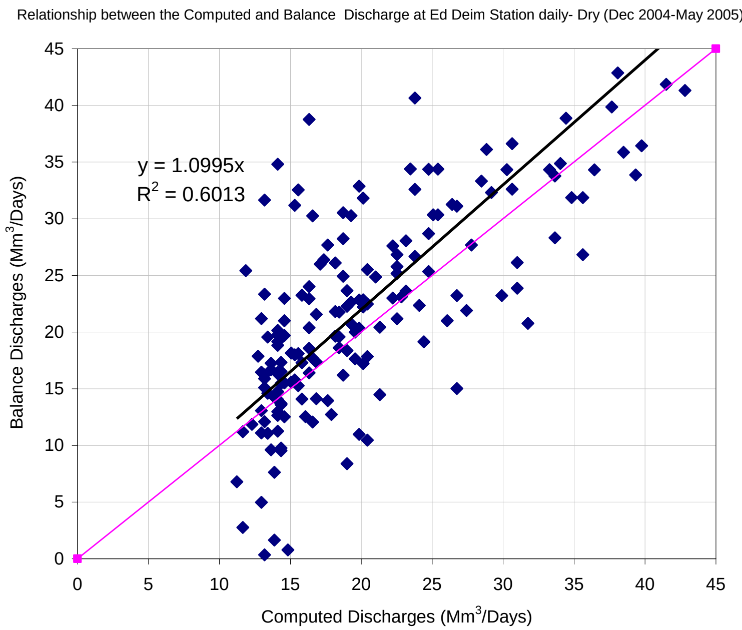

Figure 14: Comparison between the Computed & Balance Calculated daily Discharge at Ed Diem –Dry (Dec 2004 – May 2005)

The result of the balance in 2005 is not good at all and this may be due to the quality of data (the bathymetric survey of 2005 is not accurate).

Conclusion and Recommendations

References

Improving Water Management Practices in the Rahad Scheme

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Abstract

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.

Introduction

Studies of irrigation systems particularly in the developing countries always reveal a wide gap between expectation and reality. Several researchers in Sudan studied the deterioration and the low performance in Gezira scheme within the context of inadequate irrigation management and the need for institutional reforms. Baily and Lenton (1984) outlined a procedure for gathering and assessing information on water delivery performance of the Gezira scheme. The Rahad Irrigation project is considered among one of the scheme that could have a huge potential of expansion in the near future. The water supply sources for the Rahad scheme are the Blue Nile River and the Rahad seasonal river. Mena pumping station diverts water from the Blue Nile River to the Rahad scheme through the Rahad Supply canal. During the flood or wet season that is between August and October, the supply to the Rahad scheme is augmented from the Rahad Seasonal River. Water management and irrigation efficiency of the Rahad Scheme was studied by a number of researchers. Hamad (2006) investigated the performance oriented management approach for the Rahad irrigation system using remote sensing and GIS. The broader objective of Hamad work was to achieve a performance oriented attitude in managing irrigation systems through the development of a decision support tool that help to evaluate the in-season and overall season performance. The International Water Management Institute (IWMI) in Sudan, during the early nineties, carried out performance evaluation study for the Rahad Scheme (Shafique, 1994).

Despite such effort, there is no system based management style in the Rahad scheme and management relies on long experience of the staff. Consequently, operation decisions are observed to be fully determined by ad hoc request, personal experience, urgencies of the water users, and releasing more and probably unwanted water to minimize complaints and conflicts with politician. Such style of water management poses a huge burden and stresses on the scheme infrastructures in terms of maintenance and operation cost. As a result of poor water management, sedimentation is considered one of the most serious problems in the Rahad scheme. The carrying capacity of the irrigation system is decreased. The quantities of sediments entering the scheme during the period July to October 1996 was estimated to be 0.6 million ton. The total amount of sedimentation along the supply canal is reported to be 4.2 M m^3. It affect very much bed level slope, being reduced from 4.1 cm/km to 3.5 cm/km and the carrying capacity from 8.6 to 4.1 M m^3/day . The supply canal is subjected to continuous breaching whenever the discharges supplied by the pumps exceed 4.1 M m^3/day (Ahmed at al., 1996).

This study aims to investigate and develop proper operational water management tool for the Rahad irrigation project that could potentially improve the irrigation efficiency of the scheme and minimize the maintenance and operational cost of the water supply infrastructures. The study explore options of augmenting the supply from the Rahad seasonal river during the wet season (August-October) in order to minimize the sedimentation problems in the supply canal and the operation and maintenance cost of the pumping units.

Performance of Irrigation Systems: Concept and Assessment

There is almost a consensus that a good irrigation water supply system must be judged by three primary criteria, adequacy, timelines and equity. These characteristics will provide an understanding of the management capacity to allocate, schedule, and distribute water in an irrigation system. Other important criteria by which the health of an irrigation water supply can be judged include an efficiency measure, which is widely used in assessing the performance of the conveyance system. Generally the performance indicators of the irrigated agricultural system can be categorized into three (Bos et al., 1993): the water supply indicator; the agricultural performance indicators; and the economic, social and environmental indicators. Table 1 describes briefly the main performance indicators for an irrigation delivery system.

Table 1 Some Indicators of Irrigated Systems Performance (Hamad, 2006)

Water Supply Indicator	Agricultural Indicators	Socio-economic and Environmental
1. Efficiency Water Use Efficiency Conveyance Efficiency System Efficiency 2. Adequacy 3. Reliability 4. Dependability 5. Maintenance Indicator	1. Yield 2. Production 3. Land use	1. Sustainability 2. Productivity 3. Profitability 4. Users Participation 5. Cost

Irrigation Efficiency

The irrigation efficiency can be defined at different levels in an irrigation system. These are the conveyance efficiency, distribution efficiency, field application efficiency, and the overall project efficiency (BOS 1979, 1997):

$$\textit{Concveyance efficiency}: \quad e_c = \frac{V_d + V_2}{V_c + V_1}$$

$$\textit{Distribution efficiency}: \quad e_d = \frac{V_f + V_3}{V_d}$$

$$\textit{Field Application efficiency}: e_a = \frac{V_m}{V_f}$$

$$\text{Pr}\textit{oject Overall Effiency}: \quad e_p = \frac{V_m + V_2 + V_3}{V_c + V_1}$$

where: V_1= inflow from other sources, V_2= non-irrigation deliveries from conveyance system, V_3= non-irrigation deliveries from distribution system, V_d= volume delivered to distribution system, V_c= volume diverted or pumped from the river or source, V_f= volume furnished to the field, V_m= volume needed to maintain soil moisture above a minimum level required for the crop. If the flow from other sources $V_{1,}$ and the non-irrigation deliveries V_2 & V_3 are insignificant compared with the volume of water delivered to maintain soil moisture at the required stage of the crop, the project overall efficiency can be expressed as:

$$e_p = \frac{V_m}{V_c} = e_c \; x \; e_d \; x \; e_a$$

Adequacy

A fundamental concern of water delivery systems is to deliver irrigation water to adequately irrigate the crops, and its measure will reflect the ability of the irrigation system to supply enough water for satisfactory growth of the irrigated crops. This amount of water is a function of the irrigated area, the crop consumptive use requirements, water application losses, and the actual practices such as land preparation and salt leaching. On the other hand, the adequacy of water delivered is dependent on the availability of water supplies, specified delivery schedule or demand, the capacity of hydraulic structures to deliver water according to the schedules, and the operation and maintenance of hydraulic structures. An instructive measure of adequacy was first by Levine (1982), namely the Relative Water Supply (RWS):

$$RWS = \frac{Water\ Supplied}{Demand\,(Water\ required)} = \frac{Irrigation + Rain}{ET + Perc + Seepage}$$

Oad & Levine (1985), Oad and Padmore (1989) address the issue of the adequacy of water supplies to evaluate how well water was managed in irrigated rice fields under various supply levels. They slightly modified the RWS defined by Levine (1982), by using the effective rainfall instead of actual rainfall.

El Awad (1991) pointed out that, this definition however, neglects the fact that although the total supply during the whole season may be satisfactory, some periods of water stress may be experienced. A measure of the adequacy of water supplies must therefore reflect how the water supply pattern matches the evapotranspiration needs of the crops. To cater for this variation Lenton (1984) studied the adequacy of water supplies to non-rice irrigation systems, and defined a measure which is called the Water Delivery Performance (WDP). The measure takes into consideration the timing of water supply in relation to crop development:

$$WDP = \sum^{T} K_t \left(\frac{V_t}{V_t^*} \right)$$

Where:

V_t=actual volume of water delivered to the irrigation area during period t of the crop growing season

V^*= target volume of water to be delivered to the irrigation area during period t of the cropping season.

K_t= a weighing factor indicating the relative importance of the different crop stages during the period t. The values of K_t are normalized so that they sum up to unity over the whole season.

T= number of time periods in the season.

Clearly the WDP may take values between zero and unity or greater than unity in which case Lenton's suggested to take the reciprocal. According to Baily (1984) , the WDP can be mathematically defined as:

$$WDP = \frac{1}{n}\sum_{t=1}^{n} e(t)$$

$$e(t) = \begin{bmatrix} \dfrac{V(t)}{V^*(t)} & if \quad V(t) < V^*(t) \\ \dfrac{V^*(t)}{V(t)} & if \quad V(t) > V^*(t) \end{bmatrix}$$

Where: V(t) is the total volume of water entering the irrigation system during period t, $V^*(t)$ is the total target volume of water to be supplied to the system during time t, and n is the number of periods in the cropping season. WDP would equal 1.0 if the water delivered during each watering is equal to the crop water requirement for that watering. It would equal to zero if no water is delivered at all. The index could register both under-supply and over-supply within the 0-1 range. In their effort to capture the problem of adequacy variation with respect to time and location, particularly in large irrigation systems, Molden and Gates (1990) defined system performance relative to adequacy as the spatial and temporal average of the ratio of delivered or required amount of water:

$$P_A = \frac{1}{T}\sum^{R}\frac{1}{R}\left(\frac{Q_D}{Q_R}\right) \qquad Q_D \le Q_R$$

Where: P_A= adequacy index, Q_D= delivered amount of water, Q_R= required amount of water, R= region or sub region served by the system at time T. The index is calculated from the average of discrete quantities of Q_D and QR defined at discrete locations of the water delivery system in a region or a sub-region R, and for finite times t over T. When $Q_D>Q_R$, delivery is considered adequate regardless of the magnitude of the excess. Weighted averages could be used when it is desired to design water delivery priorities to a certain region in the system.

Description of Rahad Scheme

The Rahad Agriculture scheme was planned during the mid 1960s. Execution period began in 1973 up to 1977 when part of the Rahad Scheme was put under cultivation and the whole scheme fully operated in 1981. All the studies done on Rahad scheme revealed the area suitability for diversified pattern of cropping. The area of the scheme is well leveled and it extends on the eastern bank of the Rahad River. The total area is 126000 hectares (300,000 Fed) extending from South to North with a gentle slope of 10 cm per km, with total length of 120 km and an average width of 10-25 km. 95% of the soils in the area are heavy clay. Soils are classified as a very fine clay soils with clay percentage of 75% in the south and decreases towards the north. The infiltration rates of Rahad soil is moderately low (0.8-1.9 cm/hr). The hydraulic conductivity range from 1.7 – 4 cm/hr and the dry bulk density values range from 1.6 – 1.9 g/cm^3. Effective soil depth is (100-120 cm) approximately. The scheme lies in the semi dry zone with short rainy season from July to October. Annual rainfall increases southwards from 300 mm in the north to 400 mm in the South. Peak rainfall is in August. Evaporation from open water (E_0) is estimated to range from 3000 mm/annum (Wad Medani) in the North to 2450 mm/annum (Sennar) in the South. Highest daily evaporation was 10 mm/day in the North and 8 mm/day in the South during May. Maximum daily air temperature is 41.6 ^oC in the North during May and 41.3 ^oC in the South during April while minimum daily air temp is about 14.3 ^oC during January. Relative humidity (RH) is maximum during August reaching 67% and minimum during April about 18%. Maximum wind speed is during June and July reaching 4.9 m/sec. Table 2 summarize the climate in the Rahad Scheme.

Table 2 Climate Average in Rahad Scheme

Climate Variable	North of Scheme	South of Scheme	Month
Rainfall (mm)	300-350	350-400	July-October
Maximum daily air temperature (^oC)	41.6	41.3	May & April
Minimum daily air temperature (^oC)	14.3	14	January
Maximum Relative Humidity (RH) %	67	64	August
Minimum Relative Humidity (RH) %	18	21	April
Maximum Wind Speed (m/s)	4.9	3.6	June
Minimum Wind Speed (m/s)	2.2	2.2	October
Maximum Daily Evaporation (mm/day)	10	8	May
Total Evaporation (mm/year)	3000	2450	January-December

Crop rotation in the Rahad scheme began in 1977 with two course rotation and main the crops are cotton and groundnuts up to 1981. Tenancy holding in the Rahad Scheme is 22 Feddan for field crops, five Fed. For Vegetable crops and 10 Fed. For fodder crops. In the season 1981/82 sorghum (Dura) was introduced in the scheme for some local socio-economic reasons and the rotation become three course rotation: Cotton 11 Fed., Groundnut 6.5 Fed., and Dura 5.5 Fed. That rotation continued up to 1989 when wheat was introduced for national food security reasons and the rotation became a four course rotation: Cotton, wheat, groundnut and Dura 5.5 fed each. Vegetables, fodder and forestry are introduced in the rotation to satisfy the needs of inhabitants in the scheme. The adoption of free market economy in the scheme (1994) had its own implication on the Rahad rotation. The current situation for the future policy is to react positively to the market signals (i.e. supply, demand and prices) and the rotation in the scheme may include new crops such as Sugar cane, Maize, Sesame and Sunflower. The recommended Sowing Dates of the Main Crops in the Rahad Scheme for Groundnut is from June 1st to June 20th ; Cotton from early July to mid of August; Sorghum (Dura) between 1st to 10th of July; and Wheat between November 3rd to December 12th.

Scheme Management Organization

The scheme runs by the Rahad Agricultural Corporation (RAC), Irrigation Water Corporation and Farmers Union. The Rahad scheme is divided into nine divisions. Each division called group and administered by Agricultural Group Manager. The group manager is assisted by five field inspectors, an agricultural engineer and one plant protection specialist. Thirty water watchmen assist in supervising and operating the intermediate regulators of the minor canal and field outlet pipes and oversee the progress of irrigation and other agricultural activities in the field. The Irrigation Water Corporation is responsible of operating the main system of irrigation from the Blue Nile where the pumps are situated up to and including the off-take structures of the minor canals. Minor operation is done by the Rahad Agricultural Administration.

Water Supply Infrastructure of the Scheme

Figure (1), below shows schematic of the major water supply infrastructures of the scheme which consist of: (a) Mena Pumping station which divert water from the Blue Nile to the scheme; (b) Abu-Rakham barrage which serve as the major regulator of both the supply from

Rahad river and the Blue Nile River; (c) Supply canal from Mena to Abu Rakham; (d) a canalization system of main, major and minor canals which distribute water from Abu-Rakham to the field.

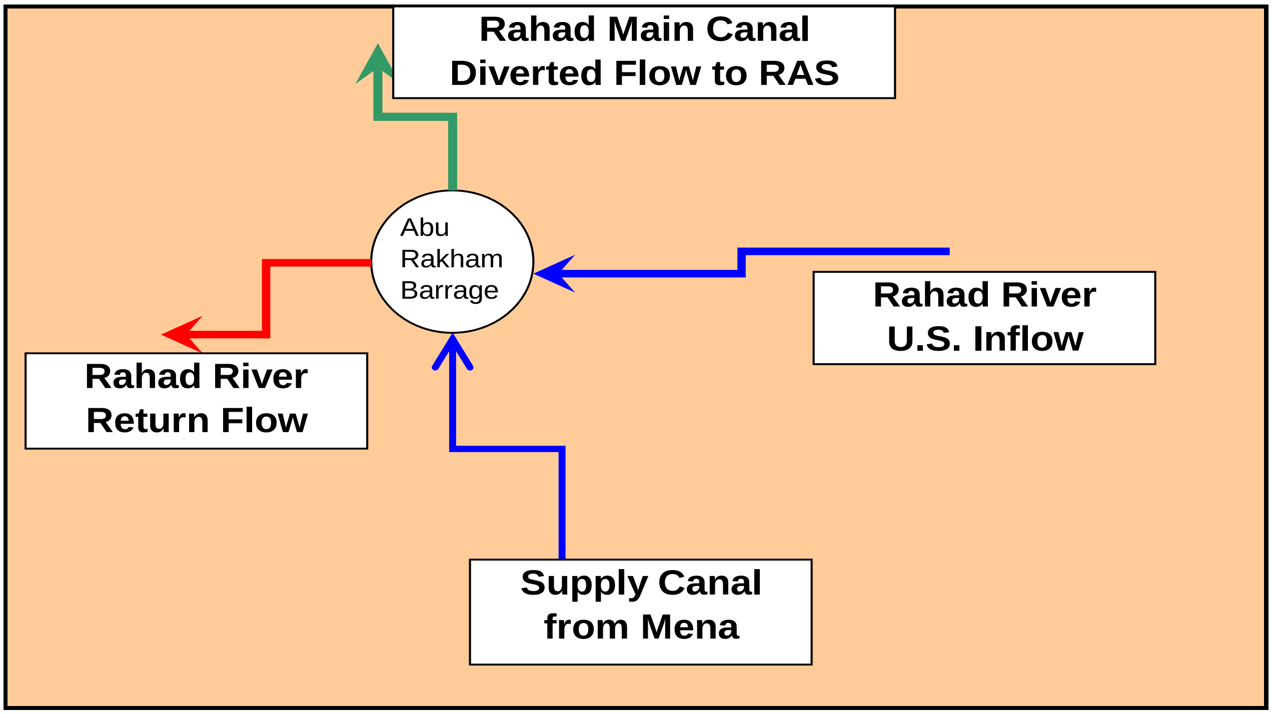

Figure 1: Schematic of the Water Supply Infrastructure (Rahad Scheme)

Mena Pump Station

Eleven electrical centrifugal pumps are suited 200 km downstream Roseries Dam on the eastern bank of the Blue Nile River for the purpose of irrigating the Rahad Agricultural Scheme. Operation head is between elevation 421.7m and 417.8m below which cavitations will take place and may cause damage to the pumps. The capacity and number of pumps was determined according to the maximum Crop Water Requirements (CWR) during the growing season. The peak CWR in the Rahad Scheme is 28 m^3/Fed/day and that figure is used in the design of all irrigation networks. The Capacity of Main Canal=228 m^3/Fed/day x 300,000 Fed = 8.4 Million m^3/day. The Capacity of the pumps is 9.55 m^3/sec per pump. The total discharges given by operating 10 pumps for 24 hrs (design capacity) are given as follows:

- Total Discharge pump capacity = 10 pumps x 9.55 m^3/sec per pump x 24 hrs/day x 3600 sec/hr = 8.25 Million m^3/day. While at low head it may reach up to 9.0 M m^3/day (10.5 m3/sec per pump). One pump is left as a reserve.

After 38 years of work, pumps situation has been deteriorated. Three pumps are out of work and the remaining eight pumps need urgent maintenance and repairs. Current operation of pumps does not exceed 20 hours per day due to power outage and lack of proper maintenance. Original design was based on 24 hrs continuous operation.

The inlet channel to Mena pumping station is 100 m long and 80 m wide. Its main function is to link the pump station to the Blue Nile River. Bed Elevation is at 413 m. Contribution of the

Blue Nile through the inlet channel and pump station is about 55% of the total seasonal consumptive use of the RAS. Seasonal sedimentation occurring during the flood was and still the main constraints which limit water availability in the RAS.

Supply Canal

The Supply canal is setup to convey discharges from pump station to the Rahad River one km upstream of Abu Rakham Barrage. It extends for 81 km from west to east with a design capacity of 105 m^3/s, water slope of 4.5 cm per km, water velocity of 0.619 m/s, bed width of 40 m and water depth of 3.6 m. The section of the can is of trapezoidal shape with side slopes 2:1, critical command of 1.72 m and full supply level maintained at elevation 432.0 m downstream the pumps. Eight bridges are set up along the supply canal. Small pumps are installed along the supply canal to irrigate some area of the Blue Nile Corporation (Total discharges of 2,000 m^3/d). Two siphons are constructed to drain rain water during the rainy season at Kilo 43 and 77. The supply canal crosses Dinder River through a Siphon at Kilo 23.

Abu Rakham Barrage

This is a diversion structure set up across the Rahad River to divert water from its normal channel into the Rahad main canal (Figure 2). Fifteen vertical sluice gates are constructed for the operation of the barrage across the Rahad natural stream. There are nine gates operated on the natural stream of the Rahad River while six gates are operated on the main canal system. Dimensions of the gates are 6m in length and 4m in width.

Figure 2: Regulators at Abu Rakham Barrage

The discharge is computed using the following equation:

$$Q = 1.431\left(O_t - 0.169\right)\sqrt{h} \qquad h \le 0.10\ m$$
$$Q = 1.178(O_t - 0.378)\sqrt{h} \qquad 0.11 \le h \le 0.25\ m$$
$$Q = 1.182\left(O_t - 0.012)\sqrt{h}\right) \qquad h \ge 0.264m$$

Where: Q is the discharge in Mm^3/day, O_t is the total underneath opening in (m) of the sluice gate and h is the head difference in (m).

Main Canal System

It extends for 101 km with a carrying capacity of 8.64 M m^3/day. The network system which is connected to the main canal consist of 215 km length of majors, 780 km of minors, 350 km of tertiary canals (Abu Ishreen) length is 4500 km. The main canal problems are the same as those of the supply canal (sedimentation).

Analysis and Results

The data collected for Rahad scheme consist of (a) historical monthly demands both requested (water indents) and actual supplied to the scheme for the Period 1987-2006; (b) Historical monthly Rahad seasonal flows and Rahad return flow after abstraction for the period 1980-2006; (c) Historical data of cultivated areas for each crop on 10-days basis for the period 2000-2004; (d) Climatological data which consist of rainfall and evaporation data on 10-days basis for the period 2000-2005; (e) Published data on crop coefficient for all the crops cultivated in the Rahad scheme; (f) Sowing dates for the crops in the Rahad scheme and (g) Capacity of the existing water supply and conveyance infrastructure of the scheme. This includes the capacity of the pumping unit at Mena, supply canal and main canals. Physical characteristics of Abu-Rakham regulators and stage-discharge relationship.

Data Pre-Screening: Supply versus Demand Analysis

To investigate the adequacy of the two water supply sources in meeting the historical irrigation demand of the scheme, the monthly supplied and requested demands (indent) were plotted and analyzed for the period 1987 to 2006 (Figures 3 to 5). It could be noted from the Figures, that the supply in some years exceed the requested demands (excess supply) and in other seasons there is a water shortage or deficit problems. The period between January 1st, 1994 to December 1999 (Figure 6), showed a continuous trend of water deficit problems in the scheme where the historical water indent or requested demand exceeds the supply at Abu-Rakham. The months of June , September, October and November are considered to be the water demand period for the crops (Figure 8). The water shortage or water stress problems normally start in the months of September, October and November. This indicate that the major water shortage is associated with the operation of Abu Rakham barrage and Mena Station, during the period which start in august and end the last week of September.

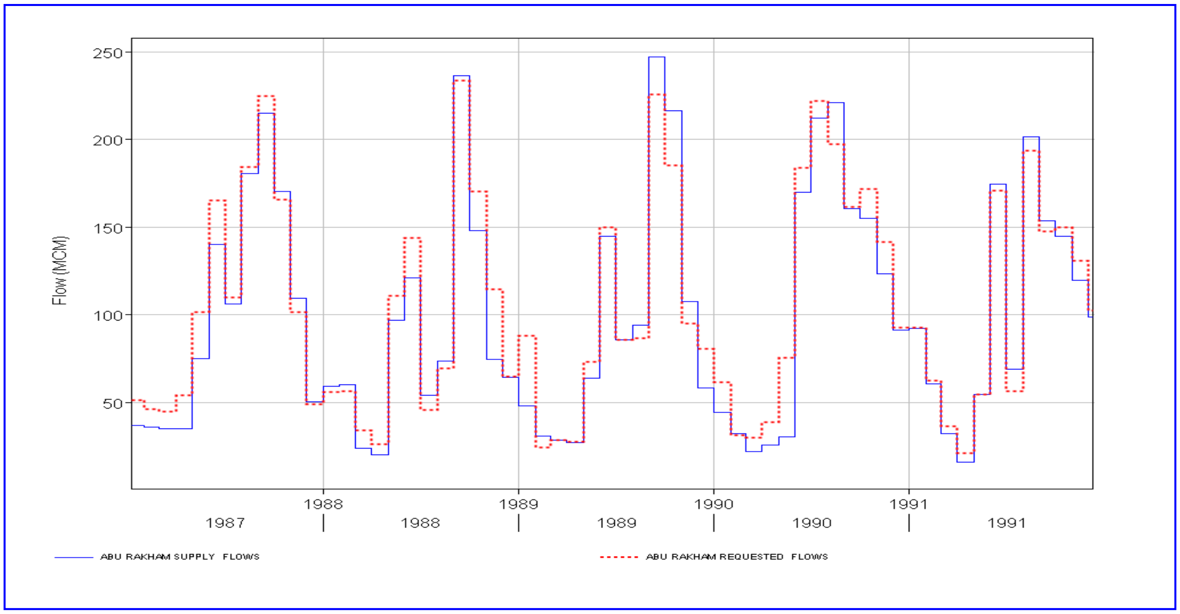

Figure 3: Supply versus Requested Demand: Abu-Rakham Station (Jan 1987 – Dec. 1991)

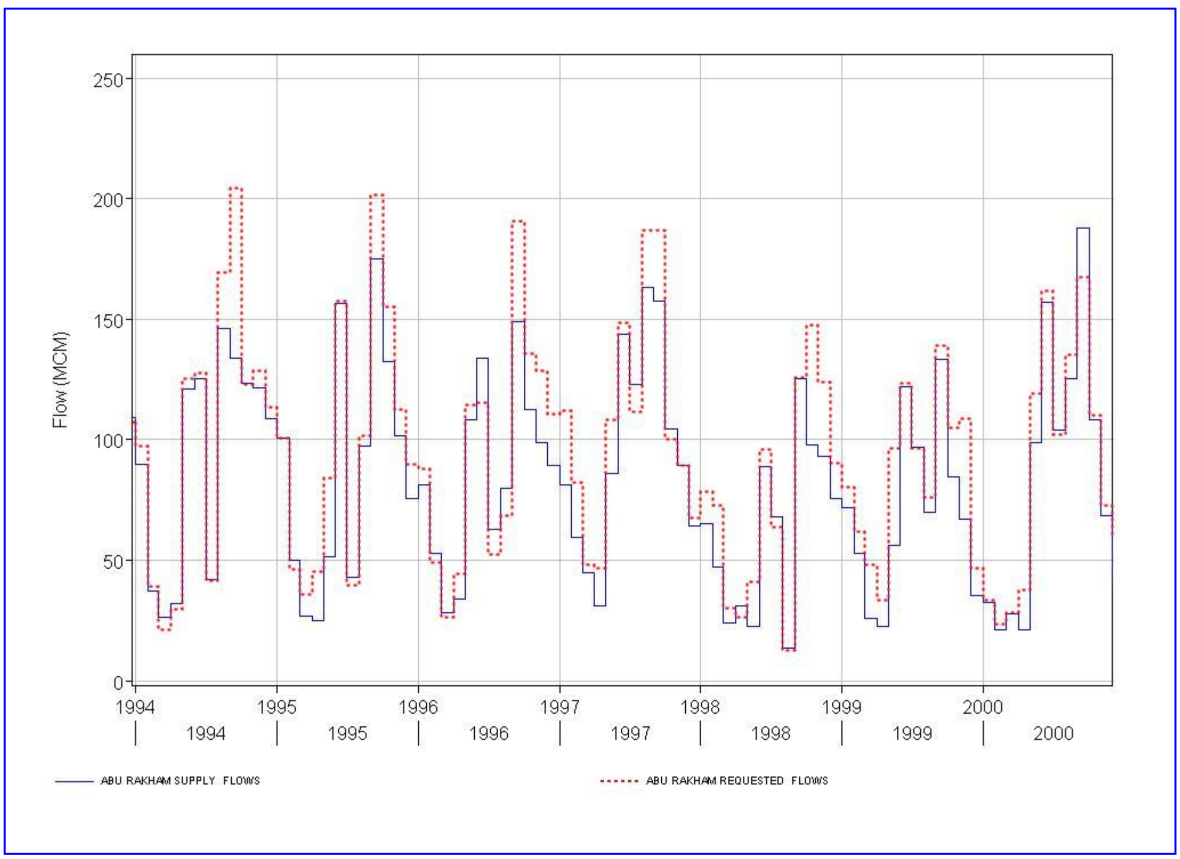

Figure 4: Supply versus Requested Demand: Abu-Rakham Station (Jan 1994 – Dec. 2000)

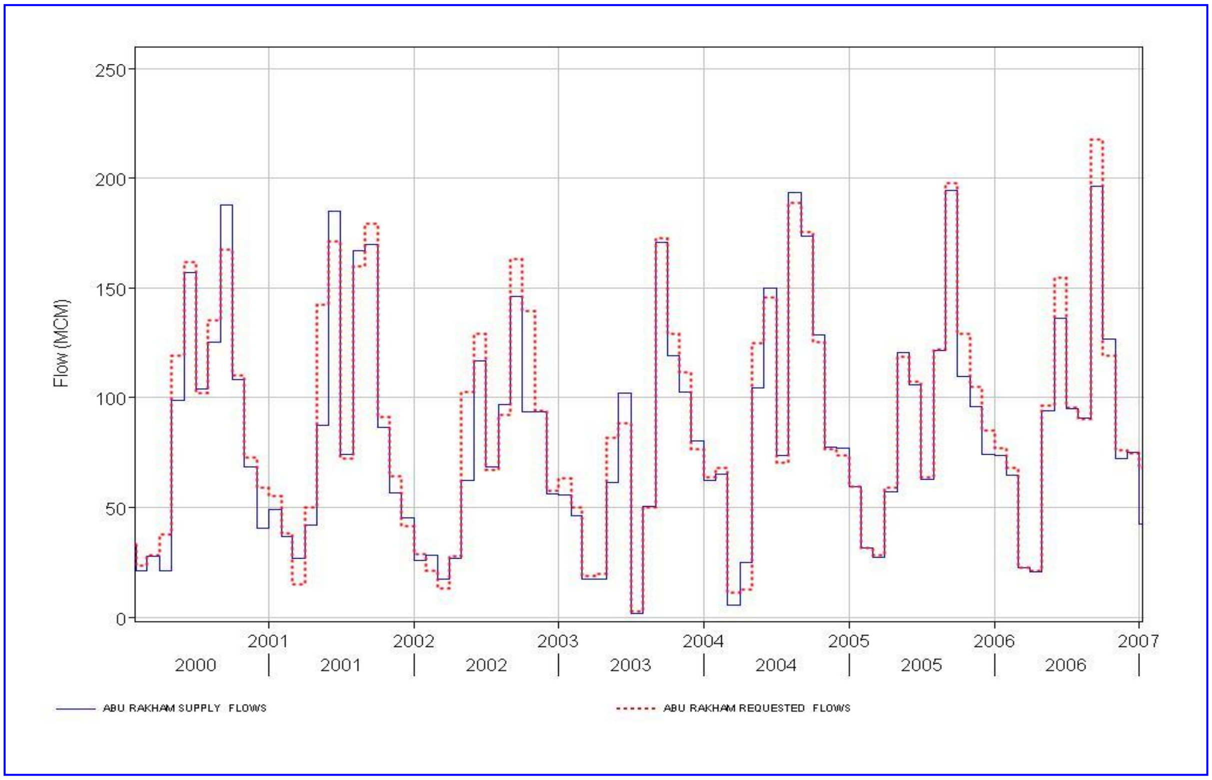

Figure 5: Supply versus Requested Demand: Abu-Rakham Station (Jan 2000 – Dec. 2006)

Estimation of Irrigation & Crop Water Requirements

To examine the water shortage problems the actual water requirements of the scheme for the years 2000-2004 were estimated based on a simple mass balance method. The mass balance equation, takes into consideration effective rainfall and actual crop water requirements or crop water uses rather than anticipated or requested demands which are based on planned irrigation areas.

The water balance method used to assess the irrigation requirements could be expressed as follows:

$$CWR = (ET_o K_c - RF)\,(Area\ Planted) + D + R + L + \Delta S$$

where: CWR represent irrigation or Crop Water Requirement, RF effective rainfall, ET_o is the reference Crop Evapotranspiration, K_c is the crop coefficient which depend on the type of crop and also varies with time, D deep percolation, R runoff, L leaching requirements and ΔS change in soil moisture storage. The central clay plane of the Sudan, where Rahad scheme is part of it, is characterized by being free from salts, flat and with high clay content. For these characters of Rahad soils, the leaching requirements, runoff and deep percolation is insignificant on water application. During each irrigation soil moisture is brought to its original level, then ΔS=0 and thus the formula becomes:

$$CWR = (ET_o K_c - RF)\,(Area\ Planted)$$

An Excel-Spreadsheet was developed to compute the crop water requirements for the Rahad scheme on monthly basis. The CWR calculations are tabulated for the Years 2000-2004 as shown in Table 3. It can be noted from the Table that, the months of August, September, October and November form the period of maximum demand and water shortage or water stress problems, with September and October considered to be the peak demand months for the growing season. On average annual basis about 45% of the water supplied to the scheme is diverted from the Rahad River at Abu-Rakham Barrage during the wet season of July to October and 55% is diverted from the Blue Nile River through Mena Pumping station. As could be realized from the Table, the total annual release from Abu-Rakham to the main canal of the project, always exceeds the net crop water requirements of the scheme with an average factor of 1.43 (i.e. Average Annual Release to the main Canal of the scheme = 1.43 x Average Net Annual Crop Water requirement). This includes the water requirements for the forested areas. Considering conveyance losses and deep percolation losses such annual quantity of supplied water should be adequate to meet scheme water demands and account for more than 30% losses. This implies that, the total annual water supplied to the scheme is adequate but the timing and management of water supply sources are the main causes of water deficit and water stresses problems during the growing seasons of the crop. It could also be noted from the table that the total annual yield of the Rahad river alone exceed the water demand for the scheme by a factor than ranges from 1.4 to 3.2. This indicate that through proper management of the regulators at Abu-Rakham Barrage the supply from Rahad seasonal river could be augmented during the months of August, September and October to meet the majority of the water demand of the scheme with minimum dependence from Mena Pump station which could possibly be functioning during the dry season only and/or as a backup to supplement the Rahad during low yield years. Such proposed operational rule for the scheme, would decrease the operation and maintenance cost of the pumping station and could potentially reduce the siltation and sediment dredging operation on the supply canal. Considering the fact that, the Blue Nile River carries high concentration of sediment during the months of August to October, minimizing the Mena Pumping operation during this period, could potentially reduce the quantity of sediments entering the supply canal of the Rahad scheme.

Table 3 Crop-Water Requirements Computations and Comparison of Supply versus Demand Rahad Irrigation Scheme for the Period 2000-2004

Month	Column (1)	Column (2)	Column (3)	Column(4)	Column (5)	Colum (6)	Colum(6)
	$ET_o \sum_{1}^{n} K_c(crop\ J) \times Area\ (crop\ J)$	RF x Total Monthly Planted Area	CWR = Column(1)-Column(2)	Mena Supply	Rahad Inflow	Rahad Return Flow	Actual Supply
	Million Cubic Meters	Million Cubic Meters	Million Cubic Meters	MCM	MCM	MCM	MCM
June	31.0	5.6	25.5	97.3	0.0	0.0	98.9
July	90.6	30.4	60.2	61.0	159.3	8.7	157.2
August	156.1	48.0	108.0	2.0	344.2	152.5	103.9
Sept	198.4	23.4	175.0	4.5	377.7	156.7	125.3
October	178.5	13.8	164.8	8.1	236.5	79.9	178.6
November	114.5	0.0	114.5	49.3	112.5	39.0	108.2
Dec.	45.6	0.0	45.6	57.4	0.0	0.0	58.5
Jan	43.8	0.0	43.8	30.6	0.0	0.0	35.5
Feb	33.2	0.0	33.2	34.4	0.0	0.0	32.5
March	14.8	0.0	14.8	21.9	0.0	0.0	21.1
April	7.4	0.0	7.4	26.9	0.0	0.0	27.6
May	13.6	0.0	13.6	19.3	0.0	0.0	21.3
Year 2000	927.5	121.2	806.3	412.6	1230.2	436.6	968.4
June	14.6	1.5	13.1	88.4	0.0	0.0	87.4
July	71.2	26.1	45.0	68.0	144.0	32.1	185.1
August	166.1	66.7	99.4	1.3	377.8	267.3	74.2
Sept	209.3	29.6	179.8	0.6	448.7	262.9	166.8
October	177.0	7.3	169.6	0.0	188.5	27.6	169.8
November	106.9	0.0	106.9	45.2	30.1	0.0	86.6
Dec.	23.4	0.0	23.4	47.2	5.4	0.0	56.6
Jan	21.2	0.0	21.2	43.8	0.0	0.0	40.7
Feb	20.3	0.0	20.3	52.8	0.0	0.0	49.0
March	15.3	0.0	15.3	46.3	0.0	0.0	36.8
April	2.8	0.0	2.8	33.8	0.0	0.0	26.6
May	9.4	0.0	9.4	50.7	0.0	0.0	42.1
Year 2001	837.5	131.2	706.3	478.1	1194.4	589.9	1021.4
June	14.6	4.4	10.2	82.1	0.0	0.0	62.3
July	71.2	54.4	16.7	81.5	87.3	23.7	116.8
August	166.1	134.2	31.9	3.1	287.1	238.1	68.5
Sept	209.3	38.0	171.3	3.9	294.5	229.4	96.7
October	177.0	1.6	175.4	70.1	128.6	44.6	146.0
November	106.9	0.0	106.9	87.3	0.0	0.0	93.6
Dec.	23.4	0.0	23.4	89.9	0.0	0.0	93.5
Jan	21.2	0.0	21.2	43.3	0.0	0.0	45.5
Feb	2.3	0.0	2.3	30.0	0.0	0.0	25.9
March	0.5	0.0	0.5	27.9	0.0	0.0	28.3
April	0.7	0.0	0.7	22.9	0.0	0.0	17.4
May	2.4	0.0	2.4	33.5	0.0	0.0	26.6
Year 2002	795.6	232.5	563.1	575.4	797.5	535.7	820.9
June	11.9	5.1	6.8	71.6	0.0	0.0	61.4
July	74.2	41.9	32.3	14.4	322.8	218.0	101.9
August	116.7	99.4	17.4	2.6	580.0	579.1	1.7
Sept	148.6	28.1	120.5	1.4	587.1	536.9	50.5
October	139.7	1.2	138.5	2.5	249.6	81.1	170.9
November	105.7	0.0	105.7	80.4	0.0	0.0	119.1
Dec.	46.8	0.0	46.8	101.2	0.0	0.0	102.4
Jan	41.8	0.0	41.8	56.5	0.0	0.0	56.2
Feb	26.0	0.0	26.0	54.3	0.0	0.0	55.7
March	2.8	0.0	2.8	49.4	0.0	0.0	46.2
April	0.7	0.0	0.7	21.7	0.0	0.0	17.5
May	2.4	0.0	2.4	23.6	0.0	0.0	17.1
Year 2003	717.3	175.7	541.6	479.5	1739.4	1415.1	800.6
June	17.2	5.7	11.5	109.7	0.0	0.0	104.5
July	70.4	43.6	26.8	29.2	211.3	90.8	149.7
August	152.8	129.7	23.1	1.6	427.0	341.2	73.9
Sept	194.4	36.7	157.7	2.0	251.6	80.6	193.7
October	182.0	1.6	180.4	20.0	213.3	97.9	173.7
November	149.1	0.0	149.1	113.8	6.2	6.2	128.5
Dec.	71.6	0.0	71.6	77.5	0.0	0.0	77.5
Jan	52.3	0.0	52.3	82.5	0.0	0.0	80.3
Feb	36.2	0.0	36.2	66.4	0.0	0.0	62.3
March	3.1	0.0	3.1	68.6	0.0	0.0	65.0
April	0.7	0.0	0.7	14.2	0.0	0.0	5.3
May	2.3	0.0	2.3	31.9	0.0	0.0	24.9
Year 2004	932.1	217.4	714.8	617.3	1109.4	616.7	1139.2

Yield Frequency Analysis for the Rahad Seasonal River

To estimate the reliable yield for the Rahad River, frequency analysis for daily time series data (1980-2006) is conducted. Flow duration curves for each day of the period July 1st to October 31st is constructed. The corresponding yields at different assurance levels were estimated from the flow duration curve for each day of the wet period. The decadal yield is then estimated by adding the up the daily yields for the 10 days period. Figure 6 shows the computed Rahad yields at different assurance level. Summary of the results are shown in Table 4.

Figure 6: Rahad Yield at Different Assurance Levels

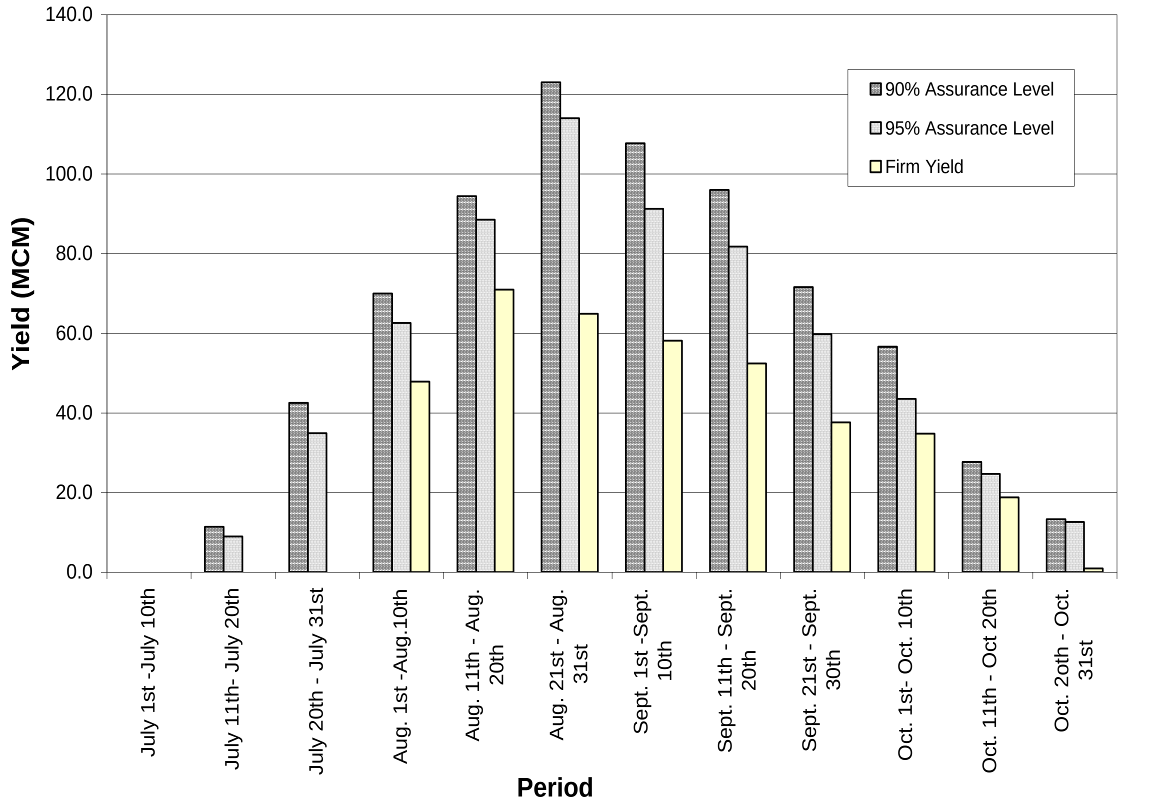

Table 4 Yield Analysis Results for the Rahad River

Decedal Period	Yield From Rahad River at Different Assurance Levels (MCM)						Net Water Requirement for Rahad Scheme (MCM)						
	Average	80%	85%	90%	95%	100%	Yr. 2000	Yr. 2001	Yr. 2002	Yr. 2003	Yr. 2004	Yr. 2005	Average
July 1st -July 10th	38.5	2.9	0.0	0.0	0.0	0.0	21.3	10.7	10.7	18.6	15.4	19.1	16.0
July 11th- July 20th	65.6	22.5	0.0	11.4	9.0	0.0	30.3	21.9	21.9	25.4	23.2	27.6	25.0
July 20th - July 31st	120.2	58.3	0.0	42.5	34.9	0.0	39.0	38.6	38.6	30.3	31.7	34.1	35.4
Aug. 1st -Aug.10th	107.0	81.2	76.1	**70.0**	62.6	47.8	47.6	50.4	50.4	35.4	46.3	40.1	45.0
Aug. 11th - Aug. 20th	120.8	103.2	99.6	**94.4**	88.5	71.0	51.6	54.3	54.3	38.0	49.8	43.3	48.6
Aug. 21st - Aug. 31st	143.9	136.3	132.7	**123.0**	114.0	64.9	56.8	61.3	61.3	43.3	56.7	48.8	54.7
Sept. 1st -Sept. 10th	133.0	126.5	116.5	**107.7**	91.3	58.2	64.4	68.6	68.6	47.9	62.8	54.0	61.1
Sept. 11th - Sept. 20th	130.7	114.5	109.2	**95.9**	81.7	52.4	66.7	69.9	69.9	49.4	64.7	56.0	62.8
Sept. 21st - Sept. 30th	113.0	90.6	80.6	**71.6**	59.7	37.6	67.3	70.8	70.8	51.2	67.0	57.3	64.1
Oct. 1st- Oct. 10th	94.2	70.7	62.4	56.6	43.5	34.8	62.6	62.9	62.9	47.7	62.2	52.7	58.5
Oct. 11th - Oct 20th	64.6	35.1	31.5	27.7	24.7	18.8	59.9	59.1	59.1	46.3	60.3	50.3	55.8
Oct. 2oth - Oct. 31st	49.5	20.6	16.3	13.3	12.6	0.9	56.0	55.0	55.0	45.7	59.5	47.9	53.2

As could be realized from the Table, Based on 90% assurance level, the yield of the Rahad seasonal river is adequate to meet the irrigation demand for the Rahad scheme for the period

August 1st to Sept 30th. For 80% Assurance level the Rahad yield is adequate to meet the demand for the period July 20th to October 10th. For the purpose of this study the 90% assurance level is selected as the design criteria for the proposed operation rule of the scheme.

The analysis of irrigation water supply adequacy is applied to evaluate if enough quantity of water is delivered when it is required. The WDP is an index for evaluation of water delivery performance (Baily 1984). The WDP takes into account both the actual and the target quantity and timing of water supply. The weighted method of computing WDP (Lenton -1984) is implemented to evaluate the adequacy of Rahad Irrigation scheme. The weighted factor K_t is taken as the ratio of CWR during the time period under consideration to the total annual CWR. The results of Irrigation Adequacy analysis are shown in Table (5) below.

Table 5 Water Delivery Performance Computation Existing Condition for the Period 2000-2004

	Coulmn (1)	Column (2)	Column (3)	Column(4)	Column (5)	Colum (6)
Month	$ET_o \sum_{1}^{n} K_C(crop\ J)\ x\ Area\ (crop\ J)$	RF x Total Monthly Planted Area	CWR =1.15x Column(1) - Column(2)	Actual Supply	$w_i = \frac{CWR_i}{\sum_{i=1}^{12} CWR_i}$	WDP
	Million Cubic Meters	Million Cubic Meters	Million Cubic Meters	MCM	MCM	MCM
June	31.0	5.6	30.1	98.9	0.03	1.0
July	90.6	30.4	73.8	157.2	0.08	3.7
August	156.1	48.0	131.5	103.9	0.14	11.0
Sept	198.4	23.4	204.7	125.3	0.22	13.3
October	178.5	13.8	191.6	178.6	0.20	18.9
November	114.5	0.0	131.6	108.2	0.14	11.4
Dec.	45.6	0.0	52.4	58.5	0.06	5.0
Jan	43.8	0.0	50.3	35.5	0.05	3.7
Feb	33.2	0.0	38.2	32.5	0.04	3.4
March	14.8	0.0	17.0	21.1	0.02	1.4
April	7.4	0.0	8.5	27.6	0.01	0.3
May	13.6	0.0	15.6	21.3	0.02	1.2
Year 2000	**927.5**	**121.2**	**945.4**	**968.4**	**1.00**	**74.3**
June	14.6	1.5	15.3	87.4	0.02	0.3
July	71.2	26.1	55.7	185.1	0.07	2.0
August	166.1	66.7	124.3	74.2	0.15	8.9
Sept	209.3	29.6	211.2	166.8	0.25	20.0
October	177.0	7.3	196.2	169.8	0.24	20.4
November	106.9	0.0	123.0	86.6	0.15	10.4
Dec.	23.4	0.0	26.9	56.6	0.03	1.5
Jan	21.2	0.0	24.4	40.7	0.03	1.8
Feb	20.3	0.0	23.3	49.0	0.03	1.3
March	15.3	0.0	17.6	36.8	0.02	1.0
April	2.8	0.0	3.3	26.6	0.00	0.0
May	9.4	0.0	10.8	42.1	0.01	0.3
Year 2001	**837.5**	**131.2**	**831.9**	**1021.4**	**1.00**	**68.2**
June	14.6	4.4	12.4	62.3	0.02	0.4
July	71.2	54.4	27.4	116.8	0.04	0.9
August	166.1	134.2	56.8	68.5	0.08	6.9
Sept	209.3	38.0	202.7	96.7	0.30	14.2
October	177.0	1.6	202.0	146.0	0.30	21.4
November	106.9	0.0	123.0	93.6	0.18	13.7
Dec.	23.4	0.0	26.9	93.5	0.04	1.1
Jan	21.2	0.0	24.4	45.5	0.04	1.9
Feb	2.3	0.0	2.6	25.9	0.00	0.0
March	0.5	0.0	0.6	28.3	0.00	0.0
April	0.7	0.0	0.9	17.4	0.00	0.0
May	2.4	0.0	2.8	26.6	0.00	0.0
Year 2002	**795.6**	**232.5**	**682.4**	**820.9**	**1.00**	**60.6**
June	11.9	5.1	8.6	61.4	0.01	0.2
July	74.2	41.9	43.4	101.9	0.07	2.9
August	116.7	99.4	34.9	1.7	0.05	0.3
Sept	148.6	28.1	142.7	50.5	0.22	7.8
October	139.7	1.2	159.4	170.9	0.25	22.9
November	105.7	0.0	121.5	119.1	0.19	18.3
Dec.	46.8	0.0	53.9	102.4	0.08	4.4
Jan	41.8	0.0	48.0	56.2	0.07	6.3
Feb	26.0	0.0	29.9	55.7	0.05	2.5
March	2.8	0.0	3.2	46.2	0.00	0.0
April	0.7	0.0	0.9	17.5	0.00	0.0
May	2.4	0.0	2.8	17.1	0.00	0.1
Year 2003	**717.3**	**175.7**	**649.2**	**800.6**	**1.00**	**65.6**
June	17.2	5.7	14.0	104.5	0.02	0.2
July	70.4	43.6	37.3	149.7	0.04	1.1
August	152.8	129.7	46.1	73.9	0.05	3.4
Sept	194.4	36.7	186.9	193.7	0.22	21.1
October	182.0	1.6	207.8	173.7	0.24	20.3
November	149.1	0.0	171.4	128.5	0.20	15.0
Dec.	71.6	0.0	82.3	77.5	0.10	9.1
Jan	52.3	0.0	60.2	80.3	0.07	5.3
Feb	36.2	0.0	41.6	62.3	0.05	3.2
March	3.1	0.0	3.5	65.0	0.00	0.0
April	0.7	0.0	0.9	5.3	0.00	0.0
May	2.3	0.0	2.6	24.9	0.00	0.0
Year 2004	**932.1**	**217.4**	**854.6**	**1139.2**	**1.00**	**78.8**

Proposed Operational Rule for Improving the Water Management of the Scheme

The proposed water management and operational rule entirely relay on the Rahad seasonal river to supply the irrigation demands during the month of July, August and September. From Table (4), the yield from the Rahad river at 90% assurance level for the months of July, August and September are 53.4, 287.4 and 275.2 MCM respectively. Such quantity of water would be available to meet the irrigation demands during this period. Any surplus or excess water could be returned to the Rahad River through the regulators at Abu Rakham Barrage. In the proposed scenario, the supply from Mena pumping station would be ceased during the months of July to September (season of high sediment concentration at the Blue Nile River). For the Month of October, it is anticipated that Mena pumping station would be operational with half capacity (that is 5 pumps for 20 Days continuous operation). Such a supply from Mena station would add 80 MCM to the 90% assurance yield of 97.6 MCM from the Rahad River making a total supply of 178 MCM for October. Summary of the proposed operational rules for the scheme is described in Table (6) below.

Table 6 Revised Operational Rule for the Scheme during the period July to October

Month	Rahad Yield 90% Assurance (MCM)	Supply from Mena (MCM)	Total supply (MCM)	Remarks
July	53.4	0	53.4	No supply from Mena station to the scheme
August	287.4	0	287.4	No supply from Mena station to the scheme
Sept.	275.2	0	275.2	No supply from Mena station to the scheme
October	97.6	80	177.6	Operate 5 pumps for 20 days

Based on the revised operational rules, the WDP for the scheme is computed for the period 2000 to 2004 as shown in Table (7) and the WDP under both existing conditions and proposed scenario are then compared as presented in Figure (7).

Year	WDP % Existing	WDP% Proposed	% Improvement
2000	74.3	87.6	17.8
2001	68.2	84.9	24.6
2002	60.6	85.3	40.7
2003	65.6	87.9	34.0
2004	78.8	85.3	8.3
Average	69.5	86.2	25.1

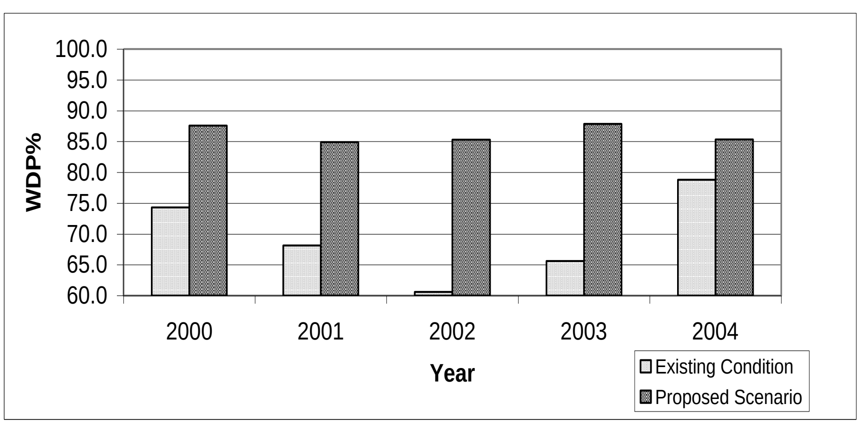

Figure (7): Comparison of Water Delivery Performance for Existing and Proposed Operational Rules

Table 7 Water Delivery Performance Computation Proposed Operation Rule

	Coulmn (1)	Column (2)	Column (3)	Column(4)	Column (5)	Colum (6)
Month	$ET_o \sum_1^n K_C(crop\ J)\ x\ Area\ (crop\ J)$	RF x Total Monthly Planted Area	CWR =1.15x Column(1) - Column(2)	Proposed Supply	$w_i = \frac{CWR_i}{\sum_{i=1}^{12} CWR_i}$	WDP
	Million Cubic Meters	Million Cubic Meters	Million Cubic Meters	MCM	MCM	MCM
June	31.0	5.6	30.1	98.9	0.03	1.0
July	90.6	30.4	73.8	53.9	0.08	5.7
August	156.1	48.0	131.5	131.5	0.14	13.9
Sept	198.4	23.4	204.7	204.7	0.22	21.7
October	178.5	13.8	191.6	177.6	0.20	18.8
November	114.5	0.0	131.6	108.2	0.14	11.4
Dec.	45.6	0.0	52.4	58.5	0.06	5.0
Jan	43.8	0.0	50.3	35.5	0.05	3.7
Feb	33.2	0.0	38.2	32.5	0.04	3.4
March	14.8	0.0	17.0	21.1	0.02	1.4
April	7.4	0.0	8.5	27.6	0.01	0.3
May	13.6	0.0	15.6	21.3	0.02	1.2
Year 2000	**927.5**	**121.2**	**945.4**	**968.4**	**1.00**	**87.6**
June	14.6	1.5	15.3	87.4	0.02	0.3
July	71.2	26.1	55.7	53.9	0.07	6.5
August	166.1	66.7	124.3	124.3	0.15	14.9
Sept	209.3	29.6	211.2	211.2	0.25	25.4
October	177.0	7.3	196.2	177.6	0.24	21.3
November	106.9	0.0	123.0	86.6	0.15	10.4
Dec.	23.4	0.0	26.9	56.6	0.03	1.5
Jan	21.2	0.0	24.4	40.7	0.03	1.8
Feb	20.3	0.0	23.3	49.0	0.03	1.3
March	15.3	0.0	17.6	36.8	0.02	1.0
April	2.8	0.0	3.3	26.6	0.00	0.0
May	9.4	0.0	10.8	42.1	0.01	0.3
Year 2001	**837.5**	**131.2**	**831.9**	**1021.4**	**1.00**	**84.9**
June	14.6	4.4	12.4	62.3	0.02	0.4
July	71.2	54.4	27.4	27.4	0.04	4.0
August	166.1	134.2	56.8	56.8	0.08	8.3
Sept	209.3	38.0	202.7	202.7	0.30	29.7
October	177.0	1.6	202.0	177.6	0.30	26.0
November	106.9	0.0	123.0	93.6	0.18	13.7
Dec.	23.4	0.0	26.9	93.5	0.04	1.1
Jan	21.2	0.0	24.4	45.5	0.04	1.9
Feb	2.3	0.0	2.6	25.9	0.00	0.0
March	0.5	0.0	0.6	28.3	0.00	0.0
April	0.7	0.0	0.9	17.4	0.00	0.0
May	2.4	0.0	2.8	26.6	0.00	0.0
Year 2002	**795.6**	**232.5**	**682.4**	**820.9**	**1.00**	**85.3**
June	11.9	5.1	8.6	61.4	0.01	0.2
July	74.2	41.9	43.4	43.4	0.07	6.7
August	116.7	99.4	34.9	34.9	0.05	5.4
Sept	148.6	28.1	142.7	142.7	0.22	22.0
October	139.7	1.2	159.4	177.6	0.25	22.0
November	105.7	0.0	121.5	119.1	0.19	18.3
Dec.	46.8	0.0	53.9	102.4	0.08	4.4
Jan	41.8	0.0	48.0	56.2	0.07	6.3
Feb	26.0	0.0	29.9	55.7	0.05	2.5
March	2.8	0.0	3.2	46.2	0.00	0.0
April	0.7	0.0	0.9	17.5	0.00	0.0
May	2.4	0.0	2.8	17.1	0.00	0.1
Year 2003	**717.3**	**175.7**	**649.2**	**800.6**	**1.00**	**87.9**
June	17.2	5.7	14.0	104.5	0.02	0.2
July	70.4	43.6	37.3	37.3	0.04	4.4
August	152.8	129.7	46.1	46.1	0.05	5.4
Sept	194.4	36.7	186.9	186.9	0.22	21.9
October	182.0	1.6	207.8	177.6	0.24	20.8
November	149.1	0.0	171.4	128.5	0.20	15.0
Dec.	71.6	0.0	82.3	77.5	0.10	9.1
Jan	52.3	0.0	60.2	80.3	0.07	5.3
Feb	36.2	0.0	41.6	62.3	0.05	3.2
March	3.1	0.0	3.5	65.0	0.00	0.0
April	0.7	0.0	0.9	5.3	0.00	0.0
May	2.3	0.0	2.6	24.9	0.00	0.0
Year 2004	**932.1**	**217.4**	**854.6**	**1139.2**	**1.00**	**85.3**

Summary and Conclusion

The results of the water demand versus supply for the Rahad irrigation scheme indicates water shortage and water stress problems during the growing season of August to October. Such water stress problems are mainly due to poor water management. It is found that the annual yield of the Rahad River at 90% assurance level could be adequate to meet the water demand of the scheme during the period of July to October. The Water Delivery Performance of the irrigation system under both existing and future proposed operational rules were evaluated. On average the WDP under existing conditions for the period 2000-2004 is found to be 69%. The proposed operational rules relies entirely on the yield from the Rahad river during the period July 1st to September 30th during which the Mena pumping station would be non-operational and the pumps would only be scheduled to operate during the month of October with half capacity (5 pumps) for a period of 20 days. Based on the proposed operational rule, the WDP for the period 2000-2004 is recalculated and the average WDP for the period is found to be 86% which reflects an improvement of about 25% over the existing situation. Such a proposed operation rule would relieve the burden on the stressed pumping unit and could potential reduce the maintenance cost of the pumping units and dredging operation on the supply canal.

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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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Abstract

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.

Key words: Irrigation and hydropower Development, Blue Nile River Basin, MIKE BASIN Model

Introduction

Pressure on water resources in the Blue Nile basin is likely to increase dramatically in the near future as a result of high population growth in all the riparian states, and increasing development-related water needs in Ethiopia and Sudan. However, in spite of the national and international importance of the region, only a relatively few studies have been conducted and there is only limited understanding of the basin's detailed climatic, hydrological, and topographical and hydraulic characteristics (Johnson & Curtis, 1994; Conway, 1997).

In this paper a water allocation model will be used to ascertain the downstream implications of proposed water resources development in Ethiopia and Sudan. The model will used to gain insight in to the potential downstream consequences of the development of physical infrastructure and water abstraction in a number of different future development scenarios. Each scenario will provide a consistent and plausible description of possible future water demand in the catchment.

Description of the study area

Blue Nile River Basin lies in the western part of Ethiopia between latitudes of 7o 45`N and 12o 46`N; and longitudes of 34o 05'E and 39o 45' E (Figure 1). The basin has an estimated area of 199,812 sq. km. About 46 % of the basin area falls in Amhara State, 32% falls in Oromia and the rest of about 22% in Binishangul-Gumuz States. It covers about 17.5 per cent of Ethiopia's land area BCEOM phase3, part1 (1998). The location of the basin has been shown on figure 1-1 with respect to the other major basins of the country.

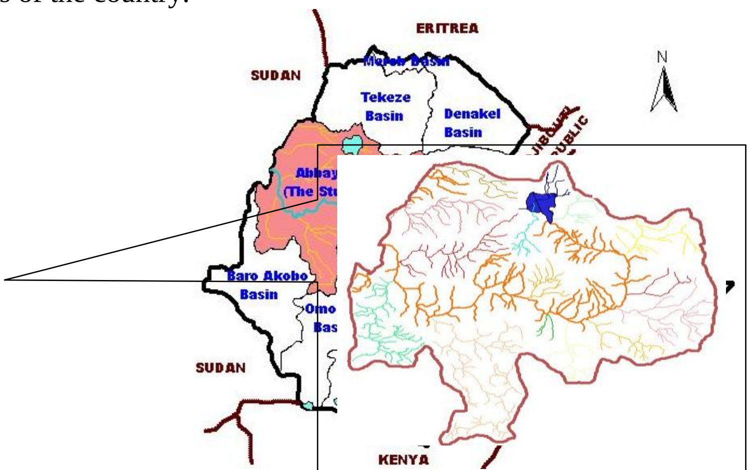


Figure 1: Location Map of the study area with respect to other basins.

Objective of the study and methodology

The main objective of this study is to simulate water allocation for major production activities (existing and planned) in the Abbay basin and to assess the impacts of upstream water allocation on downstream users.

MIKE BASIN is well suited to water resource modeling in the Abbay basins. The model specializes in assessing the potential for water resources development, particularly hydropower and irrigation by determining likely impacts of different water resources development scenarios and optimization of water allocation schemes.

The methodology adopted in the study follows data collection, organization, pre-processing and analysis based on the requirement of MIKE BASIN model.

Data

To achieve the goal of the research most of the data have been collected from the various phase of the Abbay basin master plan document and MOWR.

The data used in the study includes the streamflow data of 3 main river course and 14 tributaries gauges were used to estimate the flow at the project site and computation of Border flow volume.

The other important data includes the demand data for irrigation and hydropower, location of project sites, relevant reservoir data, precipitation and potential evaporation.

Schematization

MIKE BASIN is a network model in which the rivers and their main tributaries are represented by a network of branches and nodes. The river system is represented in the model by a digitized river network that can be generated directly on the computer screen in Arc Map 9.1 (a GIS software package) or for our case by a traced river network that can be delineated from the DEM after calculating the flow direction by the mike basin model as shown in the Figure 2.

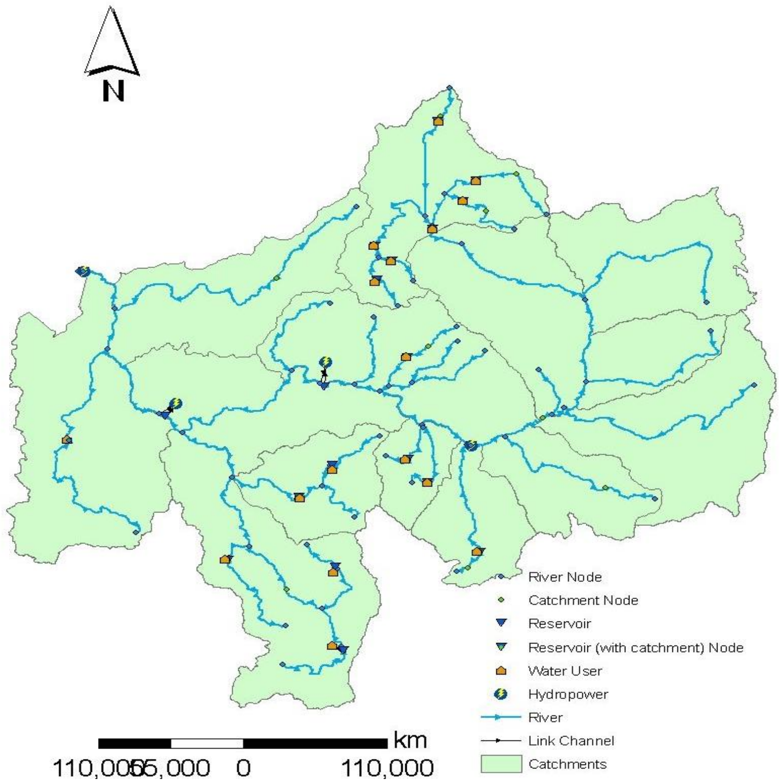


Figure 2: location of different water users and reservoirs

Border flow estimation

The streamflow data of 3 main river course and 14 tributaries gauges were utilized for the computation of border flow volume. The mean monthly flows obtained from the historical records that are converted in to specific discharges for suitability of the model. Bahir Dar, Kessie, and Border and 14 gauged tributaries were utilized. Based on these data, the overall streamflow volume at each gage sites on the mainstream and tributaries was computed by MIKE BASIN. As indicated on Figure 3 below the mean annual flow of Abbay was found to be ***50.45*** BCM at the border and **3.8** BCM at Bahir Dar below the outlet of Lake Tana. The value of border flow obtained from this analysis is almost equal to the one which is estimated on the master plan, which is 50.6BCM.

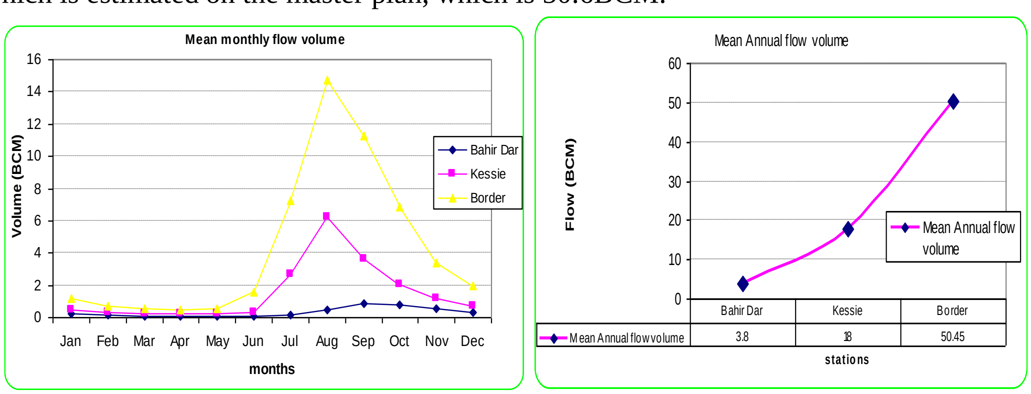


Figure 3: Mean monthly & annual flow volume of Abbay at each gage

Both Graphical and numerical performance measures should be applied in the comparison. The graphical evaluation includes comparison of the simulated and observed hydrograph, and comparison of the simulated and observed accumulated runoff. The numerical performance measures include the overall water balance error (i.e. the difference between the average simulated and observed runoff), and a measure of the overall shape of the hydrograph based on the coefficient of determination or Nash-Sutcliffe coefficient

$$R^2 = 1 - \frac{\sum_{i=1}^{N} [Q_{obs,i} - Q_{sim,i}]^2}{\sum_{i=1}^{N} [Q_{obs,i} - \overline{Q}_{obs}]^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where $Q_{sim,I}$ is the simulated discharge at time i, $Q_{obs,I}$ is the corresponding observed discharge, and $\overline{Q}_{obs}$ is the average observed discharge. A perfect match corresponds to R^2=1.

Table 1 Nash-Sutcliffe coefficient at the three main gauging stations

Stations	R^2
Bahir Dar	0.99
Kessie	0.97
Border	0.996

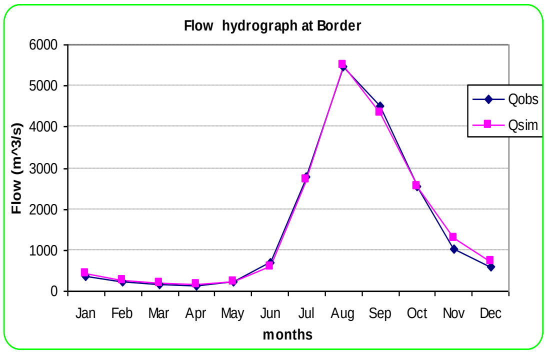


Figure 4: Comparison of Observed and Simulated Flow Hydrographs in m^3/s at Border.

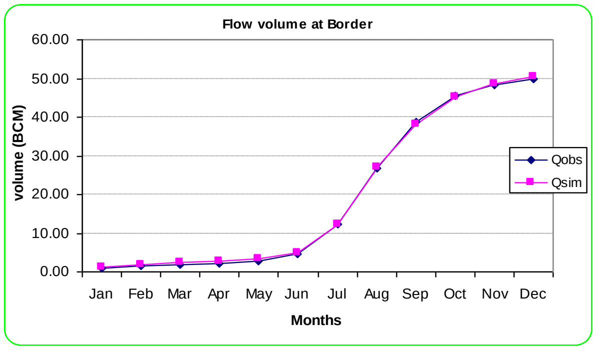


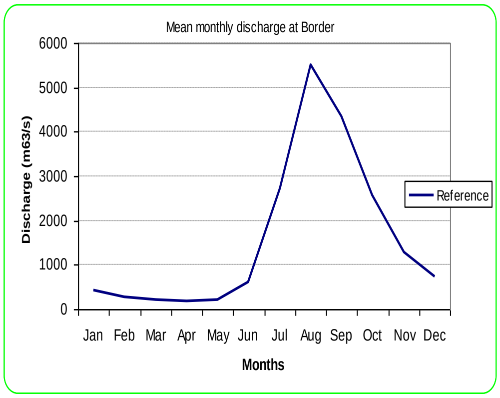
Figure 5: Comparison of accumulated observed & simulated flow volume in BCM at Border

Analysis of scenarios

The results of the analyses of the scenarios are showing the water demand deficits and relative deficits for irrigation. And also show the impact on the Abbay River flow and mainly at the Sudan Border

Reference Scenario

The average monthly discharge and accumulated volume at Sudan Border as computed by MIKE BASIN model for the Reference scenarios it illustrates the tremendous difference between peak flows between 2,500 and 5,500 m^3/s during the period July to October and base flow of less than 500 m^3/s during a prolonged period of 5 months. The average volume flowing out of the Abbay Basin is close to 50.45 BCM; 72% of which flow is the 4 months from July to October included and 6.3% during the 4 months from February to May.



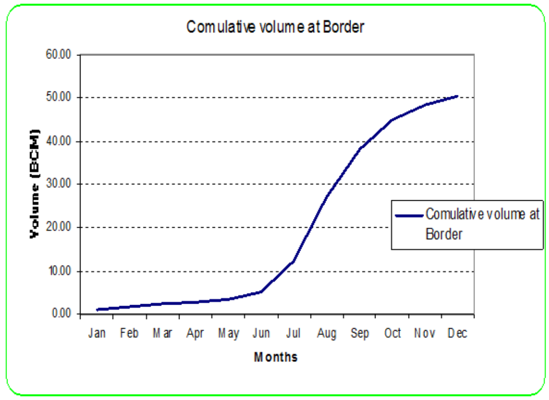


Figure 6: Mean monthly discharge at Sudan Border in m^3/s during reference scenarios

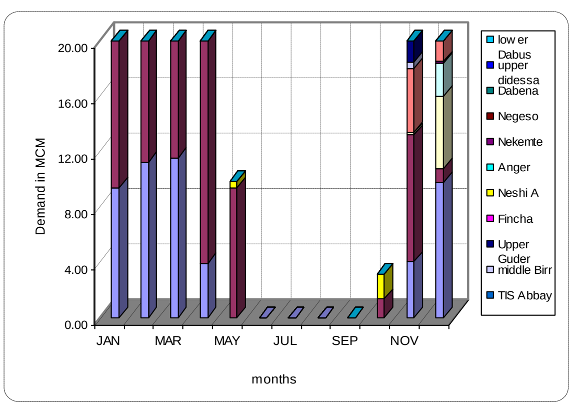
Figure 7: Cumulated Volume at Border during the reference scenario in BCM

A. All identified irrigation projects on the tributary of Abbay River with out reservoir

In this scenario, using the optimized irrigable areas of the Abbay master plan study, we can calculated the water demand of the 17 irrigation projects on the tributary of Abbay River basin. Using this, the water demand deficits of the irrigation projects without reservoir are obtained. The results of the modeling are presented in the graph for irrigation water demand deficits in MCM.

In this simulation there is a project that doesn't get water demand deficits to satisfy the irrigation water demand for the proposed irrigable area. Lower Dabus project as recommended on the Abbay master plan it doesn't require reservoir.

In this Scenario, Finchaa irrigation project having a command area of 6,205 ha has also doesn't need reservoir. But for further expansion (i.e. for irrigating more command area) providing a reservoir is compulsory.



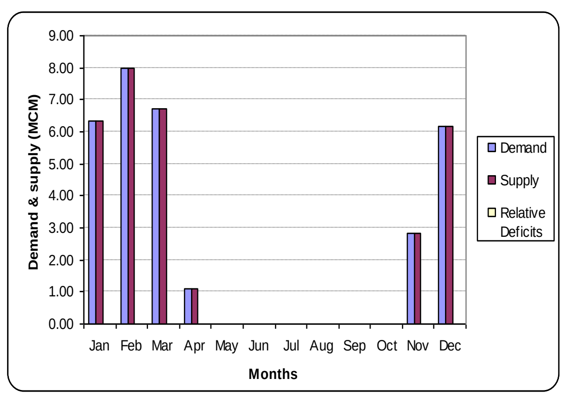


Figure 8: Water demand deficits in MCM On without reservoir scenario for identified irrigation projects

Figure 9: water demand, supply and relative deficits of Lower Dabus in MCM

B. All identified irrigation projects on the tributary of Abbay with reservoir scenario

Based on the analysis of the above simulation (i.e. without reservoir) and recommendation of the Master plans, we simulate the model with reservoirs. The water shortage problem should now be alleviated. About 1.624 BCM of water extracted annually but the total water demand is 1.699 BCM. It doesn't satisfy 0.07452BCM amount of water for all projects under consideration.

As indicated on figure 1-10 in the presence of the proposed reservoirs still there are projects in shortage of water to satisfy their monthly demand. The degree of shortage varies among projects and months. But for water users except Tana basin projects such as Ribb & Jema projects and Negesso &Neshi A, it shows almost no deficit after reservoir as shown in figure 1-10 below. To detect major failures; defined as a monthly failures grater than a threshold that has been set to 25% over a full month. Such failures are considered as able, not only to reduce the yields, but to destroy the irrigated crops completely. A table of values of the relative deficits (irrigation failures) defined by the difference between the discharge required and the discharge delivered, expressed in percent of the requirement is shown above.

Table 2: percentage reliability and number of months below the threshold

Threshold	Koga	M_Bir	Neshi	Jema	Gumera	Megech	Negeso	Rib
>25%	0	0	6	1	0	0	2	1

From the above table Special consideration should be given while implementing Neshi A and Negesso projects.

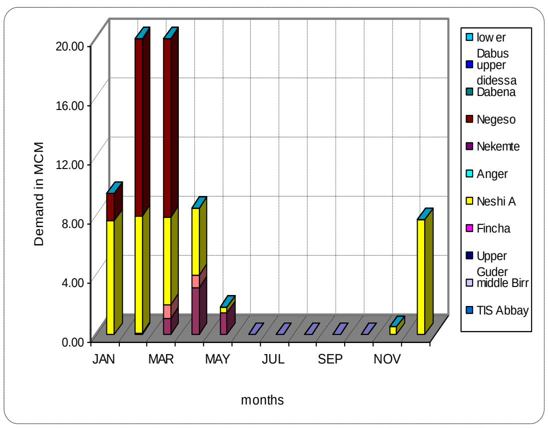


Figure 10: Average monthly demand deficits in MCM

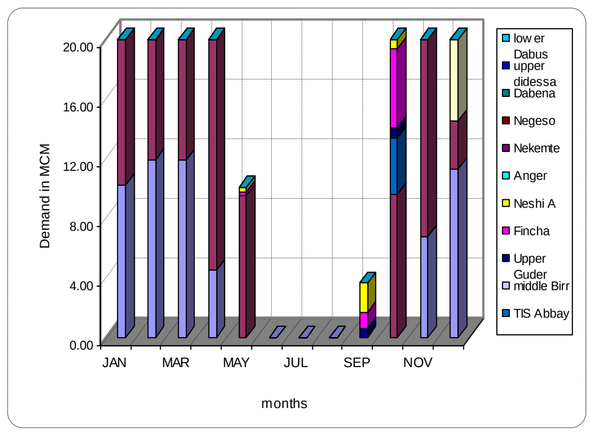


Figure 11: Average monthly water extracted for each water Users in MCM

All identified irrigation projects on the tributary of Abbay with reservoir and Karadobi hydropower projects on the main stream of Abbay. Results of this scenario are presented as follows:

- Installed hydropower and energy production amounts to 1,600MW and 5,644 GWh per year respectively.
- Better Abbay river flow distribution through out the year at Sudan border with 76% of the annual volume being discharged during the period from July to October.
- The hydrograph at the border station is smoothed again with low discharge increased by 14.63% in April and high discharge decreased by 14% in August. This is illustrated by graph below.

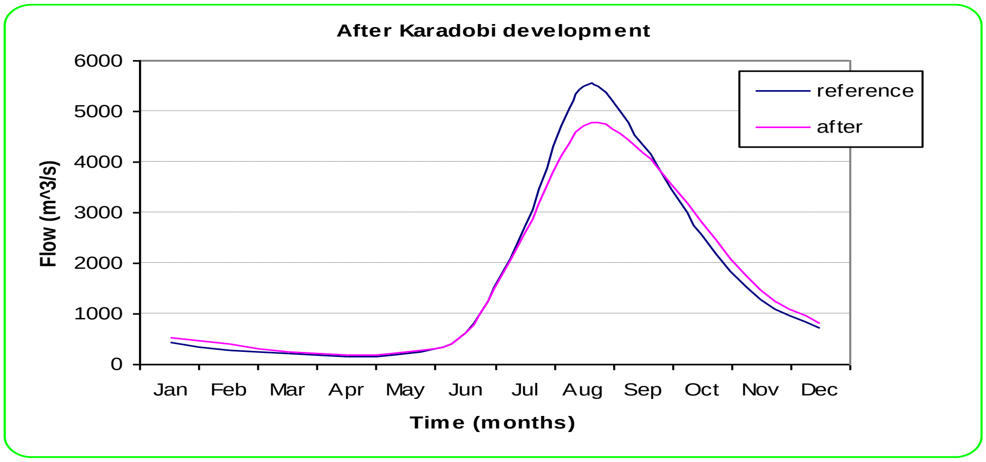


Figure 12: Flow hydrograph at Sudan Border in m^3/s after Karadobi hydropower development

Discharge before and after the project condition on the tributaries

The over all flow condition of the tributaries utilized for irrigation development and that of the main stream used for hydropower development was computed for conditions of before and after project case. The flow after the confluence of a main stream with a tributary is the sum of the upstream flow in the main stream and the flow of the tributary below the withdrawal node.
Based on the above procedure, MIKE BASIN has computed the whole tributaries and main stream flow before and after the implementation of the projects. Based on the results of the model, the following comments are given below.

- The flow in the natural stream becomes zero for a month or consecutive months. The condition needs due consideration for projects of Rib, Neshi A, Negesso, Gumera, Jema, Bir and Megech.
- Unless other downstream tributaries of the above rivers with nil streamflows augment the ecological and down streams water users demand, it will be difficult to implement the proposed irrigation potential.

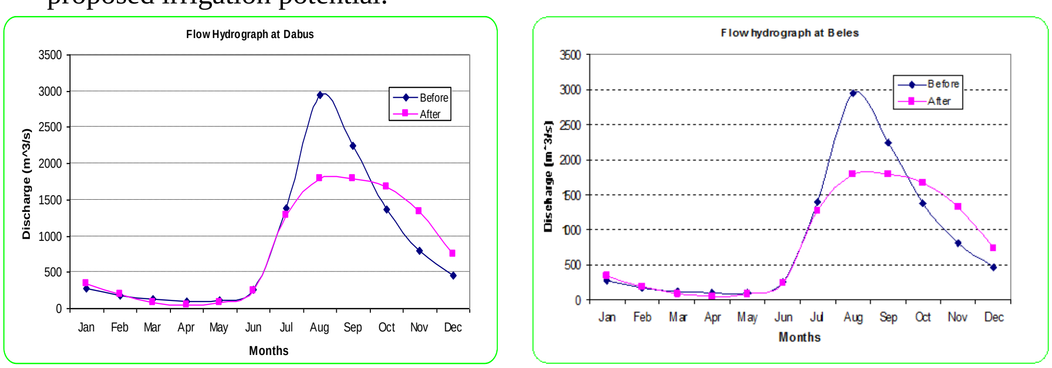


Figure 13: Mean monthly flow of Abbay before and after the projects condition just below Dabus & Beles confluence

Conclusion

From the analysis performed in this study, the total water extracted to irrigate 220,416 ha of land was 1.624BCM per year, inducing for Abbay an average annual flow reduction of about 3.04% at Sudan Border. The over all mean annual flow from the mean monthly data of the main stream gauges was estimated as 50.45 BCM at the Sudan border. As compared to the result of scenario 1 of the master plan to irrigate a command area of 440,804 ha and to generate 9,519 GWh,, the border flow reduction which was 7% as indicated on table 2-4 is compatible with the out put of this study. On the other hand the mean annual flow 50BCM given on the master plan is almost equal to the recent result 50.45BCM.

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Application of the Water Evaluation And Planning (WEAP) Model to Simulate Current and Future Water Demand in the Blue Nile

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Abstract

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.

Introduction

The Blue Nile River (known as the Abay in Ethiopia) is the most important tributary of the Nile River, providing over 62% of the Nile's flow at Aswan (World Bank, 2006). Both Egypt, and to a lesser extent Sudan, are almost wholly dependent on water that originates from the Nile. This dependency makes the challenges of water resources management in this region an international issue (Waterbury, 2002).

The Blue Nile rises in the Ethiopian highlands in the region of West Gojam and flows northward into Lake Tana, which is located at an elevation of just under 1,800 m (Figure 1). It leaves the southeastern corner of the Lake, flowing first south-east, before looping back on itself, flowing west and then turning north-west close to the border with Sudan. In the highlands, the basin is composed mainly of volcanic and Pre-Cambrian basement rocks with small areas of sedimentary rocks. The catchment is cut by deep ravines in which the major tributaries flow. The valley of the Blue Nile itself is 1,300 m deep in places. The primary tributaries in Ethiopia are the Beshio, Jema, Muger, Guder, Finchaa, Anger, Didessa and Dabus on the left bank and the Chemoga, Timochia, Bir and Beles on the right bank. The Blue Nile enters Sudan at an altitude of 490 m.a.m.s.l and just before crossing the frontier, the river enters a clay plain, through which it flows to Khartoum. The average slope of the river from the Ethiopian frontier to Khartoum is only 15 cm km^{-1}. Within Sudan, the Blue Nile receives water from two major tributaries draining from the north, the Dinder and the Rahad, both of which also originate in Ethiopia. At Khartoum the Blue Nile joins the White Nile to form the main stem of the Nile River.

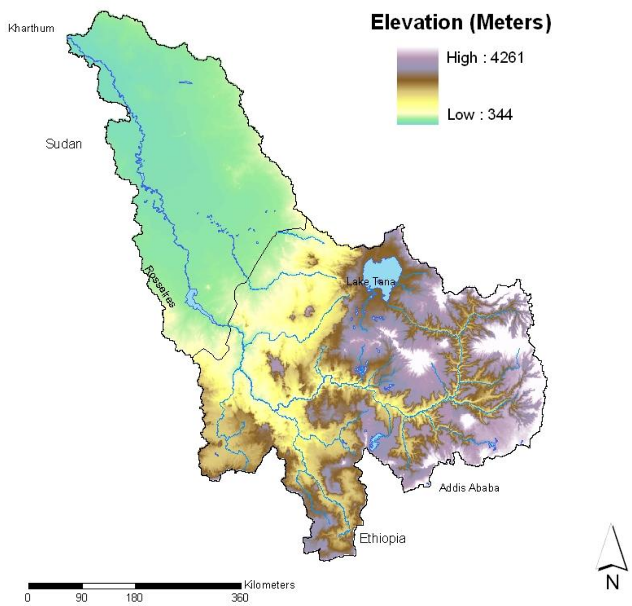


Figure 1: Map of the Blue Nile basim showing elevation, the main tributaries and key geographic features (Source: Awulachew, 2008)

Within the basin rainfall varies significantly with altitude and is considerably greater in the Ethiopian highlands than on the Plains of Sudan. Within Sudan, the average annual rainfall over much of the basin is less than 500 mm. In Ethiopia, it increases from about 1,000 mm near the Sudan border to between 1,400 and 1,800 mm over parts of the upper basin and exceeds 2,000 mm in some places. The flow of the Blue Nile is characterized by extreme seasonal and inter-annual variability. At the Sudan–Ethiopia border total annual flow varies from approximately 31 Bm^3 to 70 Bm^3. Typically, more than 80% of the flow occurs during the flood season (July to October) while only 4% of the flow occurs during the dry season (February to May).

Currently Ethiopia utilizes very little of the Blue Nile water, partly because of its inaccessibility and partly because the major centers of population lie outside of the basin. To date only two relatively minor hydraulic structures have been constructed in the Ethiopian part of the catchment (Table 1). These two dams (i.e., Chara Chara weir and Finchaa) were built primarily to provide hydropower. The combined capacity of the power stations they serve (218 MW) represents approximately 30% of the total currently installed power capacity of the country (i.e., 731 MW of which 90% is hydropower) (World Bank, 2006). The Chara Chara weir regulates outflow from Lake Tana for the downstream Tis Abay power stations. Agriculture, which is the main occupation of the inhabitants in the basin is primarily rainfed with almost no irrigation. Although there is some informal small-scale irrigation, currently the only formal irrigation scheme in the Ethiopian part of the catchment is the Finchaa sugar cane plantation (8,145 ha), which utilizes water after it has passed through a hydropower plant (Table 1).

In contrast to Ethiopia, Sudan utilizes significant volumes of Blue Nile water both for irrigation and for hydropower production. Two dams (i.e., Sennar and Roseires) have been constructed on the main river approximately 350 km and 620 km south-east of Khartoum (Table 1). These provide hydropower (primarily for Khartoum) as well as water for several large irrigation schemes, including the Gezira scheme (882,000 ha), which is one of the largest in the World. As well as irrigating land immediately adjacent to the Blue Nile River, some water is diverted from the Blue Nile downstream of the Roseires reservoir to the Rahad River, where it is used to supplement the irrigation of the Rahad irrigation scheme (168,037 ha). The total irrigated area in the Sudanese part of the Blue Nile is estimated to be 1,305,000 ha, for a variety of crops including cotton, sugar cane and vegetables. The installed power capacity at the two dams is 295 MW which represents 25% of the country's total generating capacity (i.e., 1,200 MW from both thermal and hydro power stations).

Table 1 Existing dams in the Blue Nile catchment

Dam	**River**	**Storage (Mm^3)**	**Built**	**Purpose**
Chara Chara	Abay	9,100+	2000	Regulation of lake Tana outflows for hydropower production at Tis Abay I and Tis Abay II power stations (installed capacity – 84MW)
Finchaa*	Finchaa	2,395	1971	Regulation for hydropower production (installed capacity 134 MW) and also sugar cane irrigation (8,145 ha)
Roseires	Blue Nile	3,024	1964	Regulation for hydropower production (installed capacity 280 MW) and supply to irrigation schemes (1,305,000 ha)
Sennar	Blue Nile	930	1925	Regulation to for hydropower production (installed capacity 15 MW) and supply to irrigation scheme (1,093,502 ha)

+ this is the active storage of Lake Tana that is controlled by the operation of the weir (i.e. lake levels between 1784 masl and 1787 masl). It represents 2.4 times the average annual outflow of the lake.
* a small dam located on the Amerty river (storage 40 Mm^3) diverts water from the Amerty into the Finchaa reservoir

Both Ethiopia and Sudan, plan to increase development of the Blue Nile water resources significantly in the near future. This paper describes the use of the Water Evaluation And Planning (WEAP) model to investigate scenarios of water demand in the basin and to evaluate the likely implications of upstream development on downstream water availability. Water use was simulated over a 32-year period of varying rainfall and flow. The results reported here are preliminary results derived from initial model runs.

Method

Developed by the Stockholm Environment Institute (SEI), the WEAP model is intended to be used to evaluate planning and management issues associated with water resource development. The WEAP model essentially performs a mass balance of flow sequentially down a river system, making allowance for abstractions 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).

Typically the 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 three scenarios: i) the natural situation with no abstractions, ii) the current situation and iii) future demand in approximately 2015. Time series of monthly naturalized flow data for the period 1960-1992, obtained from the Abay Basin Master Plan (BCEOM, 1998), were used as input data. Estimates of current irrigation and hydropower demand were derived from data provided by government ministries and agencies or from previous studies. This included information on water passing through the turbines of the power stations and water diverted for irrigation. It was necessary to make a lot of assumptions, particularly about return flows from irrigation schemes. In some cases demand estimates were derived based on demand at similar irrigation schemes, and simply weighted by the ratio of the scheme areas. Irrigation demand was allowed to vary slightly depending on rainfall determined for the rain gauge located closest to the scheme. Hence, in higher rainfall years, irrigation demand was reduced slightly. Net evaporation from Lake Tana and the reservoirs was estimated using data from the nearest meteorological station. Figure 2 shows the model configuration for the current situation.

For the 2015 scenario, the size of planned hydropower and irrigation development was derived from the basin master plans for Sudan and Ethiopia. This included both new schemes and proposed extension of existing schemes (Table 2). In Sudan it is planned to raise the height of the Roseires dam by 10m, to increase the area irrigated at several locations and to construct several new irrigation schemes. It is estimated that the total irrigated area will increase to approximately 2,126,000 ha. In Ethiopia it is planned to transfer water from Lake Tana to the Beles River (a tributary of the Blue Nile) for hydropower generation, to extend the Finchaa irrigation scheme and to develop several new irrigation schemes, in the vicinity of Lake Tana as well as in other sub-basins. It is estimated that the total formally irrigated area will increase to approximately 210,000 ha. In addition, it is planned to construct a very large dam (storage capacity 40.2 Bm^3) on the main stem of the Abay, at Karadobi, for hydropower (Table 2). Although the exact dates of completion of many of these schemes is unknown, these are the highest priority schemes in each country and, for the purposes of this study, it was assumed that they would all be completed by approximately 2015.

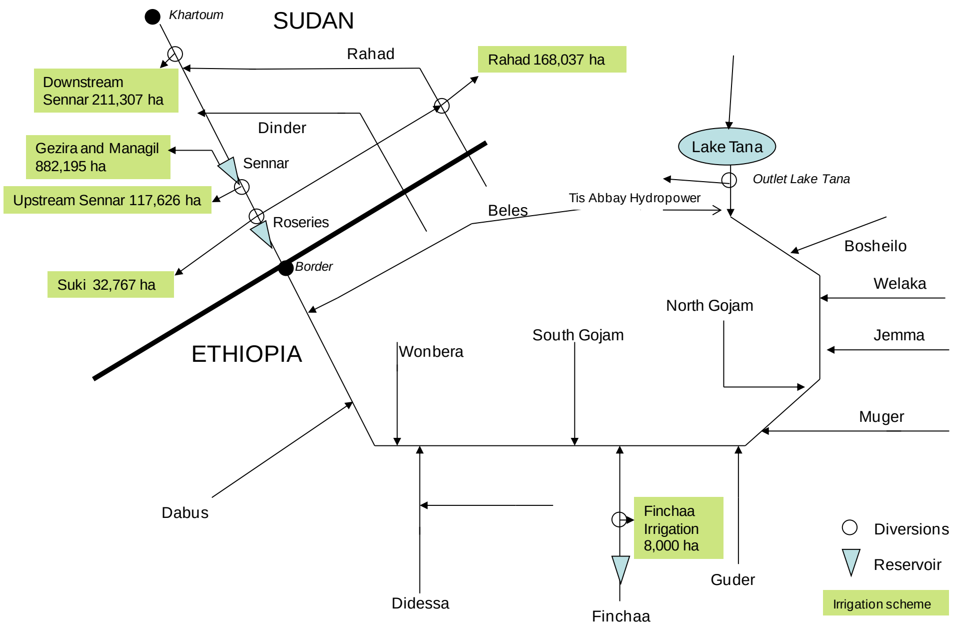


Figure 2: Schematic of the model configuration for the current situation

The water demand for new schemes was derived from basin master plans and, where available, feasibility studies. Where it is planned to extend irrigation schemes the demand was estimated based on current demand, but weighted by the new area. Again for the irrigation schemes some variability was simulated to allow for differences in rainfall. Figure 3 shows the model configuration for the 2015 scenario.

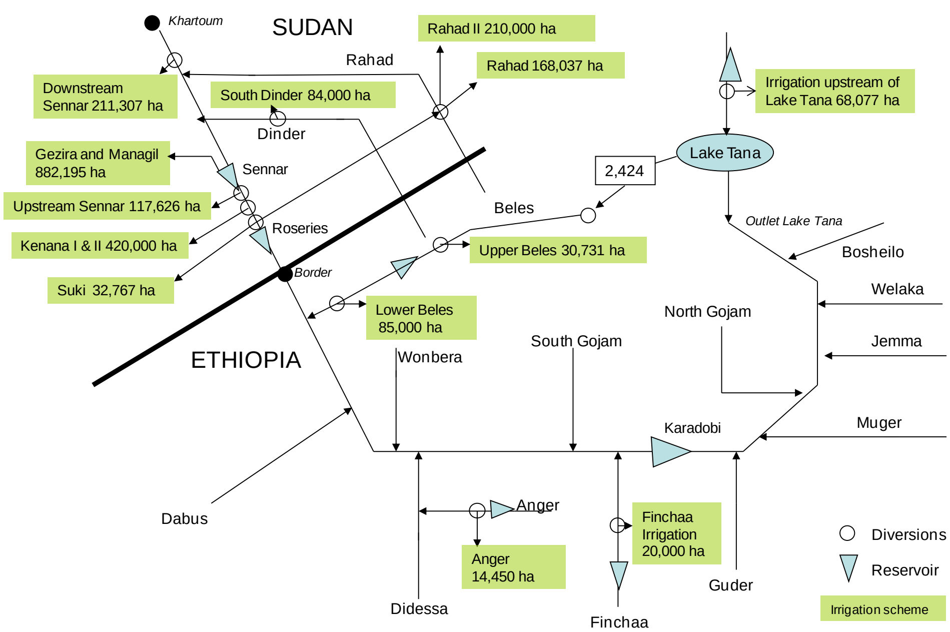


Figure 3: Schematic of the model configuration for the 2015 scenario

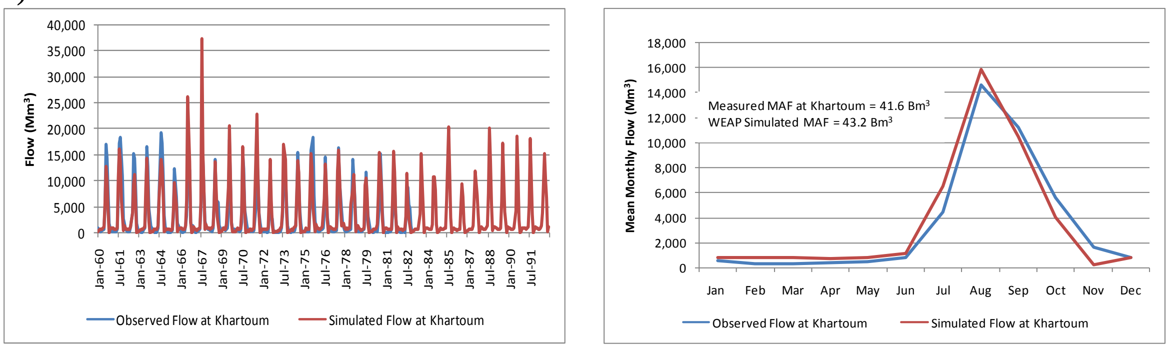
Table 2 Planned water resource development in the Blue Nile River basin, that it is assumed will be completed by 2015

Scheme	Sub-basin	Description	Completion date
Ethiopia			
Tana-Beles transfer	Tana and Beles	Transfer of water from Lake Tana to Beles catchment for hydropower production and irrigation. Average annual transfer: 2,424 Mm^3	2009/10
Irrigation in the Lake Tana sub-basin	Lake Tana	Dams to be constructed on the major inflows to Lake Tana (i.e. Megech, Ribb, Gumara and Gilgel Abay). Total storage: 1028 Mm^3 Irrigation area: 61,853 ha Average annual demand: 516 Mm^3	2012/14
Irrigation in the Beles sub-basin	Beles	Upper Beles scheme 30,731 ha Lower Beles scheme 85,000 ha Average annual demand: 1,554 Mm^3	Unknown
Extension of the Finchaa irrigation scheme	Finchaa	Extension from the west bank to the east bank using flow regulated by the existing Finchaa dam Additional irrigation area: 12,000 ha Average annual demand: 512 Mm^3	Unknown
Karadobi hydropower scheme	Blue Nile main stem	250 m high dam Total storage: 40,220 Mm^3 Live storage: 17,300 Mm^3	Unknown
Angar irrigation and hydropower scheme	Angar	Maximum irrigated area: 14,450 ha Average annual demand 202 Mm^3 Hydropower Capacity: 1.8 – 9.6 MW	2012(?)
Sudan			
Raising Roseires dam	Blue Nile main stem	Roseires dam raised by 10m to provide total (gross) storage of 7,400 Mm^3	2012(?)
Extension of Rahad irrigation scheme	Rahad	Additional irrigation area: 19,740 ha Rahad II irrigation scheme: 210,000 ha Total average annual demand: 2,432 Mm^3	2015
Extension of Suki irrigation scheme	Blue Nile main stem	Additional irrigation area: 2,940 ha Total average annual demand: 202 Mm^3	2015
Extension of Upstream Sennar	Blue Nile main stem	Additional irrigation area: 39,910 ha Total average annual demand: 749 Mm^3	2015
Extension of Downstream Sennar	Blue Nile main stem	Additional irrigation area: 44,110 ha Total average annual demand: 1420 Mm^3	2015
Kenana II and III	Blue Nile main stem	Additional irrigation area: 420,000 ha Average annual demand: 2,352 Mm^3	2015
South Dinder	Dinder	Additional irrigation area: 84,000 ha Average annual demand: 541 Mm^3	2015

Results

Figure 4 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 good. At Khartoum, observed data (obtained from the Global Data Runoff Centre) were only available for the period 1960-1982. Over this period the percentage error in the simulated mean annual flow was 3.7%. As a result of current abstractions, primarily for irrigation in Sudan, the flow at Khartoum is estimated to be approximately 7.5 Bm^3y^{-1} less than would occur naturally (i.e. 41.7 Bm^3y^{-1} rather than 49.3 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 10% difference in mean annual flow; 50.6 Bm^3 measured by Ethiopia and 45.6 Bm^3 measured by Sudan. Without detailed analysis, which was beyond the scope of the present study, it is not possible to know which of the two flow series is the more accurate. The WEAP model simulation actually lies between the two, but is closest to the Sudanese estimate with a mean annual discharge of 45.8 Bm^3.

a)



b)

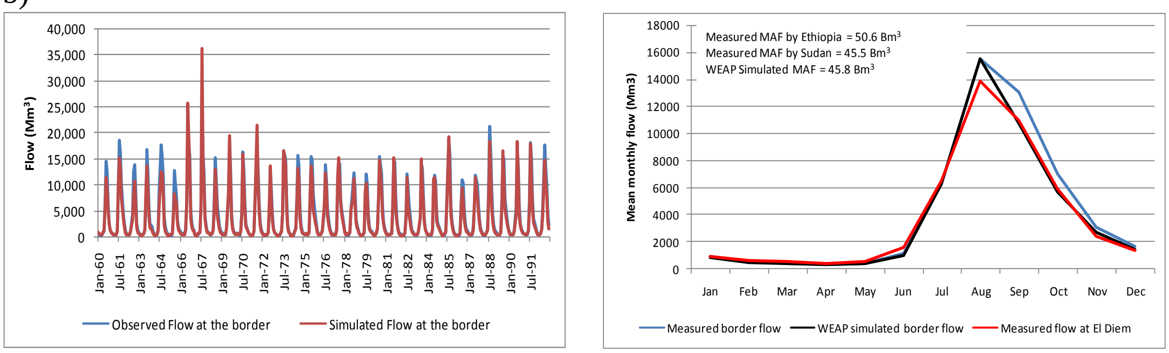


Figure 4: Simulated and observed flow series and mean monthly flows for the Blue Nile at: a) Khartoum and b) the Ethiopia-Sudan border

Figure 5 shows the simulated water levels in the Roseires and Sennar reservoirs for the current situation. Although there are no available observed data to compare with these simulated results, they do indicate how both reservoirs are operated to fill and empty each year in an attempt to reduce siltation. In some low flow years the Roseires reservoir does not fill completely.

a) b)

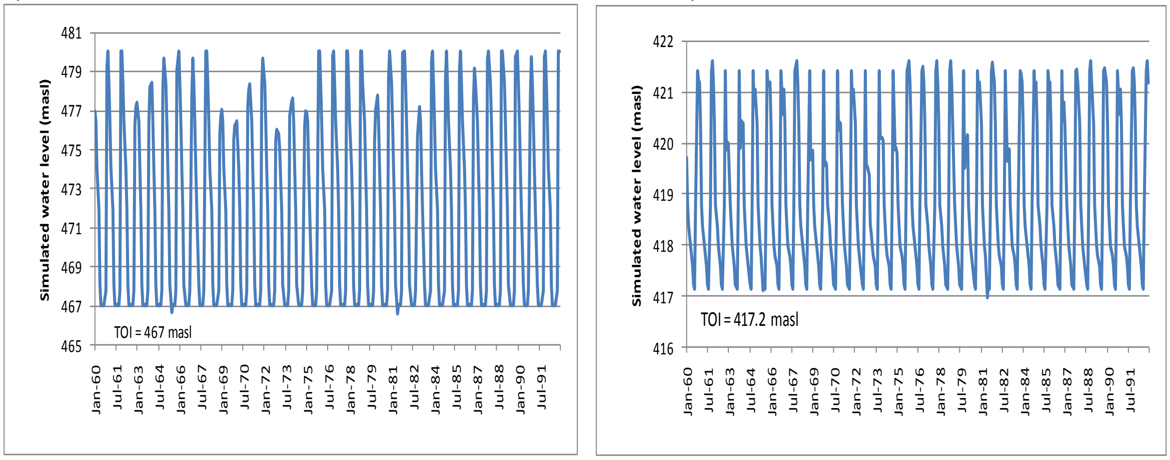


Figure 5: Simulated water levels under current conditions in a) the Roseires reservoir and b) the Sennar reservoir, Sudan

Currently irrigation water demand in Sudan greatly exceeds that in Ethiopia. Although there is some inter-annual variation, reflecting differences in rainfall, total irrigation demand in Sudan is currently estimated to average 8.5 Bm^3y^{-1} (Figure 6). This compares to an average of just 0.20 Bm^3y^{-1} in Ethiopia. With the planned irrigation development, demand in Sudan is estimated to increase to 13.4 Bm^3y^{-1} and in Ethiopia to 3.7 Bm^3y^{-1} by 2015 (Table 3). Hydropower generated in Ethiopia is currently estimated to be 1,298 $GWhy^{-1}$. With the construction of the Tana Beles transfer and the Karadobi dam this is estimated to increase to 9,930 $GWhy^{-1}$. A significant proportion of the additional electricity produced is likely to be sold to Sudan. Hydropower generated in Sudan is currently estimated to be approximately 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 Roseires dam will result in a very small increase in this amount.

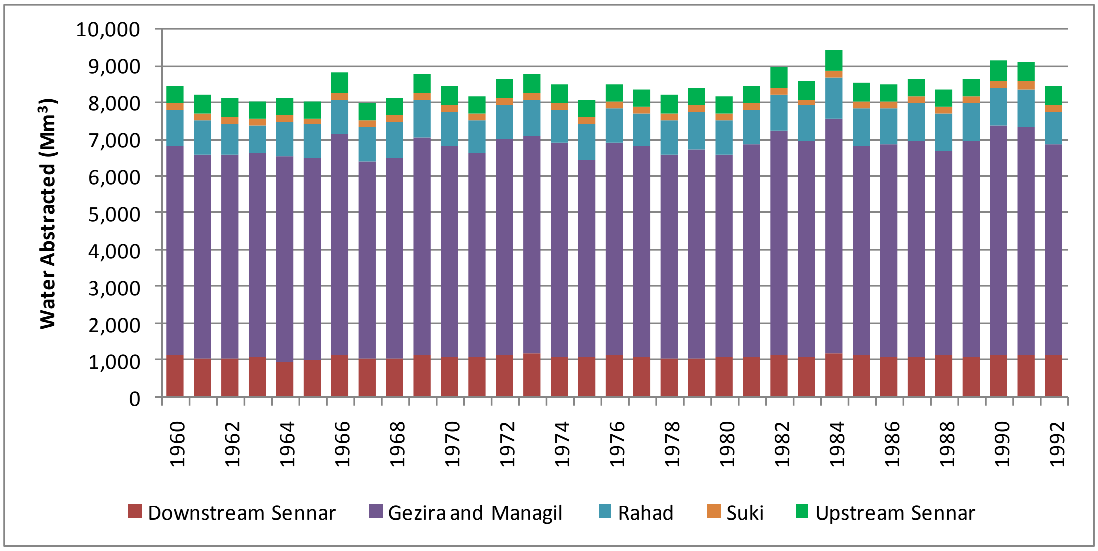


Figure 6: Estimated annual water demand for the main irrigation schemes in Sudan

Table 3 Comparison of current and future (2015) irrigation and hydropower in the Ethiopian and Sudanese parts of the Blue Nile

	Current		2015	
	Ethiopia	**Sudan**	**Ethiopia**	**Sudan**
Formal irrigation area (ha) water demand (Bm^3y^{-1})	 <10,000 0.20	 1,305,000 8.49	 210,00 3.69	 2,126,000 13.43
Hydropower Installed capacity (MW) Production ($Gwhy^{-1}$)	 218 1,298	 295 c.a. 1,000	 2,194 9,930	 295 ca 1,000

Comparison of the mean monthly flows at Khartoum for the simulated natural condition, current situation and the 2015 scenario indicates how the mean annual runoff is progressively reduced as a consequence of greater upstream abstractions. Wet season flows are reduced significantly but flows in the months January to May are increased as a consequence of flow regulation (Figure 7a). At the Ethiopia-Sudan border the current situation is almost identical to the natural condition so this not shown. However, in the 2015 scenario mean annual flow is reduced from 45.7 Bm^3 to 43.5 Bm^3. Similar to Khartoum there is a significant reduction in wet season flows, but increases in dry season flows as consequence of flow regulation (Figure 7b).

The 2015 scenario illustrates the benefit for Sudan of increased upstream regulation in Ethiopia. This is highlighted by the simulated water-levels in the Roseires Reservoir which show that it is possible to fill and empty the reservoir in all years (Figure 8). This contrasts with the current situation when in some years there is insufficient flow to fill the reservoir (see above) and is despite the fact that raising the dam will substantially increase the reservoir storage and irrigation demands will also have increased greatly.

a) b)

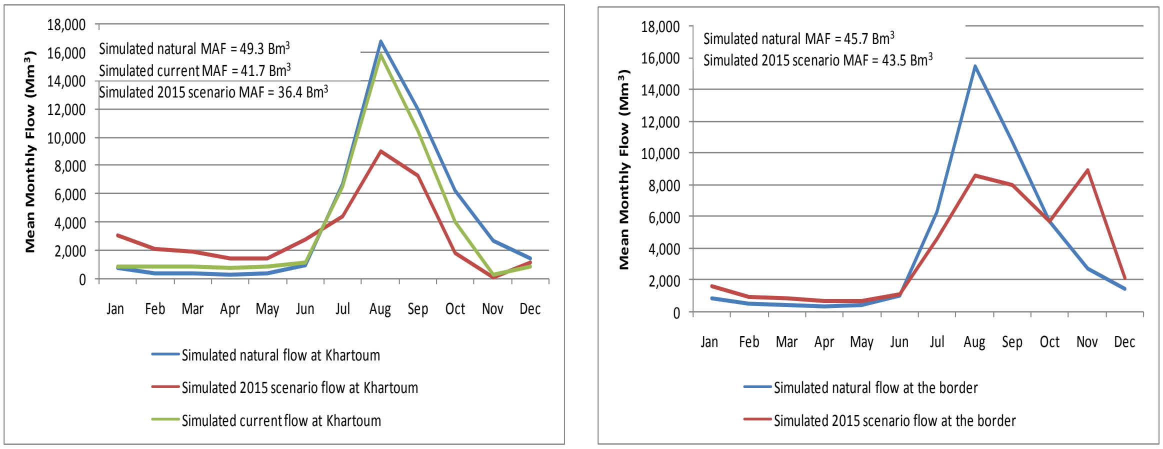


Figure 7: Comparison of simulated mean monthly flow derived for different scenarios at: a) Khartoum and b) the Ethiopia-Sudan border

a) b)

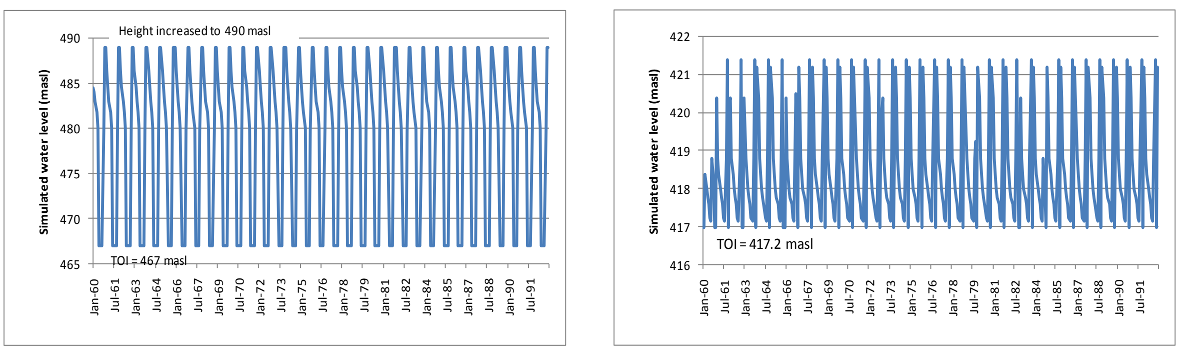


Figure 8: Simulated water levels for the 2015 scenario in a) the Roseires reservoir and b) the Sennar reservoir, Sudan

Concluding Remarks

The WEAP model has been configured to simulate the impacts of water resource development in the Blue Nile basin. Currently Ethiopia utilizes very little water but does regulate some flow for hydropower production. In contrast Sudan uses some water for hydropower production but also abstracts large volumes for irrigation. Both countries plan to develop water resource infrastructure substantially in the near future. By approximately 2015 it is estimated that the total annual consumptive demand is likely to be 17.12 Bm^3y^{-1} (i.e. 35% of the natural flow at Khartoum). Of this 3.69 Bm^3y^{-1} will be consumed in Ethiopia and 13.43 Bm^3y^{-1} in Sudan.

The results in this paper are preliminary and based on many assumptions. Where it has been possible to verify the simulations the model results are reasonable. Nevertheless, the current results must be treated with caution. In the coming months, the model will be refined using improved estimates of streamflow on the major tributaries and better estimates of irrigation demand at all schemes. In addition, it is planned to simulate another scenario based on anticipated water resource development in 2025.

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Sediment Accumulation in Roseires Reservoir

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Abstract

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.

Introduction

Reservoirs are often threatened, by loss of capacity due to sedimentation. Causes of reservoir sedimentation are many however; watershed, sediment and river characteristics are among the main natural contributing factors. Other important ones are reservoir size, shape and reservoir operation strategy. Manmade activities also play significant role particularly inland use pattern (Nazr, 2006).

Sedimentation is a complex hydro-morphological process which is difficult to predict. It has been underestimated in the past and perceived as a minor problem which can be controlled by sacrificing certain volume of the reservoir for accumulation of the sediment (dead storage). However, today’s experience revealed that it is of paramount importance in design and implementation of sediment control measures as well as in the planning, operation and maintenance phases of the reservoirs (Siyam, 2005).

Considering Reservoir sediment problem, surveys are necessary to get more realistic estimated data regarding the rate of siltation to provide reliable criteria for studying the implications of annual loss of storage over a definite period of time. This loss should be associated with particular reference of intended benefits in the form of irrigation potential, hydropower, flood absorption capacity and water supply for domestic and industrial uses including periodic reallocation of available storage for various pool levels. It will also help in proper estimation of loss of storage at the planning stage itself besides evaluating the effectiveness of soil conservation measures carried out in the catchments area of Blue Nile River (Agarwal, K.K. 2000).

Since the major cause of storage capacity change is sediment deposition the monitoring program can determine depletion caused by sediment deposition since closure of storage dam, annual sediment yield rates, current location of sediment deposition, sediment densities, lateral and longitudinal distribution of deposited sediment and reservoir trap efficiencies.

The Study Area

Roseires reservoir is located in Sudan and situated along the Blue Nile reach between the dam site and the Ethiopian border. The dam is located in the vicinity of the formerly Damazin Rapids, approximately 6 km upstream the Roseires and some 500 km south of Khartoum. This dam was built in the year 1966 for multi-propose irrigation, fisheries and hydropower (Gibb, 1996).

The watershed of the Roseires reservoir is located between longitudinal lines (11°-14°) north and longitude lines (33°-35°) east. The soil properties of the study area are clay layers covered with hilly forest at Eldeim then surround by poor Savanna in Roseires and Damazin. The climate is hot in summer with rains but is cold in winter. The temperature is between (27° - 46°c). The annual average rain fall is 700 mm and usually falls between June to October in Damazin and 1500 mm in Eldeim. Rainfall increases gradually upon going South and decreases towards the North till it is almost dry (Ministry of agriculture in Blue Nile State, 2008). Figure (1) shows the location of the reservoir within the Blue Nile system.

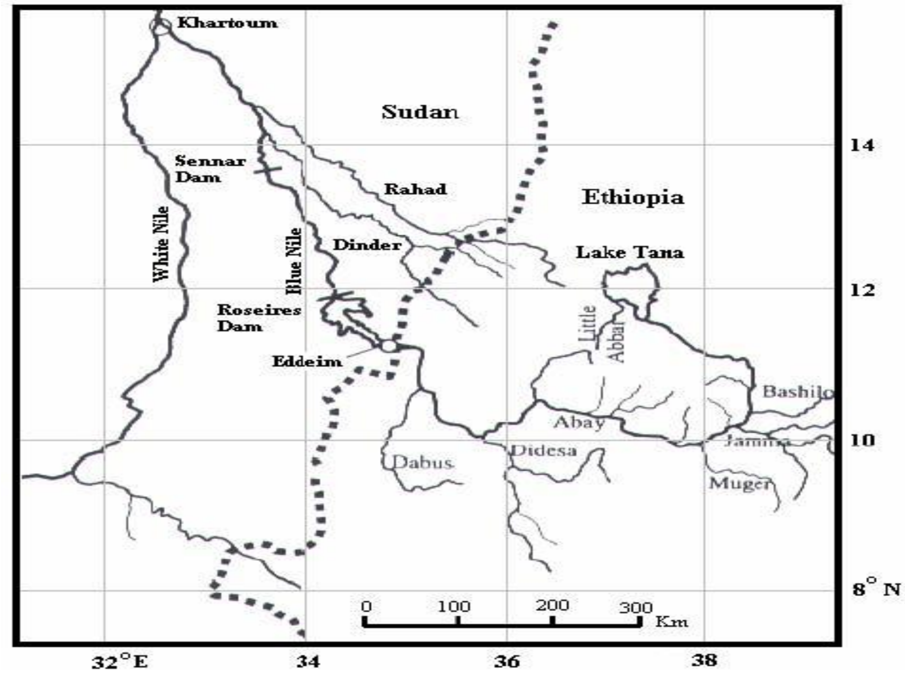


Figure 1: The Location of Roseires Dam and the Eddeim station within the Blue Nile in Ethiopia and Sudan

The Data

This study uses secondary data available from the dams' operation unit in the Ministry of Irrigation and Water Resources. The bathymetric surveys carried at Roseires reservoir (1976, 1981, 1985, 1992, 2005 and 2007) were collected and used to estimate the sediment accumulation, sedimentation rate and trap efficiency. The 1966 data was used as the base line information and all other surveys were compared to it for storage and sedimentation estimation.

Roseires Reservoir Operation

Since the trap efficiency is influenced by reservoir operation, it is important to closely examine the reservoirs in order to make judgment on their impact on trap efficiency. The roseires reservoir filling period commences after the flood peak has passed. According to the reservoir operation rules, filling may start any time between the 1^{st} and the 26^{th} of September each year depending on the magnitude of the flow at El Deim gauging station. From past experience, filling normally starts within the first ten days of September when the suspended sediment concentration is still relatively high at about 2500 mg/l. The filling period usually continues for nearly two months.

There are four main operation periods for Roseires reservoir. During the rising flood, the reservoir drawdown attains the level of 467 R.L which is the lowest operating level. Over this operation period, minimum sediment deposition is expected despite the large quantities of sediment inflow which may approach 3 M ton/day. This is particularly true after many years of continuous operation of the reservoir where a well defined channel, capable of transporting almost the whole sediment inflow past the reservoir during the drawdown period, was developed naturally (Siyam, 2005).

Due to the gradually rising water level and the relatively high suspended sediment inflow, significant sediment deposition is expected during the filling operation period. In contrast, during the third and fourth operation stages (maintaining full retention level and reservoir emptying), sediment deposition is insignificant due to the exceedingly small sediment and inflow quantities.

From the above description, only operation filling period is of importance as far as reservoir sedimentation and trap efficiency are concerned in Roseires reservoir. Therefore this is taken in consideration when estimating the trap efficiency using either Brune or Churchill method. Over the filling period, the water level at 474 m R.L is considered for the computation. The reservoir content at this mean level is used together with an annual inflow of $50x10^9$ m^3 to estimate the trap efficiency using both methods. The results are compared with measured values for the years when reservoir surveys were made.

Methods

Sediment accumulation

Sediment accumulation in the reservoir is calculated using the bathymetric survey data collected from the Dams Directorate of the Ministry of Irrigation and Water Resources. The base line was taken as the design storage capacity of the reservoir at the different levels in 1966. The storage capacity in the different bathymetric surveys compared to that of 1966 at different level enables estimation of sediment accumulation rates. Thus, the comparison between accumulated silt volumes deposited between the different surveys is obtained. This work is done using spreadsheet analysis in excel.

The accumulated volume of deposited sediment V_d can also be calculated Empirically from the following formula

$$V_d = (\text{T.E}/100) * (140x10^6 * T) / \gamma$$

Where V_d = accumulative volume of deposited sediment, m^3

T.E = trap efficiency after T years of operation (%)

T = years of operation

γ = average specific weight of deposited sediment over T years (t/m^3) calculated from Miller, 1953 formula

Siltation rate

The average silt deposit per year for the different reduced levels is calculated by dividing the sediment accumulated by the corresponding number of years of operation.

The percentage of silt deposited is obtained by the following calculation:

%age silt deposited per year = $V / A / d / N$

Where:
V = Volume of silt in the given range in m^3
A = Average surface area of the reservoir at the middle of given levels in m^2
D = difference between given levels in m.
N = number of years of operation.

Trap Efficiency

Reservoir trap efficiency is defined as the ratio of deposited sediment to total sediment inflow for a given period within the reservoir economic life. Trap efficiency is influenced by many factors but primarily is dependent upon the sediment fall velocity, the detention-storage time, flow rate through the reservoir and reservoir operation. The relative influence of each of these factors on the trap efficiency has not been evaluated to the extent that quantitative values could be assigned to individual factors. The detention-storage time in respect to character of sediment appears to be the most significant controlling factor in most reservoirs (Siyam, 2005).
Trap efficiency estimates are empirically based upon measured sediment deposits in large number of reservoirs mainly in U.S.A. Brune (1953) and Churchill (1948) methods are the best known ones.
For a given reservoir experiencing sediment deposition, its trap efficiency decreases progressively with time due to the continued reduction in its capacity. Thus trap efficiency is related to the reservoir remaining capacity after a given elapsed time (usually considered from the reservoir commissioning date).

The measured trap efficiency is computed from the following equation:

$$\text{T.E}(\%) = \frac{(V_0 - V)\gamma}{\text{T} * 140 * 10^6}$$

Where, T.E. = trap efficiency after T years of operation
V_0 = original reservoir volume, m^3
V = volume remaining after T year of operation
γ = average specific weight of deposited sediment over T years (t/m3)
γ is calculated from the following equation (Miller, 1953)

$$\gamma = \gamma_i + 0.434\kappa[(\text{T}/(\text{T}-1))*(Ln\text{T}) - 1]$$

Where γ_i the initial is value of and γ is given by: $\gamma_i = \gamma_{cl}\text{P}_{cl} + \gamma_{sl}\text{P}_{sl} + \gamma_{sa}\text{P}_{sa}$

Where P_{cl}, P_{sl} and P_{sa} are fractions of clay, silt and sand respectively of the incoming sediment while γ_{cl}, γ_{sl} and γ_{sa} are coefficients of clay, silt and sand respectively which can be obtained from the tables prepared by USPR, 1982 for normally moderate to considerable reservoir drawdown (reservoir operation 2) which is the case for Roseires reservoir.
The essence of Churchill's method is contained in a graph relating the percentage of sediment that passes through a reservoir to a so-called sedimentation index SI. This method is given by

$$\text{T.E} = 1 - S\text{I}$$

$$S\text{I} = \frac{\text{T}}{\overline{V}}$$

Where T = retention time and $\overline{V}$ = mean velocity of water flowing through the reservoir (Taher, A., 1999).
Brune's method is certainly the most widely used one to estimate reservoirs trap efficiency. Siyam (2000) has shown that Brune's curve is a special case of a more general trap efficiency function given by the following equation:

$$T.E(\%) = 100 \exp(-\beta V / I)$$

Where, in addition to the already defined terms, β is a sedimentation parameter that reflects the reduction in the reservoir storage capacity due to the sedimentation processes?
Siyam (2000) demonstrated that the above equation with values of β = 0.0055, 0.0079 and 0.015 describes well the upper, median and lower Brune's curves respectively. Brune's semi-dry reservoirs (β = 0.75), and in the case of a mixer tank where all the sediment is kept in suspension (β = 1). The Roseires Reservoir data was fitted with β = 0.056 which was the mean of the individual β values resulting from fitting the observed trap efficiency data.

Results and Discussions
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 are shown in the following subsections.

Table 1 Storage capacity

R.L	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 (1) shows the decrease in the storage capacities with time at all reduce levels. Figures 2 a 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 have been reduced to 1920.89 million cubic meters and 13.84 million cubic meters have been lost in the last two years (2005 – 2007).

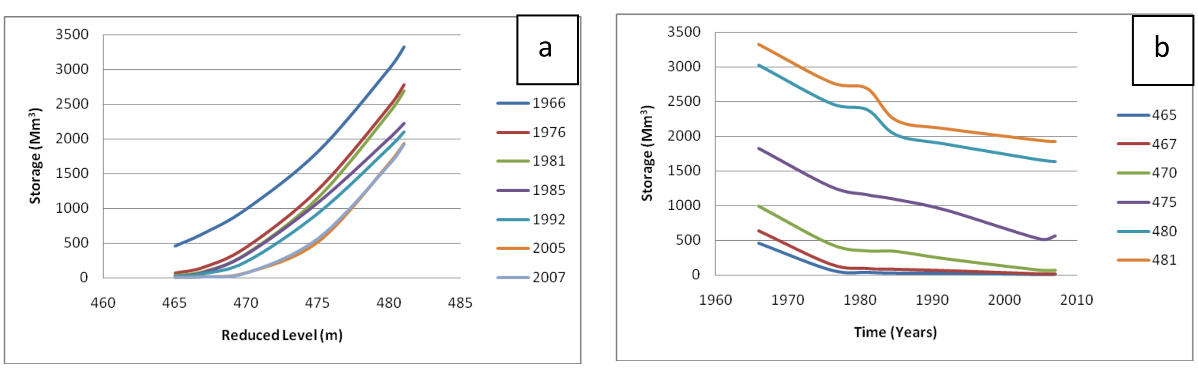


Figure 2: Variation of storage with time and reservoir level

As the initial capacity below reduced level 467 was established to be 638 million cubic meters the loss of capacity below this level was 97.8% of the initial storage. The expected total capacity at design stage of the reservoir at level 490 m was 7.4 Mm^3. However, due to the loss of capacity found now at level 481 m which amounted to 1.92 Mm^3, the expected capacity after the heightening project implementation will be 5.48 Mm^3.

Table (2) Shows the accumulated silt deposited at the different reduced levels in the different years of survey. It can be seen that there is an increase in the silt deposit with time at all reduced levels. After forty one years of operation (1966-2007), the accumulated silt volume deposit of the reservoir has amounted to 1408.1 million cubic meters. About 14 million cubic meters have been added in the last two years (2005 – 2007) i.e. about 1%. Figure (3) depicts the variation of silt deposited with time and reduced level.

Table 2 Accumulated Silt volume deposit for different surveys

R.L	**1976 (Mm^3)**	**1981 (Mm^3)**	**1985 (Mm^3)**	**1992 (Mm^3)**	**2005 (Mm^3)**	**2007 (Mm^3)**
465	386	418	428	431	449.5	447.79
467	486	547	558	578	624.29	624.02
470	548	642	650	757	919.54	919.62
475	550	665	733	889	1303.5	1254.2
480		640	1004	1138	1365.6	1386.4
481		640	1102	1225	1394.3	1408.1

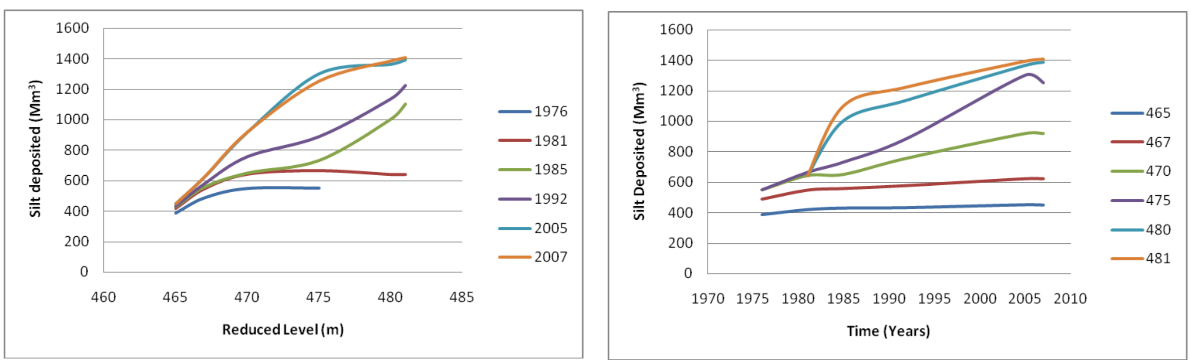


Figure 3: Variation of storage with time and reservoir level

From Roseires reservoir resurveys summarized above, the observed and computed trap efficiency values with Brune's and Churchill's methods are given in table (3). Figure shows graphically the variation of the trap efficiency with time.

Table 3 Roseires Reservoir Trap efficiency %

Years of re-survey	**1976**	**1981**	**1985**	**1992**	**1995**
T (Years)	10	15	20	27	29
Observed	45.5	36	33.2	28	26.2
Brune's methods	51	49	46	45	45
Churchill's methods	67.7	66	64.4	63.5	62.8

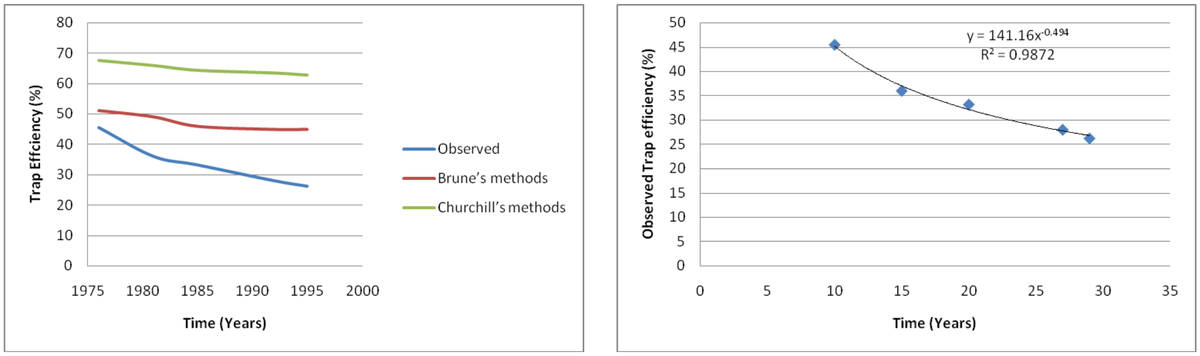


Figure 4: Variation of trap efficiency of the reservoir with years of operation

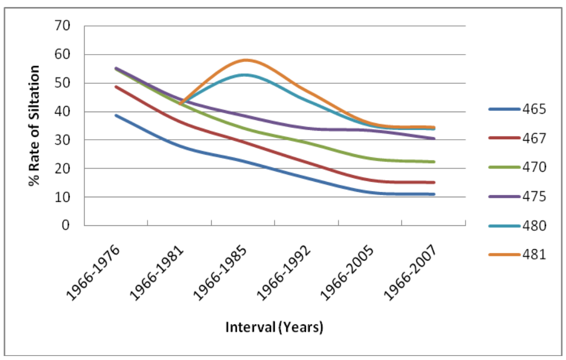
From Figure (4) it can be seen that the observed trap efficeincy is inversely proportional to the square root of operation time. This figure may be used to estimate subsequent trap efficiency of Roseiers reservoir. From the figure, the projected trap efficiency after 100 years of continuous operation will be about 14% if conditions remain the same in the mean time.
It is generally believed that the volume of deposited Sediment from the 1992 resurvey as given in Tables (1, 2) was over estimated. Making use of the results of the later resurvey in 1995, it is expected that the trap efficiency in 1992 to be close but higher than its observed value in 1995 due to the relatively short time in between the two resurveys.
From Table (3) both Brune's and Churchill's methods overestimated the trap efficiency values. The failure of these methods may be attributed to their structures as they consider only few factors. In the earlier years of the reservoir life, the rate of sediment deposited was high as reflected in the relatively high observed trap efficiency values. The deposition rate, however, decreased progressively with time as witnessed from the gradual drop in observed trap efficiency from 45.5% in 1976 to 26.2% in 1995. This trend was not reflected in the computed trap efficiency values using both Brune's and Churchill's methods which remained fairly constant over the years of observations.

Accumulation rate

Table (4) contains the average silt deposited per year for the different reduced levels. As depicted in figure (5) it can be seen that there is a decrease in siltation rate with time at all reduced levels. This phenomenon can be explained by the fact that as time passes a decrease in the reservoir storage capacity occurs; flow velocities for the same discharges are increased; the sediment carrying capacity of the flow being the limiting factor of sediment transport is in turn increased. The siltation rate has dropped from 16.01 million cubic meters per year to 15.22 million cubic meters per year at 467 reduce level and from 35.75 million cubic meters per year to 34.34 million cubic meters per year at 481 reduce levels.

Table 4 Siltation Rate for different surveys (Mm^3/Year)

R.L (m)	**1966-1976 (Mm^3/Year)**	**1966-1981 (Mm^3/Year)**	**1966-1985 (Mm^3/Year)**	**1966-1992 (Mm^3/Year)**	**1966-2005 (Mm^3/Year)**	**1966-2007 (Mm^3/Year)**
Years	10	15	19	26	39	41
465	38.60	27.87	22.53	16.58	11.53	10.92
467	48.60	36.47	29.37	22.23	16.01	15.22
470	54.80	42.80	34.21	29.12	23.58	22.43
475	55.00	44.33	38.58	34.19	33.42	30.59
480	-	42.67	52.84	43.77	35.02	33.82
481	-	42.67	58.00	47.12	35.75	34.34



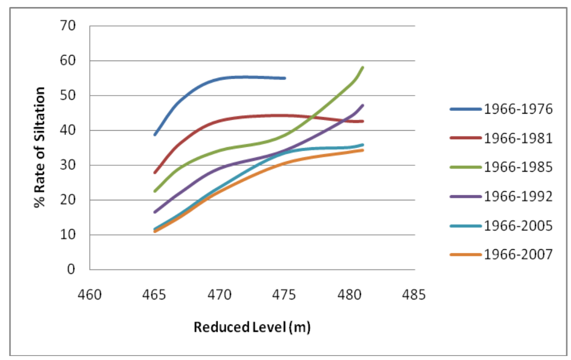


Figure 5: Variation of % siltation rate with time and reservoir level

The volume of silt deposited in the area impounded by the given reduced levels, the average surface area of the reservoir at a given reduced level and the corresponding estimate of % silt for years 2005 and 2007 are shown in table (5).

Table 5 Silt deposited per year as a percentage of storage capacity (2005, 2007)

Years	**2005**			**2007**		
Level (m)	Silt Vol. (Mm)	A(x10^{6}m^2)	%age of Silt	Silt Vol. (Mm)	A(x10^{6}m^2)Area	%age of Silt
465-467	175	4.5	50	176	3.46	62
467-470	295	17.6	14	296	18.11	13.3
470-475	384	84.1	2	335	102.9	1.6
475-480	62	236.1	0.1	132	216.14	0.3
480-481	29	273.4	0.3	22	281.62	0.2

As expected, siltation rate is generally heavy below the minimum draw-down R.L maintained during the flood period which is 467. Siltation rate is small above this minimum draw-down level. There is no increase in the percentage silt deposited in the ranges 475- 480. Figure (6) show the variation of the siltation rate for a given area in the reservoir in 2005 and 2007.

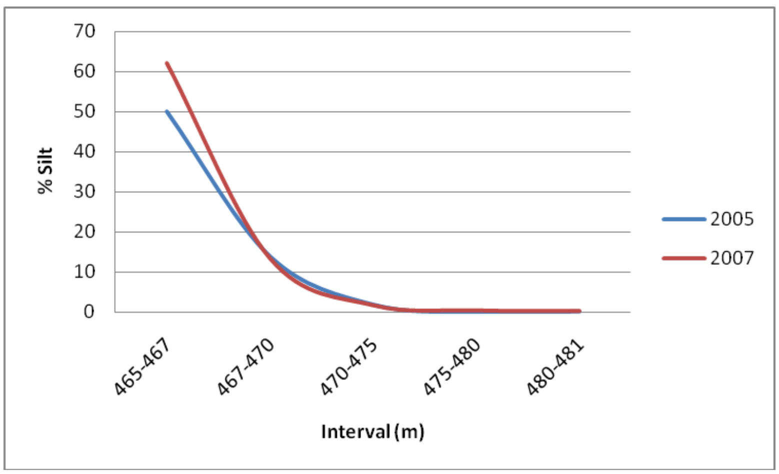


Figure 6: Variation of the siltation rate with area in 2005 and 2007

Conclusion and Recommendations

About 30% of the reservoir storage capacity is silted up. The rate of siltation at all levels is continually decreasing with time which is an indicator of decrease in storage capacity.
Siltation rate below reduced level 467 dropped from 16 million m^3/year in the period 1966-2005, to 15.22 million m^3/year in the period 2005-2007. While below 481 R.L the siltation rate was dropped from 35.75 million m^3/year in the period 1966-2005 to 34.34 million m^3/year in the period 2005-2007. The present reservoir capacity at reduce level 481 is 1920.89 million m^3 of which 6.21 million m^3 is a dead storage below R.L 467.
A relationship between observed trap efficiency and years of operation was found. The trap efficiency for the reservoir follows linearly the square root of time and is inversely proportional to it. It is projected that the trap efficiency of Roseires reservoir after 100 tears will be in the order of 14%.

It is recommended that a well-planned program for sediment data collection be established especially on the characteristics and movement of sediment in the reservoir, and Blue Nile near the Ethiopian border to monitor the effect of changes and interventions on the upstream site.

Also regular bathymetric surveys, monitoring of sediment accumulation and reservoir trap efficiency is recommended to assess the effects of the interventions.

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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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Abstract

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%.

Introduction

Ethiopia has huge potential resources which includes total of 122 billion cubic meters of surface water, 2.6 billion cubic meters of groundwater resources and 3.7 million hectare of potentially irrigable land that can be used to improve agricultural production and productivity (Awulachew et al., 2007; MoWR, 2002).

Despite these potential resources base, agricultural production are lowest in some parts of the country attributed from unsustainable environmental degradation mainly reflected in the form of erosion and loss of soil fertility (Demel, 2004).Under the prevalent rainfed agricultural production system, the progressive degradation of the natural resource base, especially in highly vulnerable areas of the high lands coupled with climate variability have aggravated the incidence of poverty and food insecurity (Awulachew et al., 2007).

Sheet and rill erosion are by far the most widespread kinds of accelerated water erosion and principal cause of land degradation in the country and their combined effect significantly affect agricultural production and productivity (Contable, 1984).The loss of nutrient-rich top soil by water leads to loss of soil quality and hence reduced crop yield. Soil erosion by water and its associated effects are therefore recognized to be severe threats to the national economy of Ethiopia .Since more than 85% of the country's population depends on agriculture for living; physical soil and nutrient losses lead to food insecurity (Luelseged, 2005).

Rapidly increasing population, deforestation, over cultivation, expansion of cultivation at the expense of lands under communal use rights (grazing and woody biomass resources), cultivation of marginal and steep lands, overgrazing, and other social, economic and political factors have been the driving force to a series of soil erosion in the basin in general and in Gumara watershed in particular (BCEOM, 1998; MoARD, 2004).

One of the possible solutions to alleviate the problem of land degradation (soil erosion) is therefore, to understand the processes and cause of erosion at a micro watershed level and to implement watershed management interventions. Effective watershed planning requires understanding of runoff and erosion rates at the plot, on hill slopes, and at small watershed scale and how these vary across the landscape. Next we must have a means to identify areas that have the potential for high erosion so that corrective actions can be taken in advance to reduce sediment production from these areas.

In recent decades, several simulation models have been developed in order to estimate, analyze soil erosion and enhanced understanding of spatial and temporal aspects of the catchments and assessment of process over large area that enables priority management areas to be identified

The purpose of this study is therefore, to determine the spatial variability of sediment yield, to identify critical micro watersheds and evaluate various conservation scenarios in reducing sediment yield based on the simulation result of a physically based and spatially distributed SWAT (Soil and Water Assessment Tool) model.

Objective of the study

The overall objective of this study is to characterize the Gumara watershed, predict sediment yield and runoff and develop management options to control erosion and sedimentation problem in Gumara watershed.

The specific objectives of the study are:

- To characterize the Gumara watershed in terms sediment yield
- Assess and evaluate the spatial variability of sediment yield in the watershed
- To identify and prioritize hot spot areas for site specific management intervention
- To cite and recommend appropriate soil and water conservation measures.

Description of Gumara Watershed

The study area is found in North West part of Ethiopia in Amhara Regional State, south Gondar Zone (Figure 1). The watershed covers partly four woredas (administrative units) namely, farta, Fogera, Dera, Iste. It is situated in the south east of Lake Tana and covers a drainage area of about 1464 km^2 .

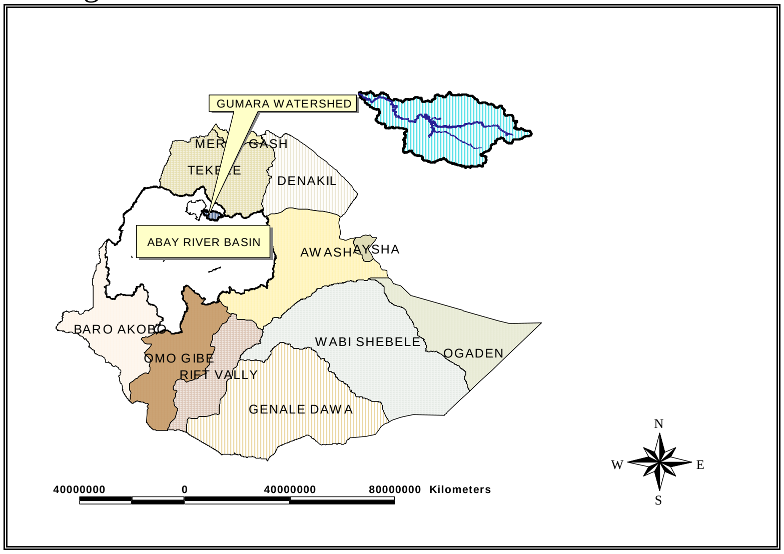

Figure 1: Major River Basins in Ethiopia and Location Map of Gumara Watershed

The major land form of the watershed includes flat, gently sloping to undulating plains, hills and mountains. The upper and middle parts of the catchment are characterized by mountainous, highly rugged and dissected topography with steep slopes and the lower part is characterized by valley floor with flat to gentle slopes. Elevation in the watershed varies from 1780 to 3678 meter above sea level with a mean elevation of 2200 meter above sea level.

More than three quarter of the watershed is intensively cultivated land and teff, maize, Barley, and Wheat are the major crops grown in the watershed. Bush or shrub land, grazing land, forest/wood land and wetland/swap are other land cover types in the watershed (WWDSE, 2007).
Based on FAO classification system, six soil types namely, Haplic luvisol, chromic luvisol, Lithic leptosol, Eutric vrtisol, Eutric Fluvisol and Chromic Cambisol are common soil types in Gumara Watershed (BCEOM, 1998; MoARD, 2004; WWDSE, 2007).

Rainfall over the Gumara watershed is mono-modal and most of the rainfall is concentrated in the season June to September and with virtual drought from November through April. The four wettest months cover 85 percent of the total annual rainfall. The dry season, being from October to May has a total rainfall of about 15% of the mean annual rainfall (WWDSE, 2007).

Methodology

SWAT 2005 (Soil and Water Assessment Tool) model integrated with GIS techniques is used to simulate runoff and sediment yield of this study. SWAT is a physically based and computationally efficient hydrological model, which uses readily available inputs .It was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time (Neitsch, et al., 2005).

Digital elevation model (DEM) data, polygon Coverage' of soils and land use, and point coverage of weather stations were used as basic input to the model. Other inputs used include daily rain fall, minimum and maximum temperature, relative humidity, solar radiation, and wind speed. We delineated the watershed using a using a 90mx90 m resolution digital elevation model (DEM) and digitized stream networks of the study area.

After watershed delineation, the watershed was partitioned in to hydrologic response units (HRU), which are unique soil and land use combinations within in the watershed to be modeled.
In this study, multiple HRU with 20 percent land use threshold and a 10 percent soil threshold were adopted.

For modeling surface runoff and sediment yield we used the SCS curve number method (SCS, 1972) and modified universal soil loss equation respectively. 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).

We used the manual calibration procedure and the model was calibrated and validated using flow and suspended sediment data measured at 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.

Result and discussion

Sensitivity Analysis

We carried out Sensitivity analysis to identify sensitive parameter that significantly affected surface runoff, base flow and sediment yield. Curve number (CNII), available water capacity (SOL_AWC), average slope steepness (SLOPE), saturated hydraulic conductivity (SOL_K), maximum canopy storage (canmx) and soil depth (SOL_Z) and soil evaporation compensation factor (ESCO) were relatively high sensitive parameters that significantly affect surface runoff.

Threshold water depth in shallow aquifer for flow (GWQMN), base flow Alpha factor (ALPHA_BF), and deep aquifer percolation fraction (rchrg.dp) were other parameters that mainly influence base flow.

We also identified average slope Steepness, USLE cover or management factor, USLE support Practice factor , average slope length, Linear factor for channel sediment routing and exponential factor for channel sediment routing as the most sensitive parameters that significantly affect sediment yield.

Calibration and validation

Once we have identified the most sensitive parameters, values of selected model parameters were varied iteratively within a reasonable range during various calibration runs until a satisfactory agreement between observed and simulated streamflow and sediment data were obtained. Five years daily flow and measured sediment data were used for flow and sediment calibration respectively.

Flow Calibration resulted in Nash–Sutt cliffe simulation efficiency (ENS) of 0.76, correlation coefficient (R2) of 0.87, and mean deviation of 3.29 % showing a good agreement between measured and simulated monthly flows.

The model with calibrated parameters was validated by using an independent set of measured flow and sediment data which were not used during model calibration. We used three years measured flow and sediment data for validation processes. Accordingly, good match between monthly measured and simulated flows in the validation period were demonstrated by the correlation coefficient (R^2) of 0.83 ,Nash-Sutcliffe simulation efficiency (ENS) of 0.68 and a mean deviation of measured and simulated flows for the monthly flow was found to be -5.4

Table 1 Calibration and validation statistic for monthly measured and simulated Streamflow

Parameter	Calibrated(1998-2002)	Validated (2003-2005)
R^2	0.87	0.83
E_{ns}(Nash-Sutcliffe model efficiencies)	0.76	0.68
D%(deviation of mean discharge)	3.29	-5.4

Table 2 Comparison of monthly measured and simulated flows

Period	Average flow (m3/s)	
	Measured	Simulated
Calibration (1998-2002)	31.63	32.69
Validation (2003-2005)	33.98	32.15

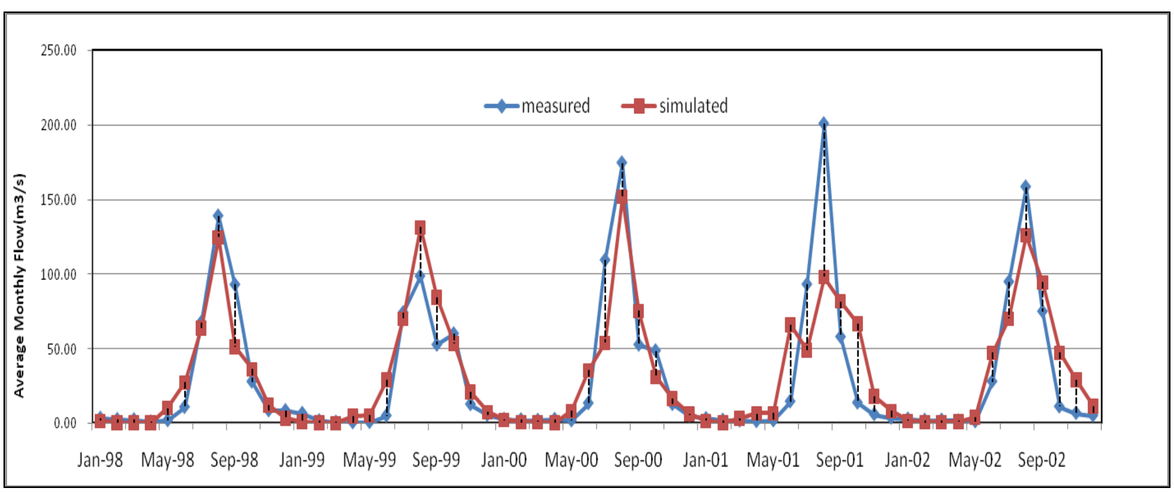

Figure 2: Calibration results of average monthly measured and simulated flow

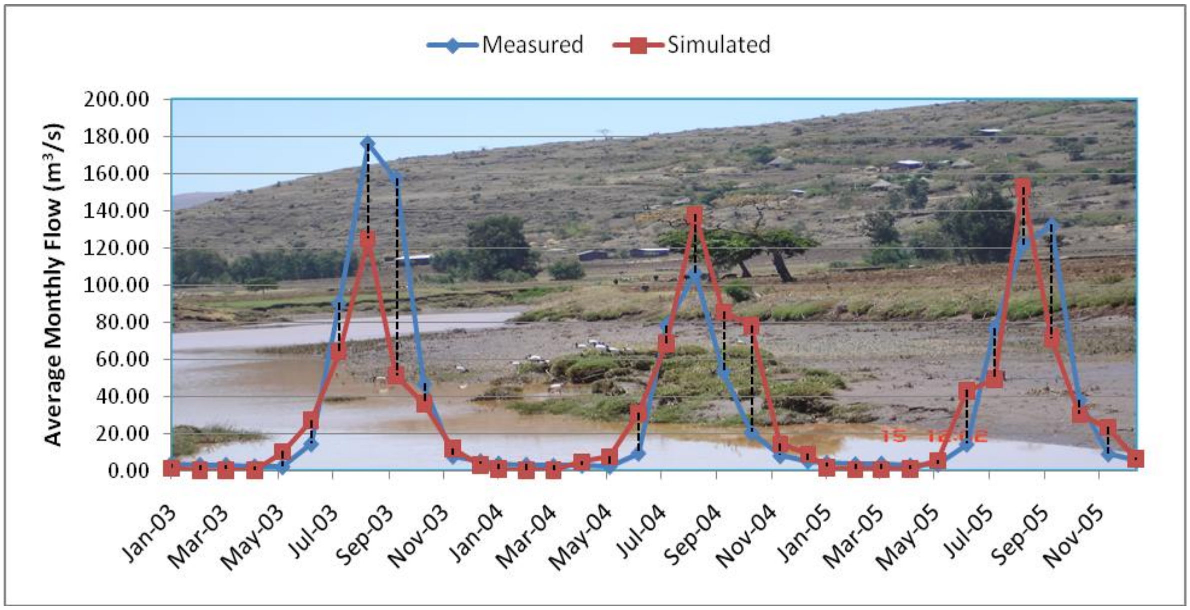

Figure 3: Validation results of average monthly measured and simulated flow

In calibrating sediment a good agreement between simulated monthly sediment yields with measured sediment yield was verified by correlation coefficient (R^2) of 0.85, Nash-Sutcliffe model efficiency (E_{NS}) 0.74 and mean deviation (D) of -14.2% . In validating sediment, a match between simulated and measured sediment was demonstrated by correlation coefficient (R^2) of 0.79, Nash-Sutcliffe model efficiency (E_{NS}) 0.62 and mean deviation (D) of -16.9%.

Table 3 Calibration and Validation results of monthly measured and simulated sediment yield

Parameter	**Calibrated (1998-2002)**	**Validated (2003-2005)**
Correlation coefficient (R^2)	0.85	0.79
Nash-Sutcliffe model efficiencies(E_{ns})	0.74	0.62
Deviation of mean discharge (D %)	-14.2	- 16.9

Table 4 Average Monthly and Annually Measured and Simulated Sediment Yield for calibration and validation periods

Simulation periods	Average Measured Sediment Yield		Average Simulated Sediment Yield	
	(t/ha/m)	(t/ha/yr)	(t/ha/m)	(t/ha/yr)
1998-2002 (calibration)	1.80	21.6	1.55	18.6
2003-2005 (Validation)	1.91	22.92	1.60	19.2

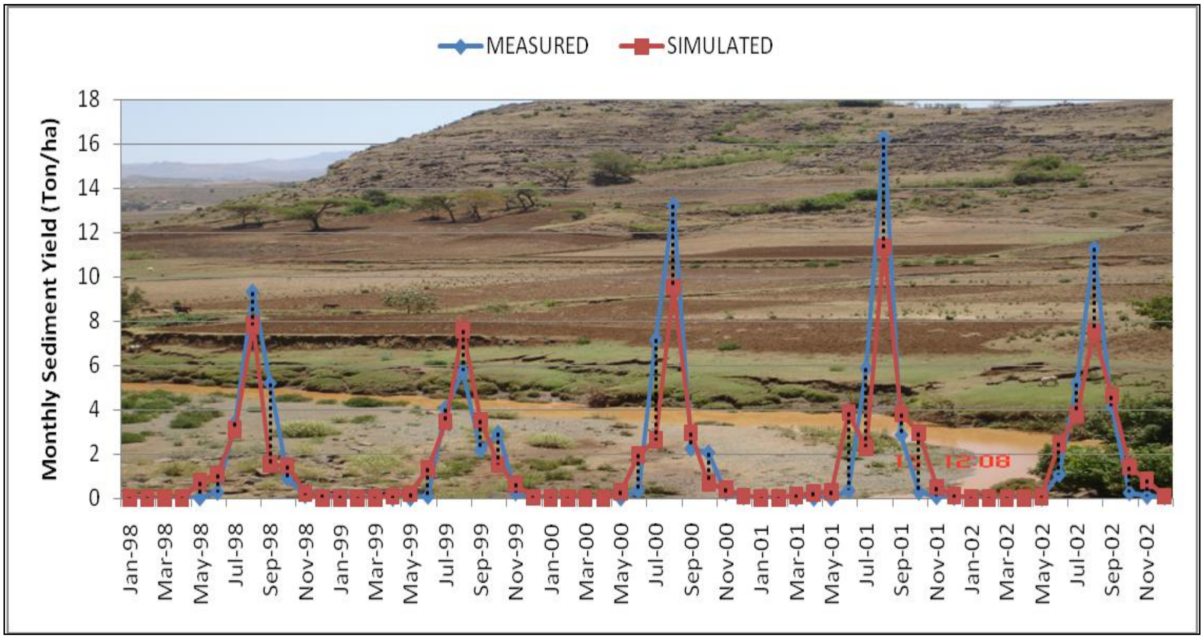

Figure 4: Calibration results of monthly measured and simulated sediment yield

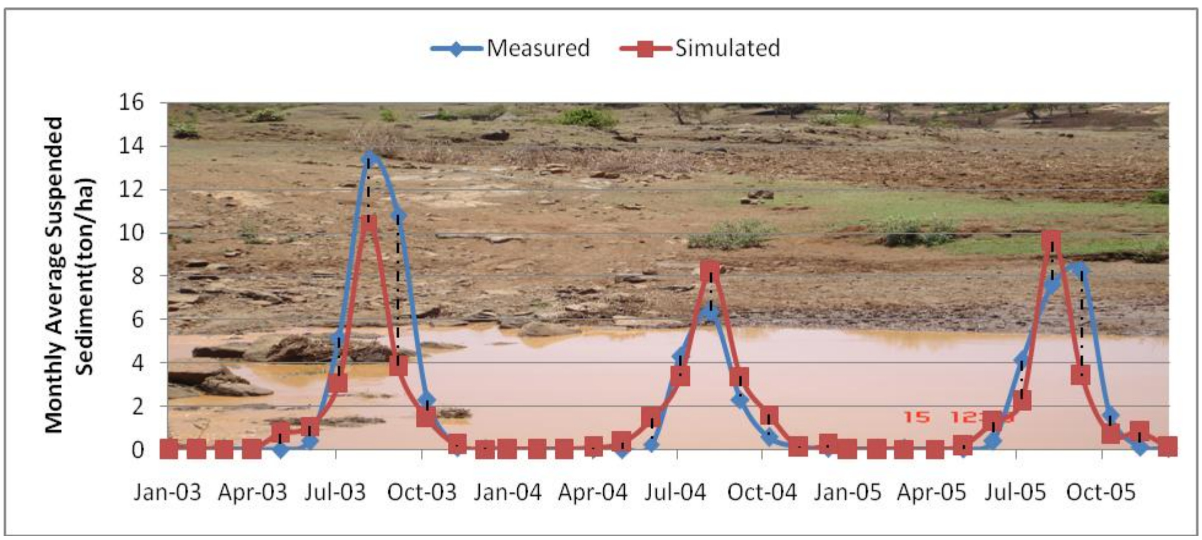

Figure 5: Validation results of monthly measured and simulated sediment yield

Spatial pattern of Sediment source areas

After Calibration and validation, the model was run for a period 10 years .From the model simulation output, sediment source areas were identified in the Watershed.10 years annual average measured suspended sediment generated from the sediment rating curve was 20.7 ton/ha/yr and the simulated annual average suspended sediment yield by SWAT model was 16.2 t/ha/yr. The spatial distribution of sediment generation for the Gumara watershed is presented in Figure 6. The spatial distribution of sediment indicated that, out of the total 30

SWAT sub basins, 18 sub-basins produce average annual sediment yields ranging from 11-22 ton/ha/yr, while most of the low land and wetland areas are in the range of 0-10 ton/ha/yr.

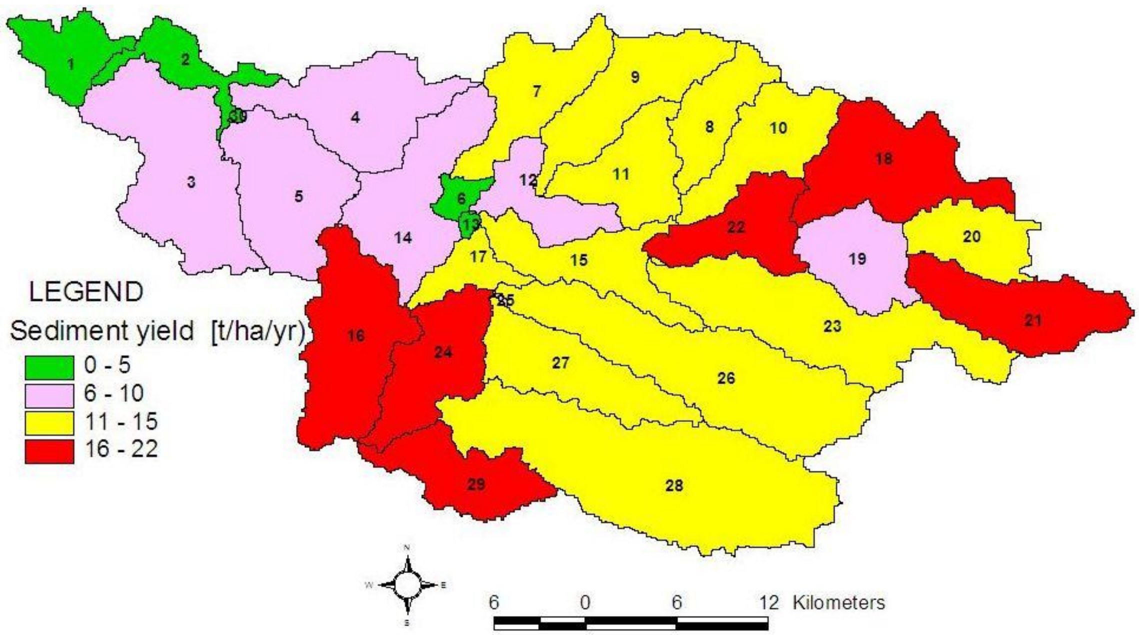

Figure 6: Spatial Distribution SWAT simulated annual sediment yield classes by sub basin (t/ha/yr), Number (1-30) are sub basin numbers

Scenario Analysis

Once the model has been validated and the results are considered acceptable, the model is ready to be parameterized to the conditions of interest (e.g., to evaluate impact of land use change, management and conservation practices). After detail 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. In evaluating Impact filter strips, three management scenarios were considered and simulated:

I. Base Case (no filter Strip)
II. Filter strip 5 m wide on all HRUs (hydrologic response units) in selected sub watersheds; and
III. Filter strips 10 m wide on all HRUs in selected sub watersheds

With implementation of vegetation strips ,an average annual sediment yields can be reduced by 58 % to 62 % with 5m buffer strip and 74.2 to 74.4 % with 10m filter strips(table 5 ,figure 7 and 8)

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	-0.62	-74.35
16	18.200	7.6	4.68	-0.58	-74.30
17	12.100	4.6	3.11	-0.62	-74.29
22	17.600	6.8	4.54	-0.61	-74.23
24	21.300	8.2	5.48	-0.62	-74.29
28	12.700	4.9	3.28	-0.61	-74.19
29	19.200	7.4	4.95	-0.61	-74.23

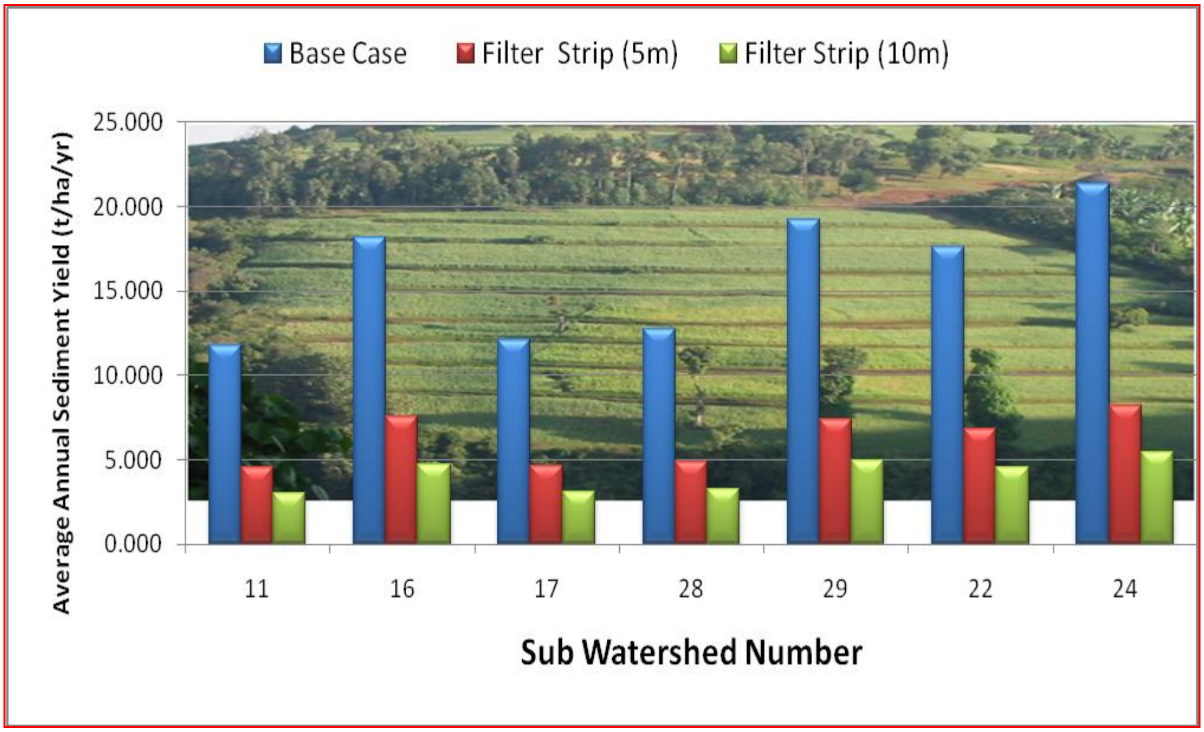

Figure 7: Reduction in sediment yield (t/ha/y) due to implementation of different width of filter strips as compared to the base case

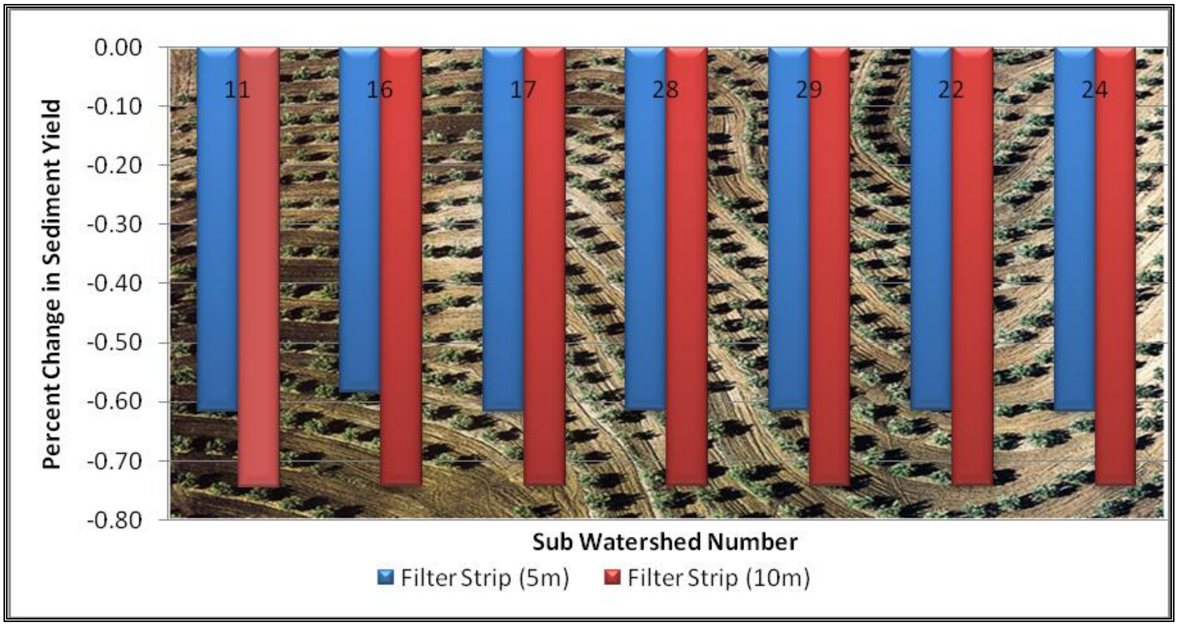

Figure 8: Percent Reduction in simulated average annual suspended sediment yield (t/ha/y) due to implementation of filter strips

Conclusion and recommendation

Even though the problem of soil erosion is recognized from gross erosion estimates and field observations, quantitative information and data are required at micro watershed level to develop alternative watershed management plans and for decision making. In this study, attempts were made to characterize the Gumera watershed in terms of sediment yield, identification of potential sediment source areas and evaluation of alternative management interventions to reduce the onsite and offsite impact of soil erosion in the watershed.

We evaluated the performance of SWAT model using Standard calibration and validation statistics. A good agreement between measured and simulated monthly streamflow was demonstrated by correlation coefficient (R^2 = 0.87), Nash-Sutcliffe model efficiency (ENS = 0.76) and mean deviation (D = 3.29) for calibration period and $R^{2\,=}$ 0.83, ENS = 0.8 and D= -5.4 % for validation periods. The model over estimated simulated flow by 3.29 % and under estimated by 5.4 % for calibration (1998 -2002) and validation periods (2003-2005) respectively.

In simulating sediment yield, correlation coefficient (R^2 =0.85), Nash-Sutcliffe model efficiency (E_{NS}= 0.74.) and mean deviation (D=-14.2%) for calibration period and R^2=0.79, ENS =0.62 and D=-16.9% for validation periods were achieved. In both calibration and validation periods, simulated sediment yield were under estimated by 14.2% and 16.9 % respectively. Considering, the acceptable limits of statistical model evaluation criteria; these result indicate a good a match between measured and simulated sediment.

A good performance of the model in the Validation period indicates that the fitted parameters during calibration period can be taken as a representative set of parameters for Gumara watershed and further simulation and evaluation of alternative scenario analysis can be carried out for other periods using the SWAT model. The SWAT model prediction verified that about 72 % of the gumara watershed is erosion potential area contributing high sediment yield exceeding the tolerance limit (soil formation rate) in the study area.

Following calibration and validation of SWAT model, two scenario analyses were tested to reduce sediment loads from critical sub watersheds. The simulation results of the two scenario analysis (using vegetation filter strips of 5m and 10 m wide) indicated that implementing filter strips can reduce sediment yield by 58 % to 74 %. Overall, SWAT performed well in simulating runoff and sediment yield on monthly basis at the watershed scale and thus can be used as a planning tool for watershed management. The study can be further extended to similar watersheds in Abay River basin, other similar areas and can bridge the gap of adequate information between processes at the micro watershed and large watershed level.

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Development of Rainfall-Runoff-Sediment Discharge Relationship in the Blue Nile Basin

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Abstract

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. 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.

Introduction

Establishing a relationship among hydrological components is the central focus of hydrological modeling from its simple form of unit hydrograph to rather complex models based on fully dynamic flow equations. Models are generally used as utility in various areas of water resource development, in assessing the available resources, in studying the impact of human interference in an area such as land use change, climate change, deforestation and change of watershed management (intervention of watershed conservation practices).

Sediments are all the basin rock and soil particles water carries away by sliding, rolling or jumping on the bed and suspended in the flow. Very fine particles move in suspension. The finer the particles and/ or the stronger the flow turbulence, the greater is the transport in suspension. Once the sediment particles are detached, they may either be transported by gravity, wind or/ and water.
Sediment transport by flowing water is strongly linked to surface soil erosion due to rain on a given catchments. Water seeping in to the ground can contribute to landslides (subsurface erosion) which may become major sources of sediments for rivers.

The whole process can be seen as a continuous cycle of: Soil erosion= detachment + transport + deposition.

Problem Statement and Justification

Flood discharge, and sediment carried assessment and monitoring for the basin using conventional methods which rely on the availability of weather data, field measurement are tedious, costly and time consuming. On the other hand, these weather data and field data are often incomplete and limited in the basin.

Soil erosion is a major problem in Ethiopia. Deforestation, overgrazing, and poor land management accelerated the rate of erosion. With the fast growing population and the density of livestock in the basin, there is pressure on the land resources, resulting in forest clearing and overgrazing. Increasingly mountainous and steeper slopes are cultivated, in many cases without protective measures against land erosion and degradation. High intensity rain storms cause significant erosion and associated sedimentation, increasing the cost of operation &maintenance and shortening lifespan of water resources infrastructure.

Specifically, the problems and constraints in the study area lack of sediment data, difficulty of gathering this data, variation of land management due to highly increasing deforestation for search of agricultural land and climate change makes the things difficult and this study with little effort and cost, continuously can predict sediment yield in the basin and sediment transported with streams flow.

Objective of the study

The objective of this study was to determine rainfall, runoff and sediment yield relationship in Blue Nile basins. The specific objectives of the studies are:

determination of spatiotemporal distribution of sediments in the Blue Nile basin,

to evaluate applicability of SWAT model in predicting sediment yield and concentration in the Blue Nile basin,

To analyze the lag time of Hydrograph, LAG and lag time of sediment graph, LAGs.

Identify sensitive regions for erosion and deposition.

Description of the Study Area

The Blue Nile (Abbay) basin lies in the western part of Ethiopia between 70 45'-120 45' N and 340 05'-390 45' E. The study area covers about 199,812 square kilometers with a total perimeter of 2440 Km.

Most of the important tributaries of the Blue Nile are located in the Ethiopian highlands (North western part of the country) with elevation ranging from about 300 to 4200m above mean sea level. According to recent study by Conway (2000), in Ethiopia only it comprises 17.1 percent of the total surface area of the country excluding Dindar and Rahad sub basins (176 000km2, out of 1.1Mkm2) with mean annual discharge of 48.5 Km3.

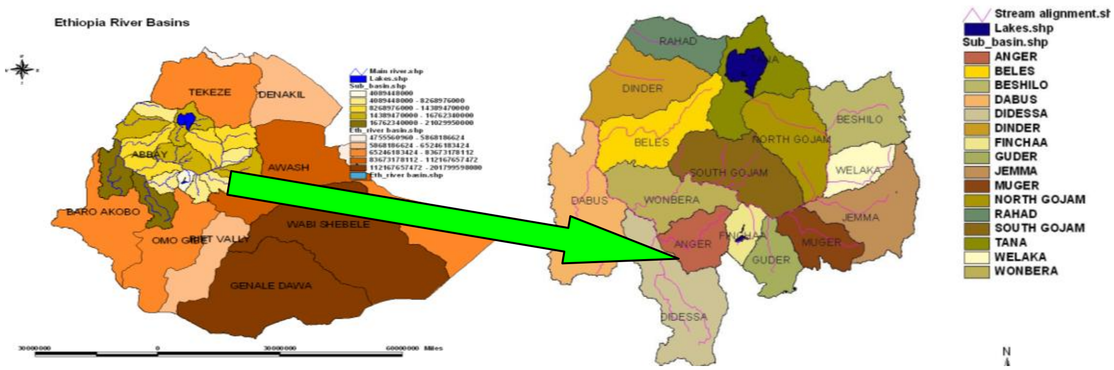


Figure 1: Ethiopian Major River Basins and sub basins of Blue Nile basin

Concepts and Practices of Rainfall-Runoff-Sediment Relationship

Hydrological modeling is a great method of understanding hydrologic systems for the planning and development of integrated water resources management. The purpose of using a model is to establish baseline characteristics whenever data is not available and to simulate long-term impacts that are difficult to calculate, especially in ecological modeling (Lenhart et al. 2002).

Soil erosion models can be separated into models simulating a single hill slope or a single field and models simulating a watershed. Determination of accurate runoff rate or volume from the watershed is a difficult task, however, some common runoff estimation methods are Rainfall-Runoff Correlation, Empirical Methods, Rational Method, Infiltration Indices method, Hydrograph Method and using different models now a days, like HEC-HMS, MOWBAL, SWAT model and others.

Several models are available for predicting erosion too, including the Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE), Modified Universal Soil Losses Equation (MUSLE), Kinematics Runoff and Erosion Model (KINEROS), and Water Erosion Prediction Project (WEPP).

For this runoff sediment relationship determination we have used SWAT model. SWAT is the acronym for Soil and Water Assessment Tool, a river basin, or watershed, scale model developed by Dr. Jeff Arnold for the USDA, Agricultural Research Service (ARS). SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time. The SWAT model is chosen for physically based, uses readily available inputs, is computationally efficient, enables users to study long-term impacts, capability for application to large-scale catchments (>100 km2), and capability for interface with a Geographic Information System (GIS).

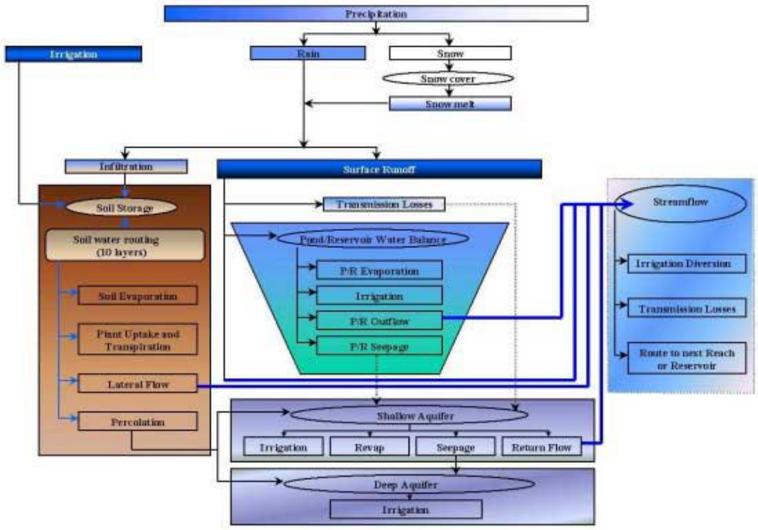


Figure 2: Overview of SWAT hydrologic component (Arnold et.al, 1998)

The hydrologic cycle as simulated by SWAT is based on the water balance equation:

$$SW_t = SW_0 + \sum_{i=1}^{t}\left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}\right)$$

Where: SWt -is the final soil water content, SW0 -is the initial soil water content on day i , t -is the time (days), Rday -is the amount of precipitation on day I, Qsurf -is the amount of surface runoff on day i , Ea -is the amount of evapotranspiration on day i , Wseep -is the amount of water entering the vadose zone from the soil profile on day i, and Qgw -is the amount of return flow on day i.

The subdivision of the watershed in to HRU enables the model to reflect differences in evapotranspiration for various crops and soils. Runoff is predicted separately for each HRU and routed to obtain the total runoff for the watershed. This increases accuracy and gives a much better physical description of the water balance.

The climatic variables required by SWAT consist of daily precipitation, maximum/minimum air temperature, solar radiation, wind speed and relative humidity.

Surface Runoff Volume is computed using a modification of the SCS curve number method (USDA Soil Conservation Service, 1972) or the Green & Ampt infiltration method (Green and Ampt, 1911).

The SCS curve number equation is (SCS, 1972):

$$\mathbf{Q_{surf} = \frac{(R_{day} - I_a)^2}{(R - I_a + S)}}$$

Where: Qsurf: is the accumulated runoff or rainfall excess, Rday is the rainfall depth for the day, Ia is the initial abstractions which includes surface storage, interception and infiltration prior to runoff, and S is the retention parameter.

$$S = 25.4 * \left(\frac{1000}{CN} - 10\right)$$

Where, CN- is the curve number for the day.

The initial abstractions, Ia, is commonly approximated as 0.2S and becomes:

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)}$$

Erosion

Transport of sediment, nutrients and pesticides from land areas to water bodies is a consequence of weathering that acts on landforms. Soil and water conservation planning requires knowledge of the relations between factors that cause loss of soil and water and those that help to reduce such losses.

Erosion caused by rainfall and runoff is computed with the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975). MUSLE is a modified version of the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1965, 1978).

MUSLE: The modified universal soil loss equation (Williams, 1995) is:

$$sed = 11.8 \cdot \left(Q_{surf} \cdot q_{peak} \cdot area_{hru}\right)^{0.56} \cdot K_{USLE} \cdot C_{USLE} \cdot P_{USLE} \cdot LS_{USLE} \cdot CFRG$$

Where: sed- is the sediment yield on a given day (metric tons), Qsurf is the surface runoff volume , qpeak is the peak runoff rate (m3/s), areahru is the area of the HRU (ha), KUSLE is the USLE soil erodibility factor (0.013 metric ton m2 hr/(m3-metric ton cm)), CUSLE is the USLE cover and management factor, PUSLE is the USLE support practice factor; LSUSLE is the USLE topographic factor and CFRG is the coarse fragment factor.

The maximum amount of sediment that can be transported from a reach segment is calculated:

$$conc_{sed,ch,mx} = c_{sp} \cdot v_{ch,pk}^{spexp}$$

Where: concsed,,ch,,mx is the maximum concentration of sediment that can be transported by the water (ton/m3 or kg/L), C sp is a coefficient defined by the user, V ch,pk is the peak channel velocity (m/s), and spexp is an exponent defined by the user.

Data availability and analysis

DEM data: The Digital Elevation Model of 90m by 90m resolution has been used. The DEM was in the format of STRM and this was processed on 3 DEM, Global Mapper Software's and imported to Arc view GIS environment.

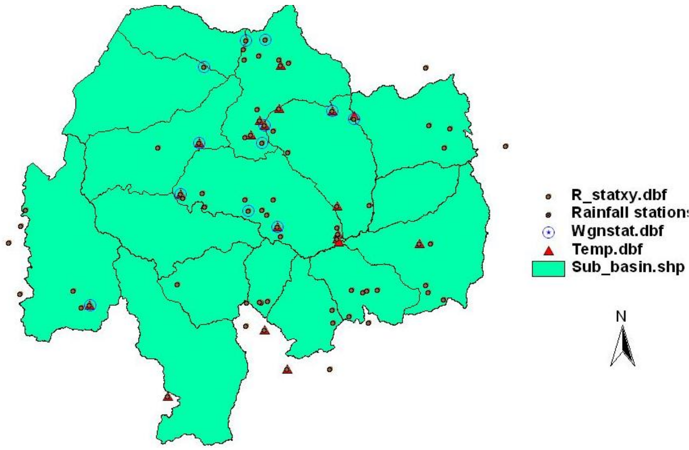


Figure3: Climate and weather generating stations in the catchment of the Blue Nile

Hydrological data: Daily flow data is required for SWAT simulated result calibration and validation.
Sediment data: There are few sites which has measured suspended sediment data in Blue Nile which is not long year recorded data. So, it is generated by regression analysis arranged as per the SWAT model and used for calibration.

Climate data: The climate data is among the most prerequisite parameter of SWAT model. These are Rainfall Data, Temperature data, Wind speed, Relative humidity and sunshine hours (solar radiation).

Materials and methodology

Materials for the study: Topographic map, DEM of the basin, Soil type map, Land use map.

Methodology

The applied methodology comprises five phases;

1) Preparation
2) Data acquisition
3) Modeling and data analyzing
4) Calibration, Validation, evaluation, and
5) Reporting.

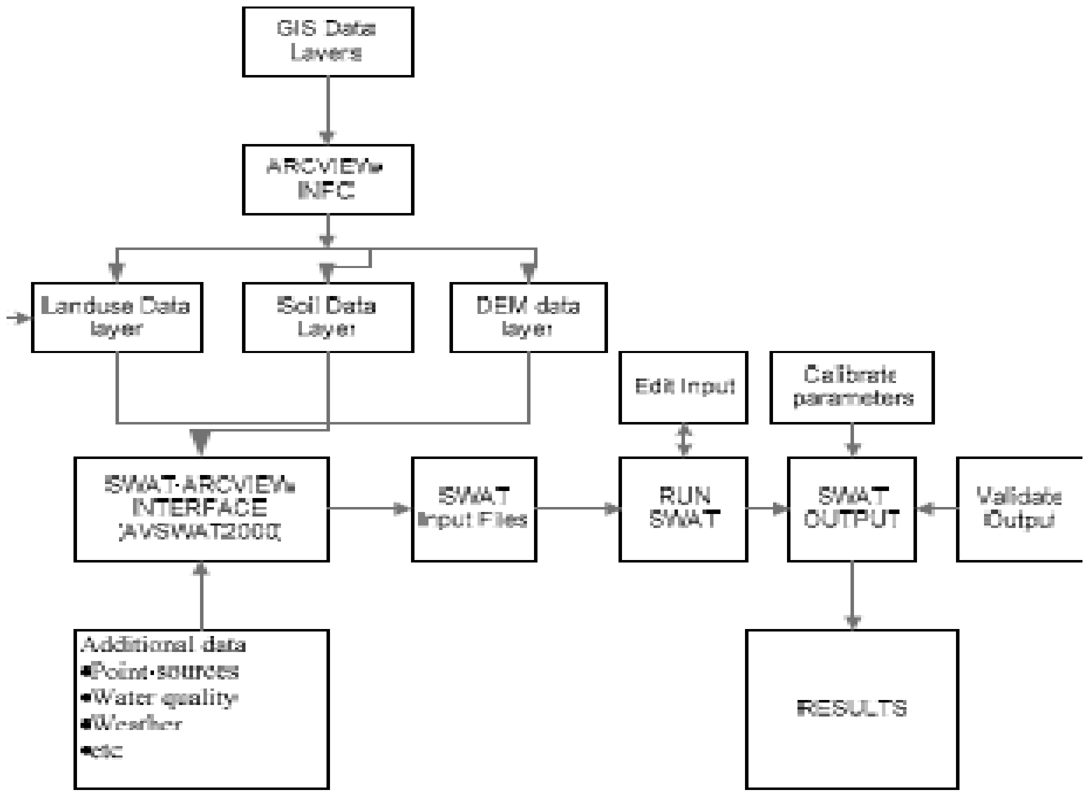


Figure 4: The general layout of Simulation diagram of SWAT model

Model Inputs

Inputs including basin area and main channel length were determined by AVSWAT (ArcView GIS interface for SWAT) from DEM of the study area. SCS curve number and overland Manning’s n values were chosen based on suggested parameters by the SWAT interface from soil and land use characteristics.

Measured daily rainfall, temperature, solar radiation, wind speed and relative humidity for the study area were used in the model.

Digital elevation model (DEM)

Topography was defined by a Digital Elevation Model (DEM), which describes the elevation of any point in a given area at a specific spatial resolution as a digital file.

Land use/cover map and soil map

Once watershed topographic parameters have been computed for each sub basin, the interface uses land cover and soils data to generate multiple hydrologic response units (HRUs) within each sub basin by GIS overlay process to assign soil parameters and SCS curve numbers. SWAT has predefined land uses identified by four-letter codes and it uses these codes to link land use maps to SWAT land use databases in the GIS interfaces.

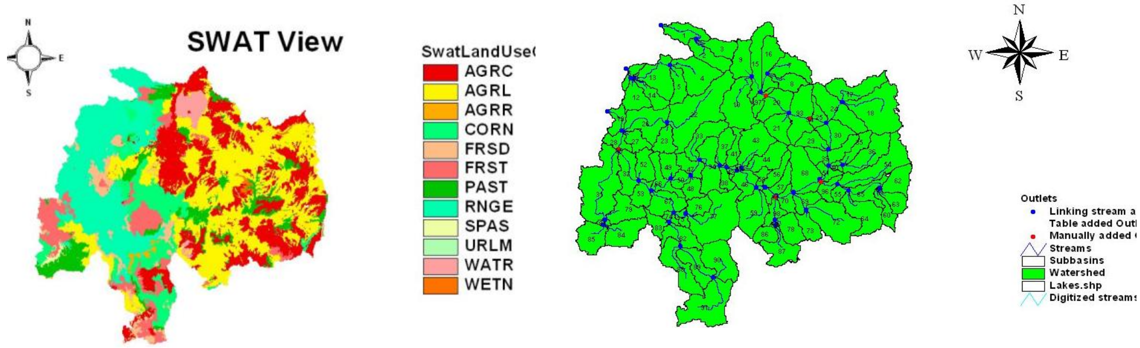


Figure 5: a) SWAT land use/cover classification & soil map of Blue Nile
b) Watershed delineated & outlets

Watershed delineation

The subdivision of a watershed into discrete sub-watershed areas enables the modeling process to represent the heterogeneity of the watershed. SWAT works on a sub-basin basis and the interface delineates the watershed in to such sub-basins or sub-watersheds based on topographic information. The total Blue Nile basin area is 199810.98 Km^2, but the delineated area becomes 190347 Km^2.

Digitized stream networks

The digitized stream networks used in this study were found from the Ministry of Water Resources (MoWR) of Ethiopia. The streams were prepared in a shape file format and together with the DEM given as an input to the model to be "burnt" during the delineation process. The model superimposed the digitized stream networks into the DEM to define the location of the stream networks and safe the time of delineation.

Weather data

This data are in daily based long year data's of many stations as much as possible. They are precipitation, maximum and minimum temperature, relative humidity, wind speed and solar radiation. On top of these data statistical analysis of monthly daily average, standard deviations, and probability of wet and dry days, skew ness coefficients and dew temperature were determined by FORTRAN program known as *WXGenParm* (J.R. Williams, 1991) and program *dew02.exe* (S. Liersch, 2003) for generating missing data (identified by -99) and predicting unmeasured and missing data in the basins.
SWAT takes data of each climatic variable for every sub basin from the nearest weather station measured from the centroid of the sub basin.

Evaporation data

It has two options, either loading measured evaporation data or choosing the methods for SWAT simulation. There are three methods of Evaporation determination by SWAT model itself: Prestily-Taylor method, Penman-Monteith method and Hargreve methods. For this study, since there is humidity, wind speed and solar radiation data limitation, Hargreve method was chosen for simulation of evaporation and evapotranspiration by SWAT model.

Sensitivity analysis

When a SWAT simulation is taken place there will be discrepancy between measured data and simulated results. So, to minimize this discrepancy, it is necessary to determine the parameters which are affecting the results and the extent of variation. Hence, to check this, sensitivity analysis is one of SWAT model tool to show the rank and the mean relative sensitivity of parameters identification and this step was ordered to analysis. This appreciably eases the overall calibration and validation process as well as reduces the time required for it. Besides, as Lenhart et al. (2002) indicated, it increases the accuracy of calibration by reducing uncertainty.

For streamflow of Blue Nile basin, it was checked at three points, (at outlet of Tana basin, near Kessie and at the Sudan Border.) In the entire study sub basin the sensitivity showed that 28 parameters were sensitive. The following are few of them which have significant effect on the results.

Table 1 Sensitivity results at Bahir Dar outlet

Parameter	Rank	Relative mean sensitivity	Sensitivity Class
CN2	1	3.04	Very high
SOL_AWC	2	1.00	Very high
ESCO	3	0.60	high
sol_z	4	0.582	high
sol_k	5	0.23	high
GE_DEALY	6	0.21	high
ALPHA_BF	7	0.059	medium
SMTMP	8	0.046	Small
canmx	9	0.0432	Small
TIMP	10	0.0417	Small
SMFMX	11	0.0172	Small

Evaluation of Model Simulation

Graphical display of simulated and observed flows is very important because the traditional method of evaluating model performance by statistical measures has limitations. Statistical indices are not effective in communicating qualitative information such as trends, types of errors and distribution patterns. In both calibration and validation processes both observed and simulated hydrographs were compared graphically.

Model Efficiency

Two methods for goodness-of-fit measures of model predictions were used during the calibration and validation periods in addition to graphical comparison for this study.

Model simulations efficiency were evaluated during calibration by using mean, standard deviation, regression coefficient (R^2), and the Nash-Sutcliffe simulation efficiency (E_{NS}) (Nash and Sutcliffe 1970).

$$r^2 = \frac{\left[\sum_{i=1}^{n}(q_{si} - \bar{q}_s)(q_{oi} - \bar{q}_o)\right]^2}{\sum_{i=1}^{n}(q_{si} - \bar{q}_s)^2 \sum_{i=1}^{n}(q_{oi} - \bar{q}_o)^2}$$

Where: q_{si} is the simulated values of the quantity in each model time step, q_{oi} is the measured values of the quantity in each model time step , $\bar{q}_s$ is the average simulated value of the quantity in each model time step. $\bar{q}_o$ is the average measured value of the quantity in each model time step.

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n}(q_{oi} - q_{si})^2}{\sum_{i=1}^{n}(q_{oi} - \overline{q}_o)^2}$$

After each calibration, the regression coefficient (R^2), and the Nash-Sutcliffe (1970) simulation efficiency (ENS) were also checked in accordance to Santhi et al. (2001) recommendation (R^2 >0.6 and ENS > 0.5).

Model calibration and validation

Model calibration is a means of adjusting or fine tuning model parameters to match with the observed data as much as possible, with limited range of deviation accepted. Similarly, model validation is testing of calibrated model results with independent data set without any further adjustment (Neitsch, 2002) at different spatial and temporal scales.

Calibration of sediment was at locations of Tana basin (Gilgel Abbay, outlet number 10 and Addis Zemen at Ribb, outlet number 7) and at Kessie (outlet number 51).

Results and discussion

The basin has been divide in to 98 sub basins with threshold area of 100, 000 ha as specified in section and 392 HRU.

Table 2 Parameters set before and after calibration of SWAT for streamflow calibration at Bahirdar station

SWAT PARAMETER	RECOMMENDED RANGE BY SENSITIVITY	INITIAL VALUE	CALIBRATED VALUE
CN_2	±50%	DEFAULT *	-40.6%
SOL-AWC	±50%	**	-25%
ESCO	0.0 -1.0	0.95	0.1
SOL-Z	±50%	**	-44%
SOL-K	±50%	**	+50%
GW_DELAY	0-100	31	40
ALPHA_BF	0-1	0.048	0.5

** Default value assigned by SWAT itself*
*** Value initially assigned by users, but it may not depends on accurate data*

Flow calibration

After sensitivity analysis has been carried out, the calibration of SWAT 2003 model simulated streamflow at the mentioned sites were done manually. The analysis of simulated result and observed flow data comparison was considered monthly and annually. Until the best fit curve of simulated versus measured flow was satisfied, the sensitive parameters were tuned in the allowable range recommended by SWAT developers.

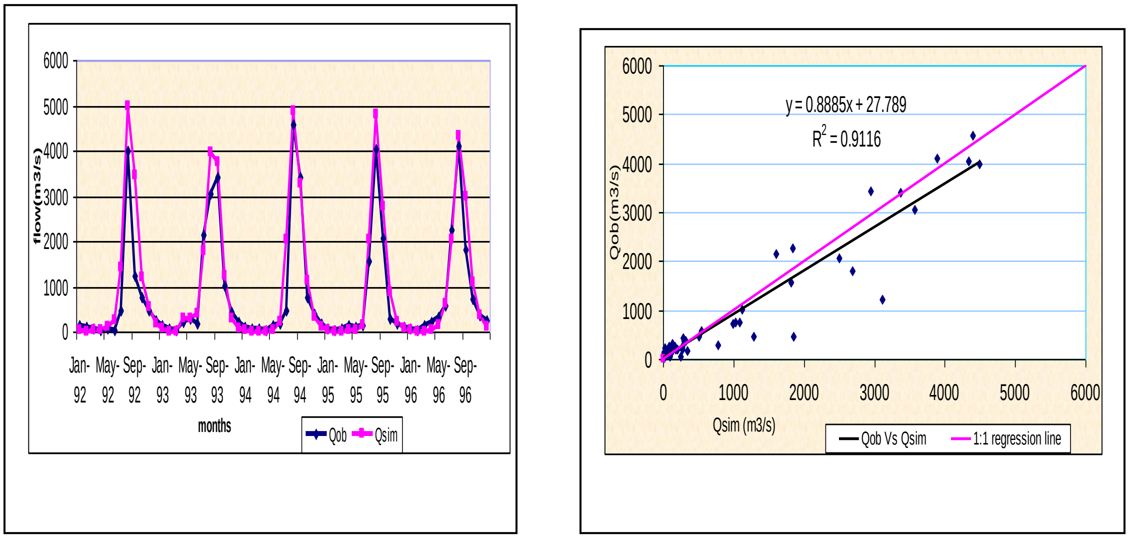


Figure 6: Simulated Vs. measured streamflow at Kessie outlet b) Regression analysis line and 1: 1 fit line

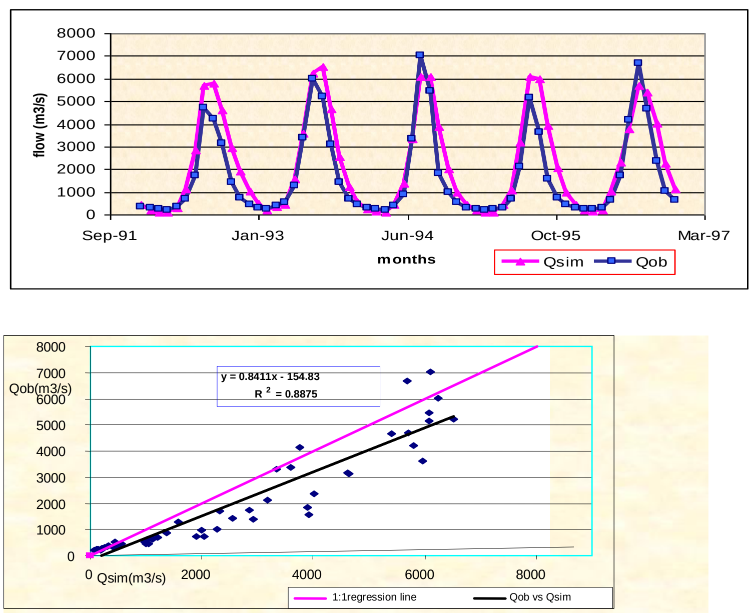


Figure 7: Simulated Vs. measured streamflow at Border outlet b) Regression analysis line and 1: 1 fit line

Table 3 Summary of calibrated and observed flow (m3/s) at the three sites

site / year		1992	1993	1994	1995	1996	Average (m3/s)	Yearly efficiency		Monthly efficiency	
								R^2	E_{NS}	R^2	E_{NS}
Bahirdar	calibrated (m3/s)	139.3	140.7	175.9	131.7	127.4	156.2	0.86	0.8	0.71	0.65
	Measured (m3/s)	138.31	153.58	188.2	57.13	135.39	145.16				
Kessie	calibrated (m3/s)	921.44	923.41	923.89	922.84	880.12	889.34	0.93	0.87	0.91	0.84
	Measured (m3/s)	638.69	931.46	989.93	658.93	912.59	818.01				
Border	calibrated (m3/s)	1811.47	2003.5	1750.7	1702.4	1849.63	1823.53	0.9	0.82	0.89	0.78
	Measured (m3/s)	1502.12	1920.3	1797.68	1299.72	1908.43	1774.42				

Flow validation

In this study the validation period is from year jan, 1998 to dec, 2000. One year from jan 1997 to dec 1997 is considered as warm-up period for model. Like as calibration, the three above-mentioned goodness-of-fit measures were calculated and model-to-data plots were inspected.

Table 4 Summary of validated and observed flow (m3/s) at the three sites

site / year		1998	1999	2000	Average (m^3/s)	Yearly efficiency		Monthly efficiency	
						R^2	E_{NS}	R^2	E_{NS}
Bahirdar	validated (m3/s)	182.1	186.2	157.9	175.4	0.89	0.75	0.78	0.69
	Measured (m3/s)	197.6	178.9	176.6	184.36				
Kessie	validated (m3/s)	1283.8	1261.8	1289.7	1278.4	0.9	0.81	0.79	0.76
	Measured (m3/s)	1129	1136.9	862.5	1087.24				
Border	validated (m3/s)	2186.6	2360.5	2140.4	2229.16	0.9	0.78	0.88	0.75
	Measured (m3/s)	2247.7	2206.2	1657.8	2037.23				

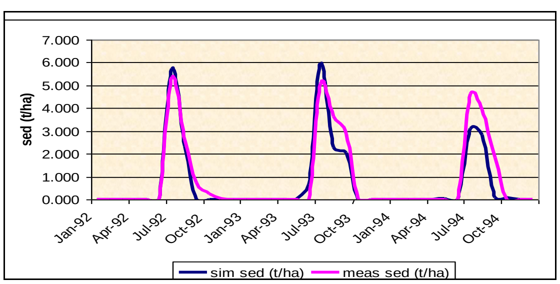
Sediment calibration and validation

In this paper the physically based SWAT 2003 model was applied to Blue Nile gauged watershed for prediction of soil erosion and sediment yield/concentration for the whole basin. SWAT model was first calibrated to flows, then to sediment. SWAT model was calibrated for sediment by comparing monthly model simulated sediment yield against monthly measured sediment yield at sites Gilgel Abbay (outlet 10), Addis Zemen at Ribb (outlet 7) and near Kessie (outlet 51).

The sediment discharge curve is derived and by using this curve monthly data for the site of calibration has been generated. To minimize the discrepancy the discharge sediment curve was derived as wet season and dry season curve separately

Table 5 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



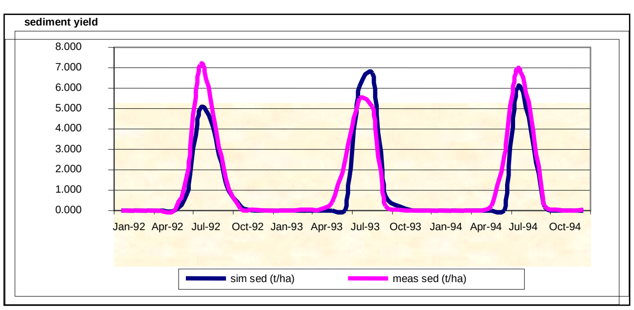
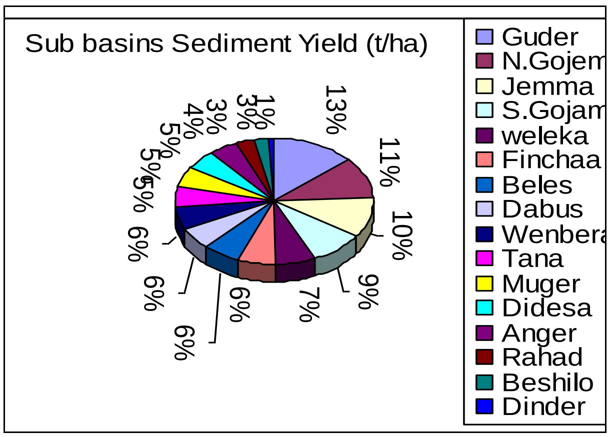


Figure 8: Observed vs simulated sediment yield at a) Addis Zemen b) at Kessie

Discussion of model output

Simulation was performed for the whole Blue Nile in Ethiopia from the year 1991 -1996 as calibration period and from 1997-2000 as validation time for runoff result and from 1991-1994 as calibration period and from 1995-2000 as validation period for sediment results. From these calibration and validation results and sites, it is possible to generalize the model work for other sub basins in the watershed of simulation since the SWAT model is distributed model and predict the same result in the calibration region for the similar HRU. For different sub basin the annual sediment yield is shown in the following chart:



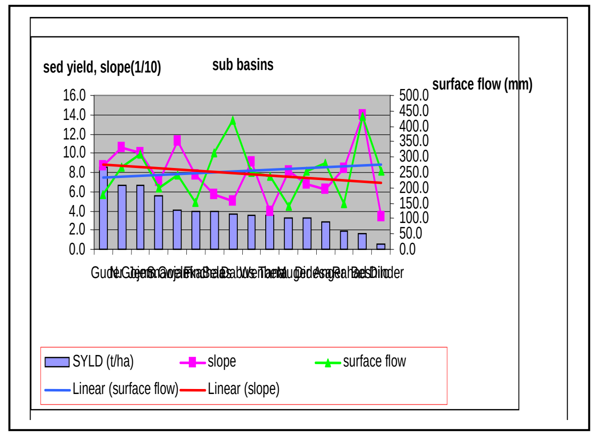


Figure 9: a) Sediment yield from different sub basin

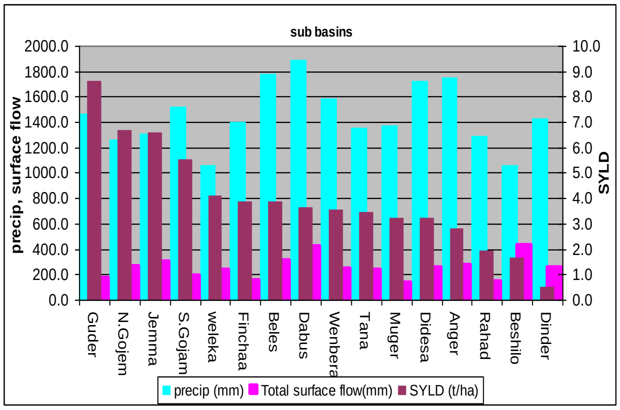
b) The graphical comparison of the effect of surface runoff and slope steepness on sediment yielding

From this diagram, the Guder, N.Gojam and Jemma are the highest sediment yielding sub basin in the mentioned order, cover 13%, 11% and 10% respectively of the whole Blue Nile basin in Ethiopia. 34% of sediment of the Blue Nile basin is eroded from these three sub basins. The amount of soil erosion or sediment yield that occurs in given watershed 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 (Dilnesaw A., Bonn 2006).

The land use/cover of the three highest sediment yielding sub basins are dominated by Agriculture; (Guder: (Agriculture=95.66%, and pastoral land=4.34%), N.Gojam (Agriculture=95.41% and pastoral land=4.59) and Jemma (Agriculture=93.89%, pastoral land= 3.42% and Corn=2.69%)). This is a key factor for erosion in these sub basins.

The slope of these three highly eroded sub basins (Guder, N.Gojam and Jemma) are stands 3rd, 4th and 6th compared to other sub basins of Blue Nile basins. This is also one of the main factors affecting soil erosion in the watershed.

Similarly, the slope of those three high sediment yielding sub basins are relatively high compared to the least sediment yielding sub basin, even though, they are not the highest compared to other medium sediment yielding sub basin (see figure 9. b above).



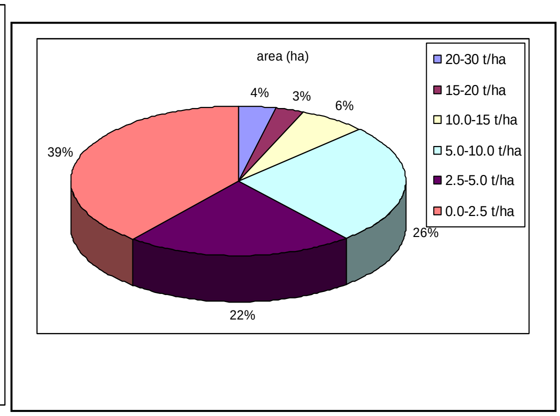


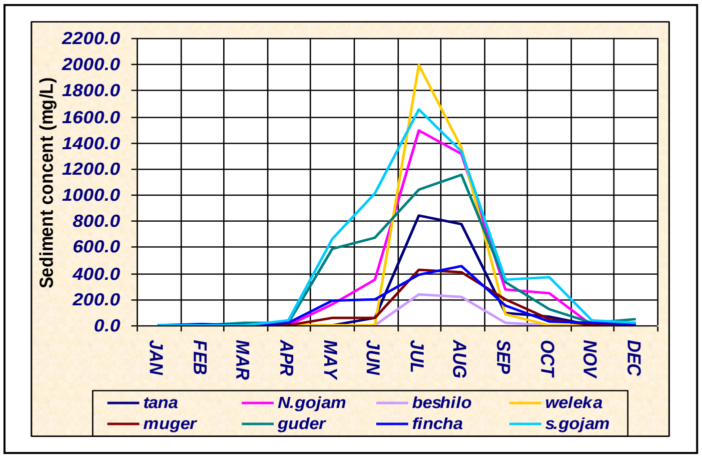
Figure 10: a) Relationship between sediment yield, precipitation and surface runoff ; b) Sediment yield percentage distribution in Blue Nile basin

As shown above on figure 9, the precipitation and surface runoff alone have no direct impact on sediment yield. From this, we can observe that, the land use/cover is the most influential parameter for soil erosion and sediment yield from a given watershed in Blue Nile basin.

Relation between Rainfall-Runoff and Sediment Yield

The relation between rainfall and runoff is a very long history as they have direct relation with some effects of watershed characteristics. But the relation of sediment with runoff and rainfall is not as such common to predict manually or empirically, but with help of recent models like SWAT, it gives the relation between the three phenomena as it considers all parameters that influence sediment yield, sediment concentration and sediment transport.

Depending on the output of SWAT model result, the relation between rainfall, runoff and sediment yield/concentration is shown, rainfall peak is come first, with sediment concentration peak the next and the peak of runoff is at the end.



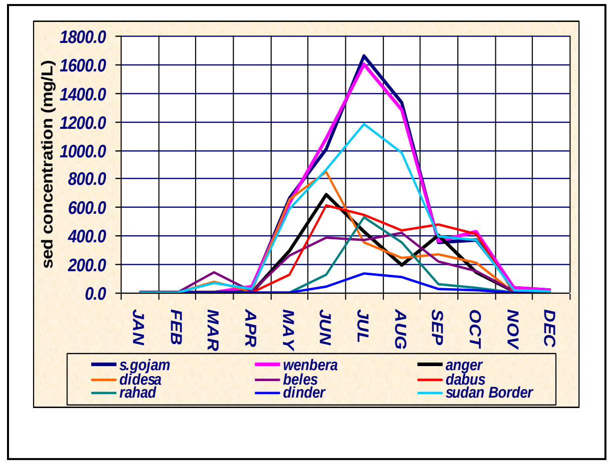


Figure11: a & b Comparisons of sediment concentration at the outlet of each subbasins

Conclusion and recommendation

Conclusion

The main objective of this thesis is to determine sediment yield in the different sub basin of Blue Nile in Ethiopia, sediment load and sediment concentration in the main rivers of the tributaries and in the Abbay River. In addition to this, the aim is to look spatial and temporal variation of sediment yield/ concentration in the basin.

As it is looked from the model performance efficiency indicator, regression coefficient (R^2) and the Nash-Sutcliffe (E_{NS}) are in the range of 0.71 to 0.91 in calibration and 0.78 to 0.88 in validation for flow analysis. Similarly, sediment model efficiency by regression coefficient evaluation is in the range of 0.71 to o.89 for calibration and 0.71 to 0.86 in validation. This shows that, the SWAT model simulates well both for streamflow and sediment yield/load in Blue Nile basin.

As looked in result and discussion part, the 34% of soil is eroded from three sub basins, Guder, N.Gojam and Jemma (in between 6-9 t/ha per average per year) that cover an area of 18.6% of total Blue Nile. In similar manner, more than 50% of soil is eroded from an area of around 16% of the whole basin (ranging from 15-30 t/ha sediment yield). The actual annual soil loss rate in the study area exceeds the maximum tolerable soil loss rate 18t/ha/y at some sub basins. But the average annual sediment yield of the whole Blue Nile basin is around 4.26 t/ha/yr and 4.58 t/ha/yr with and excluding Rahad and Dinder sub basins respectively. The total soil eroded from the Blue Nile is 91.24 Million tones and 88.96 Millions tones with and without Rahad and Dinder respectively.

When we look from the result of sediment concentration (mg/L) in the main streams of Blue Nile, Weleka, S.Gojam and Wenbera have the greater amount of concentration (in

the range of 1600 to 2000mg/L) peak monthly sediment concentration compared to other sub basins. But the sub basins that have least peak monthly concentration of sediment are Dinder, Beshilo and Muger from lowest to up and the monthly peak concentrations in these sub basins are in the range of 400 to 800 mg/L.
The sediment concentration in these sub basins become peak in the month of July, next to peak of runoff mostly in August except Finchaa, Anger, Dabus and Didesa which have peak in the month of September. Coming to annual concentration, S.Gojam, Wenbera and Sudan border are taking the lead ranging from 350 to 900 mg/L annually, and Dinder, Beshilo and Rahad are those which have least concentration ranging from 25 to 90mg/L annually.

Recommendation

The results of this model out put of areal rainfall, runoff and sediment yield/ concentration/load should be considered as an attempt to predict with SWAT model and used carefully for further study and potential project works study. We suggest that the SWAT model is a very powerful tool to fill the gap we have in area of sediment data and even on an un-quality and scarce streamflow data. we hope this result give initial information for any researchers, projects on the basin and policy makers, but it may not be remain the same result in the future as land use, management practice, weather changes are some factor which alter the present situation rapidly.
It is better for the Ethiopian situation use SWAT model for sediment data prediction prior to potential project study and plan commencement.

As a mitigation measure for prevention of severs erosion and conservation mechanism, it is recommended to cover the mountainous and hilly area with plantation and control further degradation by erosion. Further study is required in different scenarios to decide a type of coverages and extent of application on different sub basins.

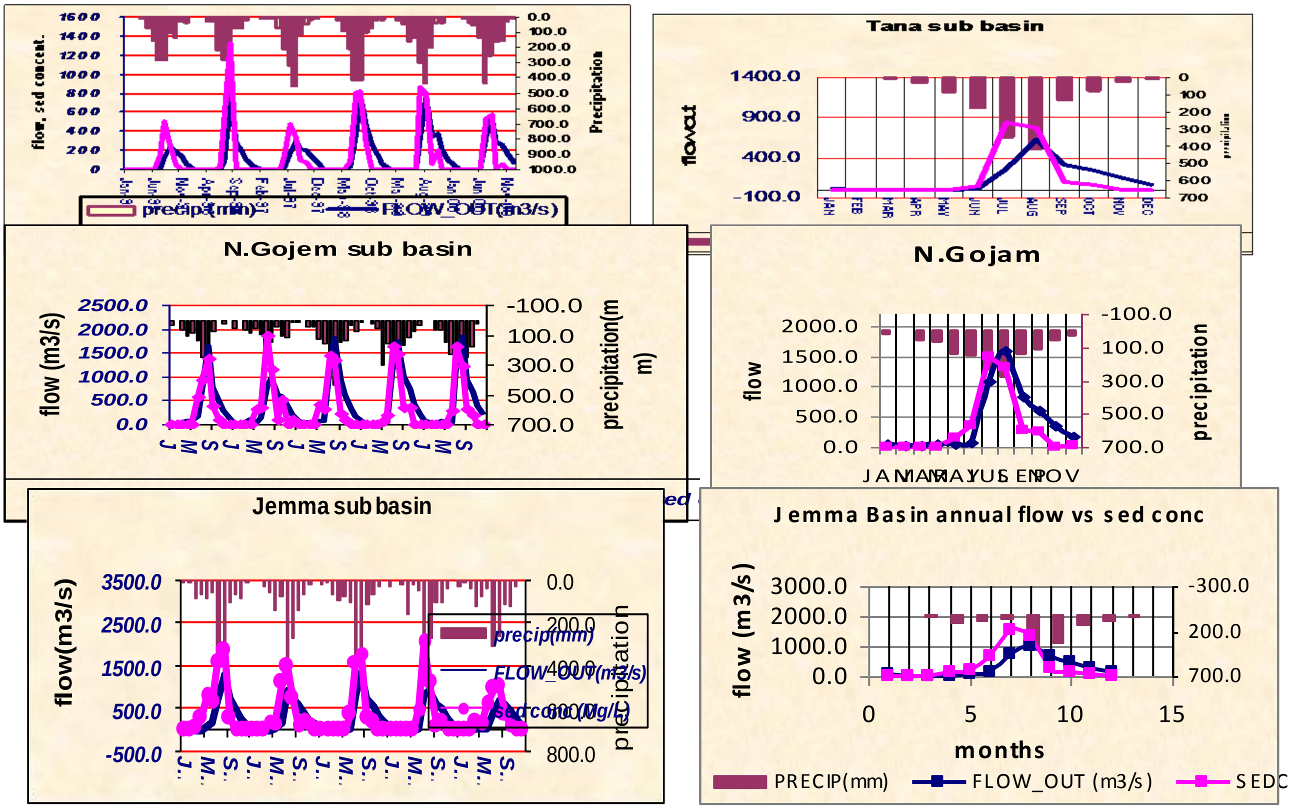


Figure12: Graphical presentation of flow versus sediment concentration relation

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Modeling of soil erosion and sediment transport in the Blue Nile Basin using the Open Model Interface Approach

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Abstract

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.

Introduction

Sediment transport degrades soil productivity as well as water quality causing worldwide problems of reservoirs sedimentation, and alternation of river morphology. These problems are more distinct in the Blue Nile basin – the main tributary of the River Nile. Rapid population increase led to fast land-use change from forest to agricultural land, and as associated with steep terrain, these changes has resulted in severe soil erosion over the

Upper Blue Nile (Nyssen, et al., 2004). The soil erosion and sediment transport processes have affected the whole Blue Nile basin negatively even though it was nutrient-rich sediment source (Nixon, 2002). The upper Blue Nile is losing fertile topsoil, exacerbating impacts of dry spells and drought, a common incident in the area. While, the reservoirs and irrigation canal in the lower Blue Nile are seriously affected by sediment deposition, leading to significant reduction of reservoirs storage capacities, and excessive de-silting costs of irrigation canals. In general, there is very limited information on how much is the soil erosion, and its impact downstream. Therefore, this paper aims for better understanding of the process at basin scale.

Methodology

The SWAT model was used to compute the soil erosion from Upper Blue Nile, routed up to the outlet (El Diem), and then SOBEK-RE was used to compute the morphological change of the river and reservoirs from the border till the Blue Nile outlet (Khartoum) and the Open Modelling Interface (OpenMI) was used to link the two models at the border.

SWAT set up

The Soil and Water Assessment Tool (SWAT) is a physical process based model to simulate the process at catchment scale (Arnold, et al., 1998, Neitsch, et al., 2005). The catchment is divided into hydrological response unit (HRU) based on soil type, land use and management practice.
The Upper Blue Nile watershed was delineated using the Digital Elevation Model (DEM) approximately 90 m grid of SRTM (http://www2.jpl.nasa.gov/srtm/index.html). The USGS landuse map of 1 km resolution (http://edcsns17.cr.usgs.gov/glcc/glcc.html) and the FAO soil map of 10 km resolution (FAO, 1995) were overlaid to obtain a unique combination of landuse and soil, hydrologic response unit (HRU). The sensitivity analysis of the SWAT computation has been done by varying key parameters value and investigating reaction on model outputs. An automatic (SWAT) sensitivity analysis has been carried out and those parameters that influence the predicted outputs were used for model calibration.

SOBEK set up

SOBEK is a one-dimensional hydrodynamic numerical modelling system capable of solving the equations that describe unsteady water flow, sediment transport and morphology, and water quality. The flow module is described by the continuity and the momentum equations and the morphological module is described by sediment continuity equation (WL/Delft Hydraulics and RIZA, 1995).

The river (1D) model constitute a length of 730 km. River cross data (surveyed in 1990) of the Ministry of Irrigation, Sudan was used. Compound structure was made from General structures and Weir to model the two dams Roseries and Sennar. A SOBEK time controller has been used to represent reservoir level simulating the operation program of the reservoir for a given year. A Chezy coefficeint of 50 both for positive and negative flow has been used. Time series discharge hydrograph has been used as upstream boundary conditions at El Deem and water level at Khartoum as downstream boundary conditions. For morphology computation, time series sediment inflow of was used us an upstream boundary conditions at El Deem and bed level of 368 m at Khartoum for downstream conditions. Time step of 4 hours and distance step of 1000m was used. The SOBEK-RE model covers the Blue Nile channel from El Deim to Khartoum, has been run for the period between 2000 and 2003. The operation of the two dams (Roseires and Sennar) has been simulated (within SOBEK) using a time controller that assimilates the observed reservoir water levels. The dam releases used as calibration variables.

Models integration

The Open Modelling Interface (OpenMI) standard is a software component interface definition for the computational core (the engine) of the hydrological and hydraulic models (Gregersen et al., 2007). The OpenMI was developed by EU co-financed HarmonIT project to address easy model linking of existing and new models. The SWAT model has been migrated into OpenMI compliant model. The detail of model development can be seen Betrie et al., 2009.

SWAT model results and discussion

The SWAT model (hydrology part) has been calibrated using daily flow hydrograph of El Deim (Ethiopia/Sudan border) station from 1981 to 1986, and validated with data from 1987 to 1996. The computed model performance using Nash-Sutcliff coefficient for the calibration and validation found to be 0.92, and 0.82, respectively. Since, the main emphasis of this paper is to compute soil erosion from upper Blue Nile and route the sediment all the way up to the confluence with White Nile at Khartoum, the detailed description of the Rainfall-Runoff model calibration and validation is given in Betrie et al., 2008.

The sediment hydrograph at El Deim used for calibration has been generated using sediment concentrations that were generated using sediment rating curve (flow sediment relations derived from historical data). SWAT sediment out flow calibrated for the period 1981 to 1986, while 1980 was used for warming the model. The calibration results show good agreement with observed sediment load, (Figure 1a). The model could simulate low flow erosion and sediment transport though this assumed zero relative to the peak period erosion in the observed data. The Nash-Sutcliffe efficiency computed to be 0.72 for the calibration period (1981to 1986), which is generally satisfactory results for soil erosion modelling (Arnold, et al., 1999,and Zeleke, 1999).

The validation of sediment modelling (1990 to 1996) is given in Figure 1b. The model was able to simulate the peak sediment for most of the years, except for 1993 and 1994, in particular when there is a sharp rise of silt content. Similar to calibration period the model could simulate sediment transport during dry period and beginning of wet period flow which is assumed zero in the observation data. The model performance NS equal to 0.66, assumed reasonable for such computation.

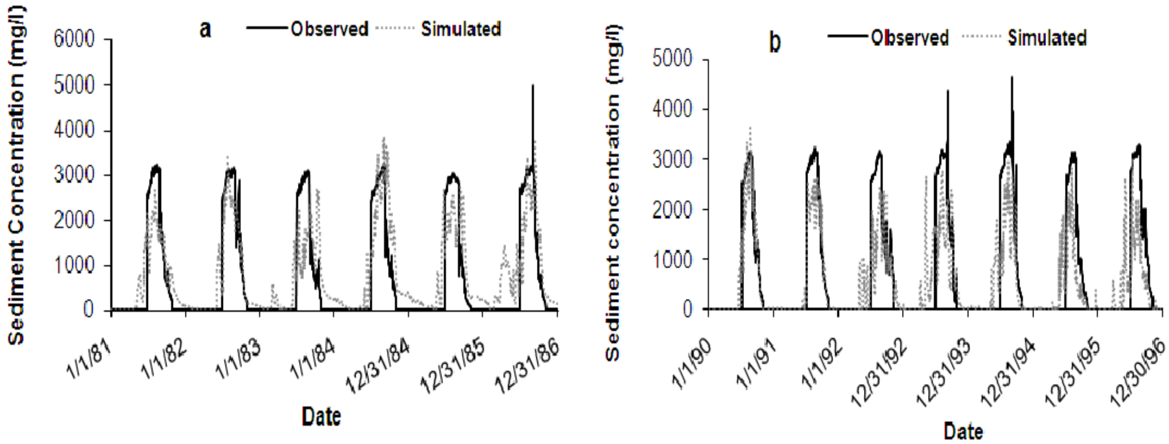

Figure 1: Observed and Simulated sediment concentration comparison during calibration (a) and validation (b) period at El Deem station.

The spatial variability of soil erosion results computed by SWAT is very useful information to assess areas of high/low sediment sources. As given by Figure 2 the highest soil erosion occurs at sub-basin 10 (16 ton ha-1yr-1). Medium soil erosion occurs in sub-basins 11 (9 ton ha-1yr-1), and 1 8 ton ha-1yr-1and low erosion occurs in the remains subbasins. Comparable result was reported by BCEOM (1998) when analyzing several years of observed data.

The total amount of soil erosion computed by SWAT at the outlet (El Deim was found to be 491 t km-2 year-1. This result was found to be within the range previous estimate such as 480 t km-2 year-1 Blue Nile catchment above El Diem (Ahmed A.S., 2006), 200- 400 t km-2 year-1 for upper Blue Nile and Tekeze basins (Mc Dougal, 1975) and 100-1000 t km-2 year-1 from Ethiopian highlands (Walling,1984). The biophysical process is that after soil erosion processes there is deposition of sediment in river channel within the Upper Blue Nile, which account 24 Million ton per year. The amount of sediment yield delivered out of the upper Blue Nile estimated to be 62 Million ton per year at Ethiopia-Sudanese boarder.

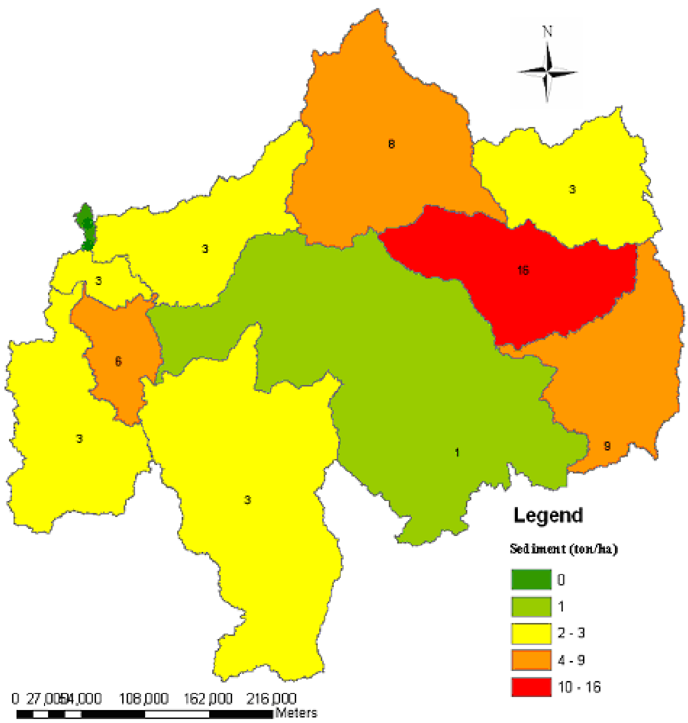

Figure 2: Simulated soil erosion in upper Blue Nile subbasins

SOBEK model results

The SOBEK model could accurately simulate the flow regime of the Blue Nile. Calibration result for the flow downstream Roseires dam is given in Figure 3a. While, the flood peak was not captured accurately, its propagation and values for the rest of the year seems very reasonable, in particular the rising and falling limb of the hydrograph. No clear reason for the mismatch of September 2000. Though likely it could be attributed to ungauged inflow from the catchment between El Deim and Roseires. Another reason could be a questionable accuracy of the dam equation while computing releases during rapidly rising flood.

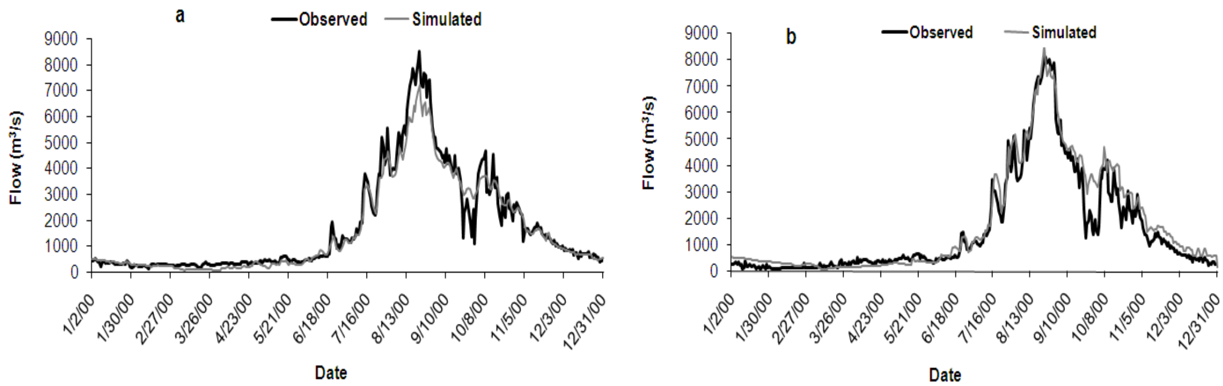

Figure 3: Observed and Simulated discharge calibration year 2000 at Roseries (a) and Sennar (b) reservoirs

The calibration result at Sennar dam (Figure 3b) shows a good fit. Unlike Roseires, peak flow has been simulated accurately. The model could not simulate sudden lowering of gate to flush sediment at the last week of September 2000. In addition, the model overestimated the falling limb, which could be due to abstraction for irrigation along the reach Roseires-Sennar.

The SOBEK model validation has been done for year 2003 at Roseries and Sennar dams. Figure 4 depicts good fit between simulated and observed discharge at Roseries and Sennar reservoirs. The rising limb and the peak flow were well captured by the model. The model did not catch the peak in the beginning of September in which the reservoir starts to be filled if the discharge is at El Deim drops to 350 M m3/day. This is attributed to the fact that during the calibration period the flow at El Deim satisfied the reservoir filling condition so the model was not trained to lower the weir in a case the flow does not drop to 350 M m3/day; in fact the flow at El Deim for the validation period was 432 M m3/day. Similar to the calibration period the model could not simulate the sudden opening of the weir to flush the sediment at both Roseries and Sennar.

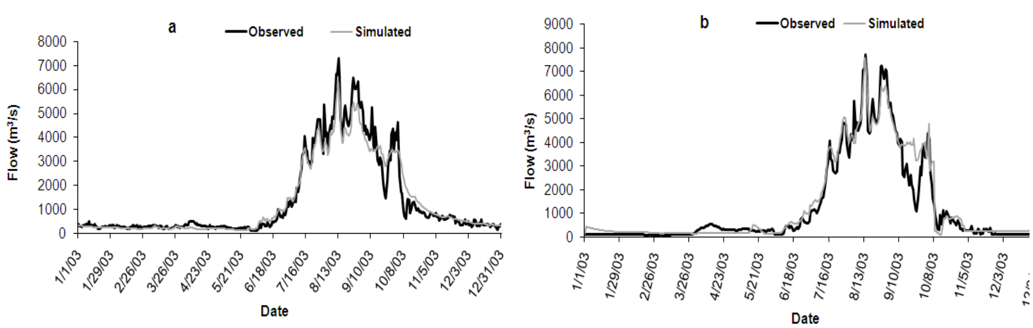

Figure 4: Observed and Simulated discharge validation year 2003 at Roseries (a) and Sennar (b) reservoirs

Since the morphological changes feedback to the hydrodynamics and the close relations between resistance and sediment transport, the calibration and verification of the hydrodynamic and sediment transport modules are closely inter-linked. Thus, after good calibration of the hydrodynamic part, the model was run in morphological mode to compute the bed level change. The sediment transport module was not calibrated along the river reach because of the data limitation on different grain size. However, the sediment transport verification result showed good fit between observed and simulated sediment concentration at Wad Elias station (Figure 5).

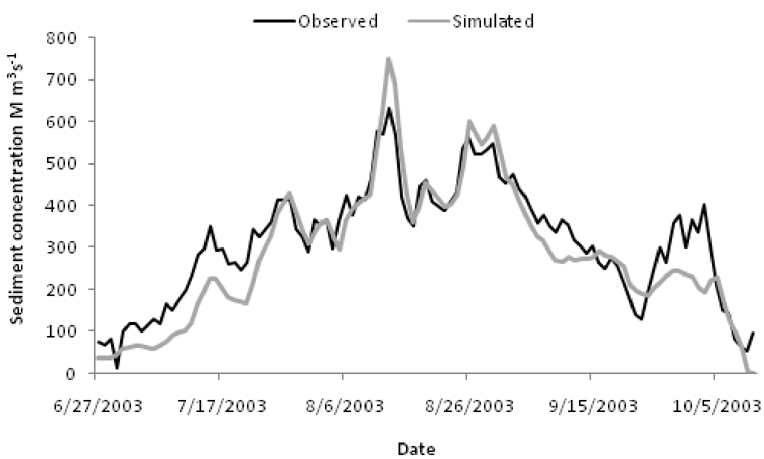

Figure 5: Sediment transport verification at Wad Elias station

The longitudinal profile of the SOBEK results showed a deposition of the suspended sediment that transported from upper Blue Nile has occurred at 35 km before Roseries dam. This is expected as to the effect of the backwater curve (Figure 6), i.e., typically development of reservoir delta. This result well agrees to the principle of reservoir sedimentation of Tarbel Resevoir, Pakistan in Sloff (1999). Close to El Deim, the beginning of the reach the model shows clear bed erosion. This is because the sediment boundary condition at upstream was consisted of only suspended sediment due to lack of measured bed load information. However, the Van Rijn sediment transport model needs bed load since it computes bed load and suspended sediment transport separately. Thus, it erodes the bed to satisfy its transport need. After Roseries dam there is severe bed erosion, could be due to increased sediment transport capacity because of the deposition suspended sediment upstream the dam. Although in reality there is erosion after the dam, it should not erode the bed that much because there is wash load which is not deposited upstream of the dam. The excessive erosion happened due to the fact the model does not solve the advection-dispersion equation which consider the wash load otherwise the effect might have been reduced. Thus, the substantial erosion just downstream the dams may not be accurate as other models that are more suitable for non-cohesive sediment transport. Nevertheless, this result could give qualitative information on river morphology behavior. Downstream of Sennar dam there is no excessive bed erosion unlike the Roseries since the sediment transport capacity is lowered due to enough eroded sediment. After Sennar to Khartoum there is local erosion and deposition as shown in Figure 6.The volume of sediment deposition at Roseries was estimated by integrating the area differences along the distance between El Diem, the mouth of the Reservoir and

Roseries dam. Annual average sediment deposition of 19 M m3 was obtained for the simulation period, which is comparable to literature values, e.g., 20 M m3/yr reported by (NBCBN-RM, 2005).

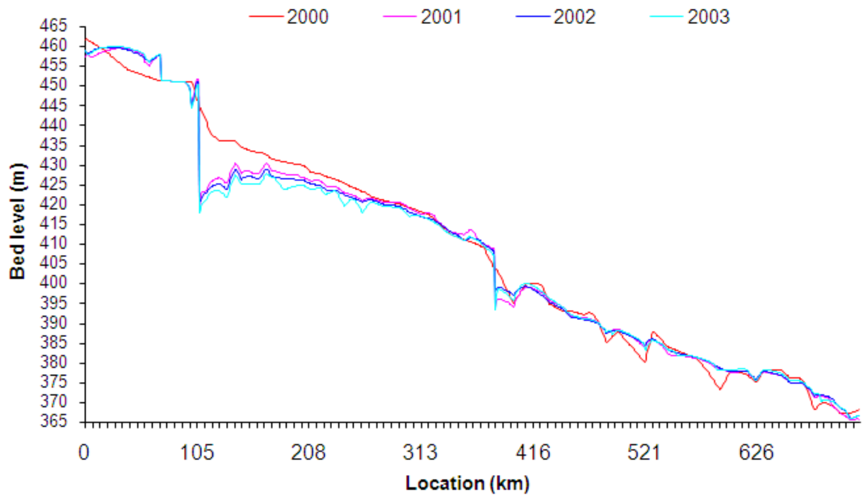

Figure 6: Erosion and deposition of Blue Nile river bed

Conclusions

The paper showed an integration of SWAT hydrological model to a SOBEK 1D hydrodynamic model using OpenMI interface. Useful information has been obtained on spatial distribution of soil erosion on Upper catchment, as well as to the total yield at outlet. The sensitive area to erosion and deposition were found to be the North and North East of Upper Blue Nile subbasins and Rosaries dam, respectively. The integrated soil erosion - sediment transport modelling showed that 86 ton per year of soil is eroded from Upper Blue Nile (at the border), 24 million ton per year deposited in the channel and 62 million ton per year transported to Lower Blue Nile at Eldiem. About 19 M m3year-1 year deposited at Roseries reservoir and the remaining transported downstream. The integrated modelling proved to be useful to study upstream-downstream interdependencies, e.g., to analyze the effect of different management practices upstream (e.g., forestation), and assess implications on flow and sediment hydrographs further downstream. These are essential information for effective basin scale water management.

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Rainfall-discharge relationships for monsoonal climates

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A*bstract*

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.

Introduction

Description and application

Doing a water balance for a watershed is simple! In many regions, rainfall intensity does not affect runoff, in which case we can simply take daily, weekly or even monthly precipitation amounts, subtract evaporation, and use the water balance to keep track of moisture content in the root zone. There is an upper limit for soil moisture (field capacity). When this is exceeded, water drains out of the profile either by percolation to groundwater, as interflow, or as surface runoff. Evaporation is dependent on soil moisture content. It is known that evaporation is zero at wilting point and approaches the potential rate when the soil is at field capacity. There is a linear relationship of evaporation and moisture content between these two points.

The watershed model has many similarities with a flowerpot. Water is added. Add too much water and it drains out. When the soil is dry the plant wilts and evaporation is reduced. A real watershed may be conceived as being composed of many "flowerpots" of different sizes. For simplicity we assume only two areas: hill slopes, and the relatively flat areas that become saturated during the rainy season. Hill slopes have high percolation rates (McHugh, 2006) and water is generally transported subsurface as interflow (e.g. over a restrictive layer) or base flow (percolated from the profile). The flatter areas that drain the surrounding hill slopes become runoff source areas when saturated (Fig. 1 shows a schematic). The profile for the hill slopes is divided into a root zone where the plants extract water and a bottom layer that transmits excess water to the stream. In the saturated contributing area all excess water becomes surface runoff. As this is our major point of interest, we simulate only the top layer (root zone) in this application.

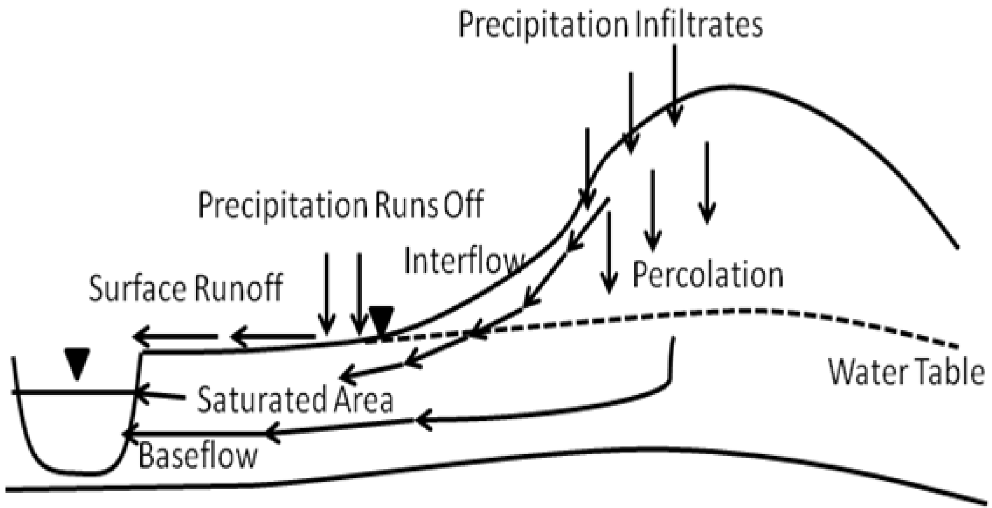

Figure 1: Schematic landscape segment

The amounts of water stored in the topmost layer of the soil, *S* (mm), for hillslopes and for runoff source areas, were estimated separately with a water balance equation of the form:

$$S = S_{t-\Delta t} + (P - AET - R - Perc)\Delta t \qquad (1)$$

where *P is* precipitation, (mm d^{-1}); *AET* is the actual evapotranspiration;, $S_{t-\Delta t}$, previous time step storage, (mm), *R* saturation excess runoff (mm d^{-1}), *Perc* is percolation to the subsoil (mm d^{-1}) and Δt is the time step.

During wet periods, when rainfall exceeds evapotranspiration (i.e., *P>PET)*, actual evaporation, *AET*, is equal to potential evaporation, *PET*. Conversely, when evaporation exceeds rainfall (i.e., *P<PET*), the Thornthwaite and Mather (1955) procedure is used to calculate actual evapotranspiration, *AET* (Steenhuis and van der Molen, 1986). In this method *AET* decreases linearly with moisture content, e.g.

$$\mathrm{AET} = \mathrm{PET}\left(\frac{S_t}{S_{max}}\right) \qquad (2)$$

where *PET* is potential evapotranspiration (mm d^{-1}). The available soil storage capacity, S_{max}, (mm) is defined as the difference between the amount of water stored in the top soil layer at wilting point and the upper moisture content that is equal to either the field capacity for the hillslopes soils or saturation in runoff contributing areas. S_{max} varies according to soil characteristics (e.g., porosity, bulk density) and soil layer depth. Based Eq. 2 the surface soil layer storage can be written as:

$$S_t = S_{t-\Delta t}\left[\exp\left(\frac{(P-PET)\Delta t}{S_{\max}}\right)\right] \qquad when\, P < PET \qquad (3)$$

In this simplified model direct runoff occurs only from the runoff contributing area when the soil moisture balance indicates that the soil is saturated. The recharge and interflow comes from the remaining hill slopes areas. There is no surface runoff from these areas. This will underestimate the runoff during major rainfall events but since our interest in weekly to monthly intervals this is not thought to be a major limitation.

In the saturated runoff contributing areas, when rainfall exceeds evapotranspiration and fully saturates the soil, any moisture above saturation becomes runoff, and runoff, *R*, can be determined by adding the change in soil moisture from the previous time step to the difference between precipitation and actual evapotranspiration, e.g.,

$$R = S_{t-\Delta t} + \left(P - AET\right)\Delta t \qquad (4a)$$

$$S_t = S_{\max} \qquad (4b)$$

In hill slopes, water flows either as interflow or baseflow to the stream. Rainfall in excess of field capacity becomes recharge and is routed to two reservoirs that produce baseflow or interflow. We assumed that the baseflow reservoir is filled first and when full the interflow reservoir starts filling. The baseflow reservoir acts as a linear reservoir and its outflow, BF_t, and storage, BS_t, are calculated when the storage is less than the maximum storage, BS_{max}

$$\mathrm{BS_t} = \mathrm{BS_{t\text{-}\Delta t}} + \left(Perc - BF_{t-\Delta t}\right)\Delta t \qquad (5a)$$

$$BF_t = \frac{BS_t\left[1-\exp(-\alpha\Delta t)\right]}{\Delta t} \qquad (5b)$$

When the maximum storage, $\mathrm{BS_{max}}$, is reached then

$$\mathrm{BS_t} = \mathrm{BS_{max}} \qquad (6a)$$

$$BF_t = \frac{BS_{\max}\left[1-\exp(-\alpha\Delta t)\right]}{\Delta t} \qquad (6b)$$

Interflow originates from the hill slopes, and landscape slope is the major force driving water movement. Under these circumstances, the flow decreases linearly (i.e., a zero order reservoir) after a recharge event. The total interflow, IF_t at time t can be obtained by superimposing the fluxes for the individual events (details are given in the Appendix):

$$IF_t = \sum_{\tau=0,1,2}^{\tau^*} 2Perc_{t-\tau}^* \left(\frac{1}{\tau^*} - \frac{\tau}{\tau^{*2}} \right) \qquad (7)$$

where τ^* is the duration of the period after the rainstorm until the interflow ceases, IF_t is the interflow at a time t, $Perc^*_{t-\tau}$ is the remaining percolation on t-τ days after the base flow reservoir is filled. To demonstrate the method we give two examples: the Abay (Blue Nile) and the Volta.

Application: the Abay Blue Nile

For the Blue Nile we predicted the ten-day averaged river discharge at the El Karo gauge station at the Ethiopian-Sudan border for 1993-1994. The ten-day averaged precipitation over the entire Abay Blue Nile basin in Ethiopia is also available for this period (Ahmed 2003, Fig. 2). Other parameters needed to simulate the discharge include: potential evapotranspiration, which varies little between years and was set at 5 mm d^{-1} during the dry season and 3.3 mm d^{-1} during the rainy season, and soil parameters (e.g., storage). Values for soil storage for the hill slopes and the contributing area were based initially on values from Collick et al. (2008) for three SRCP watersheds. Although the Collick et al. (2008) values resulted in a reasonable fit in this application, we decided to vary them slightly to improve the agreement between observed and predicted values. (The correct distribution between subsurface flow and overland flow directly determines predicted sediment concentrations: Steenhuis et al, 2008). Maximum storage values S_{max}, for different parts of the watershed are listed in Table 1.

Simulating the subsurface flow in the complex landscape of the Blue Nile required both a linear (first order) groundwater reservoir to correctly predict the base flow at the end of the dry season and zero order reservoir to obtain the interflow from the hillslope. The best fit to observed streamflow data was obtained with reservoir coefficient α of 20 mm and a τ^* of 140 days.

Observed rainfall and predicted and observed discharge are shown in Fig. 2. The various components (i.e., direct runoff and the sum of the interflow from hill slopes and baseflow) are shown in Fig. 3. At the beginning of the rainy season almost all flow in the river is direct runoff generated from the 20% of the area that has the smallest storage. As the rainy season progresses (cumulative rainfall increases), the rest of the landscape wets up and runoff is generated from the remaining 10% of the flatter contributing area, followed in early July 1993 by base and interflow from the hill slopes. Note that this corresponds to the time when sediment concentration in the river is decreasing from a maximum value (Fig. 4).

Less obvious but just as important is that the volumes of predicted and observed discharge in Fig. 2 (i.e., areas under the curves) are equal, indicating that the water balance does indeed balance within a hydrologic cycle. In other words we can account for all precipitation that does not evaporate as streamflow in the same year. Finally, this water balance is able to explain the observed runoff coefficient of (i.e., discharge/precipitation) of approximately 20-30% during the period when most rainfall occurs by distributing the effective rainfall (rainfall minus potential evaporation) over saturated contributing areas that generate direct runoff - and then interflow and baseflow after the major rainfall from the remaining 70% of the area.

Table 1 Model inputs: fractional areas of watershed, Smax values, and type of area.

Fraction of Watershed	Storage S_{max} (mm)	Type
0.2	10	contributing area
0.1	250	contributing area
0.7	500	hillside

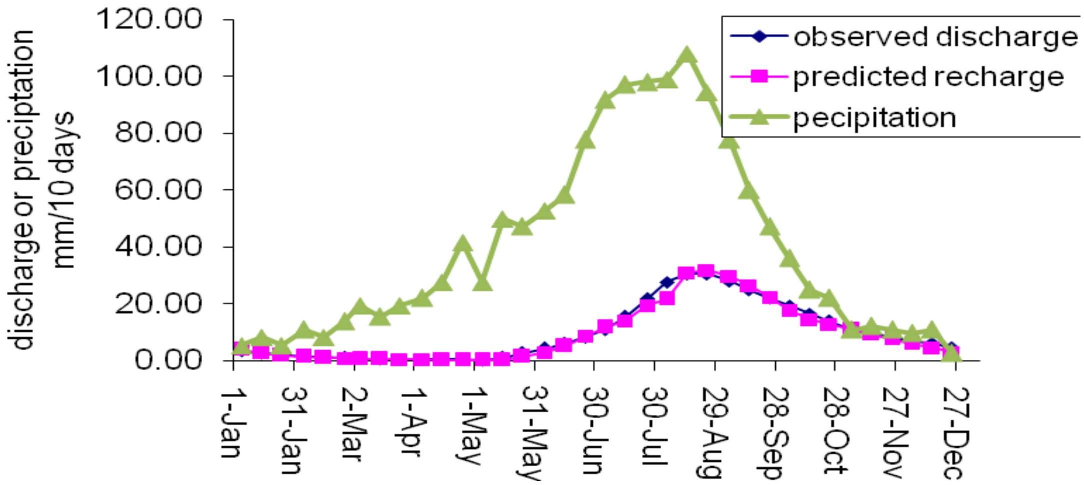

Figure 2: Ten day precipitation and predicted and observed discharge for the Abay Blue Nile at El Karo, Sudan.

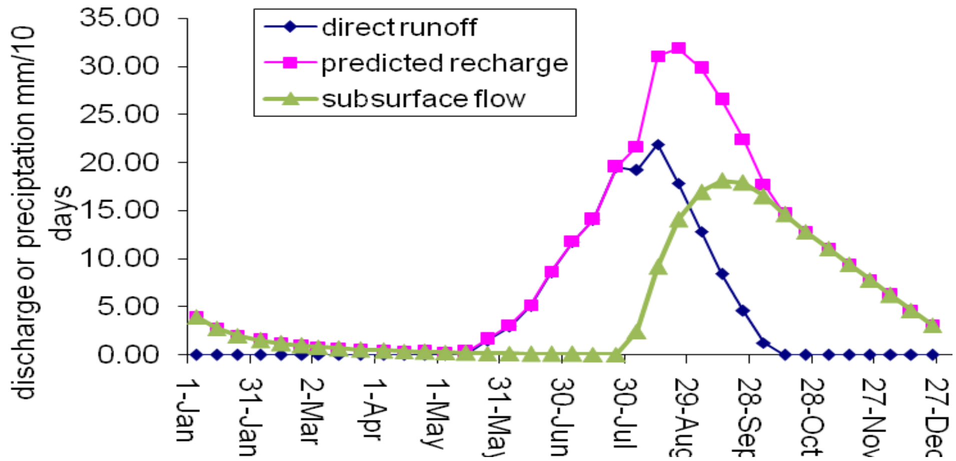

Figure 3: Predicted total discharge, direct runoff, and subsurface flow for the Abay Blue Nile at El Karo at the Ethiopian Sudanese Border

The Volta Basin

The Volta basin is much less steep than the Blue Nile basin. Although the same general principles govern water balance, practical implementation is different. In the relatively flat Volta basin, the fast and relatively rapid interflow along the hill slopes characteristic of the Blue Nile basin does not occur. This means that the zero order reservoir and the saturated areas can be neglected in Volta basin simulations and all streamflow is base flow from a linear reservoir recharged by the (relatively flat) hillside. Due to the flat slopes only a portion of the hillside areas contribute to streamflow. In the remaining area the water that percolates down to root zone is used by deep rooted vegetation during the dry season.

Precipitation data was derived from the Global Gridded Climatology (GGC) compiled by the Climatic Research Unit at a resolution of 0.50 lat/long, (New *et al.*,1999a, b). The Climatic Research Unit (CRU) (New *et al.*, 1999a, b) also provided vapor pressure data, wind speed, and temperature, used to calculate *PET* using the Penman equation. Both precipitation and *PET* estimates were made by overlaying a map of the area on a grid. Each pixel, at 0.5^{o} x 0.5^{o} per cell (1 cell ≈11,700 km^2), was weighted by that pixel's contribution to the total area, and the monthly mean was computed by adding the weighted pixels in the total area (Andreini *et al.*, 2000). To fit the predicted streamflow, two sources of stream discharge, obtained from WRI of Ghana and L'Institut de Recherche pour le Développement (ORSTOM), proved advantageous. Figure 4 shows the location of each streamflow gage. Table 2 contains the stations that had data of acceptable accuracy. Station accuracy was assessed by Taylor et al (2006).

In Table 2, best fit parameter values for the water balance are all within reasonable values from the literature, and are consistent with results from prior work in the basin. Figure 5 shows the results of monthly predictions of river discharge. The r^2 values are 0.66 for WRI data and 0.56 for ORSTOM data. The S_{max} values for the Black Volta Basin are 60 mm on average with a standard deviation of 29 mm. For the White Volta and the Oti, maximum available water contents are 112 mm and 143 mm, respectively, both with a standard deviation of 50 mm. The average available water content for the Lower Volta proper is 70 mm with the exception of Prang (the uppermost, wetter subcatchment), which has an available water content of 350 mm. These values are consistent with the parameters found in Dunne and Leopold (1978) for moderately deep-rooted crops (between 75 and 200 mm) and for clay in mature forest (above 350 mm).

The portions of available runoff that actually enter the stream (delivery ratio) for each month (the α parameter) in the White Volta, the Volta proper, and the Oti, 0.56, 0.48, and 0.48, respectively, are almost identical to the values used by Thornthwaite and Mather (Thornthwaite and Mather, 1955) for North Carolina, which, in many regards, has a similar topography as the Volta basin. Values for the Black Volta are consistently lower. The percent area of the watershed that contributes to runoff is typical for a semi-arid landscape. Average β values for the White Volta, and Oti are similar and higher than the Black Volta, which also has lower available water contents on average. As expected, the wetter the basin, the greater the contributing area.

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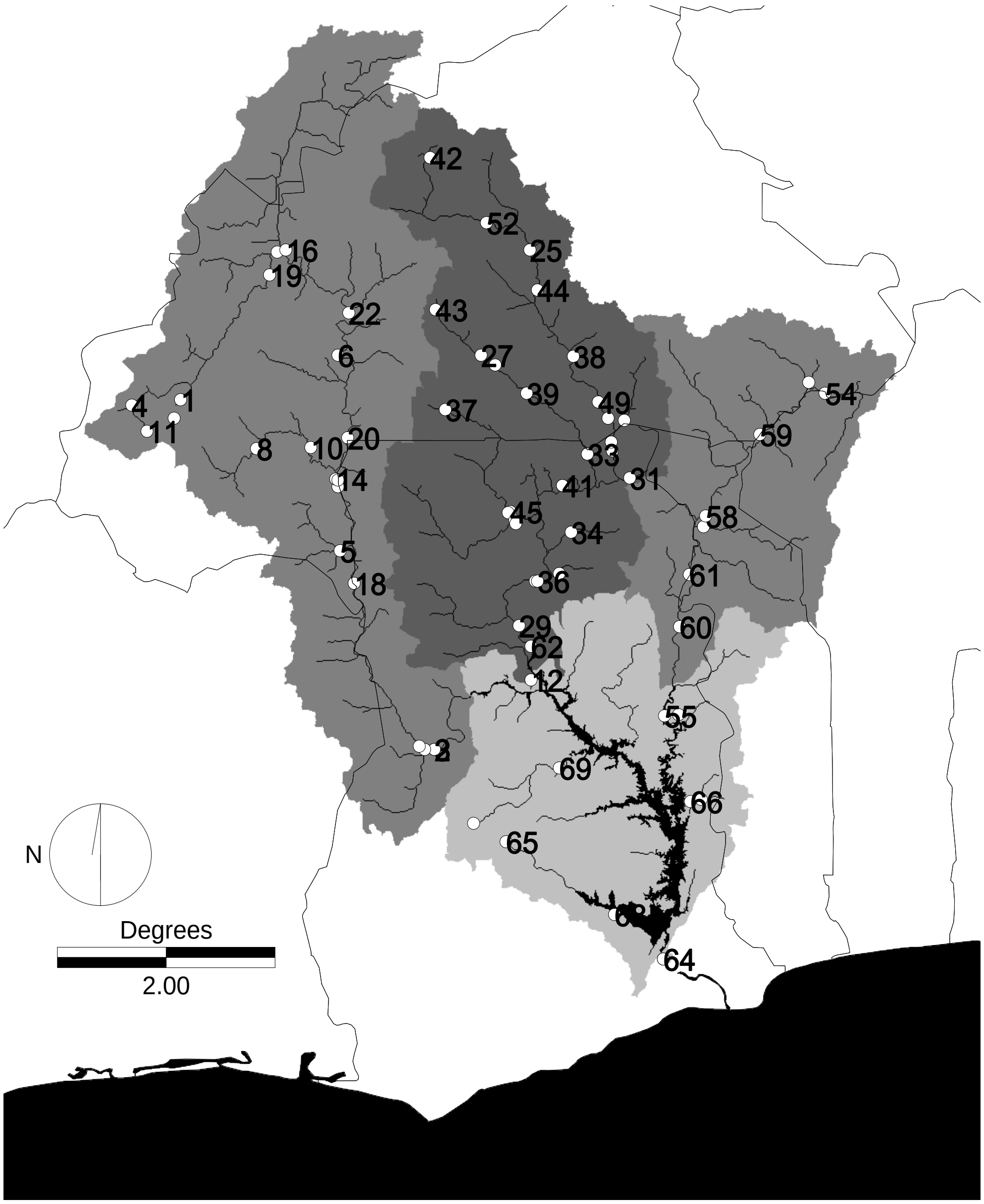

Figure 4: Streamflow gages in the Volta Basin

Table 2: Parameter values for various gages in the Volta basin

Gage Name	**S_{max} (mm)**	**□ 1/month**	**%**	**R^2**	**Years of record**
Black Volta	**60**	**0.35**	**35**	**0.60**	**18**
Bamboi-W	83	0.33	58	0.66	25
Bamboi -O	83	0.33	58	0.56	30
Tainso (Tain)	84	0.50	11	0.56	13
Bui	39	0.35	58	0.63	35
Kalbuipe (Sur)	83	0.41	20	0.66	22
Dapola	33	0.31	30	0.61	10
Lawra-W	52	0.28	32	0.64	13
Lawra-O	52	0.28	32	0.60	11
Dan (Boug)	90	0.42	21	0.63	15
Diebougou (B)	92	0.40	37	0.67	18
Ouessa	20	0.33	25	0.68	6
Banzo	74	0.44	48	0.70	40
Boromo	20	0.27	30	0.47	10
Tenado	24	0.30	41	0.55	11
Nwokuy	100	0.30	38	0.55	20
Manimenso	33	0.34	20	0.48	8
White Volta	**112**	**0.56**	**63**	**0.68**	**37**
Lankatere(Mo)	176	0.75	87	0.77	72
Nawuni-O	66	0.50	60	0.76	19
Nasia (Nasia)	163	0.55	64	0.82	33
Yagaba (Kalp)-O	109	0.61	68	0.77	58
Wiasi-O (Sisili)	86	0.62	43	0.72	23
Ngodi (Naz)-W	71	0.32	55	0.26	20
Oti	**143**	**0.48**	**68**	**0.63**	**40**
Ekumdipe (Da)	174	0.50	100	0.73	47
Sabari	167	0.40	80	0.80	31
Saboba	133	0.65	100	0.71	62
Koumangu (K)	200	0.61	100	0.86	90
Mango	161	0.35	94	0.68	42
Porga	101	0.35	47	0.70	23
Arly	27	0.30	16	0.53	6
Arly (Dou)	180	0.70	10	0.00	19
Volta Prop	**139**	**0.48**	**52**	**0.55**	**65**
Senchi (37-63)	70	0.33	69	0.72	26
Senchi (51-80)	63	0.55	59	0.37	43
Aframso (Afr)	67	0.37	50	0.53	6
Ahamnasu (A)	73	0.39	38	0.64	89
Podoe	67	0.45	18	0.34	12
Prang (Pru)	351	0.70	100	0.69	153

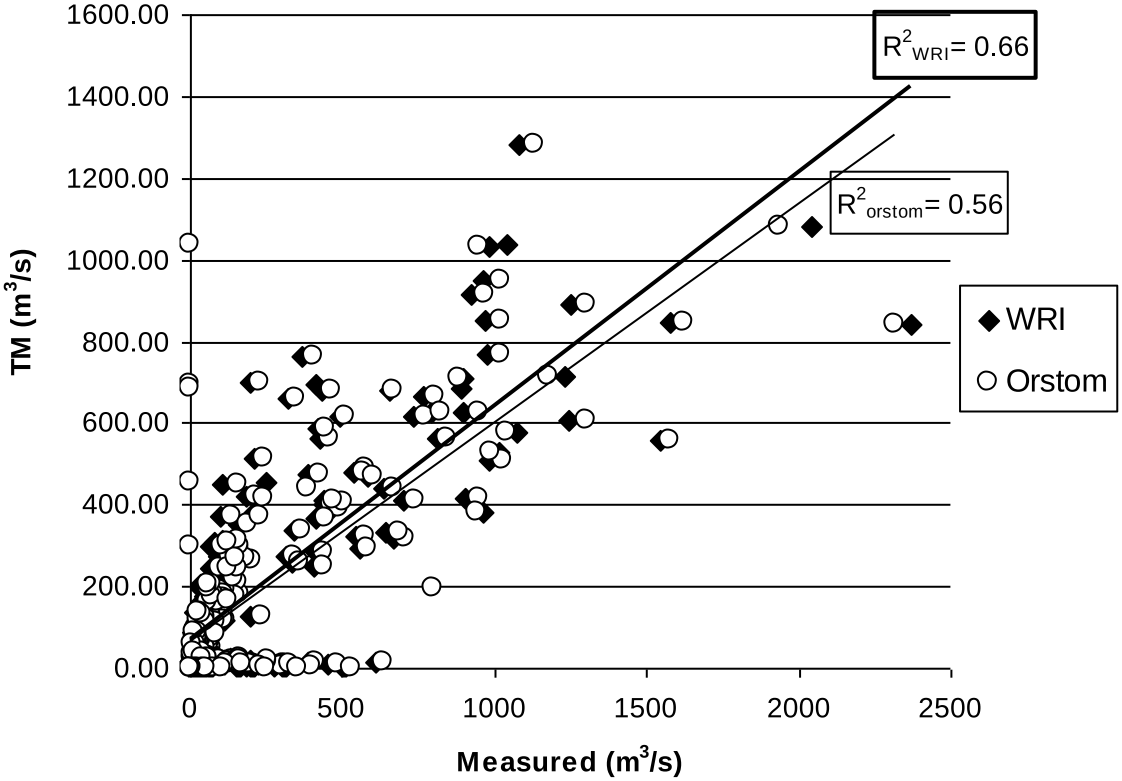

Figure 5: Predicted and observed streamflow at Bamboi

A Water Balance-Based Soil and Water Assessment Tool (SWAT) for Improved Performance in the Ethiopian Highlands

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Abstract

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 Abay Blue Nile in Ethiopia were modeled at a daily time step. While long term, daily data is largely nonexistent for portions of the Abay 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.

Introduction

Hydrologic models are used primarily to predict water quantity, peak flows, and export of water quality constituents from a watershed. One common method to determine the runoff volume in these models is the Natural Resource Conservation Service Curve Number (CN) technique. This method was initially designed for determining runoff volume for engineering design purposes, but has since been adapted for use as a tool in many temporal watershed models, including the USDA's Soil and Water Assessment

Tool (SWAT). While useful for design purposes, the CN approach has been shown to be less than ideal when used to model runoff both spatially and temporally (see Garen and Moore, 2005).
In addition to the general problems the CN has in representing spatial variability of runoff and differentiating between runoff generating processes, the method was developed by curve fitting rainfall-runoff data only from the United States and is not necessarily accurate for all landscapes. To correct for this SWAT was modified and adjusted for watersheds in the Blue Nile River Basin in Ethiopia, where the CN approach has been shown to be inaccurate in predicting runoff events.

Under Ethiopian conditions, runoff is mainly generated by saturation excess mechanisms and runoff from a given amount of rain is less in the beginning of the rainfall season than at the end (Liu et al. 2008). Although the CN method can be adapted to predict saturation excess such as this, it inaccurately assumes that similar rainfall patterns produce the same amount of runoff independent of the time of the year. This is well illustrated in Figure 1, where we applied the standard CN approach to the Anjeni watershed in the Ethiopian Highlands that has 16 years of rainfall-runoff data. It is obvious that when we calibrate the method to the storms at the end of the rainfall season, the storms at the beginning of the rainy season with less than 500 mm of cumulative precipitation are under-predicted. Therefore, in order to apply SWAT to Ethiopian conditions, the original CN method has to be replaced by a more mechanistic approach that uses soil water balances to calculate when the soil is saturated and consequently produces runoff.

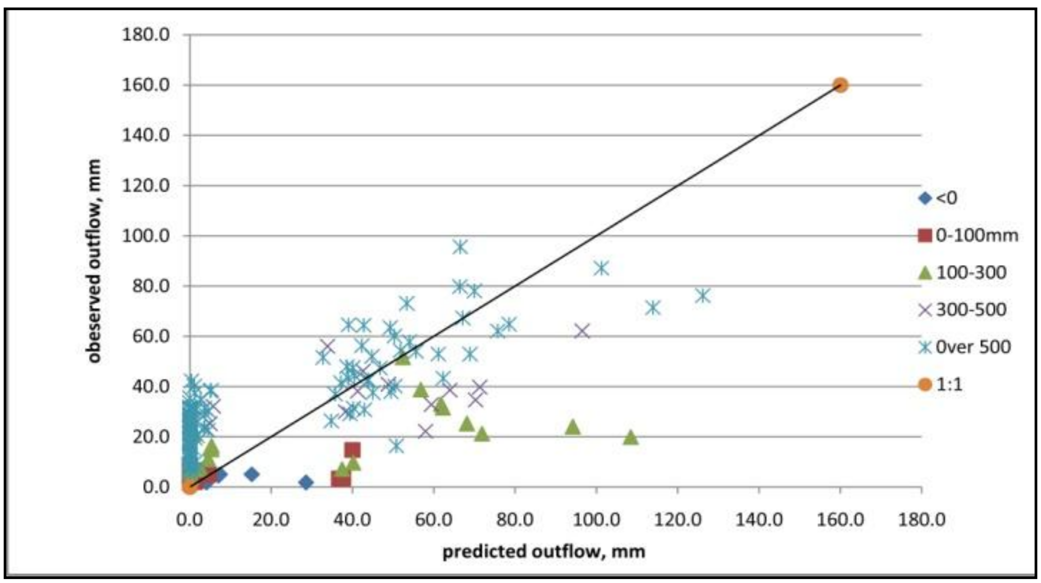

Figure 1: CN predicted runoff for an Ethiopian watershed. Runoff is grouped in ranges of cumulative rainfall.

Methods

To adjust the SWAT program to account for saturation excess runoff, a new subroutine was created in the code which circumvented the original CN calculations and used water balances to calculate saturation. The new, saturation-driven SWAT model results were then compared to the original CN-based SWAT results for a simulated period from January, 1996 to December, 2005. The new model was then calibrated using an adjusted version of SWAT's auto-calibration tool.

Original Curve Number Approach

An initial CN is assigned for each specific landuse/soil combination in the watershed, and these values are read into the SWAT program. SWAT then calculates upper and lower limits for each CN following a probability function described by the NRCS to account for varying antecedent moisture conditions (CN-AMC) (USDA-NRCS, 2004). SWAT determines an appropriate CN for each simulated day by using this CN-AMC distribution in conjunction with daily soil moisture values determined by the model. This daily CN is then used to determine a theoretical storage capacity, *S*, of the watershed for each day the model is run. The storage is then indirectly used to calculate runoff volume, *Q*, by means of the following equations:

$$CN = \frac{1000}{10 + \frac{S}{25.4}} \qquad 1$$

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad 2$$

Where *S* is watershed storage, *P* is precipitation, and I_a is initial abstraction. All terms are in mm of water, and by convention I_a is assumed to be equal to 0.2**S*.

New Water Balance Approach

To replace the CN, a simple soil water balance was calculated for each day of simulation. The modified model is therefore called SWAT-Water Balance or SWAT-WB for short. While SWAT's soil moisture routine grossly simplifies processes that govern water movement through porous media (in particular, partly-saturated regions), for a daily model, the water balance has been shown to be proficient (Guswa et al., 2002). We then used SWAT's soil moisture calculations to determine the amount of storage available for any given area of the watershed for every day of simulation. This, we called the available soil storage (mm), τ:

$$\tau = D(\varepsilon - \theta) \qquad \text{eq. 3}$$

Where *D* is the effective depth of the soil profile (unit-less), ε is the total soil porosity (mm), and θ is the volumetric soil moisture for each day (mm). The porosity is a constant value for each soil type, whereas θ varies by the day and is determined in SWAT. The effective depth is used in the calibration process and represents the portion of the soil profile in which the moisture content controls the amount of water able to infiltrate in one day. This available storage is then used to determine what portion of rainfall events can be held by the soil and what portion will runoff:

$$Q = \begin{cases} 0 & \text{if} P < \tau \\ P - \tau & \text{if} P > \tau \end{cases} \qquad \text{eq. 4}$$

Watershed description

The new SWAT-WB was initially tested on a watershed in the Blue Nile River basin in Ethiopia. The Gumera watershed, located northeast of Bahir Dar, is a 1270 km2, heavily (~95%) cultivated, watershed in the Lake Tana basin. Elevation of the Gumera watershed ranges from 1797 to 3708 meters above sea level and predominant soils are generally characterized as chromic and haplic luvisols (24% and 63%, respectively) (FAO-AGL, 2003).

Daily precipitation and temperature data for a period from 1996 until 2005 were used, while other historic climate data (relative humidity, wind speed, solar radiation) were gathered from the United States' National Climatic Data Center for the nearest station (NCDC, 2007).

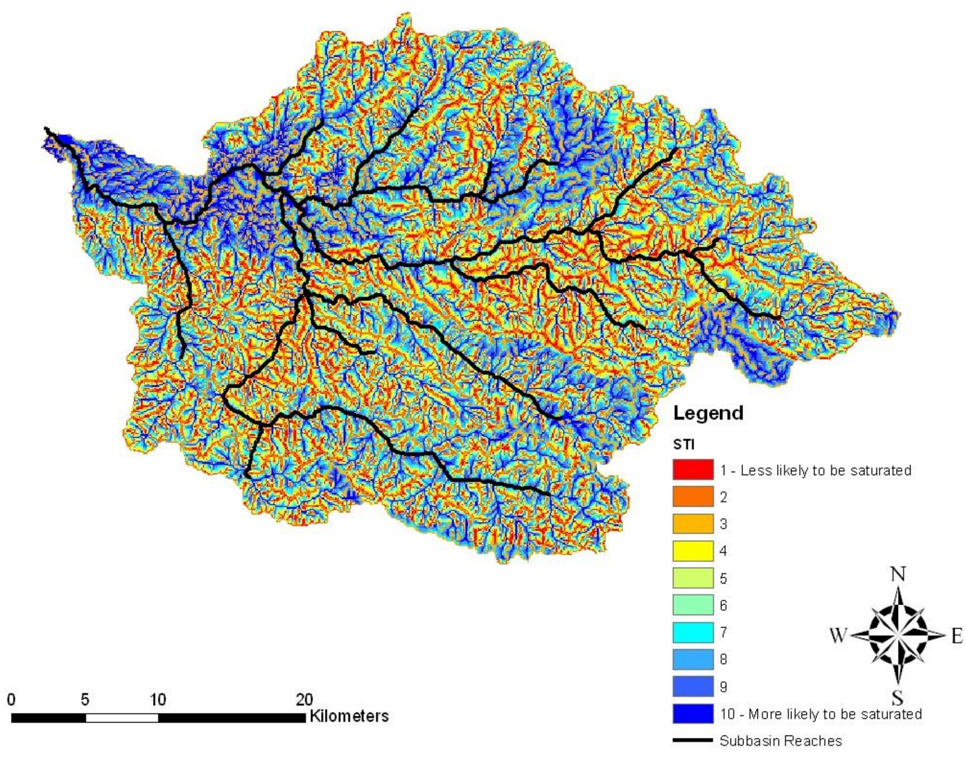

Figure 2: Soil topographic index for the Gumera basin

Results

The Gumera basin was modeled using both the original version of SWAT (SWAT-CN) and the new CN-free, water-balanced based version (SWAT-WB). In addition to these comparisons, the SWAT was also run using soil topographic indices (STI) in place of the traditional soils map required by the model, Figure 2. Previous research has indicated that STIs can be used to more accurately predict runoff generating areas (when saturation-excess is the driving force), which led to the decision to adjust the effective depth, *D*, based on the STI (see Easton et al., 2008 and Lyon et al., 2004). The STI for Gumera was then used in both SWAT-CN and SWAT-WB. Prior to any calibration, SWAT-WB returned drastically improved daily results over both SWAT-CN runs (with and without STI). Daily Nash-Sutcliffe model efficiencies were negative for both CN-based runs, indicating that simply taking the mean streamflow would have been a better predictor than SWAT; whereas SWAT-WB resulted in a daily model efficiency of 0.51. Upon calibration of hydrologic parameters using SWAT's auto-calibration tool, the daily model efficiency of SWAT-WB was 0.73.

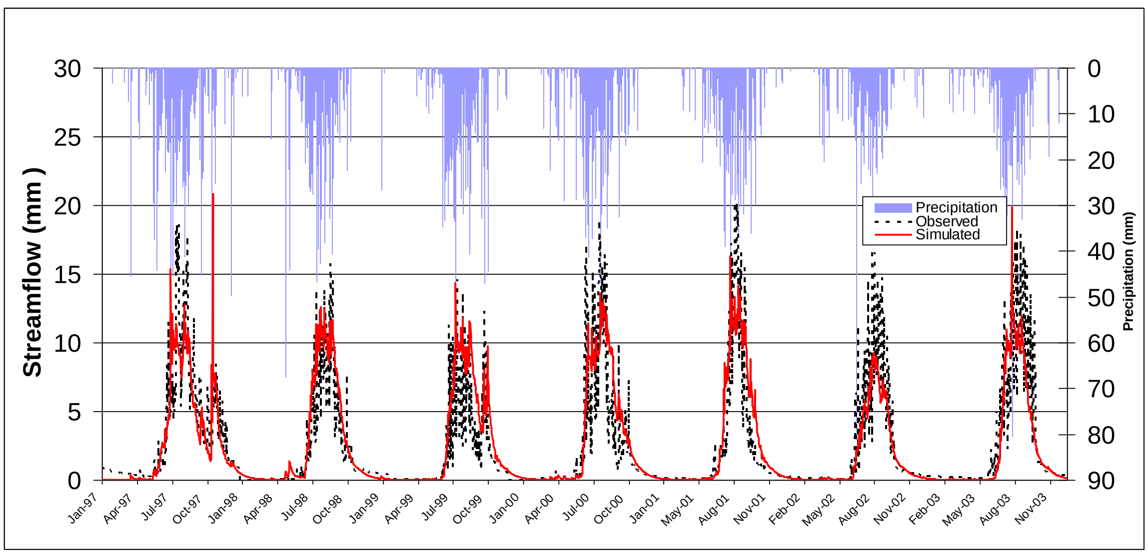

Figure 3: Observed rainfall and streamflow, as well as calibrated streamflow values modeled with SWAT-WB for the Gumera basin for 1997-2003.

Discussion

SWAT CN and most other watershed models have been developed for temperate climates where rainfall is generally well distributed throughout the year. Running models developed in the temperate climate for Ethiopia conditions with a monsoonal climate are problematic. Temperate models assume that there is a nearly unique relationship between precipitation amounts or intensity and runoff generated. This is not the case for Ethiopia as demonstration by the results of Liu et al (2008) where for three watersheds with more than 16 years of record, the rainfall relationship was far from unique. The first rains after the dry season all infiltrate and nearly no runoff is generated. As the rainfall season progresses more and more rainfall becomes runoff. Since the intensity of the rain did not affect the runoff amounts for a given storm, the runoff mechanism is saturation excess runoff (Liu et al., 2008).

Water balance models are consistent with saturation excess runoff process because the runoff is related to the available watershed storage capacity and the amount of precipitation. The implementation of water balances into runoff calculations in the Blue Nile basin is not a novel concept and often performs better (as did our results) than more complicated models in Ethiopia type landscapes (Johnson and Curtis, 1994; Conway, 1997; Ayenew and Gebreegziabher, 2006; and Liu et al., 2008). These water balance models are typically computed with monthly or yearly values because the models are generally not capable of separating base- inter- and surface runoff flow. However, to truly model erosion and sediment transport, large events must be captured by the model and daily simulations are required to do so. Thus SWAT-WB not only maintains a water balance but also calculates the interflow and the base flow component and also gives a reasonable prediction of peak flows. SWAT-WB is therefore more likely to capture sediment transport than either SWAT-CN or water budget models with monthly time steps. Note that by choosing to run models on a daily time step, the model performance always is significantly worse than for monthly or yearly time steps.

SWAT-WB is more in tune with the runoff processes that occur in the Ethiopian highlands than other models that base their runoff prediction on the NRCS curve number method. The calculations that serve as a foundation for NRCS curve number technique assume that the moisture condition in the soil can be determined by taking into account the five day previous rainfall events. As indicated above, the moisture content in monsoonal climates is changing during the first 500 mm of effective precipitation, or approximately 1-2 months. SWAT-WB, on the other hand, determines runoff volume simply by calculating the available storage in each soil profile. This value is not dependent only upon the five previous days' rainfall (as the CN method is), but instead allows for progressive saturation as the rainy season continues.

Conclusion

Daily modeling of peak streamflow and surface runoff was improved by replacement of the CN method with a water balance routine in the SWAT model. In addition to improving model efficiencies, it is also predicted that the new water-balance-based SWAT will be a better predictor of the location of runoff-generating areas of a watershed due to the inclusion of soil topographic indices. By removing the curve number and calibrating the water balance routine based on STIs, daily Nash-Sutcliffe efficiencies improved from -0.02 to 0.73, while R^2 values increased from 0.27 to 0.74.

These results indicate that SWAT performs better in a saturation-excess controlled watershed when a water balance routine is used to calculate daily runoff volumes instead of the traditional Curve Number. Further research will ideally demonstrate that these adjustments are appropriate for any region where saturation-excess runoff is dominant, not just the Ethiopian highlands.

Acknowledgements

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Session III: Watershed Modeling

Assessment of Hydrological Controls on Gully Formation and Upland Erosion near Lake Tana, Northern Highlands of Ethiopia

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Abstract

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.

(For details, please refer to the relevant poster included in the folder 'Posters' on the CD).

Assessment of Hydrological and Landscape Controls on Gully Formation and Upland Erosion near Lake Tana

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Abstract

Gully formation and upland erosion were studied in the Debre-Mewi Watershed in the Gilgil Abay 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.

Introduction

For the past five decades, gully and upland erosion has been the dominant degradation process in the Ethiopian Highlands. Erosion negatively affects soil resources, lowers soil fertility and aggravates siltation of reservoirs. While mechanisms for upland erosion are generally well understood (Haile et al 2006), gully erosion is not. Better understanding of these gully erosion processes will result in more effective erosion control at less cost. Therefore, the objective of this study was to better understand erosion processes; in particular to compare erosion rates from an active gully to those of upland fields. This comparison will be used to determine the effect of landscape position and field wetness on erosion rates.

Material and Methods

The study was performed in the 523 ha Debre-Mewi watershed located: between 11°20'13" and 11°21'58" North and 37 ° 24'07" and 37 ° 25'55" East, 30 km south of Lake Tana, Bahir Dar, Ethiopia. The elevation is between 1950 and 2309 m and slope varies from 6-35%. Average rainfall falling mainly from June to September is 1240 mm. Land use consists of rainfed agriculture in a mixed farming system with scattered indigenous tree species, including *Cordia* sp. The soils are dominated by vertisols.

The historic rate of gully development was assessed through the AGERTIM method (**A**ssessment of **g**ully **e**rosion **r**ates through **i**nterviews and **m**easurements, 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. The dimension of each rill was carefully measured after major storms to determine the volume of soil loss (Herweg, 1996; Hagmann, 1996; Bewket and Sterk, 2003). 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.

Results and Discussion

The Debre-Mewi gully (Figure 1) is an actively eroding gully system with a contributing area of 17.4 ha. According to farmers' interviews, the gully erosion started in 1980, which corresponds to when the watershed was first settled and the indigenous vegetation on the hillsides was converted gradually to agricultural land. Erosion rates for the main stem and two branches are given in Table 1. The increase in main stem erosion rate can be explained by the recently enlarging and deepening of the gully at the lower end (Figure 2). In 2005, gully extent was estimated from the 2005 Quick Bird image (0.58 m resolution). Gully boundaries were determined before the rainy season in 2008 (indicated as 2007 measurement) and after the rainy season on October 1 (the 2008 measurement) by walking the gully with Garmin GPS with a 2 m accuracy. These measurements showed that from 2005 to 2007, the gully system increased from 0.65 ha to 1.0 ha, respectively, a 43% increase in area. The following year, it increased by 60% to cover 1.43 ha in 2008.

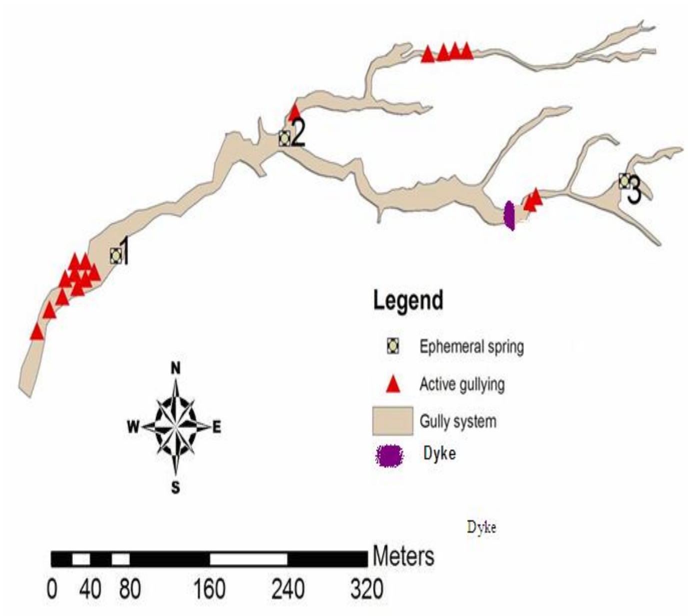

Figure 1: Drawing of the Debre-Mewi gully generated by handheld GPS tracking. Active erosion areas are indicated by triangles. Ephemeral springs are shown as well

Once gully size was determined, the rates of erosion were then calculated by determining the change in dimension of the different gully segments. The average gully erosion rate from the period from 1981 to 2008 was equivalent to 31 t ha^{-1} per year in the contributing watershed. The gully erosion rate has accelerated significantly in the last few years and in the 2008 rainy season the erosion rate was 530 t ha^{-1} (Table 1) which is equivalent to nearly 4 cm of soil in the contributing watershed. These values are very high for the region compared to the results from other studies (Daba et al., 2003 and Nyssen et al., 2006).

Figure 2: Actively forming gully at the most downstream end. Just below “1” in Figure 1

The Debre-Mewi gully is very active in a few areas as indicated by the red triangles in Figure 1. Our measurements with the piezometers show that at these locations the water table is above the bottom of the gully. An example is given in Figure 3 for the actively forming gully shown in Figure 2. In figure 3 the distances are measured from the branch with another river. The depths of the gully (Figure 3a) and the corresponding widths (Figure 3b) before and after the 2008 rainy season show that the gully is most active at distances less than 200m from the outlet. The gully advanced backward past the 187 m mark (figure 3a) and increased up to 20 m in top width (Figure 3b). In this region the water table was near the surface and approximately 4 m above the gully bottom (Figure 3A). Upstream of the 187 mark the water table is below the gully bottom (Figure 3A) and the gully is stable as can be seen from Figure 3B since the width is not increasing.

Table 1 Gully erosion losses calculated as uniformly distributed over the watershed

Gully location	Soil loss		
	1980-2007 t/ha/year	2007-2008 t/ha/year	2007-2008 cm/year
Branches	*17.5*	128	1.0
Main stem	13.2	402	3.0
Total	**30.7**	**530**	**4.0**

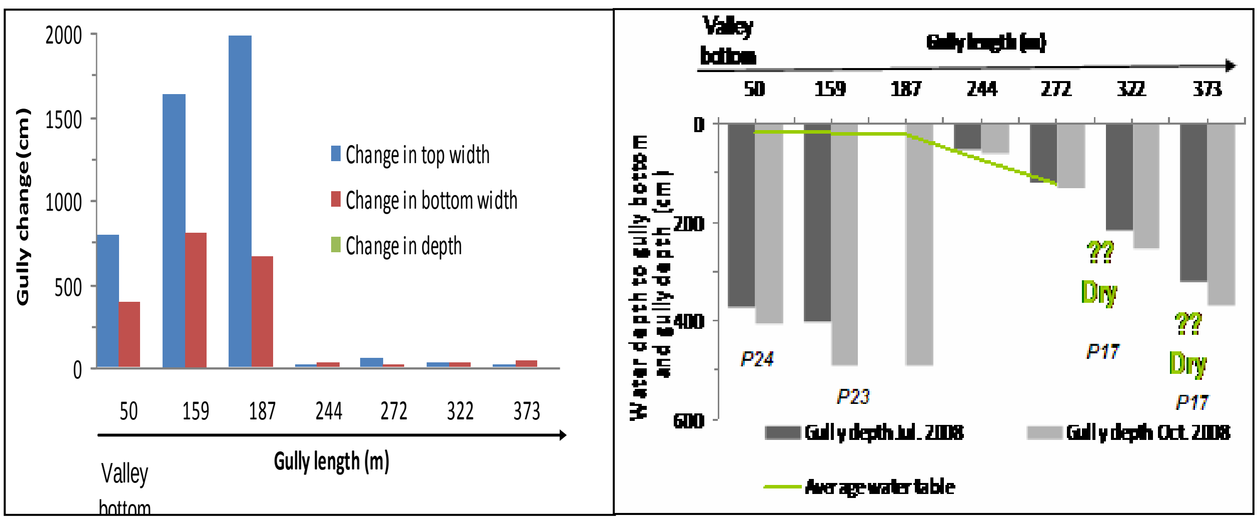

Figure 3: Gully dimensions before and after the 2008 rainy season for the main stem. a) Depths and average groundwater table; b) change in top and bottom width and depth of the gully

The average upland erosion of the 15 agricultural fields for each storm is depicted in Figure 4. These erosion rates are with traditional soil conservation practices in place, which consist mainly of small, hand dug, 10 cm deep drainage channels, which direct water to the field’s edge. Over the whole watershed, 75% of the farmers used the traditional ditches d cribed above, 61% used soil bunds and 47 % used contour plowing.

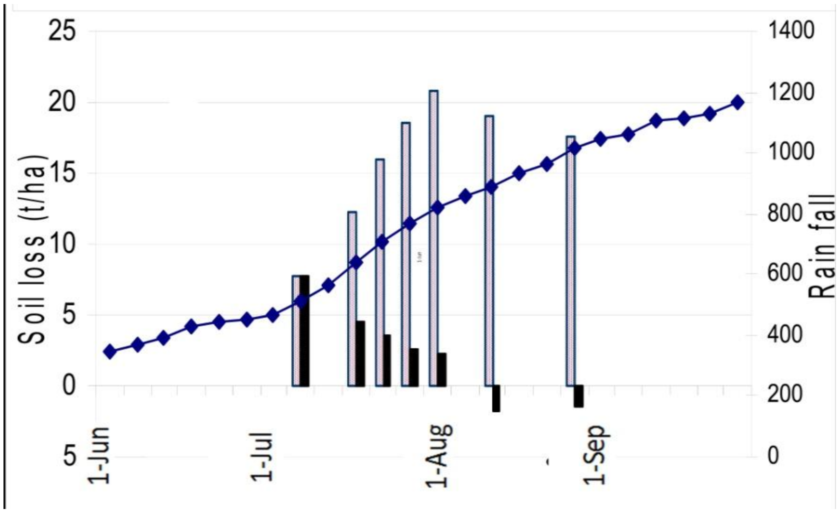

Figure 4: Average soil loss for the 15 upland agricultural fields in the Debre-Mewi watershed, the light shaded columns is the cumulative soil loss for the season. The black boxes are the soil losses for the individual storms; the line with diamonds is the cumulative precipitation for the rainy season.

The erosion is greatest at the end of June when the soil is loose and dry making it easy to erode as rills (Bewket and Sterk, 2003). After the initial rain storms, the soils wet up and plant cover is established; decreasing the rate of erosion. In late August, the rills degrade giving an apparent negative soil loss. The average cumulative soil loss is 26.6 tons/ha provided that the average bulk density of all surveyed fields was 1.21g/cm^3 and compares well with the measurement of the nearby erosion plot. By assuming the erosion caused by raindrop impact is 25% of the actual soil loss, the rate of soil loss is going to be estimated around 36 tons/ha. The tef plots had the greatest density of rills, which is likely caused by the repeated cultivation of the field and grinding of the soil by livestock traffic before sowing.

There was a greater soil loss from the fields at lower elevations than higher up the slope (Figure 5). The lower fields were either at saturation or close to saturation before the rain storm occurred; the upper fields were better drained. The erosion mechanisms for the upland agricultural fields are consistent with the mechanisms for the gully formation, because the soils near or at saturation have the least amount of adhesion between the soil particles. And therefore, have the highest erosion rates. For the gullies this results in bank failure in which the soil loses its stability causing the slumping of the gully walls and the surrounding soil (Zhu, 2003), while for the upland fields deeper rills form. When the soil is dry, the soil has no strength either, and high soil losses results. Although not observed in this study, gully banks erode easily by any disturbance such as grazing animals.

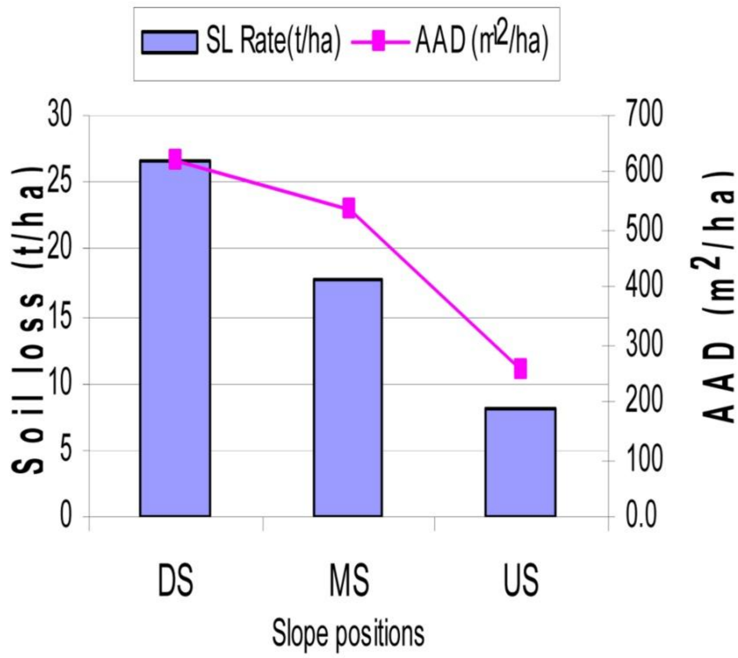

Figure 5: Erosion rate in tons /ha over the growing season as a function of slope position; where DS is down slope, MS is middle slope and US is upper slope. AAD is area actual damaged due to rill formation in m^2/ha.

Comparing the gully and upland erosion rates, we find that in 2008, the soil loss rate of the upland plots (rill erosion) is approximately 20 times less than that transported due to gully erosion. While significantly less than gully erosion, rill erosion is still nearly four times greater than soil loss tolerance and thus cannot be ignored in any planning for erosion control to save fertility on the field. On the other hand, if reservoir siltation is the primary impetus for soil conservation, gully erosion should be addressed before upland erosion.

A final question that needs to be answered is what can be done (based on the information above) to stop the advance of gully formation. It is obvious that lowering the water table below the gully bottom would be most effective. This can be accomplished with drainage lines which, in theory, are practical. Application under Ethiopian conditions, however, may be cumbersome due the relatively high cost and lack of mechanized equipment. It should be noted that buffer strips around the gully (which is sometimes advocated by engineers) do not address the basic problem, which is the fact that groundwater is too close to the surface. Once gullies are stabilized, buffer strips could be more effective, however more research needs to be done before such a conclusion can be drawn with confidence.

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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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Abstract

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.

Introduction

Soil degradation can be described as a reduction of resource potential by or on a combination of processes acting on the land, such as soil erosion by water and wind, bringing about deterioration of the physical, chemical and biological or economic properties of soil (Maitima and Olson, 2001). The principal environmental problem in Ethiopia is land degradation, in the form of soil erosion, gully formation, soil fertility loss and severe soil moisture stress, which is partly the result of loss in soil depth and organic matter (Fitsum et al., 1999). The excessive dependence of the Ethiopian rural population on natural resources, particularly land, as a means of livelihood is a underlying cause for land and other natural resources degradation (EPA, 1998)

Some forms of land degradation are the result of normal natural processes of physical shaping of the landscape and high intensity of rainfall. The scale of the problem, however, dramatically increased due to the increase in deforestation, overgrazing, over-cultivation, inappropriate farming practices, and increasing human population. Removing vegetative cover on steep slopes (slopes ranging between 15 and 50 percent) for agricultural expansion, firewood and other wood requirements as well as for grazing space has paved the way to massive soil erosion. Forest cover in the Ethiopian highlands as a whole decreased from 46% to 2.7% of the land area between the 1950’s and the late 1980’s. This is compounded by increasing numbers of livestock being forced on to shrinking pastures (Esheteu *et al*., 2006). According to Esheteu *et al*. (2006), although about 82% of the rural household energy is covered by fuel wood and supplemented by dung (about 9%) and burning of crop residues (about 8%), the land tenure and tree tenure have provided little incentive for protection of forests and tree planting.

It is estimated that over 1900 million tons of soil are lost from high lands of Ethiopia annually (EHRS, 1986). These losses of productive topsoil are irreversible for it takes many years to generate a ton of topsoil. The Ethiopian highlands, which are the center of major agricultural and economic activities, have been the victim of soil erosion for many years. It is concluded that about half of the highland's land area (about 27 Million hectares) is significantly eroded and over one-fourth (14 Million hectares) are seriously eroded. Moreover, 2 Million ha of land is permanently degraded that the land is no longer able to support cultivation (EHRS, 1986).

In the Amhara region, the soil loss due to water erosion is estimated to be 58% of the total soil loss in the country (Tesfahun and Osman, 2003). This has already resulted in a reduction in agricultural productivity of 2 to 3% per year, taking a considerable area of arable land out of production. The situation is becoming catastrophic because increasingly marginal lands are being cultivated, even on very steep slopes (Tesfahun and Osman, 2003).

To mitigate land degradation problems in Ethiopia, the government has taken different soil and water conservation measures. Nevertheless, the rate of adoption of the interventions is considerably low. Space occupied by soil and water conservation (SWC) structures, impediment to traditional farming activity, water logging problems, weed and rodent problems, huge maintenance requirement, are some of the reasons that cause farmers refrain from SWC works. In addition, top down approach in the extension activity, focusing mainly on structural soil and water conservation technologies, and land security issues contribute much to the failure of SWC works (Mitiku *et al*., 2006). The present study was conducted on one of the few successful SWC structures stabilized with biological measures to investigate the effects of integrating physical and biological conservation on some soil physical and chemical properties of the soil and subsequently on yield of crops and its implication on downstream inhabitants.

Materials and methods

Description of the study Area

The study area is located in Absela Kebele, Banja Shikudad Woreda, Awi Zone of the Amhara National Regional State (ANRS) between $10^{o}45'$ N – $10^{o}48'$ N latitude and $37^{o}03'$- $37^{o}04'$E longitude. The mean annual rainfall of the study area ranges from 1700 mm to 2560 mm, with mean monthly minimum and maximum temperature ranging from 7^{o}C to 12^{o}C, and 20^{o}C to 25^{o}C, respectively. The area has wet-cold locally known as *wet dega* agro-climatic zone (RELMA *et al.*, 2005). The study area has an altitude that ranges between 2220 and 2600 meters above sea level with undulating topography. Its slope ranges from 15% to 25%. The total area of the catchment that was treated with different type of soil and water conservation measures is about 126 ha. The length of growing period of the study area ranges between 240 and 270 days (EMA, 1982). The farming system of the area is mixed farming, which includes crop such as barley, wheat, teff, pulse crops, and livestock (mainly sheep and cattle).

Characterization of the SWC structures considered in the study

All soil and water conservation measures in the catchment area were installed for the purpose of demonstration; to diffuse extension service related to natural resource conservation to the farming community by the district and zonal agricultural bodies. The catchment area was delineated and various soil and water conservation activities were practiced since 1998. Various ages of soil bund stabilized with vegetative measure such as vetiver grass (*V. zizanioides*), tree lucerne (*C. palmensis*), sesbania (*Sesbania sesban*) and phalaris grass (*Phalaris spp.*) are found in the catchment. The catchment area was kept under close supervision by the woreda agricultural office and two guards were instantly assigned after the start of the watershed work.

The study site had original slope of 21% (slope percent prior to the construction of the structures) and 2m vertical interval were used for the spacing of bunds. All the soil bunds were constructed in such a way that a trench was excavated along a contour at 1% gradient towards the water way and the soil was thrown down hill.

Experimental design and layout

The experiment contained five treatments, which includes:

1. Control (non-conserved plots)
2. 6 years Soil bund + tree lucerne
3. 9 years Soil bund + tree lucerne
4. 9 years Soil bund + vetiver
5. 9 years Soil bund

Determinations of Soil Physical and Chemical Properties

For each treatment, a composite soil samples were collected from a 10 x 3m sampling plot using simple random sampling technique from four consecutive inter-terraces space at the deposition zone.

Soil organic carbon (SOC) was determined following the wet digestion method used by Walkley and Black (Sahelemedhin and Taye 2000). Organic matter was computed from organic carbon by multiplying each value of SOC by 1.724. Total Nitrogen was determined by Kjeldahl method (Sahelemedhin and Taye 2000).

The soil bulk densities were determined from the oven dry (at $110^{o}C$ for 24 hrs) mass of soil in the core sampler and volume of the undisturbed soil cores using core sample method (Landon, 1991) and infiltration rate was measured using double ring infiltrometer.

Results and discussion

1. Effect of Soil Conservation Measures on Soil Chemical and Physical Properties

Organic matter

Results of the experiment indicated that there was highly significant (p≤0.05) difference in OM content among the treatments. The treatments with 9-year old soil bund stabilized with tree lucerne and the 9-year old sole soil bund were not statistically different among each other. However, they have significantly higher organic matter (OM) content than that of the 9-year old soil bund stabilized with vetiver, the 6-year old soil bund stabilized with tree lucerne, and the non-conserved treatments. Although the 9-year old soil bund stabilized with vetiver had statistically lower percent OM than the sole 9-year old soil bund treatments, it was superior and had significantly ($p \leq 0.05$) highest percentage of OM than the 6-year old soil bund stabilized with tree lucerne, and the non-conserved treatment (Table 1). This indicates that years of bund establishment play a tremendous role in OM accumulation.

Table 2 Effect of SWC measures on organic matter content of the soil

Treatments	**Organic matter (%)**
Control (Non-conserved land)	1.577^{d}
6-yrs old soil bund + tree lucerne	2.470^{c}
9-yrs old soil bund + tree lucerne	5.017^{a}
9-yrs old soil bund + vetiver	3.306^{b}
9-yrs old soil bund	5.478^{a}
CV (%)	14.00
$SE_{\bar{x}}$	0.249

Means in a column followed by the same letter are not statistically different at $p \leq 0.05$

The non-conserved plots had the lowest mean value of OM than all other treatments considered in the study. Relatively the 9-year old soil bund, the 9-year soil bund stabilized with tree lucerne, the 9-year old soil bund stabilized with vetiver, and the 6-year old soil bund stabilized with tree lucerne had 71.20, 68.56, 52.30, and 36.12%, respectively higher percent OM than the control treatment. The result agrees with the finding by Million (2003) who found that organic matter content of three terraced sites with original slopes of 15, 25, and 35 % were higher compared to the corresponding non-terraced sites of similar slope. A study conducted by Kinati (2006) in the Amhara region, Enebsie Sar Mider woreda, also showed that the organic matter content of non-conserved land for a slope range between 10 and 15% were lower (mean = 1.12%) than the terraced land of corresponding slope class (mean=2.33%).

According to Bot and Benites (2005), organic matter accumulation is often favored at the bottom of hills for two reasons: one is they are wetter than at mid- or upper slope positions, and the other is organic matter would be transported to the lowest point in the landscape through runoff and erosion. The same holds true for terraced land where soils are actively eroded from the soil loss zone and deposited to the soil accumulation zone, creating spatial variability in terms of moisture and nutrient availability within the inter-terrace space.

Total nitrogen

Results of the experiment presented in Table 6 revealed that the mean total N difference due to treatment effect were significant ($p \leq 0.05$). Even though the 9-year old soil bund stabilized with tree lucerne and the 9-year old soil bund are statistically non-different in the mean value of total nitrogen, both were significantly ($p \leq 0.05$) higher than the 6-year old soil bund stabilized with tree lucerne, the 9-year old soil bund stabilized with vetiver and the non-conserved treatment. It was clearly seen that the non-conserved plot had the smallest mean value of total nitrogen (Table 2).

Table 3 Effect of SWC measures on total nitrogen content of the soil

Treatments	Total nitrogen (%)
Control (Non-conserved land)	0.125[c]
6-yrs old soil bund + tree lucerne	0.173[bc]
9-yrs old soil bund + tree lucerne	0.277[a]
9-yrs old soil bund + vetiver	0.215[b]
9-yrs old soil bund	0.284[a]
CV (%)	17.48
$SE_{\bar{x}}$	0.0187

Means in a column followed by the same letter are not statistically different at $p \leq 0.05$

Million (2003), also found that the mean total N content of the terraced site with the original slope of 15, 25, and 35% were higher by 26, 34, and 14%, respectively compared to the average total N contents of their corresponding non-terraced slope. A simple linear regression analysis showed a strongly positive relation between total nitrogen and organic carbon (R^2 =0.88)

Bulk density

The one-way analysis of variance revealed the presence of significant difference ($p \leq 0.05$ and R^2 = 0.75) in mean value of bulk density among the treatments. The non-conserved treatment was found to exhibit significantly the highest mean value of bulk density than the remaining treatments. The result also showed non-significant difference in mean value of bulk density among other treatments, which were managed through a range of conservation measures irrespective of the establishment year. In this study, the relatively lower bulk density associated with treatments conserved with various measures (Table 3) could be attributed to the presence of significantly ($p \leq 0.05$) higher content of organic matter in those treatments.

Table 4 Effect of SWC measures on soil bulk density

Treatments	Soil bulk density (g cm^{-3})
Control (Non-conserved land)	1.38^a
6-yrs old soil bund + tree lucerne	1.26^b
9-yrs old soil bund + tree lucerne	1.29^b
9-yrs old soil bund + vetiver	1.25^b
9-yrs old soil bund	1.27^b
CV (%)	2.43
$SE_{\bar{x}}$	0.015

Means in a column followed by the same letter are not statistically different at $p \leq 0.05$

Infiltration rate

The one-way analysis of variance revealed the presence of statistically significant difference ($p \leq 0.05$, $R^2 = 0.66$) in mean value of infiltration rate among the treatments. The 9-year old soil bund and 9-year old soil bund stabilized with tree lucerne had the highest mean value of infiltration rate than the other treatments. The non-conserved treatment had lowest mean value of infiltration rate (Table 4).

Table 4 The effect of treatments on infiltration rate

Treatments	Infiltration rate (cm hr^{-1})
Control (Non-conserved land)	0.24^b
6-yrs old soil bund + tree lucerne	0.28^b
9-yrs old soil bund + tree lucerne	0.73^a
9-yrs old soil bund + vetiver	0.82^a
9-yrs old soil bund	0.88^a
CV (%)	44.80
$SE_{\bar{x}}$	0.109

Means in a column followed by the same letter are not statistically different at $p \leq 0.01$.

The organic matter and percentage of clay soil separates in the treatments seemed to play the crucial role for the variation in mean basic infiltration rates. The organic matter was positively correlated ($p \leq 0.01$; $R^2 = 0.55$) with the infiltration rate and while clay percentage was negatively correlated ($p \leq 0.01$; $R^2 = 0.52$) to the same. Moreover, infiltration rate negatively correlated with bulk density of the soil. According to the rating of Landon (1991), the non-conserved, the 6-year soil bund stabilized with tree lucerne had slow infiltration rate while the 9-year soil bund treatment, the 9-year old soil bund stabilized with tree lucerne and the 9-year soil bund stabilized with vetiver treatments and had moderately slow infiltration rate.

Effect of Soil Conservation Measure on Slope Transformation

Results of the experiment indicated that the mean values of inter-terrace slope (Table 5) for the treatments were found to be significantly different ($p \leq 0.05$ and $R^2 = 0.98$). The 9-year old soil bund stabilized with vetiver had significantly the lowest inter-terrace slope than all other treatments considered in the study signifying the effectiveness of vetiver grass in bund stabilization and slope transforming ability when compared to the other bund stabilization techniques.

Differences in year of bund installation also brought a variation in inter-terrace slope, which was realized by having a lower inter-terrace slope for the aged bund than the younger one. Therefore, all 9-year old soil bund treatments (irrespective of bund stabilization technique) had the lowest mean value of inter-terrace slope percent than the 6-year old soil bund stabilized with tree lucerne. Considering age of bunds and the type of material used to stabilize them, the 9-year soil bund stabilized with tree lucerne also had significantly lower inter-terrace slope than the 6-year old soil bund stabilized with similar method.

The deposition of soil materials and debris on the upper position of soil bund (usually called accumulation zone) causes the height of the bunds to rise year after year, thereby reducing the inter-terrace slope between two successive structures.

Similar to inter-terrace slope, the mean value of bund height were also affected by age of the bunds. The older the bund the higher was its bund height. Thus, the 9-year old soil bund treatments had higher mean bund height than the 6-year old soil bund. Karl and Ludi (1999) pointed out that in the course of erosion process that forms the terrace, the topsoil below the structure would gradually move down a slope and accumulate above the next SWC structures. This would eventually increase the bund height in gradual processes. According to Desta *et al.* (2005), the rate of sediment accumulation by bunds is correlated with the soil loss by tillage because all the soils displaced by tillage remains in the accumulation zone.

Table 5 Effect of SWC measures on inter-terrace slope

Treatment	Inter-terrace slope (%)	Bund height (cm)
Control (Non-conserved land)	21.00[a]	0.00[c]
6-yrs old soil bund + tree lucerne	17.50[b]	61.50[b]

9-yrs old soil bund + tree lucerne	14.00^{c}	67.50^{b}
9-yrs old soil bund + vetiver	10.25^{e}	100.75^{a}
9-yrs old soil bund	12.75^{d}	68.00^{b}
CV (%)	3.96	9.11
$SE_{\bar{x}}$	0.30	2.78

Means in a column followed by the same letter are not statistically different at $p \leq 0.05$

Effect of the Conservation Measures on Barley Yield

The one-way analysis of variance computed for the various treatments showed that the grain yields were found to vary significantly ($p \leq 0.05$ and $R^2 = 0.96$). The 9-year old soil bund stabilized with tree lucerne was found to give significantly ($p \leq 0.05$) higher mean value of grain yield than the 9-year old soil bund, 9-year old soil bund stabilized with vetiver, 6-year old soil bund stabilized with tree lucerne and the non-conserved treatment (Table 6). Although it was not significant, the 9-year old soil bunds stabilized with tree lucerne had higher grain yield that the 9-year old soil bund treatment. The non-conserved treatment had significantly lower mean value of grain yield compared to all other treatments, which were treated with various kinds of conservation measures. The straw yield and other yield components also showed similar trend in performance as that of the grain yield at the deposition zone.

Table 6 Effect of conservation measures on grain and straw yield, and yield components at the soil deposition zone

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	No. of Plants m^{-2}	No. of Spikes m^{-2}	No. of spikelets/ spike	Plant height (cm)
Control (Non-conserved land)	561.25^{d}	622.75^{c}	350^{c}	404^{b}	7.0^{c}	44.50^{c}
6-yrs old soil bund + tree lucerne	1284.25^{c}	1233.75^{ab}	397^{ab}	431^{b}	15.75^{b}	57.75^{b}
9-yrs old soil bund + tree lucerne	1878.75^{a}	1480.00^{a}	426^{a}	478^{a}	18.25^{a}	75.75^{a}
9-yrs old soil bund + vetiver	1187.50^{c}	957.50^{b}	396^{ab}	417^{b}	16.00^{b}	69.00^{ab}
9-yrs old soil bund	1712.50^{b}	1473.50^{a}	375^{bc}	435^{b}	17.25^{ab}	77.75^{a}
CV (%)	7.82	16.47	6.55	5.79	7.01	11.5
$SE_{\bar{x}}$	51.80	95.01	12.73	12.52	0.52	3.74

Means in a column followed by the same letter are not statistically different at $p \leq 0.05$.

Higher yield associated with the conservation measures could be attributed to the presence of high level of organic matter and total nitrogen in these treatments. A regression analysis computed for the grain yield performance with organic matter and nitrogen had confirmed this fact. Organic carbon and total nitrogen were directly related

($p \leq 0.01$; $R^2 = 0.74$, and $p \leq 0.01$; $R^2 = 0.71$, respectively) to the grain yield of barley. Yield obtained from the accumulation zone of the conserved land were significantly higher than the loss zone. This signifies the presence of fertility gradient within the inter-terrace space and highest yield in the deposition zone of the conserved treatments seemed to associate with the level of OM and total nitrogen contained in the same, coupled with other desirable changes in soil physical and chemical brought by the implemented conservation measures at the spot (Table 7).

Table 7 Effect of conservation measures on grain and straw yield, and yield components at the soil loss zone

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	No. of plants m^{-2}	No. of spike m^{-2}	No. of spiklets/ spike	Plant height (cm)
Control (Non-conserved land)	561.25^{c}	622.75^{c}	350^{a}	404^{a}	7.00^{c}	44.5^{c}
6-yrs old soil bund + tree lucerne	944.25^{b}	875.50^{b}	341^{a}	373^{a}	11.50^{b}	53.0^{b}
9-yrs old soil bund + tree lucerne	1199.50^{a}	1084.75^{a}	337^{a}	365^{a}	14.75^{a}	64.5^{a}
9-yrs old soil bund + vetiver	949.25^{b}	907.00^{b}	338^{a}	357^{a}	11.50^{b}	54.5^{b}
9-yrs old soil bund	1166.00^{a}	978.25^{ab}	322^{a}	338^{a}	15.50^{a}	58.5^{ab}
CV (%)	10.08	9.27	8.84	7.56	11.29	8.08
$SE_{\bar{x}}$	48.59	41.41	14.91	13.88	0.68	2.22

Means in a column followed by the same letter are not statistically different at $p \leq 0.05$.

Causes of Soil Erosion in the ANRS of Ethiopia

Soil erosion is becoming a serious problem in Northwestern Ethiopia where the Blue Nile starts. The main causes of the problem could be:

a) Natural factors

The area is characterized by rugged and sloppy topography which causes the intensity of erosion to be very high. Mountains cover 52% of Asia, 36% of North America, 25% of Europe, 22% of South America, 17% of Australia and 3% of Africa. As a whole, 24% of the Earth's land mass is mountainous. Nevertheless, of the 3% of African mountains, Ethiopia takes 60% (Wikipedia, 2006). In Ethiopia, about 44% of the land area (>1500 m asl) has typical highland characteristics. Contrary to the country’s average, the highland part in the Amhara Region is about 70%.

b) High and erratic rainfall pattern.

The western highlands of the Amhara National Regional State receive heavy rainfall that in some places reaches well above 2000 mm. All the rainfall falls in few months time that does not usually exceed 4 months. This situation causes excessive land slide and erosion.

c) Extensive deforestation

The natural forest cover in 1962 was 40% of the country’s total area. Now the forest cover is only 2.7%. It is estimated that from 150,000-200,000 hectares of forest are destroyed every year.

d) Continues cultivation and complete removal of crop residues from the field.

Due to the small land holding per household (<1ha in Northwestern Ethiopia), there is a practice of continues cultivation without replenishing the land with appropriate amount of input. Moreover, farmers remove the residues for animal feed, plastering of their houses and fuel energy source.

e) Over and free grazing.

Ethiopia has the largest livestock population in Africa. This livestock population grazes in uncontrolled grazing system on mainly communal lands. Eventually, livestock productivity is one of the lowest in Sub-Saharan Africa. In such situation, neither the land nor the livestock are benefited.

f) Improper farming practices and development efforts.

Farmers use a 3000 years old farming practices that does not protect the land and. Moreover, huge amount of lands are washed away by road side drainage canals. However, there is no accountability for damage made on the land.

g) Over population

The Amhara National Regional State (ANRS) with the area of 157,076.52km^2 has a population of about 19,122,515 and the population density of the land is 121.7 persons km^2. From the total population, 85% is dependent on agriculture and the average land holding per household is less that a hectare. Unlike most of the world's hotspots of civilization, situated around river deltas and downstream places, centre of economic and political activities in Ethiopia is peculiarly situated in the mountain system where land resources are sensitive to degradative agents and where the resources support immense economic and ecological functions to both upstream and downstream riparian countries. Compared with the average population pattern of settlement of the world that is 1 out of 10 people lives in mountain areas, in Ethiopia, it is estimated that 9 out of 10 people or about 90% of the total population live in the highlands (Biru Yitaferu, unpublished data).

h) Socio- economic problems

Ethiopian farmers lack alternative livelihoods except agriculture and have poor socio-economic conditions. The per capita income of the region is only $92/annum and 30% of the population lives below poverty line (BoI, 2005).

i) Lack of awareness on the effect of erosion

The farmers lack of awareness on effects of erosion and they do not realize that erosion is the main cause of yield reduction year after year.

j) Poor land use policy enforcement.

The ANRS has land use policy. Nevertheless, the policy never been properly implemented. Farmers also do not take accountability for the damage they make on their lands due to violating land use policies

Conclusions and recommendations

From the results of the experiment it is possible to conclude the following:

1) The experiment confirmed the presence of heavy erosion in the Ethiopian highlands;
2) It was clearly seen that by implementing integrated soil and water practices, it is possible to significantly reduce soil erosion;
3) Upstream soil conservation practices can improve land productivity and increase yield;

4) Upstream soil and water conservation practices can make the rainwater to infiltrate in to the soil. This eventually will recharge the groundwater, and rivers and streams will have higher volume of discharges;
5) Upstream soil and water conservation practices will minimize sedimentation of dams, reservoirs, rivers and destruction of agricultural lands.

From the results of the experiment it is possible to recommend the following: In the upstream there is a need to take the following measures:

1) Rehabilitate degraded lands through
   - Improved SWC practices (Integrate physical and biological measures)
   - Practicing area closure and tree plantation schemes on sloppy lands
   - Delivering alternative fuel energy sources
2) Improve land productivity and reduce area under cultivation (steep slopes) by using
   - Improved seed
   - Integrated nutrient management
   - Integrated pest management
   - Improved agronomic and land management practices
3) Practice stall feeding (better feed supply and quick economic return)
4) Reduce pressure on the farm lands by providing alternatives to the rural community other than agriculture
4) Implement the land use policy
5) Improve awareness of the farmers on effects of erosion
6) Expand education and health services

The downstream countries could financially and technically support the upstream efforts

1) Training and research;
2) Establishment of fertilizer and pesticide factories that will improve land productivity and enclose mountains from annual crop production;
3) Invest in the agricultural processing, industry and urban sectors to minimize the pressure on mountain lands.

These joint efforts will minimize erosion rate and the amount of silt entering streams and ultimately the Blue Nile will be minimized. This in turn will significantly improve land productivity in the upstream and will cut the huge costs of silt cleaning in the dams and irrigation canals of the downstream countries using the Blue Nile.

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Session IV: Policy and Institutions

Assessment of Local Land and Water Institutions in the Blue Nile and their Impact on Environmental Management

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Abstract

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.

Key words: institutions, organizations, policy choices, Blue Nile Basin, Ethiopia

Introduction

Problem analysis
Erosion and sedimentation: major problems in the Blue Nile Basin

In this section we describe the most important environmental problems in the sub-basin, their local and downstream impacts and their possible causes. Soil erosion, nutrient depletion and deforestation are common environmental problems in the Ethiopian Highlands, not least in the Blue Nile Basin part of Ethiopia (Hagos, et al. 1999; Desta et al., 2000; ENTRO 2006).

Four main areas of high sheet erosion are found in the Abay basin (Hydosult et al, 2006b). The steep slopes around Mount Choke in East and West Gojam stand out as significant areas with a high sheet erosion hazards. This is an area characterized by high rainfall intensity causing severe soil erosion. The second widespread area of high erosion hazards occurs North and East of the Abay River in the Lake Tana sub-Basin. This area includes the steep cultivated slopes around Mounts Guna (South Gonder) and Molle (South Wello). A third more restricted area is found in the upper Jema sub-basin in South Wello on the high hills North and West of Debre Birhan. A fourth area is found South of the Abay and encompasses the upper and middle steep and cultivated slopes of the Middle Abay Gorge Sub-basin in East Wellega. Two subsidiary areas with a high erosion hazards can be seen in the Upper Didessa Valley and along the escarpment hills to the West of Lake Tana in the upper Dinder and Beles valleys (ENTRO, 2006).

Awulachew et al., (2008) and ENTRO (2006) documented the scale of erosion and sedimentation in the Blue Nile Basin (BNB). Accordingly, the total soil eroded within the landscape in the Abay Basin is estimated to be 302.8 million Mg per annum and that from cultivated land is estimated to be 101.8 million Mg Yr^{-1}. Thus about 66% of soil being eroded is from non-cultivated land, i.e. mainly from communal grazing and settlement areas. Those authors also provide disaggregated figures for scale of erosion in the three regions of Ethiopian Blue Nile Basin. Accordingly, the area of cropland subject to "unsustainable" (i.e. loss exceeds soil formation or 12.5 Mg $ha^{-1}Yr^{-1}$ are 968,900 ha, 104,000 ha and 956,900 ha in the Amhara, Beni-Shanugul Gumuz (BSG) and Oromiya regions respectively. Thus, some 2.03 million ha of cultivated land have unsustainable soil loss rates.

Of the total 302.8 million Mg of soil eroded a significant proportion is re-distributed within the landscape, the remainder reaching streams and rivers. At the Basin level the estimated Sediment Delivery Ratio (SDR) indicates that approximately 55 % of sediment remains in the landscape and does not reach the river system (Awulachew et al., 2008; Haileslassie et al., 2006). This estimate is much lower than the 90% estimated by the Ethiopian Highlands Reclamation Study (EHRS) but closer to the estimate by Hurni

(1988). The rest gets its way into the streams and ends up in reservoirs and irrigation channels in the downstream regions of the basin.
In 1990, accelerated soil erosion caused a progressive annual loss in grain production estimated at about 40,000 tones, which unless arrested, will reach about 170,000 tones by 2010. Livestock play a number of vital roles in the rural and national economy but according to one estimate some 2 million hectares of pasture land will have been destroyed by soil erosion between 1985 and 1995. Declining use of fallow, limited recycling of organic and limited application of inorganic soil nutrient sources, compounded with the high level of erosion, have also exacerbated the problem of nutrient depletion of the major soils in the sub basin affecting crop productivity (e.g. Haileslassie et al., 2005).

In economic terms, soil erosion in 1990 was estimated to have cost (in 1985 prices) nearly Ethiopian currency (ETB) 40 million in lost agricultural production (i.e. crop and livestock) while the cost of burning dung and crop residues as fuel was nearly ETB 650 million. Thus in 1990 approximately 17% of the potential agricultural GDP was lost because of soil degradation. The permanent loss in value of the country's soil resources caused by soil erosion in 1990 was estimated to be ETB 59 million. This is the amount by which the country's soil stock should be depreciated in the national accounts or which should be deducted (as capital depreciation) from the country's Net National Income (NNI (Sutcliffe, 1993; Bojo and Cassells, 1995).

Deforestation is also going unabated because of growing demands from construction, fuel wood and farm land. In many areas of Ethiopian highland, the present consumption of wood is in excess of sustainable growth. This implies the degree of mining of the natural vegetation and impacts on water resources (i.e. through runoff and erosion). Estimates of deforestation, which is mainly for expansion of rainfed agriculture, vary from 80,000 to 200,000 hectares per annum (EPA, 1997). Although there are no specific estimates for the sub-basin, the Ethiopian Forestry Action Program (EFAP) estimated the full value of forest depletion in 1990 to have been about ETB 138 million or some 25% of the potential forestry GDP of ETB 544 million (EFAP, 1993).

Soil erosion, agricultural run-off and domestic and industrial effluents cause serious negative externalities in downstream environments. In fact, although estimates of costs are missing, there are reported signs of increasing pollution and pollutants load on water bodies and reservoirs in the sub-basin and beyond. MoWR (2007) reported that increased nutrient loads (from sewage, pit latrines and fertilizers) are contributing to increased pollution, affecting eco-system health in the sub-basin. The social costs include loss of life and agricultural production due to pollution and eutrophication of fresh water resources, sedimentation of water reservoirs, siltation of irrigation channel, (Ekborn, 2007). This underlines the far reaching consequences of environmental degradation on ecosystem health, land and water productivity. Understanding these consequences and their possible causes are important research questions that need to be pursued for improved management of land and water.

As presented above the lists of proximate causes of land degradation are apparent and generally agreed and there are other underlining causes behind these causes. Understanding the underlining causes have greater use for policy making. Factors underlying these direct causes include population pressure, poverty, high costs of and limited access to agricultural inputs and credit, fragmented land holdings and insecure land tenure, and farmers' lack of information about appropriate alternative technologies (Hagos, et al. 1999; Desta et al., 2000). Many of these factors are affected by government policies on infrastructure and market development, input and credit supplies, land tenure, agricultural research and extension, conservation programs, land use regulation, local governance and collective action, and non-governmental programs (Hagos, et al. 1999; Desta et al., 2000). And a lot has been done in terms of understanding the specific roles of the set of factors in different contexts in Ethiopia and elsewhere (Gebremedhin and Swinton, 2003; Gebremedhin et al., 2003; Hagos and Holden, 2006; for a review see Yesuf and Pender, 2005). However, there is a little attempt to understand the broad macro, institutional and organizational issues that influence land and water management decisions, which is the focus of this paper.

Research rational and objectives

Land and water institutions play a vital role in managing and sustaining resources as well as in economic development and poverty alleviation (Ananda et al., 2006; Hannam, 2003). The institutional issues that the Ethiopian land and water sector is grappling with can be classified into three main areas: ecological destruction due to high level of environmental (mainly land) degradation; poor performance of rainfed agriculture, low level of water resources development, and transition from a soil conservation focus to an integrated land and water management system that takes the hydrological boundaries into account. A lot of concerted efforts are going on to reduce land degradation, improve the productivity of rainfed agriculture and to develop the water resources of the country in integrated manner.

On the research side, there is little attempt to understand the broad macro, institutional and organizational issues that influence land and water management decisions and addresses the understandings of upstream and downstream linkages. There is inadequate understanding of the policy and institutional failures that shape and structure farmer incentives and investment decisions (Shiferaw et al., 2007). There is no doubt that the creation of an enabling environment for farmers and agencies to adopt management practices that reduce water and land degradation and improve food security is crucial (Hannam, 2003). This is particularly important in view of mitigating impacts of upstream water resources development on downstream stakeholders dependent on the Blue Nile Basin.

For example in response to increasing demand for food and contrastingly dwindling agricultural production, the Ethiopian government is considering Tana-Beles Sub-Basin as the development corridor and thus embarked on development of irrigation and hydropower development projects in the Tana and Beles Sub Basins. This requires designing institutions that can provide legal and policy framework to define: activities that are prohibited or allowed in a certain areas, the incentive structures and policy instruments to enable action, and responsible body to enforce the provisions and careful choice of policy instruments. Designing institutional mechanisms to sustainably manage the land and water resources of the country has been an important legal and political concern in Ethiopia. Lately, the government of Ethiopia has come up with various measures to enable sustainable land and water management. But little has been done in understanding the design of the institutional arrangements and choice of policy instruments. Such analysis of institutions and their design features provides useful insights, contributing to institutional reform debate in land and water management in the study sub basin. The overall objective of the study is, therefore, to carryout assessment and gap analysis of institutional arrangements for improved land and water management in the highlands the Blue Nile Basin (taking Tana and Beles Sub-Basin of Ethiopia as an example). The specific research questions include:

- What are current and envisaged changes in policies and institutional arrangements for improved land and water management in regions within the Ethiopian Abay Blue Nile?
- What are the design features of the existing/envisaged institutional changes?
- Whether the current level policy, institution and processes effectively respond to the emerging issues (e.g. land degradation, water shortage, climate change and variability, upstream downstream relations, etc.).
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Following problem analysis, in this introductory part, the second chapter outlines the approach taken to identify and evaluate the features of the institutional framework and institutional design criteria that can used to evaluate land and water related institutions in Tana Beles Sub-basin. It also briefly discusses the study site and data sources. In the result sections it highlights existing formal and informal institutional arrangements and their design features. Based on the analysis presented in section four, the study draws key conclusions and policy recommendations.

Study Methodology

The study site

The focus of this study is the Tana Beles Sub-Basin in North western Ethiopia. The Tana and Beles Sub-basins are important Sub-basins of Blue Nile (also called Abay) River Basin and are located in the Amhara and Benshangul Gumuz Regional States. The Tana Sub-basin is fully located in the Amhara National Regional State and covers parts of the West Gojam, North Gondar and South Gondar Zones. The Beles Sub-basin, on the other hand falls within the two regional states and drains the Agew Awi Zone[1] of the Amhara and Metekel zone of the Benshangul Gumuz National Regional States. The total area of

[1] Zone is the second administrative unit in a region

the Tana and Beles Sub-Basins is about 30,000 km^2. Lake Tana, the largest fresh water lake in Ethiopia, covers an area of 3,042 km^2. It is at the heart of the Tana Sub-Basin whereas the Beles River that drains the Beles Sub-Basin is the largest right bank tributary of the Blue Nile and joins the main stream just before the Ethio-Sudanese Border (Figure 1).

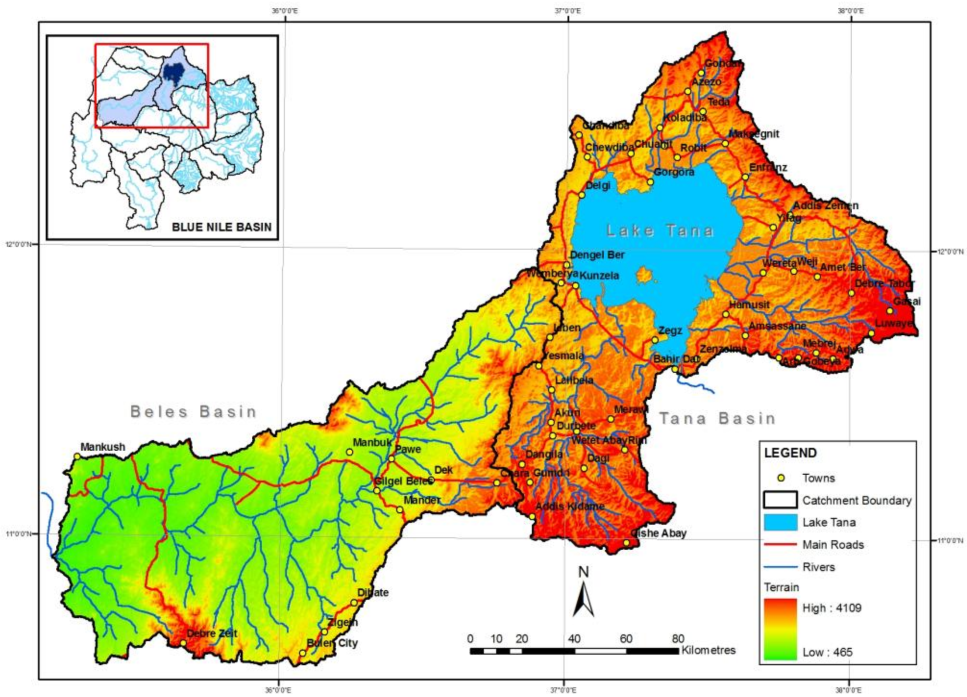

Figure 1: Location map of Tana and Beles subbasins

Analytical framework

Overall approach

In this study, we analyzed institutional setups for sustainable land and water management at national, regional and sub-basin and local scales. Formal institutions in Ethiopia are structured at federal and regional levels and informal institutions are locally instituted. The informal institutions lack linkages with the formal institutions and among themselves affecting information flow and their effective involvement in land and water management. The regional states adopt federal land and water institutions, as they are, or, as in some case, develop region specific institutions based on the general provisions given by the federal policies and institutions (e.g. Rural Land Administration and Use). Therefore, in this paper we focused more on the assessment of federal land and water management institutions and policies as they apply to regional, sub-basin and local scales. Moreover, we shaded light on the synergy between informal and formal institutions and the challenges they face in executing their responsibilities.

Institutional designing criteria

Following the frameworks developed by Ananda et al. (2006); Hannam (2003) and Bandaragoda (2000), we identified the following criteria to evaluate the design features of land and water related institutions in Tana and Beles Sub-Basins. If institutions are to succeed in their function, they are expected to have and develop clear institutional objectives by taking various constraints they face in to account. The question of whether institutions have clear institutional objectives and how they develop them is a pertinent question to assess institutional design features. In a given socio-economic context, both formal and informal institutions have bearings on shaping behavior of actors. How formal and informal institutions influence each other is another important issue we address here to assess performance of land and water institutions. Institutions will perform better if they institutionalize adaptive management given the persistent changes in the bio-physical and socio-economic environments. In this case exploring the forms of adaptive management institutions utilize, whether it involves evolutionary – trail and error approach; passive – lessons from the past used to develop best single policy, or active – learning focused and participatory and uses policy and its implementation as tools for learning, is critical. Key here is to assess how institutions maximize the level and effectiveness of institutional learning, without compromising institutional stability.

Finally, translating these objectives requires due process of implementation and enforcement. The institutions' enforcement capacity is hence critical. Besides what are the typical forms of enforcement: self-enforcement vs. third-party enforcement? These criteria and the key questions summarized, in Table 1, are used to evaluate key land and water institutions in the study site.

Table 1: Institutional design criteria

No.	Institutional design criteria	Key issues\questions
1.	Clear institutional objectives	▪ What are the key objectives from among the many objectives? ▪ What are the key constraints in meeting these objectives? ▪ Is there a transparent process of adjusting institutional objectives?
2.	Interconnectedness with other formal and informal institutions	▪ What is relationship between formal and informal institutions and the influence of each on institutional performance? ▪ Are informal institutions constraints to formal institutions? ▪ Are there cases where informal institutions substitute formal institutions?
3.	Adaptiveness	▪ What is the adaptive capacity of institutions to changes in technology, private and political tests and preferences? ▪ What are the common forms of adaptive management?
4.	Appropriateness of scale	▪ Spatial scale? ✓ Boundaries of natural resource institutions. ✓ Establishment of local groups using social boundaries ✓ Administrative scale? ▪ Who is responsible for its implementation?
5	Compliance capacity	▪ Dealing with incompleteness in costs ▪ Dealing with violations of norms, laws and polices? ▪ What are the typical forms of enforcement?

Data capturing mechanisms

This study was done as part of the research project on "Improved water and land management in the Ethiopian highlands and its impact on downstream stakeholders dependent on the Blue Nile" financed by the Challenge Program for Water and Food. This study falls under the policy and institutions component of the project. This component of this project was developed in recognition of the fact that every intervention is implemented in a unique context where not only physical factors, but also institutions and policies, will influence its impact. To develop successful interventions it is, therefore, important to understand the context in which these interventions are to be implemented.
A combination of different approaches was used to gather data for the study. These included:

- Literature review based inventory of local and regional policies, formal laws and regulations, informal rules and practices, and formal and informal organizations;
- Stakeholder analysis of the knowledge of policy, interests related to the policy, position for or against a policy, linkages between key stakeholders, etc. 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 in both regions, and important NGOs working in the two regions in the area of land and water management.
- Institutional analysis – a closer look into the roles and responsibilities of the various stakeholders, their interactions and lack thereof, policy frameworks and gaps to understand the institutional setting in the Ethiopian Blue Nile Basin. Institutional analysis was done based on a defined institutional framework to identify key design features and evaluate the performance of these features. The data collected from diverse sources was compiled and analyzed to prepare this report.

Results

Land and water related institutional arrangements

'Institutions' in this study is defined broadly to include not only formal organizations, but also informal organizations, laws, customs and social practices that influence people's behavior in a society or economy. Organizations can be defined as "structures of recognized and accepted roles" (Merry 1993; cited in Bandaragoda 2000). Organizations are groups of individuals with defined roles and bound by some common purpose and some rules and procedures to achieve set objectives (Bandaragoda 2000). The institutional framework for water resources management in a river basin context consists of established rules, norms, practices and organizations that provide a structure to human actions related to water management (Bandaragoda 2000). Saleth and Dinar (1999a; 1999b) classified water management institutions into three main components: water polices, water laws and water administration. In this section, we describe the exiting institutional arrangements and assess the appropriateness of the arrangement in meeting the following issues.

- Whether the key stakeholders have clearly defined objectives to explore the value and usefulness of the existing institutional framework as accepted by the stakeholders.
- What does cohesiveness and the functioning of the various elements of the existing institutional framework look like?
- Whether there are scopes for integrated natural resources management in the sub-basin?
- What are the needs for institutional reform in the land and water sectors?
- What are the important policies, strategies and guidelines in relation to land and water management?

In Ethiopia land and water related organizational arrangement are broadly categorized into three different tiers: basin /sub-basin level organizations, federal (national) level and regional (state) and local level organizations. Critical issues here are: do these organizations have clear mandates; how are they related to each other; and what need to be improved in terms of organizational arrangements for better performance and what are the most important policy instruments developed to accomplish their roles and responsibilities. But first on organizational arrangements

National level land and water related organizations

The roles and responsibilities for land and water management at the federal level are promulgated through the definition of powers and duties of the executive organs (proclamation No.471/2005). Accordingly, the organizations/ministries that currently exist at the federal level and are directly involved in the development and management of land and water resources include: Ministry of Water Resources; Ministry of Agriculture and Rural Development; Environmental Protection Authority, and other affiliated authorities and agencies. A brief description of their roles and responsibilities is given below.

Ministry of Water Resources

The Ministry of Water Resources (MoWR) in Ethiopia, established in 1995, has the following powers and duties as spelt out in proclamation No.471 /2005 (FDRE, 2005a). These include *inter alia* inventory of the country's surface water and groundwater resources; basin level water management and benefit sharing; develop water infrastructure; issue permits and regulate the construction and operation of water works; and administer dams and hydraulic structures.

Ministry of Agriculture and Rural Development (MoARD)

The MoARD, established in 2001, is responsible for initiating agricultural and rural development policies; food security strategies and extension programs, and ensuring conducive environment for development, supporting regions in expanding agricultural and rural development as well as monitoring the food security program. According to proclamation No.471/2005, the MoARD's powers and duties include: to develop and implement a strategy for food security, rural development, and natural resources protection; support development of local (through expansion of cooperatives and the provision of credit facilities) and export markets; development of rural infrastructure and promotion of improved rural technologies and disaster prevention and agricultural research. So far, overarching strategies such as the Agriculture Development Led Industrialization (ADLI) strategy, the rural development strategy, commercialization of the smallholder agriculture, etc., were developed at the federal government level, through the MoARD.

Environmental Protection Authority (EPA)

The EPA is the government regulatory authority responsible for environmental protection. EPA aims "to formulate policies, strategies, laws and standards, which foster social and economic development in a manner that enhance the welfare of humans and the safety of the environment, and to spearhead in ensuring the effectiveness of the process of their implementation" (FDRE, 2002, p. 2). This is envisaged to be achieved through: development of enabling policy and regulatory frameworks; preparation and implementation of proactive environmental management systems; enforcement and compliance mechanisms and community empowerment; improving education and awareness and availing information and fostering participation in decision taking; and identification and availing of environmentally sound technologies and best practices and resource mobilization and channeling. The government has further defined the institutional frameworks, responsibilities and mandates for the implementation of the environmental policy (FDRE, 2002).

Regional level organizations

Regional bureaus, in Ethiopia, have been established with similar designations and responsibilities as the federal ministries described above. The most relevant state level bureaus in relation to land and water management include bureaus of water resources Development, Agriculture and Rural development (BoARD), and Environmental Protection and Land Administration and Land Use Authority (EPLAUA). We briefly describe the roles and responsibilities of the regional bureaus.

Regional Bureaus of Water Resources development

The major regional water sector offices have the responsibility to manage resources on behalf of MoWR. They are also mandated to administer resources under their geographical jurisdiction, i.e. non-transboundary and non-trans-regional water bodies. In Amhara and BNG the water bureau is made accountable to the regional president and administration council[2] (CANRS, 2004; *BGRS, 2006*). In BNG regional state it is called bureau of water, mines and energy bureau with wider mandates responsibilities. Their roles and responsibilities, in relation to land and water management, include: develop region-wide polices, strategic plans, directives, standards and manuals concerning the management of water resources in line with the federal water policies and laws; issue permits in relation to WRD; develop the water resources of the region; help solve water related conflicts; devise a system of integrated water resources management; maintain the health of water bodies from pollution, support the development of water institutions, etc.

[2] There is still the view that the role of regional bureaus is not well-defined (NBI, 2006, p. 16).

Bureau of Agriculture and Rural Development

Similar to the federal ministry, the regional bureaus are established, their roles and responsibilities defined by law (CANRS, 2006a; BGRS, 2006). Accordingly, their roles and responsibilities, in relation to land and water management include: develop laws on the conservation and utilization of forest and wildlife resources; coordinate food security programs; provide agricultural extension services; provide support for the expansion of water harvesting and irrigation development activities; promote market-led agriculture development and create efficient agricultural input and product marketing systems, etc. (including through organization of cooperatives). Unlike the federal ministry, conservation of soil and water resources is not mentioned as one of the prime responsibilities of the bureau.

Environmental Protection and Land Administration and Land Use Authority (EPLAUA)

EPLAUA is the regional equivalent of the federal EPA. The major roles and responsibilities of EPLAUA include: ensure interventions are carried out in a manner that will protect the welfare of human beings as well as sustainably protect, develop and utilize the resources; create conducive atmosphere by which the management, administration, use of rural land of the region could be appropriately decided pursuant to federal and regions policies (BGRS, 2006; CANRS, 2006a). To this end, EPLAUA in Amhara[3] has developed regional environmental regulations and strategies based on federal environmental policy; environmental impact assessment (EIA) procedures to support development projects; issued directives to implement the rural land administration and land use; and issues environmental clearance to development projects. Furthermore, EPLUA coordinates environmental protection efforts of NGOs and community organizations besides developing strategies, polices to protect and conserve natural resources of the region and to be executed by implementation offices; (e.g. developed guidelines for soil and water conservation in 2007 (see EPLAUA, 2007)

Non-governmental organizations (NGOs)

Although there are many NGOs operating in both regions, Water Aid in BNG and Sustainable Water Harvesting and Institutional Strengthening in Amhara (SWISHA) are the two active actors working in the water sector, particularly in developing the water related institutions.

SWHISA is a CIDA supported six-year project co-managed by Amhara National Regional State (ANRS) and to support training programs, pilot and demonstration projects related to rain water harvesting for irrigated agriculture production. The project

[3] In BNG, EPLAUA is in the process of developing environmental regulations and other policy instruments.

strives to strengthen water related capacity of regional institutions and farmer associations to develop and promote sustainable water harvesting and the use of water for irrigation. So far SWHISA has been involved in the development of byelaws for irrigation cooperatives (Personal correspondence). Likewise, Water Aid, although primarily engaged in provision of domestic water, has help the regional government in developing guidelines in organizing water users associations and tariff setting for sustainable operations and maintenance of water points.

Basin or sub-basin level organizations

In Ethiopia, there is no basin authority responsible for the Blue Nile[4]. The national Water Policy (MoWR, 1999; p.13) calls for the establishment of basin-level institutions with the aim “to ensure efficient, successful and sustainable joint management of the water resources of the basins through concerted efforts of the relevant stakeholders”. The establishment of river basin organizations (RBO’s) is envisaged to happen phase by phase. Their establishment is considered one of the main instruments to implement integrated water resources management through river basin plans and effective joint management by relevant stakeholders.

Hitherto, a proclamation for the establishment of River Basin Councils and Authorities has been issued (FDRE, 2007). This proclamation stipulates the establishment of River Basin High Councils and Authorities through regulations to be issued by the Council of Ministers (Art. 3(1)). When it is deemed necessary, the proclamation stipulates, two or more river basins may be put under the jurisdiction of a single Basin High Council and Authority.

There is an on-going effort to establish a river basin authority for the Abay, which is the major sub-basin of the Nile. An institutional study already undertaken pointed out the need for: (1) networking between water related actors, (2) coordination of their water related activities, plans and projects, (3) a sound knowledge of water resources, water uses and of their interactions and (4) a power to administer water resources in the basin (Gizaw, 2004). The legal basis for establishing the river basin authority is pending the enactment of establishment regulation to be issued by the council of ministers.

Watershed level organizations

There is no formal land and water related organizations that operate at the watershed level in Ethiopia. In some watersheds there is informal (ad-hoc) watershed development committees established as part of integrated watershed development projects, mostly by NGOs. But the life and functions of such project-related institutions are dependent on the specific project objectives and are likely to vanish with phasing out of the project.

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[4] There is one functioning river basin authority in Ethiopia for the Awash basin whose major responsibility is the distribution of irrigation water and collection of tariffs.

Local level organizations

At the Woreda (district level), Water Desks are responsible for planning, budgeting, implementing and monitoring and follow up of water projects and programs. These local water desks report to a Woreda level government administrative body called the desk for rural development, not directly to the regional water bureaus. The rural development government body, in turn, reports to the Woreda Council, the locally based highest authority. Urban Water Supply Utilities have traditionally been accountable to the regional water resource development Bureaus.

Water user associations (WUAs) and irrigation cooperatives (ICs) are the most common local institutions engaged in water management at the level of the landscape or hydrological units. WUAs could be defined as social units commonly organized by communities themselves for their own benefits of fair water distribution, improved water delivery and accounting. They are headed by a respected personality from within, leading the effective functioning of the irrigation operation services. The role of WUA is commonly restricted to the distribution of water among members, rehabilitation and maintenance of canals and address water related conflicts. WUA are sometimes threatened by parallel established government-supported ICs, which have broader operational scopes (besides water distribution and operation and maintenance also providing marketing, credit and extension services) and have stronger links with government institutions.

The Amhara National Regional State Cooperative Societies Establishment Proclamation (Zikre Hig No., 134, 2006) provides a comprehensive legislation by which cooperative societies are organized and managed. The region has developed an irrigation cooperatives organization guideline 2/2001 (CPB, 2001). The Cooperative Promotion Bureau is responsible to organize, register and train; give other technical supports to cooperative associations (CPB, 2001; p. 4). The document calls for establishment of ICs in traditional and modern schemes, which is tantamount to a call for transforming traditional WUAs, which do not have formal legal status, to ICs. This is a risky venture given the multiple functions of ICs and poor performance of ICs so far in irrigation water management. This happens in the backdrop of the successful performance of traditional WUAs, despite having limited tasks, in distribution of water among members, rehabilitation and maintenance of irrigation infrastructure and addressing water related conflicts. A better option could be to facilitate the legalization of WUAs so that they could access the formal saving and credit markets.

There are also Water and Sanitation (WATSAN) Committees responsible for the management of drinking water points, operational and maintenance of water points, and provides sanitation training to members. Those are formed for the proper organization and management of drinking water supplies. The members often received training and users' fees are usually collected to finance the maintenance and repair of public water supply schemes. For example in Farta Woreda (Gumera watershed) about 270 WATSAN has been trained.

The land administration committees (LACs) have been formed and trained in all Kebeles in order to assist the EPLAUA with the land registration process. During the discussions held with key informants in the Koga and Gumera watersheds number of other local institutions have been identified. Those includes: *Churches, Edir, Ekub, and Debo*. Despite the fact that those institutions are deeply anchored to the local tradition, most of them have weak linkage to the formal land and water management institutions and activities in the sub basins. Neither have they recorded bylaws. Exceptionally Ethiopian churches are involved in forest conservation. From our observation during field visits we realized that forest in churches seemed to be the remnant pieces of the past forest ecosystems and thus the preserved ones can be read as a blueprint for the lost ecosystems. They can also serve as springboard to restore the forest ecosystem in the extent one may require.

Land and water related policies and guidelines

Various policies and laws have been lately promulgated by the government of Ethiopia with the intention of improving land and water management. These belong to the class of formal institutions promulgated at the federal and regional levels. We intend to describe the key intents and features of these polices and laws in this sub-section. In doing so the critical questions raised include:

- What are the policies and legal instruments in place to tackle environmental problems?
- Do land and water relate policies and laws have clear objectives? If so, are these objectives reflected in a clear and unambiguous manner?
- What are the main features of the policies and laws, particularly in addressing downstream and upstream linkages and their scope for integrated natural resources management in the sub-basin? In other words, does the exiting policy setting create enabling environment for integrated water resource management (IWRM)?
- Are there policy gaps or in legislative framework that affect effective organizational performance? This question address the issue of compatibility between exiting laws, customs, policies and organizational arrangements; Where do informal rules overrule formal rules (dysfunctionality) and rules in use due to lack of proper enforcement or due to disregard towards the spirit of the written laws?
- What do the enforcement mechanisms and compliance behavior of different agents look like?

Here, we present important land and water related policies and laws and their implications on environmental management.

National conservation strategy

The conservation strategy of Ethiopia (FDRE, 1996) provides an umbrella framework, detailing principles, guidelines and strategies, for the effective management of the environment. It elaborates the state of the resource bases of the country as well as the institutional arrangement and action plans for the realization of the strategy. The strategy aims to meet the over goal of improving the environment of human settlements to satisfy the physical, social, economic, culture and other needs of the inhabitants on a sustainable basis (FDRE, 1996). The document emphasizes the need to ensure the empowerment and participation of the people and their organizations at all levels in environmental management activities; and raise awareness and promote understanding of the essential links between environment and development.

The document outlines the importance of:

- Providing security of tenure for land and natural resources by clearly defining and strengthening land and other natural resources tenure rights and responsibilities so as to support sustainable agricultural, pastoral, forestry and fisheries production and a sustainable urban environment;
- Achieving coordinated, integrated and participatory local plans and land use decisions to achieve ecologically, socially and economically sustainable state and private sector land utilization;
- Ensuring that disadvantaged members of the community are fully involved in the development, management and use of natural, human made and cultural resources and the environment and thus social, cultural and economic sustainability is achieved.

Environmental policy

The Environmental Policy of Ethiopia (EPE), which was approved on April 1997, has an overall policy goal to "improve and enhance the health and quality of life of all Ethiopians, and to promote sustainable social and economic development through the sound management and use of natural, human-made and cultural resources and the environment as a whole, so as to meet the needs of the present generation without compromising the ability of future generations to meet their own needs" (FDRE, 1997a).

EPE emphasizes the need for arresting land degradation and promote improved environmental sanitation and health. To this end the Ethiopian Environmental Protection Authority has issued three major proclamations; namely, Establishment of Environmental Protection Organs (FDRE, 2002c), which re-establishes and re-defines the functioning of an Environmental Protection Authority (EPA) as an autonomous Federal Government

Organ, Environmental Pollution Control (FDRE, 2002e), and Environmental Impact Assessment proclamation (FDRE, 2002d) in the country.

Environmental Organs Establishment Proclamation, enacted in 2002, besides making EPA as an autonomous Federal Government Organ established the Environmental Protection Council (EPC). EPC oversee EPA's activities, as well as the activities of sectoral agencies and environmental units with respect to environmental management. It also ensures coordination among sectoral ministries and agencies on environmental matters. The proclamation stipulates the need for the establishment of environmental organs by regions. Mandates of the regional environmental organs are to enable regions to coordinating the formulation, implementation, review and revision of regional conservation strategies; environmental monitoring, protection and regulation; ensure the implementation of federal environmental standards or, as may be appropriate, issue and implement their own no less stringent standards; and prepare reports on the respective state of the environment and sustainable development of their respective states and submit them to the Authority (FDRE, 2002c, Art. 15).

The Environmental Pollution Control Proclamation prohibits the release of pollutant into the environment by any person engaged in any field of activity. Any person who causes any pollution shall be required to clean up or pay for cleaning up of the polluted environment. The installation of sound technology that avoids or reduces, to the required minimum, the generation of waste and, when feasible, recycling of waste is encouraged (FDRE, 2002b).

To enforce this, EPA is empowered to formulate practicable environmental standards based on scientific and environmental principles and in consultation with relevant agencies (FDRE, 2002b). The standards are required to include standards for the discharge of effluents into water bodies and sewerage systems; air quality standards that specify the ambient air quality and give the allowance amount of emissions for both point and non-point air pollution sources; standards for the types and amounts of substances that can be applied to the soil or be disposed of on or in it; waste management standards specifying the levels allowed and the methods to be used in the generation, handling, storage, treatment, transport and disposal of the various types of waste. So far, EPA has prepared Provisional Standard for Industrial Pollution Control (EPA, 2003) and draft proposal of Ambient Environmental Standards (EPA, 2004), and a regulation for the enforcement of the standards in Ethiopia. Regional states are required to develop their own standards, even stringent ones considering their specific situations. This proclamation also specifies clearly the function of law enforcement of the EPA and of the Regional Environmental Agencies, in charge of taking administrative or legal measures against a person violating the law and releasing any pollutant to the environment. Two approaches are advocated by EPA in pollution control; namely: encouraging cleaner production (voluntary) and requirement to use of best available technologies (end-of-pipe control).

The EIA proclamation empowered EPA to prepare procedure, regulations, guidelines and standards to effectively implement and enforce EIA proclamation. Environmental guidelines are among the tools for facilitating the inclusion of environmental issues and principles of sustainable development into development proposals. To this effect, sectoral environmental impact assessment guidelines on agriculture, transport, industry, tannery and settlements have been prepared. In addition to these, a general guideline for facilitating EIA in all sectors has been prepared (EPA, 2003). The provisions include:

- Without authorization from the authority or from the relevant regional environmental agency, no person shall commence implementation of any project that requires EIA;
- Any licensing agency shall, prior to issuing an investment permit or a trade or an operating license for any project, ensure that the authority or relevant regional environmental agency has authorized its implementation; and
- EIP study or permission does not exonerate the proponent form liability to damage.
- Through this directive EPA is expected to identify projects not likely to have negative impacts, and so do not require environmental impact assessment and those that do have and requires EIA. Furthermore, EPA has developed an EIA guideline, the purpose of which is to ensure that proponents, the government and all other interested and affected parties have the opportunity to participate meaningfully in the EIA process and facilitate EIA in all sectors.

Water related policies, laws and regulations

The most important water related policies, strategies, regulations and guidelines in Ethiopia include: Water Resource Management Policy (MoWR, 1999); Water Resources Management Proclamation and Regulation (MoWR, 2000); and National Water Sector Strategy and Water Sector Development Program (MoWR, 2004). The range of relevant policies point to the complexity of numerous institutional mandates relevant to water management. Each of these is briefly described below.

Federal Water Resources Management Policy, Regulation and Guidelines

The Ethiopian Federal Water Resources Management Policy stated that the goal of the policy is "to enhance and promote all national efforts towards the efficient, equitable and optimum utilization of the available water resources of the country for significant socio-economic development on a sustainable basis" (MoWR, 1999, p.1). The fundamental principles of the Ethiopian Water Resource Management Policy are that (i) water is a natural endowment commonly owned by all the people of Ethiopia, (ii) every Ethiopian citizen shall have access to sufficient water of acceptable quality, to satisfy basic human needs, (iii) water shall be recognized both as an economic and a social good, (iv) water resource development shall be underpinned on rural-centered, decentralized management, participatory approach as well as integrated framework, (v) management of water resource shall ensure social equity, economic efficiency, systems reliability and sustainability, (vi) the participation of all stakeholders, user communities specially that of women, shall be promoted in water management. The policy has a series of highly relevant provisions, in particular regarding the IWRM approach. These include:

- Enhance the integrated and comprehensive management of water resources that avoids a fragmented approach;
- Recognize water as a scarce and vital socio-economic resource and manage water resources on a strategic planning basis with long term visions and sustainable objectives;
- Ensure that water resources management is compatible and integrated with other natural resources as well as river basin development plans and with the goals of other sectoral developments in health, mines, energy, agriculture, etc.;
- Recognize and adopt hydrologic boundaries or "basins" as the fundamental planning unit in the water resources management domain; and
- Promote and advocate institutional stability and continuity in water resources management and ensure smooth transition during times of changes.

More specifically the document provides additional relevant provisions on the enabling environment:

- Promote appropriate linkage mechanisms for the coordination of water resources management activities between the Federal and Regional Governments;
- Establish phase-by-phase Basin Authorities, for efficient, successful and sustainable joint management of the water resources of the basins through concerted efforts of relevant stakeholders,
- Create conducive environment for the enhancement of linkages and partnership between the Federal and Regional States on the basis of the constitution for the realization of efficient, sustainable and equitable water resources management, and provide the legal basis for active and meaningful participation of all stakeholders.

The policy also addressed cross cutting and sectoral issues such as water allocation and apportionment, environment, watershed management, water resources protection and conservation, technology and engineering, water resources management information systems, monitoring, assessment and auditing, water cost and pricing (economics of water), groundwater resources, disasters, emergencies and public safety, transboundary water stakeholders, gender, research and development, water quality management and enabling environment. The sectoral part of the policy has incorporated specific issues on the area of water supply and sanitation, irrigation and hydropower.

Although the issues addressed in the policy are equally important, the issue of water allocation, a basin development approach, integration of developments, water pricing, cost recovery, and water financing could be taken as key pillars for the future development and management of water resources. We present these issues briefly for closer scrutiny. The water policy provision on water allocation and apportionment indicates that it is to be done in accordance with a permit system for uses of irrigated agriculture, commercial animal rearing, industry, mining, urban water supply, etc; while no permit is required for use of water by peasants, artisan miners, traditional fishermen, traditional irrigation, water mills, hand-dug wells. The supervising body (MoWR) is responsible for determining the allocation and manner of use of water resources among various uses and users; and for issuing directives to prevent inappropriate use and wastage of water. More specifically, the policy directs that:

- The basic minimum requirement for basic human and livestock needs as well as environment reserve has the highest priority in any water allocation plan;
- Water allocation gives the highest priority to water supply and sanitation, while apportioning the rest for uses and users that result in highest socio-economic benefits;
- Encouragement of water allocation need to be based on efficient use of water allocation, which is based on efficient use of water resources that harmonizes greater economic and social benefits;
- Water allocation shall be based on the basin, sub-basin, and other hydrological boundaries and take into considerations the needs of drought prone areas;
- Adopting the principle that water allocations shall not be made on permanent basis, but rather on agreed time horizon that fits best with the socio-economic development plans; and
- Priority is given, generally, to multi-purpose projects as compared to single purpose for optimum water utilization as well as for fair administration of water uses in reservoir operations.

The policy document underlines the importance of an integrated approach to water resources development for optimal utilization of the country's water resource. Integrated water resources management promotes the coordinated development and management of water, land and related resources to maximize economic and social welfare in an equitable and sustainable manner. The policy document has also recognized and adopted hydrologic boundaries or "basins" as the fundamental planning unit and water resources management domain. It indicates that water resources management need to be compatible and integrated with other natural resources as well as river basin development plans and with goals of other sectoral developments in health, mines, energy, agriculture, etc. To this end, river basin integrated development master plan studies have been carried out on six river basins: Abbay, Baro-Akobo, Gibie-Omo, Tekezie, Wabi Shebelle and Mereb Genale Dawa river basin. Presently, similar studies are being carried out in the Rift Valley river basin. Comprehensive potential projects in water supply, irrigation, hydropower, flood control, fisheries, recreation, navigation, industry, etc have been identified. Priority for development of these projects has been set; and implementation of some has started.

With regard to transboundary waters, the policy explicitly calls to (i) study Ethiopia's stake and national development interests in the allocation and utilization of transboundary waters; (ii) promote the establishment of an integrated framework for joint utilization and equitable cooperation and agreements on transboundary waters; (iii) ascertain and promote Ethiopia's entitlement and use of transboundary water based on those accepted international norms and conventions endorsed by Ethiopia; and (iv) foster meaningful and mutually fair regional cooperation and agreements on the joint and efficient use of transboundary waters with riparian countries based on "equitable and reasonable" use principles; comply with those international covenants adopted by Ethiopia, and manage transboundary waters accordingly.

Furthermore, the water resources management policy has given importance and recognition to the value of water. In order to significantly contribute to development, water shall be recognized both as an economic and a social good; and the policy has clearly recognized the disadvantaged groups of the population by citing that, "although all water resources development ought to be based on the economic value of water, the provision of water supply services to the underprivileged sectors of the population, shall be ensured based on a special social strategy" (MoWR, 1999). The most important role of water valuation relates to demand management and better allocation of water among the various uses. The value of water depends on its quantity, quality, location, access, reliability and time of availability. Valuing water is linking the concern that water uses must be able to meet different social, economic and environmental functions. Priority in water allocation is given to human and animal consumption, followed by irrigation.

The water policy has specific stipulations pertaining to tariff setting, requiring that (i) tariff structures are site-specific and determined according to circumstances; (ii) rural tariff settings are based on the objective of recovering operation and maintenance costs while urban tariff structures are based on the basis of full cost recovery; (iii) adopt a "social tariff" to enable poor communities to cover operation and maintenance costs; (iv) establish progressive tariff rates, in urban water supplies, tied to consumption rates and flat rate tariffs for communal services like hand pumps and public stand pipes. The Water Resources Management policy also stipulates the following provisions relevant to irrigation:

- Ensure that irrigation development is integrated with the country's socio-economic development strategy and overall water sector development strategy, especially with regard to agricultural development led industrialization;
- Irrigation development strategies should promote socio-economic development while ensuring participatory and sustainable development;
- Ensure that adequate resources are devoted to irrigation development particularly in capacity and institution building;
- Irrigation development should take the interest of the end users into account, particularly the rural women;
- Develop strategies for the development of small-, medium- and large-scale irrigations schemes to meet the country's food, raw materials, and foster economic development;
- Support traditional irrigation schemes to ensure improved with water harvesting, delivery and water management efficiency;

- Protect irrigation water from pollution, reduce damage and maintain irrigation water quality;
- Develop water allocation mechanisms to ensure social equity, economic growth and environmental sustainability; and
- Integrate appropriate water drainage service with irrigation development works;

The main actors in irrigation development are identified as: farmers, service cooperatives, governmental and nongovernmental organizations' and the local people who will live in and near the irrigation development. Participation from all of these stakeholders, as well as transparency and social equity in irrigation development, are priorities. With regard to financing, the irrigation water policy calls for the establishment of norms and procedures for financing sustainability and viability; the promotion of credit facilities and bank loans; and appropriate cost recovery systems and mechanisms for all irrigation schemes.
Following the Water policy, the government of Ethiopia has issued Water Resources Management Proclamation to enable proper management, protection and utilization of the country's water resources. This proclamation provides the basic legislative framework for the country with respect to the management, planning, utilization and protection of water resources. The stated purpose of the proclamation is "to ensure that the water resources of the country are protected and deployed for the highest social and economic benefits of the people of Ethiopia; to follow up and supervise that they are duly conserved; to ensure that harmful effects of water are prevented; and that the management of water resources are carried out properly" (Art. 3). The basic trust of these fundamental principles is that water resources management and administration in the country should be based on the National Water Policy, the Integrated River Basin Master Plan Studies (IRBMPs) and the Water Resources Laws of the country.

According to the proclamation, the right to allocate and apportion water is best bestowed upon the legal jurisdiction of the Ministry of Water Resources in its capacity as supervisory body. The legal provisions in the proclamation, with regard to ownership of the resources and its allocation and apportionment, clearly show that the development, management, utilization and protection of all water resources in the country lies effectively in the hands of the Federal Government.

Regional states and local administrative bodies, without requiring any new law for water, are strictly obliged by law to implement the water policy and the water proclamation in accordance with set directives and guidelines provided by the Federal Ministry of Water Resources. Moreover, this proclamation confirms the duality of management arrangements, i.e., surface waters whenever linking two or more Regions or being transboundary clearly falls under the Federal level while water resource within the jurisdiction of regions are addressed by the Regional States legal provisions.

A federal Water Resources Management Regulations (MoWR, 2004), while its contents are similar to those covered in the proclamation, but details the procedures as to how the various legal materials contained in the proclamation are to be effected on the ground. In particular the regulations present a further elaboration of the main requirements for the issuance of permits for different uses of water and the conditions for the issuance, as well as the level of water charge and procedure for licensing water operators.

The MoWR still retains the mandate to issue permits for large bulk of water resources of the country although it can delegate it further to any relevant body. This is also true for collection of fees and water uses charges. Furthermore, tariff rates are determined for different water uses at national level, without intervention of Regional States.

Water sector strategy and development program

The Water Sector Strategy provides the framework, which contains ways and means of attaining the intended objectives. The goals and guiding principles remain the same with that of the policy. The strategy sets the road map on how to make meaningful contributions towards improving the living standard and general socioeconomic well-being of the n people. These objectives include:

- Realizing food self-sufficiency and food security;
- Extending water supply and sanitation coverage to large segments of the society;
- Generating additional hydropower and enhancing the contribution of water resources in attaining national development priorities; and
- Promoting the principles of integrated water resources management.

The Ethiopian Water Sector Development Program (WSDP) is taken as an instrument to translate the Ethiopian Water Resources Management Policy into action. The 15-year WSDP has five major components: Water Supply and Sanitation Program; Irrigation and Drainage Program; Hydropower Development Program; General Water Resources Program; and Institutions/Capacity Building Program.

In view of the enormous water demand in the country, the WSDP has adopted the following water resource development priorities.

- Making clean drinking water available to the larger segments of the society, including water for sewerage purposes;
- Making water available for livestock in critical areas such as the pastoral areas;
- Expanding irrigated agriculture to the maximum possible extent;
- Meeting hydropower generation capacity needs arising from electricity demand in the economic and social sectors; and
- Providing water for the industrial development.

Within the overall priority provided above, the highest priority has been given to the programs and projects, which are ongoing and their implementation is expected to continue during the period of the plan; those that require rehabilitation and reactivation; were started, but for some reason their implementation was discontinued; have already been subject to appraisal and are already being considered for possible funding; have been identified in master plan studies; have been considered for capacity building; and re indicated in the Nile Basin Initiative and the Eastern Nile Subsidiary Action program.

Recognizing that WSDP is a national water plan, stakeholders including public, private sector, NGOs, international development partners and communities are anticipated to participate in the implementation of the Program. To this end, the detailed implementation arrangements of the WSDP are worked out to address the roles of various stakeholders, be it government institutions such as the Federal Ministry of Water Resources or Regional Water Bureaus. Various organs are proposed to be established towards implementing WSDP such as an Inter-Ministerial Steering Group; Federal Program Management Unit (FPMU); Regional Program Management Unit (RPMU); Sub-Program level teams under the FPMUs and RPMUs. These entities are not established as yet (NBI, 2006).

Land use and land administration

A series of proclamations on Rural Land Administration and Use (FDRE, 1997b; 2005c) and Land Expropriation and Compensation (FDRE, 2005b) provide the legal framework for rural land administration and use. The laws define rights of land holders and theirs obligations. In line with the constitution of Ethiopia, proclamation declared land to be the property of the state. Hence, it may not be sold or mortgaged. One of the important provisions of the proclamation is the provision on the rights of land users to get and use land freely through land distribution and/or by bequeath or gift. Holding rights are defined in the Federal Constitution (FDRE, 1995) as "the right any peasant shall have to use rural land for agricultural purposes as well as to lease and, while the right remains in effect, bequeath it to his family member; and includes the right to acquire property thereon, by his labor or capital, and to sell, exchange and bequeath same" (Art 2 Sub Art. 3). The state also has the ultimate power to enact laws about utilization and conservation of land. Art. 51 of the constitution states that the Federal Government shall enact laws for the utilization and conservation of land and other natural resources (FDRE, 1995). Art. 52 also states, that Regional Governments have the duty to administer land and other natural resources according to Federal laws. Both proclamations vested Regional Governments with the power of land administration (defined as "the assignment of holding rights and the execution of distribution of holdings") (FDRE, 1997b, Art. 2.6). They also called for land registration and certification to reduce land conflicts and encourage long-term investment in rural lands.

Lately, the government has come up with land expropriation and compensation proclamation (FDRE, 2005b) which states that “a landholder whose holding has been expropriated shall be entitled to payment of compensation for his property situated on the land and for permanent improvements he made to such land (Ibid: p. 3128)”. Compensation for permanent improvement to land shall be equal to the value of capital and labor expended on the land (Ibid.). A rural landholder whose landholding has been permanently expropriate[d] shall, in addition to the compensation payable, be paid displacement compensation which shall be equivalent to ten times the average annual income he secured during the five years preceding the expropriation of the land (Ibid.).

Following the 1997 and 2005 federal land related proclamations, regional governments came up with their own proclamation on rural land administration and use (For instance see CANRS 2006b). In doing so, they formalized land-lease practices between farmers with contracts up to a maximum of 25 years. Furthermore, the regional proclamations paved the way for land titling, by registering all arable lands, to the landholders who received land during the last land redistribution or through inheritance from their close kin. By doing so, the regional governments hope to boost farmers' sense of security, which, in turn, may encourage investment in erosion reducing and landing quality enhancing technologies. Preliminary studies on the impact of land certification on tenure security long term investment and functioning of land markets indicate that they are having significant impacts on both accounts (Hagos, 2007; Holden et al., 2007). Similar policies were also promulgated in all the major regions of Ethiopia (Deininger, et al. 2007).

Important provisions of the land administration and use proclamation, both federal and state, that have provided incentives that encourage farmers to improve their management and make additional investments on their land include (FDRE, 1997; 2005; CANRS 2006b):

- Right to use has no any time limit;
- Right to transfer holdings in bequeath or donation;
- Transfer right in rent to any person for a maximum of 25 years;
- Right not to be expropriated without consent of the user or unless it is to be used for public services;
- Right of any person deprived from his land holding to get compensation for the permanent property he had developed on the land;
- Right of the state to deprive holding rights if gross damage occurs over land due to mismanagement;
- Land measurement and registration; and
- Granting a legal land holding certificate where in the land holding certificate shall indicate the main provisions of right and obligations of the land holder.

The new proclamations also have specific regulation on land use obligations of the land user. The land use regulations include: any rural land shall have land use plan and any rural land with 60 % slope and above shall not be used for farming and free grazing other than forestry, perennial plants and development of forage for animals (CANRS 2006b, p. 8). The obligations of the land user include: protect the land under his/her holding or land obtained in rent and conserve the surrounding; to plant trees around his/her land and properly protect them; undertake trench terracing and favorable soil conservation activities to use the land forms which are 31 to 60 % slope for perennial plants and to use land based on land use plan (CANRS 2006b, p. 21). Non-compliance is likely to lead to deprivation of use rights and penalty. The Rural land Administration and Land Use of the Amhara National State (CANRS 2006b), for instance, indicates that where land is degraded due to weakness, not to conserve it, the household will be obliged to transfer the right to use land in rent temporarily for a person who undertakes an obligation; if not corrected it goes from suspending him from using his right for a limited time up to expropriating with compensation. In the extreme case, he shall be made to pay compensation for the damage pursuant to civil code in addition to measures above (p. 23).

Integrated watershed management guidelines

This guideline was developed with the intension of promoting and expanding participatory community watershed development in Ethiopia. This is an attempt to streamline the experiences of various actors (GOs and NGOs) in participatory watershed development, combined with the need to have a common and standardized, more effective approach to the country as a whole (Lakew et al. 2005). The guideline aims to build upon exiting community-based participatory watershed efforts to harmonize and consolidate planning procedures at the grass-roots level. The intent is to provide development agents and communities with a workable and adaptable planning tool. Another objective of the guideline is to provide practical guidance on the correct selection of technologies under different conditions and their correct implementation (Lakew et al. 2005).

Analysis of Institutional Setup

In the subsequent section, we will closely analyze the institutional design architecture of institutions in the Tana and Beles Basins and in Ethiopia in general. Five criteria will be used to structure our discussion: presence of clear institutional objectives; interconnection between formal and informal institutions; institutional adaptiveness; appropriateness of scale; and compliance capacity.

Institutional design architecture

In terms of clarity of institutional objectives, the institutional arrangements for land and water in Ethiopia in general and BNB in particular are 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 by law duties and responsibilities. The policies and laws in place have also clear objectives and some have developed strategies and policy instruments to meet these objectives. That said, however, there are important problems noticed in the organizational setting and some questions about the institutional arrangements that remain to be answered. Important policy gaps are identified as well.

Like elsewhere in Ethiopia in Tana and Beles Basins, there are at least three federal and other subsidiary agencies and the same number of regional bureaus/authorities working in the area of land and water and environmental protection. The government tried to define the roles and responsibilities of government bodies, a careful look into the work portfolios of ministries indicate the presence of overlaps in mandate between MoWR and MoARD, EPA. For instance, MoWR and MoARD have both responsibilities related to water resources development, although MoWR focuses on medium and large-scale works while MoARD focuses on small-scale irrigation and micro water harvesting. The broad areas of integrated natural resource management also fall into the mandates of these two ministries and the EPA.

It seems there is a problem of split jurisdiction here, which may create problems in implementation and enforcement. EIA and water pollution control also fall under the jurisdiction of EPA and MoWR. There is already possible overlapping of responsibility between on the one hand the general and broad mandate of EPA and Regional Environmental Bureaus or Authority in the field of pollution control and on the other hand the IWRM framework that promotes integration of all aspects of water resources. If these two organizations work separately, this would lead to a clear duplication of effort and waste of resources. The critical questions here are: to what extent these overlaps in mandates mean duplication of efforts and conflict of mandates? An equally important issue is to what extent are these overlaps minimized through joint planning and coordination? Furthermore, who is responsible, mandated by law, for regulating that tasks and responsibilities are fulfilled by the responsible ministries and agencies? What specific linkages and information sharing mechanisms are in place to ensure institutional harmony and efficient information and resource flows?

As indicated earlier, MoWR is responsible for water resources that are transboundary in nature and not confined within a regional state while regional Water bureaus are responsible for water resources within their jurisdiction. At the same time, MoWR is responsible for developing medium and large scale schemes in the whole country while responsibility to develop small scale schemes falls under the jurisdiction of regions, to be more precise under the Bureau of Agriculture and Rural Development. This separation of mandates between the federal water ministry and the regional water bureaus is artificial, to say the least, and is contrary to the principles of IWRM. In this line, an important point here is whether central ownership of these resources is compatible with decentralized management, one of the principles of IWRM, which is also advocated in the Ethiopian water policy documents. Several questions also arise from this situation: what is the role of the regional bureau of Water Resources Development? Is its role limited to provision of domestic water supply in the regions as small scale irrigation also falls under the jurisdiction of the Bureau of Agriculture and Rural development? Is the MoWR in a position to issue water permits and collect water charges at national scale? Or could be more efficient to delegate parts of its mandate to regional water Resources Bureaus? The same questions could be raised on the relationship of other ministries (i.e. MoARD and EPA) to their counterpart in the regions.

In addressing these questions we developed an actor linkage matrix for the Tana Beles Sub-Basin (see Table 2) where we explored information flows and linkages. We found three types of information exchange and linkages within the federal ministries and regional and between the two. There are, at least in theory, formalized and institutionalized information flows and linkages between organizations falling within the same sector, example between the MoWR and BoWR or MoARD and BoARD, etc. There are indirect information flows and linkages between close neighbor sectors (e.g. land and water). The mechanisms of indirect information flows and linkages are usually through reports to a higher body (regional president or Prime Minister) and discussions at the regional/federal council of ministers level. As stated earlier, the EPE calls for the establishment of Environmental Protection Council (EPC), which oversee EPA's activities, as well as the activities of sectoral agencies and environmental units with respect to environmental management. It is also expected to ensure coordination among sectoral ministries and agencies on environmental matters. Although whether EPC is operational as yet or not is not known, a project based ad-hoc coordination platform, where national steering committee is established, is usually used to oversee the planning and implementation of a project. The committee defines, terms of reference for contractors/consultants, evaluates the outputs thereof. Any water related project is, in principle, subject to EIA based on EPA guidelines. Horizontal communications between ministries and bureaus belonging to different sectors is seldom common. There are hardly any information flows and linkages between sectors not apparently related. The lack of Integrated Information Management System exacerbates this problem of poor communication. The organization of ministries, bureaus and departments, hence, seems to follow 'disciplinary' orientation while problems in the sector call for interdisciplinary and integrated approach. For instance, there is no structural and coordinated linkage among the various stakeholders that are involved in the water sector activities, even between the two key institutions, i.e. Ministry of Water Resources and the Regional Water Bureaus (Gizaw, 2004). On the other hand, research institutes have limited direct linkage the development ministries/bureaus. There is hardly any linkage and information flow between the formal and informal organizations.

In summary: a high frequency of overlapping and conflicting roles and responsibilities between institutions reported (NBI, 2006: p. 3). NBI (2006) also identified poor inter-sectoral collaboration and control as one of problems related to roles and responsibilities of organizations. Concerns existed that roles and responsibilities between levels remained ill-defined and resulted in implementation inertia and even failure (NBI, 2006). This could lead to inability to achieve the goals of the sectors. Additionally, the stakeholders may not collectively drive some synergic benefit from being able to integrate their administrative efforts. Both protective institutional responses and lack of effective coordinating mechanisms are featured as reasons (NBI, 2006).

In this line, 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 institutional responsibilities and redesigning organizational structures may be called for in the light of the changes and development needs of the country, the frequent, at times endless, restructuring process has certainly produced uncertainties, made capacity building difficult and affects the political will to push for change. NBI (2006) documented many challenges related to implementation within weak institutional environments that were evident, with particular awareness of the need to build substantial capacity at decentralized levels (p.5).

Table 2 Actor linkage matrix in the Tana Beles sub-Basin (map of information flow and linkages between major actors)

↓	BARD	BWRD	EPLAUA	AARI	SHWISA (NGO)	Water Aid (NGO)	MoARD	MoWR	EPA	EIAR
BARD		IFL	IFL	FFL	FFL	NFL	FFL	IFL	IFL	IFL
BWRD	IFL		IFL	IFL	IFL	FFL	NFL	FFL	IFL	NFL
EPLAUA	IFL	IFL		IFL	IFL	NFL	NFL	NFL	FFL	IFL
AARI	FFL	IFL	IFL		NFL	NFL	IFL	NFL	NFL	FFL
SHWISA (NGO)	FFL	IFL	IFL	IFL		NFL	NFL	NFL	NFL	NFL
Water Aid (NGO)	NFL	FFL	NFL	NFL	NFL		NFL	IFL	NFL	NFL
MoARD	FFL	NFL	NFL	NFL	NFL	NFL		IFL	IFL	FFL
MoWR	NFL	FFL	NFL	NFL	NFL	IFL	IFL		IFL	IFL
EPA	NFL	NFL	FFL	NFL	NFL	NFL	IFL	IFL		IFL
EIAR	NFL	NFL	NFL	NFL	NFL	NFL	NFL	NFL	NFL	

Codes: FFL= Institutionalized flow & Linkage**; IFL=** Indirect flow& Linkage**; NFL=** No flow & Linkage at all.

In terms of the role of different organizations in the development of new polices and laws, in relation to natural resource management, the federal ministries were instrumental in developing key policies and laws while regional bureaus kept a lower profile (see Table 3). In some case, regional bureaus developed proclamations and guidelines to implement federal policies and in some cases they adopted federal polices as they are. The regional Rural Land Administration and Use proclamations and guidelines falls under the former category while water related policies, regulations and guidelines have remained fall into the second category. Noticeably, there was limited research input in the development policies, as policy research in the country is at best fragmented and rudimentary to yield outputs that are worth of policy uptake.

Level of influence

Roles			**Responsible**
High			EPA/MoWR/MoARD

Medium			EPLAUA/BARD/ BWRD
Low			EIAR/AARI
	Negative	**Neutral**	**Positive**

Table 3 Role and influence of organization in policy change in the Tana Beles sub-basin: Land and water management

The policies and laws hitherto developed in Ethiopia are said to reflect global policy changes or the widespread adoption of the IWRM principles (NBI, 2006). Not surprisingly, the policies are reflections of the institutional arrangements as the major intents and objectives of the policies and laws reflected the roles and responsibilities of organizations that developed them. The narrow disciplinary orientation that we witnessed in organizational arrangement is also manifest in the key trusts of these policies. It is known that sustainable land management has a lot of bearing on water availability and quality, the water policy in Ethiopia, however, does not consider the need for improved land management in relation to water resources development. The limited coordination between MoWR and MoRAD also manifests in this. Informal institutions seem to play a critical role in the *modus operandi* of many organizations.

There is no doubt that a lot of progress has been made lately in creating an institutional framework for improved land and water management in Ethiopia. However, there are cases where informal institutions substitute formal institutions. Informal institutions here are understood as those, contrary to the written polices and laws, unwritten codes of practice that shape organizations behavior. One policy gaps that still calls for immediate action is the management of transboundary waters. The Ethiopian water policies (for that matter all other riparian countries in the Nile) advocate for integrated water resources development, where the planning unit should be a river basin. Practices, however, deviate a lot form the written policy. Actual water development interventions follow a piecemeal approach. There is uncoordinated and unregulated harvesting of the countries' ground and surface water resources. Adequate upstream and downstream considerations are also lacking in the implementation process. Mechanisms for cost and benefit sharing between upstream users (who cause the degradation and could control it if they have the incentive) and downstream users (who could gain more from improved management of land and water upstream and loose due to poor management of the same) are not in place in the water policy of the country. At the basin scale, while important progress has been made though the NBI and individual efforts of countries (e.g. promulgation of proclamation for the establishment of river basin organizations in Ethiopia), still the riparian countries could not come up with mechanisms for equitable and efficient distribution of the Nile water. Still old rules govern in the distribution of the Nile water in general and the Abay Blue Nile in particular.

The focus of all the water organizations is on surface water and groundwater, i.e. blue water. While rain water is the major contributor to livelihood in the basin, particularly in the Ethiopian highlands, little attention is given to it in the policies and strategies and in the organizational arrangement of the water sector. Polices leave out rain water management which has a great bearing in the sustenance of both surface water and groundwater (NBI, 2006). The lack of focus on green water is another policy gaps that cells for remedy.

Furthermore, there is discrepancy between the stipulations of the law and the practice in cost recovery. The laws indicate that water schemes, potable or irrigation, are expected to operate on a cost recovery basis. The policy, for instance, stipulates that if these schemes are located in rural areas, they are at least expected to cover operation and maintenance costs of those schemes. However, practices throughout the country (not only Tana Beles sub-basin) indicate that farmers are not made to pay for operation and maintenance. This encourages overuse of water and poor management of water structures. Moreover, lack of effective cost recovery mechanisms often inhabits the ability of organizations to sustain themselves and fulfill their mandates (Gizaw, 2004; NBI, 2006).

While Ethiopia's water development and environmental protection policies and laws recognize the need and importance of taking proper EIAs in pursuing any water related development intervention, traditional practices still dominate: environmental considerations are given limited consideration in water resources development. Or if they did, this is done without the involvement of EPA/ EPLAUA. As indicated earlier, both EPA and MoWR resources seem to be mandated to care for the protection of water pollution. This has become a potential source of conflict, where MoWR, and specially the regional BoWR, does not seek to secure environmental clearance from EPA/EPLUA for water related intervention. MoWR/BoWR seems to grant permits without go-ahead from EPA/EPLUA.

There is also confusion in the definition of the appropriate scale. Regional bureaus and federal office are organized on the basis of administrative scale, i.e. regions or the country. On the other hand, the relevant water resources policy and watershed management guidelines advocate the basin or watershed to be the basic planning unit for intervention. A critical constraint against effective river basin management is the commonly prevalent conflict between boundaries of river basins and those of political units (nations, regions, districts, etc). The administrative boundaries also pose potential constraint in management of small watershed that fall between two districts or PAs. This calls for establishing viable and acceptable institutional mechanisms for shared management of water resources in the river basin or watershed. While the major rivers in the Abay Blue Nile are transboundary in nature, there are no transboundary organizations as yet responsible for the management of water resources at a basin scale. Many development interventions within the sub-basin are not centered on watersheds. However, the ground for the establishment of river basin organizations seems to be in the making although taking watersheds as development domains is hardly practiced.

Enforcement capacity of institutions is another indicator against institutional performance is evaluated. The issue here is: how are violations of accepted institutions dealt with and what are the typical forms of enforcement by land and water institutions. If there are enforcement problems, what are the major causes of these problems? Overall, assessment is that regulations on water resources management, pollution control, land use rights related to water, watershed development, environmental quality and pollution control standards are not effective or enacted because of enforcement capacity (NBI, 2006). The major government regulatory agency, EPA, complains of inadequate staff and resources to do proper enforcement of environmental provisions. The same story is also heard in the regions, where inadequate manpower and resources constrain enforcement. Moreover, in the regions, they complain of lack of environmental pollution standards to do effective job of enforcement and EIA. On the development wide, there is lack of systematic monitoring and evaluation of policy implementation (NBI, 2006). The poor record in monitoring and evaluation is highly linked with the absence of an integrated system of information management at the country level or at the sub-basin level. While the land and water organizations, both in the country and regions, are mandated to collect and store relevant data to support decision making, the data collection is at best inadequate and haphazard. There are attempts, for instance, to establish Water Resource Information Center (WRIC) at the MoWR. In fact, the Ethiopian Water Management Policy (MoWR, 1999, p. 10) calls for the establishment of Water Resources Information Center (WRIC) and indeed to this effect the Ministry has now created Data and Information and GIS Center (WoWR, UNESCO and GIRDC, 2004). However, as yet there is no Integrated Information Management System in place to enable information sharing and exchange between organizations and support timely policy decision making. In the light of this, various organizations keep and maintain a wide range of data to meet their purposes although the quality and coverage of the data maintained by each organization is generally appraised as weak (MoWR, UNESCO and GIRDC, 2004; p. 75). On top of this, there is a considerable weakness at all levels of the regional water sector institutions in keeping proper records of data and information. There is also a lack of standard procedures for gathering and storing of data and information. Data management is not done in a way conducive to enable easy data sharing. This is more so at the basin scale, i.e. across countries.

We have described the various land and water institutions in Ethiopia and the Tana-beles basin. Interesting in this regards is to assess how these institutions evolved, particularly the type of adaptive management pursued. Although, a rigorous analysis is called for in how specific polices, laws and organizations evolved. It seems apparent that adaptive evolutionary management is the typical type of strategy followed in drafting institutionalizing these policies and organizations. Institutions – broadly meant the rules of the game and the actors – in the Tana Beles sub-basin or Ethiopia are developed through a series of trial and error. This explains partly the omnipresent process of restructuring of the ministries/ bureaus and revisions of policies and laws in the country /regions.

Another related issue is the adaptive capacity of institutions to changes in socio-economic and bio-physical contexts, i.e. technology, climate change and water scarcity, market factors, environmental and health risks, etc. Institutional efficacy is measured not only in fulfilling daily work mandates but also in developing forward looking solutions to emerging issues. Looking into the dynamics of the institutional settings in the Abay Blue Nile basin, there is hardly any indication that the emerging challenges are reflected upon and strategies to address these issues developed. There are allusions in the policy documents that envisaged water sector and broader development strategies in the country (sub-basin) are expected to provide mechanisms to mitigate some, if not all, of these challenges. However, these strategies assume that there is plenty of water potential to tap in from in the sub-basin. Economic water scarcity is considered a greater challenge than physical water scarcity. Climate change scenarios and their impact on water resources are hardly taken into account in the development of these strategies.

Choice of policy instruments

We described the overall intent and main features of the various land and water related policies in Tana Beles sub-basin in the proceeding sections. Now we make a more focused discussion of the choice in policy instruments to enforce these policies and laws. These policies and laws will be understood in the light of their intent to influence actors (policy makers, practitioners, land and water users, etc.) to change their behavior such that the policy goals of sustainable resource use are met and externalities are minimized. Externalities are internalized if individuals account for effects of their actions on others. Imposing costs on others requires compensating them, and providing benefits for others requires being compensated for them (Kerr et al., 2007).

According to Kerr et al. (2007), the most important criteria in designing effective policy instruments include: cost-effectiveness (administratively feasible, with low transaction costs); direct targeting (addressing the problem more directly will have fewer side effects); creates strong incentives to comply (easily monitored or self-monitoring are more feasible and cost-effective); has long-term impacts (avoid short time fixes); protects poor people's livelihood (helping poor people or at least not harming them); does not concentrate costs on a particular group (avoids uneven distribution of costs and benefits to encourage collective action) and replicable across scale and context (mechanisms effective in multiple settings). Policy makers will take account of these criteria in developing certain policy instruments. However, the weight given to a given criteria in choosing policy instruments could vary from context to context. The performance of different instruments is not the same in all contexts either. The performance of the same policy measure judged against these criteria could vary a well: different approaches for internalizing externalities tend to perform better against some criteria than others, so tradeoffs are inevitable (Kerr et al., 2007).

There are different types of policy instruments and approaches to internalize externalities (Pagiola et al., 2002; Sterner, 2003; Kerr et al., 2007). These include: moral suasion and social conventions; regulatory limits and economic penalties; taxes on negative externalities; tradable environmental allowances (permits for negative externalities); investment subsidies; indirect incentives; payment for environmental services; change in property rights; facilitation in negotiation and conflict resolution. For the sake of convenience, theses instruments could be broadly classified in to two broad categories: economic incentives and market-based instruments and command-and-control (coercive) instruments (Kolstad, 2000). OECD (2007) indicates that instrument mix rather than a single instrument are effective in addressing specific environmental problems because of two main reasons: many environmental problems are of multi-aspect nature; certain instruments can mutually underpin each other. Our intention here is to uncover the policy instruments chosen in the major land, water and environmental policy of the country and assess whether they are effective in addressing the major environmental problems in the sub-basin and the country in general. The focus here will be on the Environmental Policy, Land Use and Land Administration, Integrated Watershed Management Guideline and Water Resources Management Policy.

Table 4 Essential elements of water and land management policies

Instrument/element	**WRMP**	**EPP**	**LULA**	**WSG**
General intent of the policy/law	✓	✓	✓	✓
Jurisdiction – spatial and administrative scales	✓	✓	✓	✓
Responsibility (establishes or enables commitment)	✓	✓	✓	✓
Goals and objectives	**?**	**?**	**?**	**?**
Duty of care (Ethical, legal responsibility, attitude, responsibility or commitment)	✓	✓	✓	✓
Hierarchy of responsibilities (‘rights and obligations’ of hierarchies)	**?**	✓	✓	✓
Institutional changes (statements of an intended course of action/ needed reform or legal change)	✓	✓	✓	✓
Climate change scenarios	X	X	**?**	**?**
Upstream-downstream linkages	X	X	✓	✓
Role of educational activities	X	X	X	X
Need for research and investigation	X	X	X	X
Community participation	✓	✓	✓	✓
Water/land use planning	**?**	**?**	✓	**?**
Financing	✓	**?**	**?**	**?**
Enforcement/regulation (SE vs. TPE)	**?**	✓	✓	**?**
Mechanisms for dispute resolution	**?**	**?**	✓	**?**

<u>Codes:</u> WRMP is for Water Resources Management Policy/ Regulation/ Guideline; EPE is for Environmental policy of Ethiopia; WSG is for Watershed Management Guideline ;

LAUP is for Land Administration and Use policy; X is for not clear, ✓ is for clearly reflected, ? is for uncertain

The Ethiopian Environmental Policy document, without making any serious discussion, lists a series of policy instruments with the aim of improving environmental management in Ethiopia. The possible policy options listed to control/minimize environmental pollution (i.e. air, water, land, etc.) are summarized on Table 5

Command-and-control (coercive) instruments

Regulation/administrative and legal measures against offenders, technology standards (requirements to install sound technology or apply methods to recycle waste, if required), closure or relocation of any enterprise and permits in the case of hazardous waste or substances fall under this category. However, EPA has not developed relevant pollution standards for different kinds of effluents. In fact, in Tana Beles project, lack of standards was considered as one of the bottlenecks for effective pollution control and EIA.

The new proclamations on land use and administration also have specific regulations on land use obligations of the land user. The land use obligation requires any rural land shall have land use plan prepared and approved by EPLAUA. In actual land use, any rural land with 60 % slope and above shall not be used for farming and free grazing other than forestry, perennial plants and development of forage for animals (CANRS 2006b, p. 8). The policy also lists a set of obligations of the land user to protect the land under his/her holding or land obtained in rent and conserve the surrounding; to plant trees around his/her land and properly protect them; undertake trench terracing and favorable soil conservation activities to use the land forms which are 31 to 60 % slope for perennial plants and to use land based on land use plan (CANRS 2006b, p. 21). Non-compliance is likely to lead to deprivation of use rights and penalty.

The Water Resource Management Policy underpins the need to make the basin as a major planning unit for water resources development. And this is expected to influence the behaviors of many stakeholders involved in land and water management, although its realization into action is falling behind.

Incentives and market-based instruments

Pollution charges (clean up or pay the cost of cleaning up), registration, labeling and packaging (in the case of hazardous materials) as per the applicable standards fall under this category. EPA may also issue waiver to newly established firms from applying these stringent standards. The guideline also provides incentives for the introduction of methods that enable prevention or minimization of pollution into an existing undertaking. In this case, importation of new equipment that is destined to control pollution shall, upon verification by the authority, be exempted from payment of custom duty. It also promises to provide any environmental rehabilitation or pollution prevention or clean up project with financial and technical support, to the extent that its capacity allows (FDRE, 2002c).

Table 5 Typology of policy instruments in Environmental Management (X= not clear, ✓= clearly reflected,?= uncertain)

Policy instruments	**IWSM**	LULA	**WRMP**	**EP**	**Responsible**
Information and education	✓	X	X	✓	**?**
Regulations/standards	**?**	✓	**?**	✓	EPA/EPLAUA
Incentive-based					EPA/EPLAUA
Subsidies	**?**	✓	**?**	✓	
Taxes	**?**	**?**	**?**	**?**	
Charges/penalties	**?**	✓	✓	✓	
Certification (property rights)	**?**	✓	**?**	**?**	
Cost and benefit sharing	?	?	✓	?	MoWR
Cost Recovery	?	?	✓	?	MoWR
Public programs (PSNP, FFW, CFW/ Free labor contribution, etc.)	✓	**?**	**?**	**?**	MoARD/ BoARD
Conflict resolution	✓	✓	**?**	**?**	EPLAUA/social courts

Codes: IWSM is for Integrated Watershed Management; LAUP is for Land Administration and Use policy; is for WRMP is for Water Resources Management Policy/ Regulation/ Guideline; EP is for Environmental protection policy/guideline

As far as incentives for improved agricultural land management include (FDRE, 1997; 2005; CANRS 2006b) providing unlimited right to use land; right to transfer holdings in bequeath or donation or lease; right not to be expropriated without consent and without due compensation for the permanent property developed on the land; and the right of the state to deprive holding rights if gross damage occurs over land due to mismanagement; and land measurement and registration and granting of a legal land holding certificate.

The water policy has specific stipulations pertaining to tariff setting that call for rural tariff settings to be based on the objective of recovering operation and maintenance costs while urban tariff structures are based on the basis of full cost recovery. However, it also calls for adoption of a "social tariff" to enable poor communities to cover operation and maintenance costs and to establish progressive tariff rates, in urban water supplies, tied to consumption rates and flat rate tariffs for communal services like hand pumps and public stand pipes. Users from irrigation schemes are also required, at least, to pay to cover operation and maintenance costs. The institutionalization of cost recovery schemes and

tariff setting is expected not only to generate funds for maintaining water points/schemes but also change users' consumption behavior.
The WSM guideline aims to institutionalize community-based participatory watershed efforts to enable watershed development planning at the grass-roots level. The guideline provides more of a working tool to implement participatory watershed management. The intent is to provide development agents and communities with a workable and adaptable planning tool. Another objective of the guideline is to provide practical guidance on the correct selection of technologies under different conditions and their correct implementation (Lakew et al. 2005). However, the implementation modalities are not clearly spelt out.

In summary the various policy documents propose a mix of policy instruments, some incentive based and other command-and control type instruments. The policy instruments are clearly formulated in terms of their general intents, although lacking in terms of specific objectives and goals, jurisdiction and responsibility, hierarchy of responsibilities and proposed institutional changes (see Table 4). On the other hand, some features of the policy instruments are not well articulated. Particularly lacking are issues related to climate change scenarios, upstream-downstream linkages, role of education and research, financing, conflict resolution and enforcement.

Overall there is tendency to focus on command-control type policies, this more so in the environmental policy documents, than carefully devised incentive mechanisms for improved environmental management. The tone in the policy documents is heavily loaded with the need for third party enforcement (the relevant ministry/agency supervising and regulating economic agents' behavior) than to relay on self-enforcement. This does not mean the government should not assume a role in environmental management. On the contrary, international and local experiences indicate that the government has a key role to play in providing incentives to actors to adopt improved environmental management strategies. Through proper incentives farmers, for instance, could be motivated to build up their soil capital, prevent soil loss and nutrient leakage, and hence reduce downstream externalities. But there is a consensus that policy instruments building on command and control, like regulations and mandatory soil conservations schemes, have limited or negative effects (Pagiola et al., 2002; Sterner, 2003; Kerr et al., 2007; Ekborn, 2007). Likewise, information and extension advise have had limited, although generally positive impacts. Arguably extension advice is a necessary but insufficient measure to reduce downstream damage, mainly due to poor farmer incentives to fully prevent soil loss (Ekborn, 2007). There are suggestions for increased use of positive incentives, like payment for environmental services, to address land degradation problems in Developing countries (Ekborn, 2007). Gebremedhin (forthcoming) argues that various forms of incentives have been provided to land users to conserve the land resources in Ethiopia and elsewhere in eastern Africa. However, most of the incentives were aimed at mitigating the effects of the direct causes of land degradation. The underlying causes of land degradation remained largely unaddressed.

Hence, there is a need to carefully assess whether the proposed policy instruments address incentive problems of actors form improved environmental management.

Conclusions and Policy Recommendations

Land and water institutions play a vital role in managing and sustaining land and water resources as well as in enhancing economic development and poverty alleviation. The institutional issues that the Ethiopian land and water sector is grappling with include restoring ecological destruction due to high level of environmental (mainly land) degradation; improving the poor performance of rainfed agriculture, low level of water resources development, and transition from a soil conservation focus to an integrated land and water management system that takes the hydrological boundaries into account. While a lot of concerted efforts are going on redress these problems doing it in integrated manner so that upstream and downstream linkages are understood remains a big challenge. On the research side also, a lot has been done in terms of understanding the micro determinants of farmers' decisions in land and water conservation, however, there is a little attempt to understand the broad macro and institutional and organizational issues that influence land and water management decisions. The objective of the study was, hence, to carryout a preliminary assessment and review of institutional arrangements for improved land and water in Ethiopian part of the Blue Nile. The study describes the various formal and informal institutional arrangements (with more focus on the former) that are in place currently and their design features in order to identify those institutions related to superior performance. The analysis of institutions and their design features provides useful insights, contributing to institutional reform debate in land and water management in Ethiopia.

Our results indicate that the institutional arrangements for land and water, in Ethiopia in general and BNB in particular, are 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 by law duties and responsibilities. The policies and laws in place have also clear objectives and some have developed strategies and policy instruments to meet these objectives. In spite of these improvements, there is a high frequency of overlapping and conflicting roles and responsibilities between institutions besides poor inter-sectoral collaboration and control as one of problems related to roles and responsibilities of organizations. Particular concerns exist that roles and responsibilities between levels remained ill-defined and resulted in implementation inertia and even failure. This could lead to inability to achieve the goals of the sectors. Additionally, the stakeholders may not collectively drive some synergic benefit from being able to integrate their administrative efforts. Both protective institutional responses and lack of effective coordinating mechanisms are featured as reasons (NBI, 2006).

Moreover, the organizations involved in land and water management were marked by frequent restructuring and re-organization over the last few years and the process seems to be going on. While adjusting institutional responsibilities and redesigning organizational structures may be called for in the light of the changes and development needs of the country, the frequent, at times endless, restructuring process has certainly produced uncertainties, made capacity building difficult and affects the political will to push for change.
The policies and laws hitherto developed in Ethiopia are said to reflect global policy changes or the widespread adoption of the IWRM principles (NBI, 2006). Not surprisingly, however, the policies are reflections of the institutional arrangements as the major intents and objectives of the policies and laws reflected the roles and responsibilities of organizations that developed them. The narrow disciplinary orientation that we witnessed in organizational arrangement is also manifest in the key trusts of these policies.

There is no doubt that a lot of progress has been made lately in creating an institutional framework for improved land and water management in Ethiopia. However, there are cases where informal institutions substitute formal institutions, pointing to dysfunctionality of formal institutions. Cases where practices deviate a lot form the written policy include: lack of integrated water resources development (in spite of the written policy for it); inadequate upstream and downstream considerations in development interventions; lack of mechanisms for cost and benefit sharing between upstream users (who cause the degradation and could control it if they have the incentive) and downstream users (who could gain more from improved management of land and water upstream and loose due to poor management of the same); and at the basin scale, absence of agreement for equitable and efficient distribution of the Nile water. Furthermore, while Ethiopia’s water development and environmental protection policies and laws recognize the need and importance of taking proper EIAs in pursuing any water related development intervention, traditional practices still dominate: environmental considerations are given limited consideration in water resources development. Or if they did, this is done without the involvement of EPA/EPLAUA. Informal institutions seem to play a critical role in the *modus operandi* of many organizations.

There is also confusion in the definition of the appropriate scale. Regional bureaus and federal office are organized on the basis of administrative scale, i.e. regions or the country while the relevant water resources policy and watershed management guidelines advocate the basin or watershed to be the basic planning unit for intervention. A critical constraint against effective river basin management is the commonly prevalent conflict between boundaries of river basins and those of political units (nations, regions, districts, etc). The administrative boundaries also pose potential constraint in management of small watershed that fall between two districts or PAs. This calls for establishing viable and acceptable institutional mechanisms for shared management of water resources in the river basin or watershed.

Judged by their enforcement capacity, another indicator of institutional efficacy shows that regulations on water resources management, pollution control, and land use rights related to water, watershed development, environmental quality and pollution control standards are not effective or enacted because of enforcement capacity (NBI, 2006). The major government regulatory agency, EPA, and its regional counterparts complain of inadequate staff and resources to do proper enforcement of environmental provisions. Moreover, lack of environmental pollution standards are cited as reasons for weak enforcement in environmental protection and EIA. On the development side, there is lack of systematic monitoring and evaluation of policy implementation which is linked with the absence of an integrated system of information management at the country level or at the sub-basin level.

With regards to adaptiveness of institutions in the Tana Beles sub-basin or Ethiopia, it seems apparent that adaptive evolutionary management is the typical strategy followed in drafting and institutionalizing these policies and organizations. Institutions are developed through a series of trial and error type adaptations. This explains partly the omnipresent process of restructuring of the ministries/ bureaus and revisions of policies and laws in the country /regions. In terms of the adaptive capacity of institutions to changes in socio-economic and bio-physical contexts there is hardly any indication that emerging challenges are reflected upon and strategies to address these issues developed. There are allusions in the policy documents that envisaged water sector and broader development strategies in the country (sub-basin) are expected to provide mechanisms to mitigate some, if not all, of these challenges. However, these strategies assume that there is plenty of water potential to tap in from in the sub-basin. Economic water scarcity is considered a greater challenge than physical water scarcity. Climate change scenarios and their impact on water resources are hardly taken into account in the development of these strategies.

The various policy documents propose a mix of policy instruments, some incentive based and other command-and-control type instruments. The policy instruments are clearly formulated in terms of their general intents (although found lacking in terms of specific objectives and goals), jurisdiction and hierarchy of responsibilities and proposed institutional changes, etc. Overall there is tendency to focus on command-and-control type policies, more so in the environmental policy documents, than carefully devised incentive mechanisms for improved environmental management. The tone in the policy documents is heavily loaded with the need for third party enforcement (the relevant ministry/agency supervising and regulating economic agents' behavior) than to relay on self-enforcement. This does not mean that the government should not assume a role in environmental management. On the contrary, international and local experiences indicate that the government has a key role to play in providing incentives to actors to adopt improved environmental management strategies. But there is a consensus that policy instruments building on command and control, like regulations and mandatory soil conservations schemes, have limited or negative effects (Pagiola et al., 2002; Sterner, 2003; Kerr et al., 2007; Ekborn, 2007). Likewise, information and extension advise have had limited, although generally positive impacts. There is a need for increased use of positive incentives, like payment for environmental services, to address land degradation problems in developing countries (Ekborn, 2007). Gebremedhin (forthcoming) also suggests the need to carefully assess whether the proposed policy instruments address incentive problems of actors form improved environmental management.

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Benefit-Sharing Framework in Transboundary River Basins: The Case of the Eastern Nile Subbasin

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Abstract

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.

Introduction

Water is a unique resource that plays a central role in the functioning of human society and ecosystems. Now-a-days, as the demand for freshwater begins to outstrip the available supply global water crisis is becoming more evident. Currently, one billion people in the world live without access to clean water and about two billion have got no access to sanitation. The UN forecast has shown that more than half of the world's population suffers from the direct consequences of water scarcity. If the current situation continues unabated, the same organization believes that over the next two decades the average supply of water per person worldwide will drop by a third. For instance, it is projected that by 2025 half of African countries will experience water stress and the sharing of water will play a significant role in inter-state relations amidst a combination of burgeoning population and recurrent drought/famine in some parts of the continent (Tesfaye, 2001). Such water scarcity and even worse water stress in the African continent will limit the growth of nations, brings about declines in their human health and further degrades their resource base (Alavian 2000).

Although 60 percent of the African landmass is covered by transboundary river basins that produce more than half of the continent's renewable water resources, about one-third of its population (ca. 300 million people) is experiencing increasing water scarcity. As stated by Lautze et al (2007), such a large dependence on transboundary waters requires the adoption of transboundary water governance in all regional water strategies in the continent. The key to these strategies is forging cooperation among riparian states that share the dozens of transboundary rivers found in Africa. As stated by Grey and Sadoff (2007), cooperative management of shared river basins can provide opportunities to (a) increase the scope and scale of benefits, (b) generate basin-wide benefits and (c) establish and sustain transboundary institutions. Cooperation becomes important not only to improve water availability but also to tackle problems of soil erosion, mitigate drought, ensure food security, avail hydropower and to prevent and monitor water pollution. In short, cooperative transboundary water resource development is critically important in helping to alleviate poverty and obtain economic benefits, including but not restricted to flood control, irrigation and hydropower development activities.

Now more than ever before, there is a stronger emphasis on the sharing of benefits rather than physical water. Many writers consider volumetric water allocations among riparian states in shared river basins as obsolete and traditional (Grey and Sadoff , 2007; Giordano and Wolf, 2003; Lautze and Giordano, 2007). They believe that such a stance brings about winners and losers or zero-sum negotiations. Instead, they opt for equitable sharing of benefits that is based on mutual agreement. The distribution of water benefits, they believe, can bring about positive sum outcomes as has empirically been observed in the case of the Mekong, Senegal, Orange and Columbia River Basins. According to Qaddumi (2008), benefit sharing has been proposed as an approach to bypass the contentious issue of property rights. The idea is that if the focus is switched from physical volumes of water to the various values derived from water use in multiple spheres, including economic, social, political, and environmental– riparians will correctly view the problem as one of positive-sum outcomes associated with optimizing benefits rather than the zero-sum outcomes associated with dividing water. Even then, the author of this paper believes that the significance of water allocation for the hitherto disadvantaged co-basin states such as Ethiopia should not be minimized or sidelined.

The aim of this study will hence be to highlight the concept of benefit sharing and benefit sharing framework in general terms as well as in the context of the Easter Nile sub-basin. By so doing, the study attempts to define and conceptualize benefits in the context of shared water resources and discuss the framework of benefit sharing in terms of typologies, scenarios, directions, valuations, optimization/ maximization, distributions and costs. The study has looked into on-going and planned EN projects, most particularly the joint multi-purpose project (JMP) to test the relevance and applicability of benefit sharing and to suggest the way forward.

It should at the outset be stated that the issue of benefit sharing is in its infancy, having neither a fully tested methodology nor a planned worldwide experience (Woodhouse and Phillips, 2009). Most of the international literature generated to date on the sharing of benefits is of a 'soft' nature, and there is a need for much greater specificity. The aforementioned authors stated that where transboundary benefit sharing currently exists, it is more often the result of long-term influences and activities than a deliberately planned approach. Besides, the fact that benefit sharing encompasses economic, environmental, social and political elements with some of them being measurable and others not makes the issue much more complex. It is against these sets of limitations that the study tries to shed some light into the concept and framework of benefit sharing, with particular reference to the Eastern Nile sub-basin.

The concept of benefit sharing

Benefits can mean anything that society recognizes as valuable, such as livelihood improvement, food security, gender equality, amelioration of ecosystems and biodiversity, aesthetics, ethics etc. As stated by Woodhouse and Philips (2009), benefit sharing is an outcome of a collaborative effort at different levels that in the end can reduce costs and increase outputs. In the context of transboundary basins, benefit sharing can mean the management of water more effectively across all sectors with the intent to generate benefits to all stakeholders. The idea of benefit sharing revolves in and around sectoral optimization, with the optimization of water use in one sector leading to optimization of water use in another sector.

Looked at from upstream-downstream perspective, for instance watershed management projects in upstream states can yield shared benefits through control of floods, reduction of siltation, prevention of water pollution, availability of more water in the basin and reduction of erosion in downstream states. Similarly, upstream joint investments in the production of hydropower can avail power at reasonable price to the co-riparian states. The effects and impacts of joint investments will be felt in the basin via developments such as irrigation and power, which in turn can ensure food security, mitigate drought and avail renewable energy.

In any transboundary river basin, cooperation can yield economic, environmental, social and political benefits. The economic benefits may include power production and transmission, agricultural intensification, fisheries and industry, while the environmental benefits include watershed management, soil conservation, water regulation, flood control and afforestation. Similarly, the social capital benefits may include capacity building, training and skill sharing, while the political ones stability, integration, cooperation, rural water supply and rural electrification. The list is not exhaustive and may include more benefits that may or may not be measurable. That is why it becomes a difficult and complex task to calculate benefit sharing. It is hence incumbent upon the riparian states to identify value and share the bundle of benefits in a manner that is agreed as fair and transparent.

Benefit sharing should also include all forms of available water while building scenarios. These include blue water (surface plus ground), green water (water entrenched in the soil) and grey water (water that can be re-usable after treatment). Similarly, the 'basket of benefits' approach is preferred and recommended than a project by project approach. The importance of the 'basket of benefits' approach lies in the fact that it spells out all possible benefits from common resources and joint investments. As argued by Woodhouse and Phillips (2009:9), "negotiating on a project by project basis can easily result in a stalemate – whereas the basket of benefits approach means opportunities can be modified and changed until an acceptable outcome is agreed by all".

Benefit sharing framework

In this section, attempts will be made to illustrate the underlying set of ideas or frameworks of benefit sharing in terms of typologies, aspects and scenarios.

Typologies of benefits

As stated by Sadoff and Grey (2002a), with better management of the 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 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’.

As exemplified in Table 1, there are challenges and opportunities embedded in the aforementioned benefits. Transboundary cooperation could enable basin states to overcome various challenges, such as degraded watersheds, increased demand for water, tense regional relations and regional fragmentation and furnishes opportunities, such as improved water supply, soil conservation, more agricultural and power production, cooperation and integrated regional markets and cross border trades.

Table1: Types of cooperation and benefits on international rivers

Types of cooperation	The challenge	The opportunities
Type 1: increasing benefits *to the river*	Degraded water quality, watersheds, wetlands, and biodiversity	Improved water quality, river flow characteristics, soil conservation, biodiversity and overall sustainability
Type 2: increasing benefits *from the river*	Increasing demands for water, sub-optimal water resources management and development	Improved water resources management for hydropower and agricultural production, flood-drought management, environmental conservation and water quality
Type 3: reducing costs *because of the river*	Tense regional relations and political economy impacts	Policy shift to cooperation and development

Type 4: increasing benefits *beyond the river*	Regional fragmentation	Integration of regional infrastructure, markets and trade

Source : Sadoff and Grey. 2002: 393

Some real world examples of economic and non-economic benefits that can be accrued as a result of cooperation endeavors will be mentioned hereunder (summarized from Sadoff and Grey, 2002a).

(a) 'Benefits to the River' ('Ecological River): Cooperative efforts to restore and protect shared river basins have been exemplified by Rhine River (ibid). Due to the pollution of the Rhine, Salmon (fish) disappeared from the river in the 1920s. In due cognizant of the problem, the ministers of the eight riparian states met in 1987 and came up with a plan to repopulate the river with Salmon under the motto 'Salmon 2000'. As a result of the concerted efforts made by the basin states and the allocation of enough fund, Salmon resurfaced in Rhine as planned in 2000. The lessons one can draw from this example is how cooperation on shared water resources yields ecological benefits to the river.

(b) 'Benefits from the River' (Economic River): in this context, two examples could be given. The first one refers to the Senegal River where Mali, Mauritania, Guinea and Senegal are cooperating to regulate river flows and generate hydropower using common resources and designing fair benefit sharing mechanisms. The Senegal River Basin Organization (OMVS) achievements to date include: (a) the construction of two dams and hydropower plants, (b) implementation of environmental management projects, (c) creation of the observatory of the environment and (d) adoption of a water charter (ENTRO, 2007).

The second example takes us to the Lesotho Highlands Water Project (LHWP) that has been designed to harness the Orange River for the benefit of both Lesotho and South Africa. As noted by Vincent Roquet & Associates Inc. (2002: 50), LHWP had dual purposes: (i) to control and redirect a portion of the water of the Orange River from the Lesotho mountains to the Vaal River basin through a series of dams and canals for utilization in the Guateng Province of South Africa, (ii) to take advantage of the head differential between the highlands and lowlands of Lesotho to generate hydropower in Lesotho to meet its own needs.

In order to attain both purposes, the two parties have agreed to share the cost of construction in rough proportion to the share of their anticipated benefits. According to the agreements reached between the two countries, South Africa has agreed to pay Lesotho royalties for water transferred for 50 years (it currently accounts for 5% of Lesotho's GDP) and Lesotho will receive all the hydropower generated by the project. Both parties have considered the water and power deals as equitable allocations of benefits (Sadoff et al, 2002a).

(c) 'Because of the River' (Political River): the costs incurred due to the presence of shared water resources have remained higher in rivers flowing through arid and semi-arid environments, such as the Jordan, Nile and Euphrates-Tigris. Tensions and disputes, which have long remained the norms than exceptions in these river basins, inhibited regional integration and facilitated fragmentation. As noted by Sadoff et al (2002a: 398) with reference to the above-stated rivers, "little flows between the basin countries except the river itself – no labor, power, transport or trade".

(d) 'Benefits beyond the River' (Catalytic River): it envisages other flows than the river itself, such as improved communication and trade (ibid). The same authors (2002a: 399) stated that "cooperation on shared river management can enable and catalyze benefits 'beyond the river', more directly through forward linkages in the economy and less directly through diminished tensions and improved relationships". A good example for such a benefit is the Mekong Basin. During years of conflicts in the region, Laos always provided hydropower to Thailand. Similarly, Thailand has always purchased gas from Myanmar and Malaysia and hydropower from Laos and China. In effect, the riparian transactions brought about mutual dependency.

Aspects of benefit sharing

In line with the above-stated typologies of benefits, one can assert that the most important aspects of benefit sharing that need to be addressed include benefit sharing for whom, by whom and because of whom. One needs to identify the stakeholders who are involved in benefit sharing, i.e. whether it is government to government or people to people or civil society to civil society. In other words, benefit sharing should be looked at different levels and need not be restricted at the macro level alone. One also needs to go beyond large infrastructure projects such as, the generation of streams of electricity or the prevention of watershed degradation. The grass root benefits that trickle to the rural poor be it in terms of rural electrification or small-scale irrigation need to be identified.

In order to trace the direction of benefits, we need to pose questions, such as where do benefits go and whether they go to the people or the private sector. This will lead us to the fundamental question of valuing benefits by which we need to weigh, for instance, watershed/flood protection benefits versus increments in high value cash crops because of irrigation benefits. Once this is done, the next task will be to monetize (value) benefits and share them by building mechanisms. One also needs to take into consideration the different aspects of benefit sharing including direct vs. indirect, tangible vs. immeasurable, planned vs. spillover and domestic vs. transboundary.

In line with what has been stated above, the basin states need to ponder over issues related to the mechanisms of benefit sharing in the basin, the time scale involved in reaping shared benefits, the likelihood of benefits being realized in terms of planning in time scales (ten, fifteen, twenty years or more), the degree to which the existing political economies in the basin affect the fairness and transparency of benefit sharing. There must be a minimal level of benefit sharing in a descending order that will take us into a real economic integration on the basis of shared resources, i.e. 'benefits beyond the river'. For instance, the planned power transmission between Ethiopia and the Sudan should not be taken as end in itself but rather as a means to an end. The grids should rather be used as drivers of integration irrespective of the time it takes to generate benefits to Ethiopia or to translate the benefits to real growth. One needs to bring in lessons from attempted regional integrations in Africa and elsewhere where there had been problems of translating political agreements into economic benefits. The integration attempts failed simply because there was a major lag between political will and economic benefits that in turn resulted in the frustrations of people.

Benefit sharing does not only mean the generation of benefits. It should also look at the distribution of benefits and the distribution of costs. Costs have to be part of the benefit-sharing framework with a built-in benefit-cost sharing mechanism.

Scenarios of benefit sharing

Prior to the construction of big dams in upstream states (e.g. Ethiopia, DRC), there is a need to come up with short, medium and long-term scenarios. Scenarios could be considered as phases or time perspectives of benefit sharing. Short-term works of strengthening the already established links and benefits through different initiatives and continuous rational dialogue among co-basin states could be considered as short-term scenario. A medium-term scenario could be tracking and improving in-country institutional arrangements for shared resource use and cooperation as well as in building benefit-cost sharing mechanisms. In the long term, one can think of efforts needed to bring about investments in multi-purpose joint development projects and programs that can potentially yield a ‘basket of benefits’.

The short-term scenario in shared river basins may dwell on the benefits that have already been achieved in the basin. These include, among others, the establishment of river basin institutions, such as the NBI (‘benefits to the river’), the continuous dialogue that is taking place between Nile riparian states to come up with a permanent Nile Basin Commission and the building up of confidence among the relevant stakeholders who have got a stake in the river. The medium scenario could, for instance, be changes in the regulation of reservoirs, which would maximize hydropower potential, develop irrigation, control flood and reduce siltation. These benefits can facilitate cross-border trade amongst the riparian states. Lastly, long-term impacts could be funding joint multi-purpose projects such as, large-scale irrigation, watershed conservation and biodiversity conservation.

There are also medium-term long impacts and long-term high impacts. The former include a bundle of benefits related to access to markets for different goods, development of joint flood protection measures and joint water management, while the latter the development of integrated river basin management system combining power transmission with dams and irrigation, so called high impact multi-purpose projects. A good example for the latter could be the envisaged/planned multi-purpose project on the Blue Nile River at Kara Dobi site in Ethiopia.

Although, in principle, cooperation is a search for win-win solutions, still optimization or maximization of benefits needs to be quantified in time, place and in terms of the maximum value that can be generated. Different types of intervention in different countries jointly or unilaterally may have multiple benefits and costs differentiated by space/place and time. Optimization of benefits among basin countries needs also to be considered in the context of dynamic economic, social and political relations in the basin. Trade relations, experience of joint programs, similarity in major policy direction, tradition of cultural and social relations and history are among factors that would influence the venture of benefit sharing and cooperative arrangement.

An important task that deserves close attention is identifying the focus of the benefit sharing and ensuring ways of supporting the economic and social development of the people in the basin without losing sight of conserving water resource for long term use, controlling watershed degradation, minimizing any political upheavals among the basin states, and facilitating cross-border trade. Of course, every measure to realize each component would have effects on other components of the basin network.

It should also be made clear that in reality the political economies of some basin states may not low other basin states to have an optimal benefit. For instance, more environmental benefits may bring about less economic benefits and vice versa. The former may have long-term economic benefits but may not generate short-term gains. For instance, the benefits of watershed program may require 20 to 30 years of realization times. Each basin state can hence seek to optimize but need to agree on the nature of the framework of optimization. In order to sort out such benefits, the Nile basin states need to draw lessons from the Lesotho Highlands Conservation Project where there have been lots of debates about benefit sharing frameworks. As has been discussed in the previous section, the Lesotho Highlands Project brought about water for South Africa, power and royalties for Lesotho but miseries for people who used to live in the inundated areas. Examples for the latter include externalities such as, displacement, resettlement and environmental changes. The parties have failed to give support measures for development and welfare opportunities for local and regional communities that have negatively been affected by the project, e.g. cash compensation. Despite the completion of the Lesotho Project, there are still quite a lot of controversies on the actual impact, with the resettlement issue being still outstanding.

Benefit sharing in the context of the eastern Nile sub-basin

The Nile is the longest river in the world that traverses 10 states. The basin encompasses 3.35 km2 areas, i.e. 10 percent the continent's landmass, and is inhabited by 40 percent of Africa's population. The Nile Basin is home to 160 million people in ten riparian states, namely Burundi, Democratic Republic of Congo (DRC), Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania and Uganda. Of the ten Nile riparian states, four of them live under 'water scarcity' situations.

Due to the prevalence of centuries of hydropolitical stalemates in the Nile Basin, costs 'because of the river' have remained high in the basin. The various attempts that were made to forge cooperation and bring 'benefits to the river' amongst the co-basin states via Hydromet, Undugu and TECCONILE did not bring the desired fruit. A strong departure has been made with the launching of the Nile Basin Initiative (NBI) in 1999 in Dar es Salaam, Tanzania. It has been established as a transitional mechanism pending the establishment of a permanent Nile Basin Commission. The latter requires, inter alia, the signing or ratification of a Cooperative Framework Agreement (CFA), which is still in limbo. The major objectives of the NBI include addressing the region's brewing water conflict, reducing poverty and promoting economic integration (ibid). The establishment of the NBI is in conformity with the 1992 Dublin Principles and the Rio Conference, which called for global consensus for a participatory cooperative approaches to water and water resources development. As stated by Alavian (2008:8) "the fact that this many countries [10] with very different economic, political and development objectives and positions have recognized that there is more to be gained by cooperation than conflict, with water as the catalyst, is a major step forward".

The NBI is composed of two complementary programs, namely the all-basin Shared Vision Program (SVP) and the sub-basin Subsidiary Action Programs (SAP). The latter are meant to come up with investment programs with the intent to translate the vision into action. In the Eastern Nile sub-basin, ENTRO has come up with a number of projects, which include, among others, watershed management, irrigation & drainage, Ethio-Sudan power transmission, regional power trade and Joint Multipurpose Program (JMPs). Some, if not all of the projects, have gone through feasibility stages and are awaiting funds for their implementation. Of these projects/programs, this study has considered JMP as an example to contextually discuss the benefit sharing framework.

JMP is a joint undertaking by the three EN countries, namely Egypt, Ethiopia and Sudan, to use the shared resources as entry points to foster economic integration through multi-purpose projects that go beyond the water sector (ENTRO, 2008). Its immediate development objective is to undertake cooperative and sustainable development and management of the shared Blue/Main Nile water resources through multipurpose storage/dam and power systems infrastructure, watershed and floodplain management and the 'selective' development of irrigation systems. According to ENTRO (2007), four elements are included under JMP: (i) watershed and environmental management, (ii) enhanced agricultural production, (iii) infrastructure with linked river and power systems, and (iv) leveraged Growth and Integration.

It has been recognized by ENTRO that cooperative development and management of the Eastern Nile Basin, as one river system, offers tremendous opportunities for economic development. This could be achieved through a multi-country, multipurpose program of activities that could increase power supplies, build reservoir capacity and enhance agricultural production that can mitigate natural resource degradation, alleviate poverty and support more sustainable livelihoods for the peoples of the EN sub-basin. According to Blackmore and Whittington (2008), a large dam with over-year storage on the Abbay (Blue Nile) is suggested to achieve the aforementioned benefits. The same authors believe that a large multipurpose dam on the Abbay would meet the criteria for JMP investments, including the generation of multipurpose benefits to all the three EN countries in terms of hydropower, irrigation, flood control and regional cooperation. Put in a nutshell, such JMP activities “would make better use of the Blue Nile water to produce more food and fiber, while at the same time reducing sedimentation and enhancing environmental values” (Ibid:73).

Blackmore and Whittington (2008) have also itemized the benefits that can be accrued to all the three EN countries after the construction of a large dam on the Blue Nile. The authors mentioned that Ethiopia stands to benefit in financial terms from the sale of large amounts of hydropower to downstream riparians; Sudan would benefit in several ways, including flood control, improvements in seasonal navigation and reduction in sediment loads reaching Sudanese reservoirs, while Egypt benefits from upstream storage by receiving alternative sources of reliable power and increased opportunities for trade, regional integration and cooperation.

Of the various projects of the JMP, special attention has been given to the development of sustainable watershed management due to the existence of close inter-relationships between watershed, environmental management and enhanced agricultural production. ENTRO (2008) asserted that in the absence of watershed management interventions, soil erosion, environmental degradation and deforestation will continue at accelerated rates, reducing agricultural productivity and increasing the numbers of households falling at and below the poverty line.

The JMP and other ENTRO projects should however consider a number of things related to the identification of bundle of benefits (water and non-water related ‘basket of benefits’) and the realization of the ‘equitable sharing of benefits’ to the Eastern Nile countries. In the context of benefit sharing, the power benefits in Ethiopia should be weighed against the bundle of downstream benefits in terms of flood control, availability of more water downstream that could be used for irrigation due to regulated release as well as watershed management in Ethiopia. Thus, for example, the downstream co-riparians should generate benefits for Ethiopia, if the latter releases flows which could otherwise be utilized upstream (at least theoretically).

Under the joint development program, i.e. JMP, there must be (a) a benefit sharing treaty of the EN countries that should entitle the three riparian states to a lump sum payment for various downstream and upstream benefits, (b) a sound financial framework for transboundary water resources development which includes, among others, methods for equitable sharing of the costs, the benefits and the risks and (c) building financial mechanisms for joint ownership of assets. It should also be borne in mind that the perception of benefits (and their usefulness) will alter over time, and any international agreement based on benefit-sharing scenarios will need to take account of this.

The challenge appears not only in the identification of benefits but also to put them in a realistic framework as funded and agreed upon by EN governments on multilateral basis. Once this is done, the next important step would be to treatise the benefit sharing. Efforts should hence be made to come up with the Eastern Nile Basin Benefit sharing Treaty rather than restricting ourselves to the Eastern Nile Basin Waters Agreement.

Conclusions

Due to the growing demand for freshwater in many parts of the world, including Africa, water scarcity is becoming the norm than exception. In Africa, where there is a large dependence on transboundary waters and about one-third of its people live under water scarcity situation, transboundary cooperation becomes imperative. Cooperation does not only avail more water in the basins but also tackle problems related to soil erosion, drought, food insecurity, and power shortage and water pollution.

Transboundary cooperation can yield positive sum outcomes if more emphasis is made on the sharing of benefits rather than water. This does not however mean that the volumetric allocation of shared waters should be shelved aside. The emphasis on sharing of benefits than water is borne more out of pragmatism and convenience than persuasion.

Looked at from upstream-downstream perspective, joint or cooperative investments at both levels can yield a stream of shared benefits, including flood control, silt reduction, power production and added water. These shared benefits in turn enable the riparian states to ensure food security, mitigate drought and avail renewable energy. It is incumbent upon the riparian states to list out, value and share the benefits in a manner that will be taken as fair and transparent.

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 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 whom 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 NBI in 1999 has been marked as a strong departure compared to its predecessors. ENSAP and with it

ENTRO have identified a number of project, of which JMP stands as one of the most significant ones. It aims to undertake multipurpose and multi-country programs of activities encompassing watershed and environmental management; enhanced agricultural production and renewable energy. When this project gets grounded, it could mitigate natural resources degradation, alleviate poverty and enhance agricultural production in the Eastern Nile sub-basin. There is a possibility for the three Eastern Nile countries to accrue transboundary benefits.

As things stand now, the three EN 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 EN countries should establish institutions that will manage benefit sharing scheme and address issues such as mechanisms of delivering benefits.

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Transboundary Water Governance Institutional Architecture: Reflections from Ethiopia and Sudan

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Abstract

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.

Introduction

According to IWMI's 2006 Comprehensive Assessment Report, water scarcity (both physical and economic) is a major concern for developing countries in their effort to move out of poverty and meet the Millennium Development Goals (Molden 2007). The Comprehensive Assessment also argues that with the current global water demands and the increasing population, the demand for water will outstrip the available and potential water resources if the current water development model is continued. Furthermore, water resources do not coincide with administrative or political boundaries. Consequently, there is a need to go beyond national interests and engage in transboundary water cooperation. This paper is based on the ongoing upstream-downstream project which is being carried out by IWMI and its partners in Ethiopia and Sudan. This project covers the transboundary Blue Nile River, which is known as the Abbay in Ethiopia.

The concept of transboundary natural resources management is strongly related to 'bioregionalism', which views the world as consisting of contiguous but discrete 'bioregions' with the boundaries of each bioregion defined by nature rather than legislation or political expedience (cf. Wolmer 2003). According to Tessera "The Nile River Basin in general hosts problems which call for regional or sub-regional cooperation" (Tessera 2006: 44)" The severe erosion in the upper catchments of the Abbay/Blue Nile River Basins has impacts downstream within and across political borders. Since river basin problems cut across political borders, cooperation across the Nile River Basin is necessary. In river basin management, absolute sovereignty does not work since transboundary cooperation is needed. Sudan, for instance, views upstream reservoirs in Ethiopia as being an efficient way to control floods and an efficient way to store water as it reduces loss of water through evaporation in either Sudan or Egypt which have higher temperatures compared to Ethiopia. The Wall Street Journal adds that 'Engineers from both countries agree that dams in the cool and moist Ethiopian highlands, storing water in deep natural gorges, would lose far less water to evaporation than the Aswan Dam in the hot, dry Egyptian desert. They calculate the savings on evaporation could compensate for the amount of water Ethiopia proposes to use for irrigation' (The Wall Street Journal 23 November 2003).

The Nile Basin Initiative is an attempt to promote an Integrated Water Resource Management approach within the Blue Nile River Basin. This is based on the realization that sedimentation and siltation of dams and reservoirs downstream is a function of upstream land uses. The increased frequency and magnitude of drought in the Ethiopian Highlands has also affected the quality and quantity of water downstream in Sudan and Egypt (cf. Tessera 2006). The impact of environmental degradation is forcing countries to cooperate in order to address 'common dangers' which cannot be effectively addressed without the cooperation of other countries. Tessera (2006) notes that the impact of land degradation in the sub-basin can hardly be solved by any means other than cooperative watershed management. Silt accumulation in the Roseires Dam in Sudan is largely attributed to the upstream activities in the Ethiopian Highlands. The Atbara and Blue Nile are said to contribute 53% of seasonal waters but contribute 90% of the sediment in the Nile (Tessera 2006). Sedimentation is also negatively affecting the Sennar and Aswan Dams and the related irrigation schemes. The Upstream-Downstream project has found that total storage loss in Sennar due to sedimentation is 660 Mm3 (i.e. 70% of its original capacity) since the dam was built in 1925 and for Roseires is 1,200 Mm3 (i.e. 40% of original capacity) since the dam was built in 1964 (Field visit 22-27 February 2008). Despite sedimentation being bad for most dams and water reservoirs, in Egypt the building of the Aswan High Dam has further denied downstream farmers the rich silt which made the Nile valley very productive. This complicates assessment of costs and benefits of upstream downstream water users within a river basin.

Downstream impacts of sedimentation include reduced benefits from irrigation, hydropower, navigation, water quality, water quantity, flood control, fishing, and recreation. Poor water quality will result in more expensive water purification methods such as the special filters for the Khartoum water supply (Shapland 1997). Removal of sediment in Sudan's reservoirs and related irrigation schemes accounts for half of the operation and maintenance budget (cf. Ahmed 2000; Conway 2000). Sudan is further spending US$800 million in flood mitigation measures. If mechanism could be put in place upstream which would result in the reduction of, say, the flood mitigation budget, Sudan may be willing to contribute financially towards sustainable upstream watershed management costs. The Payment for Environmental Services (PES) component of this study has found out that farmers are largely willing to pay in kind – rather than in cash for improved upstream land and water management which benefits the downstream dwellers (Alemayehu et al. 2008).

Steps towards transboundary cooperation

Attempts at cooperation and benefit sharing within the Blue Nile Basin go back to the 1960s. The 1959 Water Sharing Agreement allocated the Nile waters as follows: Egypt 66%, Sudan 22% and surface evaporation and surface seepage at High Aswan Dam at 12%. Ethiopia was not included in this water sharing agreement, nor were the other basin countries (FAO 2007, p.8).

In 1967 the Hydrometeorological Survey of the Equatorial Lakes (Hydromet) was launched with the support of the United Nations Development Fund (UNDP), with the primary objective of enhancing the collection of hydro meteorological data. Hydromet operated until 1992. In 1993 the Technical Cooperation Commission for the Promotion and Development of the Nile (TECCONILE) was formed whose intention was to promote development (World Bank 2005). In 1993, the Canadian International Development Agency (CIDA) funded 10 Nile 2002 Conferences which aimed at promoting dialogue and cooperation within the Nile Basin. In 1995 CIDA supported the development of a Nile Basin action plan under the auspices of TECCONILE. In 1997 the Nile Basin Council of Ministers requested the World Bank to lead and coordinate their donor activities (World Bank 2005). In 1997, with UNDP support, the riparian countries also established a forum for dialogue on a 'Cooperative Framework' for the Nile Basin, with three representatives from each riparian country.

In February 1999, the Nile Basin Initiative succeeded the TECCONILE. The NBI was spearheaded by the Council of Ministers of Water Affairs of the Nile Basin states (Nile Council of Ministers or Nile-COM). 'The NBI seeks to develop the river in a cooperative manner, share substantial socioeconomic benefits, and promote regional peace and security. The NBI started with a participatory process of dialogue among the riparian countries that resulted in their agreeing on a shared vision: to achieve sustainable socioeconomic development through the equitable utilization of, and benefit from, the common Nile Basin water resources, and a Strategic Action Program to translate this vision into concrete activities and projects' (World Bank 2005).

Institutional Design Issues

Transboundary River Basin institutions must represent the interests of the member states without bias. This will result in the transboundary institutions acquiring legitimacy and the necessary support.
Enabling policies and institutions should be in place to be able to monitor and enforce compliance. The institutions carrying out this exercise must have meaningful powers but they must also be accountable to both the upstream and downstream water users, with higher level institutions having oversight powers only. It is important to recognize that the need to satisfy societal requirements has expanded beyond the objective of simply water supply. Increasingly a diversity of concerned parties and organizations seek input into water related decision-making processes. The downstream and upstream water users need to participate actively, not only in the first negotiation process, but also in the fine-tuning of the transboundary water management arrangements over time.

Transboundary water governance institutions must not be disconnected from local level institutions. This entails that there must be nested institutional arrangements where small local institutions form the building blocks, which come together to create larger management institutions. Thus multiple layers of management that link small-scale interactions to larger, and ultimately basin scale actions. Experiences elsewhere demonstrate that there tends to be a disconnection between the river basin management institutions and the water users who are supposed to be served by the transboundary water management institutions. For instance, at societal level, the Mekong River Commission remains far removed from the basin water users (Hirsch 2006).

Experiences from the southern Africa region through the Southern African Development Community (SADC) Protocol on Shared Watercourse Systems and its subsequent amendments has helped to de-securitize the issue of transboundary water management (Turton 2008; Ramoeli, 2002) and enabled Transboundary water management institutions to be viewed as part of regional integration.

An institutionalized transboundary knowledge database is an important component of sharing knowledge and resulting in confidence in the data used by the transboundary institutions. The data is available to all stakeholders. In the Nile River Basin – the Nile Basin Initiative is attempting to do that. The southern African countries have similar initiatives for the Limpopo and Zambezi River Basins (Turton 2008; Ramoeli 2002). The Volta Basin Technical Committee also includes all the six riparian countries in data collection and validation (Lautze et al. 2008).

Benefit sharing in transboundary water governance

Whilst benefit sharing seems to have made significant strides theoretically, there are still a number of operational issues which need to be resolved in the context of benefit sharing in transboundary water governance. In this paper, benefit sharing is viewed as offering flexibility to riparians to separate the physical distribution of river development (where activities are undertaken), from the economic distribution of benefits (who receives the benefits of those activities.) This allows riparians to focus firstly on generating basin-wide benefits (a positive-sum exercise), and secondly on sharing those benefits in a manner that is agreed as fair (see Sadoff and Grey 2005; cf. Turton 2008). Research findings in the Upstream-Downstream study have to be juxtaposed to the wealth of global experience on benefit sharing (Sadoff and Grey 2002, 2005; Yu 2007). The Payment for Environmental Services (PES) results under the upstream-downstream project are an important move in that direction. Benefit sharing takes place at various scales and levels. In Ethiopia for instance, it may vary from a small watershed project, to regional government, which may or may not coincide with hydrological zones, going up to the transboundary level where international law and conventions begin to apply.

Who benefits and who loses from benefit sharing – some studies from Latin America are beginning to caution that benefits can potentially accrue to the most powerful whilst not addressing the needs of the poor and female headed households. An understanding of the power relationships at different scales will help inform the structuring of benefit sharing. In the Senegal River Basin, for instance, an artificial river flood is provided each year in order to support local livelihoods (UNESCO 2003).

How do you develop sustainable and targeted funding mechanism which will be used to 'compensate' those bearing the costs of watershed and transboundary river basin management? Selling electricity at a cheaper price to the upstream country might benefit the country as a whole – but not the specific watershed community. This might result in poorly targeted incentives which might not reward the poor upstream farmers who are bearing the cost of upstream river basin management. How are the payments going to be made? Should the reward be for only good management or also for actively improving the upstream areas within the river basin? Who pays and for what? (Poras and Grieg-Gran, 2007). Most current transboundary benefit sharing initiatives are largely funded by donors and non-governmental organizations.

Upstream-downstream cooperation delves into broader international relations and political economy issues. What makes transboundary basin level management successful? What is the power balance amongst the states that are involved (Hegemony, neo-hegemony or realisms in international cooperation)? Transboundary Basin Management in the Blue Nile seems to indicate power asymmetry that might be reflected in who shapes what is considered 'knowledge'. Despite the establishment of ENTRO, 'scientific'5 data still seem to be contested and hardly shared (although this could be improving). Confidence building and establishing trust will need to take place first before detailed discussions on benefit sharing (cf. Sadoff and Grey 2005).

Transboundary benefit sharing presents different benefit sharing matrices in which water allocation need not be the only potential benefit. It is possible to share benefits from water without sharing the actual water (cf. Sadoff and Grey 2005). Within the Blue Nile this is still a contested issue which needs to be resolved especially in light of the 1959 Water Sharing Agreement between Egypt and Sudan. Any transboundary river basin management has to be grounded within the specific political and historical settings rather than being an imposition of blue print solutions (cf. Merrey et al 2007).

[5] Scientific data especially concerning the Nile can easily be politically 'tainted' in order to reflect the various country positions?

Finally, transboundary benefit sharing is premised on the assumption that it's feasible to establish these costs and benefits. In most river basins good practices take a lot of time to produce results and this is further complicated by natural phenomenon such as climate change and changing rainfall patterns which also potentially contribute towards land degradation. Establishing causality in most river basins causes a lot of difficulties. 'Values' are also normative, and largely depend on the specific contexts and communities and it is often difficult to have a common understanding across sub-national level – let alone international boundaries. The physical size of the basin means that local level institutions dealing with local issues often find it difficult to acknowledge issues facing others in the basin, who may be located many hundreds of kilometers away, and for whom the key issues may be very different.

Conclusion

While transboundary water governance is the way forward for an integrated approach to water management, there are number of issues that such an institutional architecture needs to address. For the fluid 'benefits beyond boundaries' to be meaningful to all the individual countries involved, the issue of benefit sharing mechanisms need to be critically reviewed in practice. Equity has also to be assessed at various levels from the transboundary to the local level. Will equity at the transboundary level necessarily imply equity at local level? How can all the stakeholders' maxmize the benefits whilst minimizing the costs. Finally, transboundary institutional architecture has to be grounded in the water historical trajectories. How do you deal with past agreements on water sharing while moving forward with one shared vision on transboundary water management? This is a further complex equity issue which addresses the weight that needs to be given to existing water use.

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Prospect of Payments for Environmental Services in the Blue Nile Basin: Examples from Koga and Gumera Watersheds, Ethiopia

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Abstract

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.

Key words: Upstream; downstream; improved land and water management; Blue Nile Basin; Transboundary Rivers

Introduction

The Nile Basin is one of the oldest river basins in the world where its ancient inhabitants managed the land and water resources to make the valley a cradle of civilization, and hitherto the national economy of the riparian countries remains heavily dependent on land and water resources (Arsano, 2004). Competition for water exists between nations and economic sectors. Present and potential conflict over water in the basin and watershed scales stems from the increased food and agricultural needs generated by a rapidly growing population. This potential conflict can also be viewed from the perspective of deteriorating regulating ecosystem services in upstream and its impacts on water quality and irrigation and hydropower infrastructures (e.g. sedimentation) in downstream parts of the basin (Arsano, 2004; Haileslassie et al., 2008). In view of postulated new development projects (e.g. irrigation and hydropower) along the Blue Nile, to meet countries growing food demand, it is important to explore mechanisms that can restore healthy ecosystem functioning and sustainable water uses in upstream and downstream regions of the basin.

Payment for Environmental Services (PES) is a new and more direct conservation paradigm to finance conservation programs. The principle of PES referred as those who provide environmental services should be compensated for doing so and those who receive the services should pay for the provisions (Stefano, 2006; Wunder, 2005). Thus, PES is a sound principle to share the costs and benefits of environmental conservation on an equitable basis among all stakeholders. This also applies to a watershed and means: upstream communities produce watershed protection services at an opportunity cost, while the downstream communities are consumers of these services with no payment. Such benefits are positive externalities to the downstream communities and PES aims at internalizing these benefits and to channel it to the upstream communities as an incentive to pursue their watershed conservation practices. In addition to its offsite impacts, erosion directly affects the livelihoods of the upstream community through land degradation and dwindling agricultural productivity.

Therefore, PES principles applied to watershed management must accommodate the downstream farm households willingness to compensate (WTC) the ecosystem service provider and willingness of the both upstream and downstream farmer to pay (WTP) for restoration of watershed's ecosystem services. To date little attention has been paid to the use of PES as a tool for improved land and water management. This study was undertaken in Gumara and Koga watersheds of the Blue Nile Basin (Ethiopia). Large scale irrigation schemes are under construction in the downstream parts of these watersheds. In both watersheds, high rates of erosion and sedimentation are anticipated and mechanisms to mitigate impacts on the livelihoods of the community in upstream and reservoirs in downstream are a major concern. The major objectives of this study were:

i) To investigate willingness of the sample farm households to pay (WTP) for restoration of ecosystem services and to examine the downstream farm households willingness to compensate (WTC) the ecosystem service provider (i.e. the upstream farmers);
ii) To explore socio-economic and institutional drivers of WTP and WTC.
iii) To estimate the mean value of WTP and WTC.

Material and Methods

Location and biophysical settings of the study areas

Gumera and Koga watersheds are located in Tana sub-basin (Eastern part of the Blue Nile, (Figure 2.1.)). The rivers draining Koga watershed originate from Mount Wezem and discharge into Gilgel Abay which eventually drain into Lake Tana (Figure 2.1.). While Gumera originates from Mount Guna and discharges into Lake Tana. The high run-off and associated sediment flow from the upper part of these watersheds have serious consequences on the downstream users and water bodies (e.g. Lake Tana and reservoirs developed for irrigation). Koga and Gumera watersheds exhibit an elevation range of 1890-3200 and 1782-3704 meter above sea level (masl (EMA, 1980)) respectively.

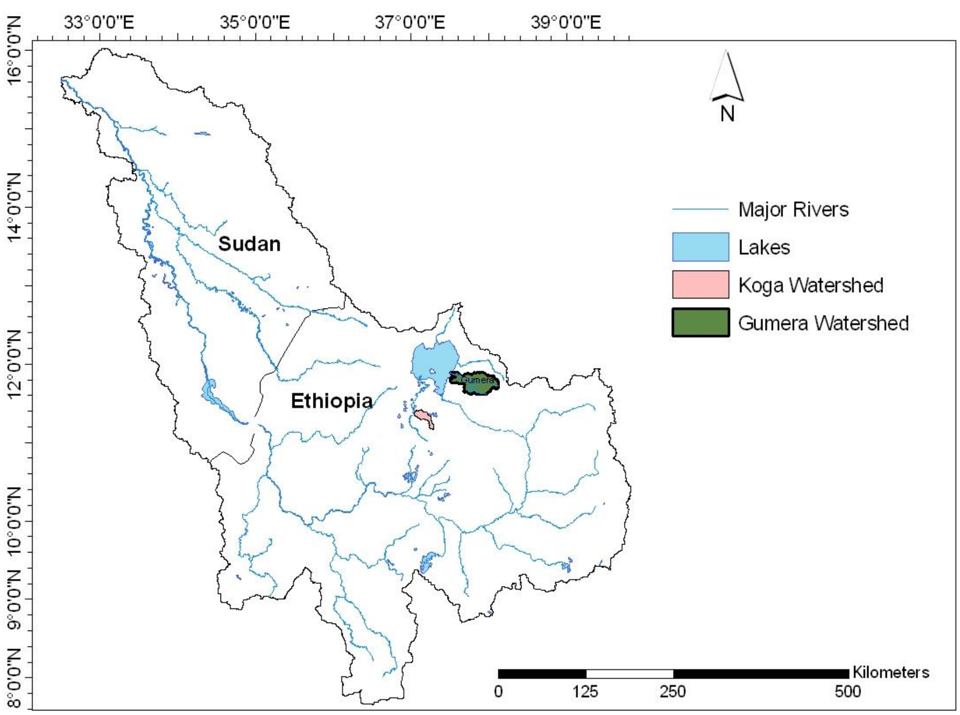

Figure:1 Location map of Koga and Gumera watersheds

As the result of this elevation difference, variables such as climate, vegetation and soils show discrepancy (WRDA, 1994; FAO, 1986; FAO, 1984). The study watersheds exhibit two major traditional climatic zones in Ethiopia: the **DEGA (2300-3200 MASL) AND WOYNADEGA (1500-2300 MASL).** Woynadega climatic zone has a cool to warm semi humid climate, with mean annual temperatures more than 200C. Dega climatic zone has a cool and humid climate with annual temperature ranging between 10^0C and 20^0C. The highest mean monthly rainfall, for both study watersheds, is recorded in July while the highest potential evapotranspiration is in May.

Agriculture is the main stay of livelihood in both study watersheds. Crop and livestock production are fully integrated and thus the production system can be referred as crop-livestock mixed system. Traditionally, rainfed production of cereals, dominated by barley (*Hordeum vulgare*) and wheat *(Triticum durum* and *Triticum aestivum)* in upstream areas and teff (*Eragrostis tef)*, millet *(Eleusine coracana)*, noug (*Guizotia abyssinica*) maize (*Zea mays*) in the downstream, is the main livelihood strategy in the two watersheds. Additionally rice (*Oryza sativa)* and pulses such as chickpea (*Cicer arietinum*) and rough pea (*Lathyrus hirsutus***)** are important crops in the downstream of the Gumera watershed. In the study watersheds, livestock play an increasingly important role in household budget and coping strategies during times of drought. Livestock provide meat, milk, energy. Manure fulfils important role through nutrient cycling between and within farms, which enables the continued use of smallholder farms. Farmers usually have cattle (e.g.*Bos indicus*), sheep (*Ovis aries*), goat (*Capra hircus*), horse (*Equus caballus*), and donkey (*Equus asinus*).

Frequent flooding and severe erosion (1,643 Mg $km^{-2}yr^{-1}$) are major problems in the downstream and upstream of Gumera watersheds respectively**.** In Koga watershed, erosion rate as high as 1.66 Mg $km^{-2}yr^{-1}$are reported (MOWR, 2005). In response to increasing demand for food and contrastingly dwindling agricultural production, the Ethiopian government is considering Tana sub basin as the development corridor and thus embarked on irrigation and hydropower development projects in the sub basin. Accordingly dams in Gumera and Koga are under construction to irrigate 23,000 and 7,000 ha respectively (MoWR, 2005).

Sampling and data collection technique

This study is part of the project called "Improved water and land management in the Ethiopian highlands and its impact on downstream stakeholders dependent on the Blue Nile Basin". The primary goal of the project is 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 minimum negative impacts – and possibly positive impacts – downstream within Ethiopia and across international borders (e.g. Sudan). Therefore the sampling process focused on highlands of the Blue Nile basin and stratification of community into upstream and downstream.
In this study a multi-stage sampling technique was used to select the sampled farm households. In the first stage, Koga and Gumera watersheds were objectively selected as irrigation schemes are under development and upstream of the watersheds are degrading

due to strong magnitude of erosion. More importantly, it is often indicated that the sedimentation of those dams and reservoirs will reduce the lifespan of the schemes and thus mechanisms of improving regulating ecosystem services are strongly sought. In the second stage, Peasant Associations (PAs), the lowest administrative units in Ethiopia, were selected using random sampling procedure. In the third stage, sample farm households were selected from each PAs using the lists of the farm households (in each PAs) obtained from the PAs offices. 175 respondents from the upstream and 150 farmers from the downstream communities were selected and a total of 325 farmers were interviewed. Finally structured and pretested questionnaire was administered to the sample farm households, in March 2008, to collect data on socioeconomic, policy and institutional characteristics that related to households' WTC and WTP for improved land and water management activities.

Theoretical and analytical models

Theoretical framework and hypotheses

Households decision whether to participate in a PES scheme or not could be modeled using random utility theory (RUT). Consider an individual who has to choose between two choice set of alternatives, for instance whether to participate or not participate. Assuming that the individual has perfect discriminatory power and unlimited information-processing capacity, allowing the individual to rank the alternatives in a well-defined and consistent manner, then the individual acts rationally and chooses the alternative with the highest level of utility. The researcher however does not observe the individual's utility function. The indirect utility function (U_i) can be decomposed into a utility function that depends solely on factors that are observed by the researcher (V_i) and other unobservable factors that influence the consumer's choice (ε_i). The utility faction could, hence, be written as:

$$U_i = V_i + \varepsilon_i$$

Equation 3 gives the true but unobservable (latent) utility for alternative i, V_i is the observable systematic component of utility, and ε_i is the factor unobservable to the researcher and treated as a random component (Hanemann, 1984). V_i thereby becomes the explainable proportion of the variance in the choice and ε_i the non-explainable. As the researcher cannot observe the individual's true utility function, a probabilistic utility function is used in the estimation. The most appropriate probabilistic choice model to apply depends on the assumptions made about the random parameter.

Assuming that the individual can choose between two alternatives, i and j, then the probability that alternative i is chosen is given by:

$$P_i = \Pr ob(U_i > U_j) = \Pr ob(V_i + \varepsilon_\varepsilon > V_j + \varepsilon_j) = \Pr ob(V_i - V_j > \varepsilon_j - \varepsilon_\varepsilon) \quad i \neq j$$

From this it can be seen that the higher the probability for choosing an alternative, the larger the difference in observed utility. Since probability is defined on a cardinal scale, so are the estimated utility scores (which is the reason why we obtain meaningful WTP estimates). The input of the model is the observed choices, while the output, i.e. what is to be estimated, is the difference in utility for the two alternatives, ($V_i - V_j$), characterized by the utility for each attribute. Every respondent makes a discrete choice and has chosen either alternative i or alternative j. As the choices are aggregated over individuals (taking personal characteristics into account, if possible), the total observed per cent of the sample that chooses alternative i is interpreted as the probability that an individual with specific personal characteristics chooses alternative i. This is the same as saying that the probability of choosing alternative i increase as the difference in estimated utility between the two alternatives increases. Treating V_i as a conditional indirect utility function and assuming that utility is linearly additive, the observable utility for alternative i can be written as:

$$V_i = \beta x_i + \mu_i$$

where $x_i = (x_{1i}, x_{2i}, ..., x_{pi})$ is the vector of the attributes (including a possible price attribute) and covariates that influence the choice for alternative i, and β is the weighting (parameters) of the attributes.

The model given in Eq. 5 can be used to model the determinants of WTP. Furthermore, following the theoretical model and empirical results of different studies on PES elsewhere as well as considering the information from the informal survey, the following x_i variables were hypothesized to influence farmers WTP and WTC

Educational level of the household head: This is a dummy variable, which takes a value 1 if the household head is literate and 0 otherwise. Farmers' ability to acquire, process and use information could be increased by education. Thus, education has been shown to be positively correlated with farmers WTP and WTC for improved land and water management practices (Tegegne, 1999; Ervin and Ervin, 1982; Noris and Batie, 1987, Pender and Kerr, 1996, Asrat et al., 2004). Education is expected to reflect acquired knowledge of environmental amenities. Therefore, it is hypothesized to have a positive role in the decision to participate in improved land and water management practice so as to be farmers WTP and WTC for improved land and water management activities.

Age of the household head: The effect of farmer's age in improved land and water conservation decision can be taken as a composite of the effect of farming experience and planning horizon. Whereas, longer experience has a positive effect, young farmers on the other hand may have longer planning horizon and hence, may be more likely willing to participate in improved land and water management. With more age farmer can become risk averse to engage in improved land and water conservation practices. The net effect could not be determined a priori. Featherstone and Goodwin (1993) suggested that age greatly matters in any occupation and it generates or erodes confidence. As a matter of fact, older farmers are more likely to reject in practicing improved land and water management practices. On the contrary, younger farmers are often expected to take risk due to their longer planning horizon (Tesfaye et al., 2000; Befikadu et al. 2008). Therefore, in this study it is hypothesized that age has a negative influence on the willingness to participate on improved land and water conservation activity.

Asset holdings: This variable represents the total amount of asset such as livestock and tree. Animal raring is one component of the farming system of the study area. The number of livestock owned (in tropical livestock unit (TLU)) by a farmer was hypothesized to positively relate to farmers' willingness to participate in improved land and water management practices (Haileslassie et al., 2008, under review). Farmers own more number of livestock, the probability of willing to pay for improved land and water management increases (Dasgupta (1989). On the other hand, number of trees (e.g. *Eucalyptus camaldulensis*) on homestead and distance farm plots was hypothesized to influence WTP and WTC positively. Farmers in the study areas are claiming that tree plating is becoming the best strategy to generate cash for the farm household (Pender and Kerr 1997).

Size of own cultivated land: This variable represents the total owned cultivated land by a household. It is an indication for the wealth status of a household. As land ownership is equated with asset ownership, a farmer with large cultivable land is considered to be wealthy. In addition, a farmer who owned a large size of cultivated land is expected to have enough land to practice improved land and water management activities. Farm size is often correlated with the wealth that may help ease the needed liquidity constraint (Bekele and Holden, 1998). Norris and Batie (1987) found that large farms are more likely to use conservation technology than small farms. Therefore, it is hypothesized that size of the cultivated land is positively related with WTP and WTC the cost of improved land and water conservation activity.

Distance to the nearest development center: This variable refers to the time a household may need to walk to get the extension agent. The further an extension office located from farmers' home, the less likely it is that farmers would have access to information. Therefore, distance to the nearest development center is expected to be negatively related to farmers' willingness in improved land and water management practices.

Dependency ratio: An increase in consumer – worker ratio (dependency ratio) reduces the capability to meet subsistence needs, and also increase the personal rate of time preference (Bekele and Holden, 1998). Thus, this variable is expected to have a negative effect on farmers' willingness to participate in improved land and water conservation activities.

Slope of the parcel: This variable is a dummy variable for slope category of a parcel, which takes a value 1 if the slope is steep and 0 otherwise. The slope category of the parcel has been found to positively affect the farmer's decision to invest in conservation technology (Ervin and Ervin, 1982; Norris and Batie, 1987; Gould et al, 1989). The slope variable is thus expected to have a positive effect on farmers' willingness to participate in soil conservation practices.

Information, training and visit: Information, training and visiting has big role in awareness creation about improved land and water management practice. It increases farmers' willingness to practice improved land and water management activities. In the context of this study, it refers to farmer participating in soil and water conservation training program, radio/video show, participation on farmers' field day, and participation in land and water conservation related meetings. If a nation desires a progressively increasing number of farmers to undertake improved watershed conservation activities, the implementation of substantial training program should get a high priority (Joyce, 2001). Therefore, information, training and visiting were expected to be correlated positively and significantly with farmers' willingness to participate in improved land and water management practices.

Assistance in land and water conservation practice: This variable is a dummy variable, which refers to any form of watershed conservation support provided to the farmers in the study area. It takes a value 1 if the respondent received any assistance from any source and 0 otherwise. It is obvious that improved land and water conservation activity is costly and it is difficult to see the benefit in the short term planning horizon. In other words, physical watershed conservation practices require more labor, cash and materials, which the farmer cannot afford. It is expected assistances in cash, material, technical and any other incentives encourages the farmers to engage in conservation practices and in this study we hypothesized that assistance will have positive and significant effects on farmers' willingness to participate in improved land and water management practices.

Contingent valuation methods and scenario settings

For this study, contingent valuation method (CVM), econometric estimation and descriptive statistics were applied. Contingent valuation method (CVM) can estimate the value that a person places on a good. Many applications of the CVM deals with public goods such as measuring WTP for environmental changes, for risk assessment, in litigation, in policy formulation and for evaluating investments (Alberini and Cropper, 2000). In this study, we used the so-called double-bounded dichotomous-choice format to illicit users' WTP. Initially land degradation impacts, possibilities and benefits of rehabilitation covering the following scenarios were elaborated to the sample farmers:

- Soil erosion has a serious on-site impacts agricultural productivity through removal of the most nutrient-rich top soil (e.g. 1,643 Mg $km^{-2}yr^{-1}$ in Gumera and 1.66 Mg $km^{-2}yr^{-1}$ for Koga watershed (**show photos**). On average this will result in a yield loss of equivalent to 200US$ ha^{-1} yr^{-1}.
- Off-site damage of erosion consists of deterioration in the quality of water and downstream sediment deposition on reservoirs (**show photos**). For instance, in Gumara, if the current situation will continue, the reservoirs capacity will decrease by 2% in five years and this has strong implication on irrigable areas and yield.
- But this trend can be mitigated through an integrated watershed management intervention that involves participation of upstream and downstream farmers. The estimated average investment for such land rehabilitation in Ethiopia is 1370 ha^{-1}. Farmers' participation will be through WTP and WTC either in labor or in cash.

Next, a dichotomous choice payment question asks the respondent if he/she 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, a follow up bid is presented as $B_i^d andB_i^n$, where $B_i^d \leq B_i \leq B_i^u$). The bid value (B_i) is varied across respondents. It is important to note that the dichotomous choice approach does not observe WTP directly: at best, we can infer that the respondent's WTP amount was greater than the bid value (B_i^d) or less than the bid amount (B_i^n), and form broad intervals around the respondent's WTP amount. Mean WTP is estimated statistically from the data of responses obtained from respondents using STATA software.

Econometric estimation

Double-bounded dichotomous choice payment questions typically require a different type of statistical analysis, based on the assumption that if the individual states his/her willing to pay for the given bid amount, his/her WTP might be greater than the bid. If the individual declines to pay the stated amount, than his/her WTP might be less than the bid. In both cases, the respondent's actual WTP amount is not observed directly by the researcher. Let WTP* be unobserved willingness to pay, which is assumed to follow a distribution F (θ), where θ is a vector of parameters, and form an indicator, I that takes on a value of one for 'yes' responses and zero for 'no' responses. The probability of observing a 'yes' (or I =1) when the respondent has been offered a bid equal to B_i is:

$$\Pr(I_i = 1) = \Pr(WTP_i^* > B_i) = 1 - F(B_i;\theta),$$

Whereas the probability of observing a 'no' (or I =0) is simply $F(B_i;\theta)$, i.e. the cumulative density function (CDF) of WTP evaluated at the bid value. The log likelihood function of the sample is:

$$\sum_{i=1}^{n}\left[I_i.\log(1 - F(B_i;\theta)) + (1 - I_i).\log F(B_i;\theta)\right]$$

If WTP is normally distributed, $F(\theta)$ is the standard normal cumulative distribution function and $F(B_i;\theta) = \Phi(B_i;\sigma - \mu/\sigma)$, where the symbol Φ denotes the standard normal CDF, μ is mean WTP and σ is the standard deviation of the distribution. The parameters θ can be estimated directly by maximizing (2) using Maximum likelihood estimation technique. The econometric results are reported in section 4 below.

Results and Discussion

Descriptive results

Sample household characteristics for selected continuous variables

Table 1 depicts eight continuous variables that characterize households' WTP and MWTP across the sample strata. The mean age of the sample farm household head was 42.8 and the mean age values for willing and non willing farmer, to pay for improved watershed management practices, were 41.1 and 46 respectively (Table1). A closer look at the age structure of the sample farmers indicates that the mean age of those willing farmers were younger than non willing farmers.

The mean size of land holding by the sample farm household is depicted on Table 1. The overall mean value of land holding in the study sites was 1.8ha. There were no apparent differences, in mean size of land holding, between upstream and downstream. Mean differences in size of land holdings by willing and non-willing farmers was not also strong (about 1.81 ha for willing and 1.84 ha for non-willing with T value of 0.292). Perhaps frequent land redistribution that took place in the region can better explain this weak disparity. Despite the increasing trends of land leasing practices in the study watersheds, the mean value of leased-in land by the sample household was only 0.0002 ha and thus could not influence the overall mean of land owned.

Unlike the size of land holding, mean values of assets on land (e.g. number of trees and livestock measured in Tropical Livestock Units (TLU6)) showed apparent differences between upstream and downstream and between the willing and non-willing farmers. For example the mean values of trees per sample farm households for downstream farmers were three times higher than the upstream. There were also distinct differences between non-willing (149.6 trees per sample farm households) and willing (556.2) farmers. We found that number of trees owned were negatively correlated with distances of the farm to nursery sites (r= 0.56; p=0.03). Similar trends of TLU possession were observed. In general, the association between farmers' willingness to pay in cash for improved land and water management and the assets on land could be accounted for by the fact that trees and livestock are major sources of household cash income and thus enable the farmers to invest in improved land and water management.

Based on adult male equivalent (Table1), the mean available labor force per sample households was 3.04 and 2.64 for male and female respectively. In both upstream and downstream the mean values for adult labor forces tends to be stronger for male than the female and clustered around 3 and 2.5 respectively.

Sample household characteristics for selected dummy variables

Descriptive result of selected seven dummy variables is indicated on Table 2. Three of those are related to smallholders' institutional environment (i.e. access to credit, assistance and training in improved land and water management). Institutions are critical for farmers' decision in interventions. They create an environment and incentives that can either enable or undermine their efforts (e.g. Asrat et al., 2003). In upstream part of the study watersheds, 62% willing and 38% non-willing farmers got credit during the past twelve months. Respective figure for the downstream area was 80% and 20%. This result indicated that shortage of money (liquidity constraint) might discourage farmers to engage in improved land and water conservation activities. Farmers' willingness to spent

[6] The TLU values for different species of animals are: 0.7 for cattle; 0.8 for horse/mule; 0.5 for donkey; 0.1 for goat/sheep and one Tropical Livestock Unit (TLU) is equal to 250 kg

time for improved land and water management practices was higher than to spend some amount of money. This could be related to limited income source (see Appendix 1).

Education increases farmers' ability to get process and use information (Asrat et al., 2003). Our results show that 53 per cent of the sample farm households were illiterate. There was no significance difference between the upstream and the downstream community. Interestingly, the respective percentages for willing and non-willing farmers vary across upstream and downstream and, in both cases, indicated that the majority of farmers who were willing to pay for improved land and water managements were literate (Table 2). A very closely related dummy variable is farmers training in land and water conservation practice. This helps farmers to know available options for soil conservation and makes land users more receptive to conservation structures. In our result, a good proportion of those willing to pay, reported to have participated in different trainings related to improved land and water management practices. For example, out of the total upstream sample household heads, 65% of the willing and 35% of non willing farmers have participated in training respectively. Respective values for the downstream sample farm household were 72% for willing and 28% for non willing farmers (Table 2 and Appendix 2). There were also stronger relation between farmers' willingness to pay and institutional variables such as access to credit, distances to nursery sites and access to development center.

Table1 Descriptive results of continues variables for WTP in cash (Koga and Gumera watersheds, Blue Nile basin, Ethiopia)

Strata	WTP in cash		Age	Tree	DOA (in km)	DNR (in km)	TLU	CLI	Labor	
									Adult female	Adult male
Upstream	Non willing	Mean	46.50	78.57	14.80	6.24	4.20	0.26	2.79	3.22
		Std. D	13.61	158.72	4.96	5.91	2.64	0.51	1.16	1.39
	Willing	Mean	41.14	264.48	13.12	4.77	5.77	0.17	2.62	3.05
		Std. D	12.95	738.25	3.80	3.88	4.94	0.43	1.34	1.41
	Total	*Mean*	*43.47*	*183.74*	*13.85*	*5.41*	*5.09*	*0.21*	*2.69*	*3.13*
		Std. D	*13.47*	*571.28*	*4.41*	*4.90*	*4.17*	*0.47*	*1.26*	*1.40*
Downstream	Non willing	Mean	44.95	291.68	16.49	3.54	4.88	0.21	2.71	3.32
		Std. D	12.84	816.84	5.64	3.90	2.34	0.61	1.21	1.97
	Willing	Mean	41.13	814.08	13.04	3.54	5.83	0.21	2.54	2.82
		Std. D	12.09	1691.80	5.43	2.40	4.32	0.48	1.18	1.46
	Total	*Mean*	*42.09*	*681.74*	*13.91*	*3.54*	*5.59*	*0.21*	*2.58*	*2.95*
		Std. D	*12.35*	*1532.93*	*5.67*	*2.84*	*3.93*	*0.51*	*1.19*	*1.61*
All samples	Non willing	Mean	45.98	149.61	15.36	5.34	4.42	0.24	2.76	3.25
		Std. D	13.32	495.35	5.23	5.45	2.55	0.54	1.17	1.60
	Willing	Mean	41.13	556.21	13.08	4.12	5.80	0.19	2.57	2.93
		Std. D	12.47	1357.50	4.73	3.23	4.61	0.46	1.26	1.44
	Total	*Mean*	*42.83*	*413.59*	*13.88*	*4.55*	*5.32*	*0.21*	*2.64*	*3.04*
		Std. D	*12.97*	*1147.93*	*5.02*	*4.18*	*4.06*	*0.49*	*1.23*	*1.50*

Source: the survey result
DNR is for distances to nursery; DOA is for distance to Woreda office of agriculture; Std.D is for standard deviation, CLI is for crop land irrigated

Table 2 Descriptive results of dummy variables for WTP in cash (Koga and Gumera watersheds, Blue Nile basin, Ethiopia)

Attributes		Upstream						Downstream						Total	
		Willing		Non-willing		Total		Willing		Non -willing		Total			
		N	%	N	%	N	%	N	%	N	%	N	%	N	%
Education	Illiterates	50	54.35	42	45.65	92	52.57	60	74.07	21	25.93	81	54	173	53.23
	Otherwise	49	59.04	34	40.96	83	47.43	52	75.36	17	24.64	69	46	152	46.77
ALD	No	12	70.59	5	29.41	17	9.71	28	73.68	10	26.32	38	25.33	55	16.92
	Yes	87	55.06	71	44.94	158	90.29	84	75	28	25	112	74.67	270	83.08
Assistant ILWM	No	77	58.78	54	41.22	131	74.86	68	75.56	22	24.44	90	60	221	68
	Yes	22	50	22	50	44	25.14	44	73.33	16	26.67	60	40	104	32
Training	No	63	52.5	57	47.5	120	68.57	62	76.54	19	23.46	81	54	201	61.85
	Yes	36	65.45	19	34.55	55	31.43	50	72.46	19	27.54	69	46	124	38.15
Access to credit	No	48	51.61	45	48.39	93	53.14	53	69.74	23	30.26	76	50.67	169	52
	Yes	51	62.2	31	37.8	82	46.86	59	79.73	15	20.27	74	49.33	156	48
Slope of the parcel	Otherwise	16	43.24	21	56.76	37	21.14	2	66.67	1	33.33	3	2	40	12.31
	Flat	83	60.14	55	39.86	138	78.86	110	74.83	37	25.17	147	98	285	87.69
Responsibility	No	63	53.85	54	46.15	117	66.86	76	72.38	29	27.62	105	70	222	68.31
	Yes	36	62.07	22	37.93	58	33.14	36	80	9	20	45	30	103	31.69

Source: the survey result
ILWM is for improved land and water management; ALD is for awareness of land degradation

Households willingness to pay for environmental service restoration

In this section, we evaluated the sample households' WTP in cash or labor for improved land and water management practices. About 64.9% of the samples were willing to pay in cash (Table 3). All respondents were offered with follow-up questions to determine whether they were expressing a protest bid against the valuation or they placed no value on the resource, due to the course of CVM. Accordingly, 66.7% of the upstream farmers were not willing to contribute money. We observed a stronger willingness from the downstream sample households compared to their fellow farmers in the upstream. Accordingly, 53.1% 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 (e.g. number of trees and TLU). In general our 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 depends on the envisaged returns from investment and farmers' financial capacity to invest. Interestingly, farmers' willingness to pay in labor was twofold 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 the gaps?

Table 3 Farmers WTP in cash 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 (cash month^{-1})	99	76	112	38	211	114
WTP (labor MD month^{-1})	169	6	147	3	316	9

Source: the survey result
WTP is for willingness to pay; MD is for man day

As indicated in Table-4, the average labor contributions for upstream and downstream farmers were 3.3 and 3.9 man-days per month (MDmonth^{-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$ha^{-1}). Taking mean current land holding per household and inflation since the time of estimate in to account, a farm household may require about 13,104 ETB (1,365 US$) 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, although this amount is substantially less than the estimated costs of restoration. This trend could be argued from Stefanie et al. (2008), point of view. Stefanie et al. (2008), suggested that PES is based on the beneficiary-pays rather than the polluter-pays principle, and as such is attractive in settings where Environmental Services (ES) providers are poor, marginalized landholders or powerful groups of actors. The authors also make distinction within PES between user-financed PES in which the buyers are the users of the ES, and government-financed PES in which the buyers are others (typically the government) acting on behalf of ES users. In view of those points it can be concluded that improved ES will required the coordinated effort of all stakeholders: including the government, upstream and downstream community

Table-4 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 MD month^{-1} (upstream)	175	3.3	3.15	3.40	0.0000
MWTP in labor MD month^{-1} (downstream)	150	3.9	3.69	4.01	

Source: the survey result
MWTP is for mean willingness to pay; ETB is for Ethiopian currency which is 1US$ is equivalent to 9.6 ETB; MD is for man day

Determinants of upstream and downstream farmers' willingness to pay

In this section, selected explanatory variables were used in the interval regression model to analyze determinants of farmers' WTP for improved land and water management. A total of 23 explanatory variables (14 continuous and 9 dummy) were included in the model of which only significantly related variables are presented in this report (Table 5).

Table 5 Estimate of the interval regression model (Koga and Gumera watersheds)

Explanatory Variables	Downstream users			Upstream users			All samples		
	Coeff.	SD.E	P>z	Coeff.	SD.E	P>z	Coeff.	SD.E	P>z
Educational level	-1.87	4.67	0.69	-11.24	3.79	0.00***	-6.29	2.91	0.03**
Age of the household head	-0.45	0.19	0.02**	-0.19	0.15	0.22	-0.33	0.12	0.01**
Start Bid ~y	0.60	0.17	0.00***	0.46	0.14	0.00***	0.55	0.11	0.00***
Financial and technical assistant	5.37	3.95	0.17	4.31	3.48	0.22	5.76	2.64	0.03**
Training	-3.99	3.95	0.31	6.81	3.78	0.07*	1.78	2.72	0.51
Own cultivated land	-0.26	0.42	0.54	0.35	0.18	0.06*	0.17	0.17	0.33
Access to credit	1.98	4.11	0.63	5.31	3.69	0.15	4.73	2.65	0.08*
Number of trees owned	0.00	0.00	0.04**	0.00	0.00	0.86	0.00	0.00	0.03**
Distance to output market	-0.08	0.53	0.88	-0.42	0.49	0.38	-0.54	0.28	0.05**
Distance to nursery site	-0.18	0.78	0.82	-0.74	0.42	0.08*	-0.63	0.37	0.08*
Distance to agricultural office	-0.78	0.35	0.02**	-0.72	0.64	0.26	-0.77	0.29	0.01**
Livestock owned in TLU	0.67	0.58	0.24	1.22	0.45	0.01**	0.74	0.34	0.03**
Slope of the parcel	9.91	13.74	0.47	7.74	4.54	0.09*	10.44	4.29	0.02**
Adult male in the household	2.80	1.52	0.07*	-1.19	1.36	0.38	0.56	1.00	0.57
Adult females in the household	-1.20	1.82	0.51	-3.23	1.57	0.04**	-2.25	1.20	0.06*
Constant	7.88	18.13	0.66	12.25	12.64	0.33	12.01	9.65	0.21
Lnsigma	2.99	0.08	0.00***	2.90	0.09	0.00	2.99	0.06	0.00***
Sigma	19.79	1.64		18.18	1.59		19.89	1.19	
	N =150 LR chi2 (24) = 37.11 Prob > chi2=0.0317 Log likelihood = -212.27658 52 left-censored observations 0 uncensored observations 0 right-censored observations 98 interval observations			N =175 LR chi2 (23) =74.79 Prob > chi2=0 Log likelihood = -186.71088 83 left-censored observations 1uncensored observation 0 right-censored observations 91 interval observations			N =325 LR chi2 (25) =103.70 Prob > chi2=0.0000 Log likelihood = - 409.16806 135 left-censored observations 1 uncensored observation; 0 right-censored observations 189 interval observations		

Source: the survey result***, ** and * indicate significant level at 1%, 5% and 10% respectively.

The maximum likelihood estimate of the interval regression model shows 15 explanatory variables to significantly determine farmers' WTP. Of the 23 explanatory variables hypothesized to influence farmers' WTP for improved land and water management practices, fourteen variables were less powerful in explaining farmers' willingness to pay in cash. The Log-likelihood ratio test for the significance of the overall mode is -409.16806 for 135 left-censored observations and 1 uncensored observation; 0 right-censored observations and 189 interval observations. A host of household, asset holding, plot characteristics and institutional support related variables were found to be significant in explaining households' WTP. More specifically, the coefficients of educational level, age of the household head were found significant at 10% probability level or less. From the households' asset holdings, number of trees planted, number of livestock holdings in tropical livestock unit (TLU), and total adult female household member were found to be significant at 5% probability level. Institutional support related factors such as training (information and visit), and assistance in land and water conservation techniques and distance to the office of agriculture (proxy measure of access to extension service) were found to be significant at 1% probability level. Finally, plot level characteristics such as slope of the parcels and average land holding were found significant. The specific effects of these variables and their policy implications are discussed blow.

Educational level of the household head: the education level variable was significant at (P< 0.01) and had a positive association with farmers' willingness to pay in cash for improved land and water conservation practices. Farmers' ability to acquire, process and use information could be increased by education. Besides, education reflects acquired knowledge of environmental amenities. Thus, this variable positively correlated with farmers' willingness to pay in cash for improved land and water management practices. Number of studies suggested similar results (e.g. Tegegne, 1999; Ervin and Ervin, 1982; Noris and Batie, 1987; Pender and Kerr, 1996; Asrat et al., 2004). From our results it can be also realized that keeping the influences of other factors constant, every extra year of schooling increase the probability of farmers' willingness to pay cash by 3.62%. This implies that education could be an important policy instrument for improved environmental management.

Age of the household head: this variable was significant at (P<0.05) and had a negative influence on farmers willingness to pay in cash for land and water conservation activities. This contradicts with Bekele and Drake (2003) who suggested that farmers' age does not influence the conservation decision. This means also with more age farmer can become risk averse to engage in improved land and water conservation practices. The effect of farmer's age in improved land and water conservation decision can be taken as a composite of the effect of farming experience and planning horizon (e.g. Tesfaye et al., 2000). In general, older farmers are more likely to reject practicing improved land and water conservation practices. On the contrary, younger farmers are often expected to take risk due to their longer planning horizon (e.g. Befikadu, 2007). The result shows that a one year increase in age, keeping other factor constant, decrease the probability of farmers' WTP in cash for improved land and water conservation practice by 0.01%. In general, this suggests that research has to come up with conservation technologies that can reduce risks and yield returns in the short term.

Asset holdings: we report on the effects of livestock, tree holding and labor availability on the households' WTP. Livestock holding represents the total number of livestock, measured in Tropical Livestock Unit (TLU). Livestock is important household asset and is claimed as important means of cash income for households in both study areas (e.g. Haileslassie et al., 2008, under review). This is particularly important in farming system where farmers are producing non-cash crops and off-farm income is very limited (e.g. upstream areas of both watersheds). The model showed a significant and positive relation at 5% probability level for this variable. In other words as farmers own more number of livestock, the probability of WTP increases. This can be explained by two main reasons: firstly more livestock ownership means more assets possession, which in turn increases households' ability to make investment decisions. Secondly, as farmers own large livestock population, they need to have land and water available to them to provide their livestock population with sufficient and quality feeding and drinking water increasing investment in land and water conservation. Dasgupta (1989) and Rogers and Shomaker (1971) reported similar result. With the ceteris paribus condition holding, the probability of being willing to pay increases by a probability of 0.14% as livestock ownership increased by 1 TLU. Probably this may contrasts with recent thought about effects of increasing livestock population and resultant ecosystem degradation (e.g. overgrazing). In practical terms policy makers must focus on increasing the products and services per unit of livestock than the mere increase in number to attain the impacts of livestock ownership on farmers' willingness to invest in land and water management. Interestingly farmers in both study areas (mainly downstream) plant trees (e.g. *Eucalyptus camaldulensis*) on homestead and distance farm plots. Farmers in the study areas are claiming that tree planting is becoming the best strategy to generate cash for the farm household. Which is why the coefficient of number of tree on farm of the household was significant at 5% probability level and affects farmers' willingness to pay positively. Pender and Kerr (1997) also suggested that farms income have a significant effect on land and water management investment. A unit increase in this variable, with the assumption of ceteris paribus; the probability of farmer's willingness to pay in cash for improved land and water conservation activates increase by 2.6%. Moreover, on the effect of households' labor endowment on their WTP, we found that households with more number of female adults have significantly lower probability (1.08 %) of being willing to pay. This could be related to their female adults' income generating capacity as labor markets could be gender segregated.

Size of own cultivated land: this variable represents the total cultivated land owned by a household and it is significant for upstream farmers at 5% probability level. For an agrarian community, like our study areas, land size is an indication of wealth status of a household (e.g. Bekele and Drake, 2003). As land ownership is equated with asset ownership, a farmer with large cultivable land is considered wealthy (Haileslassie et al., 2007). The size of cultivated land is also often associated with a means that might help ease the needed liquidity constraint (e.g. Bekele and Drake, 2003) as land could be transferred temporarily through land transactions. Number of empirical study suggested that farmers who have large farms in the upstream are more likely to use conservation technology (e.g. Bekele and Holden 1998; Norris and Batie, 1987). It can be argued also that farmers with smaller plots were not willing to pay for soil conservation practices because of inconveniences created by some physical conservation measures during farm operation : e.g. turn oxen during ploughing and cultivation, further squeezing the small parcel owned by the farm household (Asrat et al., 2004).

The result of our model agrees with those suggestions and revealed that farmers' willingness to pay increase by the probability of 0.008% as the size of own cultivated land increase by one unit with the assumption of ceteris paribus. This could be argued from perspective of policy options that eradicate poverty and increase land and water productivity, as increasing land size could not be an issue in the face of high population pressure in the area. However, policy maker could still enhance conservation by promoting technologies that do not compete for more space.

Distance to the offices of agriculture: this variable is significant at 1% probability level and affects farmers' WTP negatively. It refers to the time a household may need to walk to get to the agricultural office. The negative sign of the coefficients indicates that as the distance of agricultural office from homestead increases, farmers would have less access to information and other services. Thus, they would not be willing to participate in watershed conservation activity (DBOA, 2007). This result showed that keeping the influences of other factors constant, farmers' WTP decrease by 0.16 % as distance of the district increases by 1 kilometer. Perhaps policy and institution measures that improve farmers' access to information and other services could help in increasing farmers' willingness to participate in such activities.

Information, training and visit: information and training increases farmers' willingness to practice improved land and water management activities (Pender and Kerr, 1998). In context of this study, this variable refers to farmer participation in improved watershed conservation training program. It also refers to radio or video shows related to watershed conservation and make use of improved land and water management practices, participating on farmers' field day, meetings, and visits of other farmers who practiced improved land and water management. If the nation desires a progressively increasing number of farmers to undertake improved watershed conservation activities, the implementation of substantial training program should get a high priority (e.g. Joyce 2001; Pawlos 2002). A unit increase in this variable, all other things being kept constant, leads to an increase in the probability of farmers' WTP in cash for improved land and water conservation activates by 0.18%. Finally, policy and institutional measures that improve farmers' access to information, skills and training must be a target to achieve the objectives of improved ecosystem services.

Assistance in land and water conservation practice: this variable was significant at 1% probability level and affects positively farmers' WTP in cash. Assistance refers to any form of watershed conservation support provided to the farm household in the study areas. Physical soil conservation measures are labor intensive and require technical, financial and material inputs, which farmers may not be able to afford by themselves (e.g. Asrat et al., 2004). This implies also that assistance from any source encourages farmers to adopt physical conservation measures. In Ethiopia, involvement of Non-Governmental Organizations (NGOs) and Governmental Organization (GO) in the soil and water conservation has a long history (Gebremedhin and Swinton, 2003). Thus, assistances in the form of safety net or food for work program were almost a norm for decades of soil and water conservation initiatives. Besides these farmers are also provided with technical support through the regular extension channel or specific NGO interventions that ranges from defining contours to establishing different types of SWC measures. This study indicated that the probability of farmers' willingness to pay increase by 6.6% as assistance in land and water conservation practice increase by one unit, keeping other factors constant.

Slope of the plot: specific plot level characteristics may predispose farm plots to erosion. For instance, sloppy lands are more susceptible to erosion. Including such variables in adoption regression is quite vital. Accordingly, we found that slope of household's plots have significant and positives effect on farmers' WTP in cash for improved land and water management practice at 10% probability level. This implies that households that have on average sloppy plots are more willing to pay for improved conservation as they have the understanding that such plots are susceptible to degradation. Our model outputs and empirical studies in Ethiopia and elsewhere showed similar trends (e.g. Shiferaw and Holden 1998; Ervin and Ervin, 1982; Norris and Batie, 1987; Gould et al, 1989). Finally it can be concluded that targeting farm households with steeper landscape unit can bring tangible changes in designing PES schemes.

Downstream households' willingness to compensate for the upstream farmers

The downstream users' of environmental services WTC the upstream environmental service providers in cash were also assessed in this study. Land degradation has serious on-site and off-site impacts for upstream and downstream users in the study area (e.g. Awulachew et al., 2008). The off-site damage through sedimentation and flooding instigated major concern mainly as related to safety and sustainable uses of ongoing construction of irrigation infrastructures. The result of this study showed that, of all downstream sample farm households, 83.6 % were willing to compensate the upstream farmers for the ecosystem regulation services they provided. The remaining 16.4 % were not willing to compensate the upstream farmers in cash. As indicated in previous section the mean values of WTP/WTC indicated by farmers will not be sufficient to undertake the commensurate measures to reduced land and water degradation. Therefore a policy measure that encourages community and intergovernmental cooperation and also considering watershed management as part of the investment in irrigation infrastructure is important. In the subsequent paragraph we shed light on selected explanatory variables for willingness to compensate.

A total of 13 explanatory variables (10 continuous and 3 dummy) were included in the model (Table 6). The maximum likelihood estimate of the interval regression model shows six explanatory variables to significantly determine downstream farmers' WTC. These are access to credit, total family size, ratio of irrigation to cultivated land, livestock holdings (in TLU), and distance to agricultural office. Interestingly, the model indicates stronger willingness from Koga watershed service users when the two watersheds are separated. Though 7 explanatory variables were not significant in explaining downstream farmers' WTC, clear trend of relation between the dependent and independent variables could be traced. Most of those explanatory variables correspond with those for willingness to pay presented in section 3.3 and therefore further explanation of variables can be referred to particular section.

Table 6 Estimate of the interval regression model for farmers WTC (Koga and Gumera watersheds, Blue Nile basin, Ethiopia)

Explanatory Variables	Coef.	dy/dx	Std. Err.	P>z
Start bid	0.013728	0.002388	0.012163	0.259
Age	-0.01751	-0.00305	0.011794	0.138
Educational level (dummy 1=illiterate and 0 otherwise)	-0.13372	-0.02349	0.325927	0.682
Access to credit	0.643803	0.114452	0.329956	0.051**
Sex	-1.02892	-0.28513	0.693857	0.138
Total family size	-0.23304	-0.04053	0.083337	0.005***
Adult male in the household	0.070711	0.012298	0.108249	0.514
Ratio of irrigated to cultivated land	-3.82163	-0.66466	1.936619	0.048**
Number of trees owned	6.58E-05	1.15E-05	0.000107	0.538
Off farm income	-9E-05	-1.6E-05	0.000163	0.579
Livestock owned (TLU)	0.110001	0.019131	0.056892	0.053**
Distance to agricultural office	-0.05925	-0.01031	0.033094	0.073*
Watershed (1=Gumera and 2=Koga)	1.035345	0.181854	0.381166	0.007***
_Cons	2.334752		1.051206	0.026
	Number of observation =146			
	LR chi2 (24) = 32.34			
	Prob > chi2= 0.0021			
	Log likelihood = -49.073538			
	Pseudo R2= 0.2478			

Source: the survey result
***, ** and * indicates significant level at 1%, 5% and 10% probability respectively.

Access to credit: this variable is significant at 5% probability level and affects farmers' WTC positively. It refers to whether the sample farm household had credit in the last couple of years or not. Access to credit for agricultural purposes can relax farmers' financial constraints. Our results show that downstream farm households with access to institutional credit are willing to compensate the upstream farmers for ecosystem services they provide. In this study, with the assumption of ceteris paribus, the probability of being willingness to compensate the upstream farmers increases by 0.11% for additional increment in access to credit service.

TLU owned is found significant at (P< 0.05) and affects, positively, the downstream users' decision to compensation. This means also as the downstream farmers own large livestock units, the chance of WTC increasing. With the assumption of ceteris paribus, the probability of being willingness to compensate the upstream farmers increases by 0.64% for additional increment in livestock ownership.

Total family size was also found significant at 1% probability level and affects farmers' WTC negatively. This refers to the total number of family members in a household. Accordingly, keeping the influences of other factors constant, downstream farmers' WTC decrease by 0.23% as the total family increases by 1 person. This may imply that farm households with larger family size are relatively cash constrained. Distance to the agricultural office was also found significant at 10% probability level and affects farmers' WTC negatively. The negative sign of the coefficients was as anticipated indicating that as the distance of agricultural office from homestead is long, farmers would have less access to information and services, thus, they would not be willing to participate in watershed conservation activity and will not be willing to compensate. Keeping the influences of other factors constant, downstream farmers' willingness WTC decrease by 0.06 % as distance of the district increases by 1 kilometer.

Unlike our expectation the ratio of irrigated land to total land holding of sample farmers shows a negative relationship to farmers WTC. This may contrast with the suggestion given with the land size and the underlying reason may need further study. The result also showed that there are differences between sample farmers in Goga and Gumera in terms of the proportion of WTP and WTC: sample farmers in Koga watershed showed more WTP and WTC than Gumera watershed. This can be explained for by the fact that farmers in Koga watershed have great expectation, since the constriction of Koga dam is almost completed.

Conclusion and Policy Implications

The major objectives of this study were to investigate farmers' WTP for restoration of ecosystem services and to examine willingness of the downstream environmental service users to compensate for the cost of improved land management in the upstream areas and to explore socio-economic and institutional drivers WTP and WTC. We also estimated the mean value of WTP and WTC. In view of the results the following conclusion and policy implications can be drawn:

i) More than half of the respondents were willing to pay in cash and 97.2% were willingness to pay in labor for restoration of environmental services. Furthermore, 83.6% of downstream sample farm households indicated their WTC the upstream farmers for the ecosystem regulation services they provided. Those finding substantiate our hypothesis of PES as an instrument for conflict resolution between upstream and downstream users and sustainable uses of land and water resources. However, the low magnitude of farmers' bid can be a challenge for its realization and thus a sole user-financed PES scheme may not be feasible in short term. Alternatively, we suggest a combination of environmental service paid by the users and government-financed PES schemes. The modality for government support can be part of investment in irrigation infrastructure. This can be also linked to global target of increasing soil carbon through land rehabilitation and tree plantation.

ii) As part of this study, number of livestock, size of arable land, and number of trees owned 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. In agrarian community access to those productive resources is strongly linked to level of poverty (e.g. Haileslassie et al., 2007). Also the positive relation between the probability of accepting the start bid, farmers' total income, and tree plantation substantiate this argument. Therefore policy options that target poverty reduction through intensification of agriculture must be promoted. These approaches may include increased adoption of technologies that improves product and productivity of the livestock and crop production.

iii) Explanatory variables such as education, awareness and access to information and credit were also influencing those farmers' decision positively. Institutions and policy measures that enhance environmental education must be promoted. This means also that policy makers must target both formal and informal education and include watershed management, upstream downstream relation and sustainable resources use into the formal education curricula to achieve the desired result.

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Appendixes

Appendix Table-1 Descriptive results of continues variables of WTP in labor by strata (Koga and Gumera watersheds, Blue Nile basin, Ethiopia)

Strata	WTP in labor	Age	Tree	Distance to agr. Off. in km	Distance to nursery site in km	TLU**	Crop land irrigate d	Adult female	Adult male	
Upstream	Non willing	Mean	46.33	14.17	12.33	7.45	5.28	0.17	2.17	3.17
		Std. D	16.79	15.94	5.13	6.50	3.49	0.41	1.33	1.72
	Willing	Mean	43.37	189.76	13.91	5.34	5.08	0.21	2.71	3.12
		Std. D	13.39	580.47	4.39	4.85	4.20	0.47	1.26	1.39
	Total	Mean	43.47	183.74	13.85	5.41	5.09	0.21	2.69	3.13
		Std. D	13.47	571.28	4.41	4.90	4.17	0.47	1.26	1.40
Downstream	Non willing	Mean	52.00	2666.67	14.59	3.06	4.76	0.00	1.33	4.00
		Std. D	6.93	1258.31	1.23	1.22	3.25	0.00	1.53	2.00
	Willing	Mean	41.89	641.23	13.90	3.55	5.61	0.22	2.61	2.93
		Std. D	12.37	1514.55	5.72	2.86	3.95	0.52	1.17	1.61
	Total	Mean	42.09	681.74	13.91	3.54	5.59	0.21	2.58	2.95
		Std. D	12.35	1532.93	5.67	2.84	3.93	0.51	1.19	1.61
All samples	Non willing	Mean	48.22	898.33	13.08	5.98	5.11	0.11	1.89	3.44
		Std. D	14.01	1467.97	4.25	5.62	3.21	0.33	1.36	1.74
	Willing	Mean	42.68	399.78	13.90	4.51	5.33	0.21	2.66	3.03
		Std. D	12.93	1137.44	5.04	4.14	4.09	0.49	1.22	1.50
	Total	Mean	42.83	413.59	13.88	4.55	5.32	0.21	2.64	3.04
		Std. D	12.97	1147.93	5.02	4.18	4.06	0.49	1.23	1.50

Source: the survey result

Table 2 Descriptive results of dummy variables of WTP in labor by strata (Koga and Gumera watersheds, Blue Nile basin, Ethiopia)

Attributes		Upstream						Downstream						All samples	
		Willing		Non -willing		Total		Willing		Non -willing		Total			
		N	%	N	%	N	%	N	%	N	%	N	%	N	%
Educational states	Illiterates	87	94.57	5	5.43	92	52.57	78	96.30	3	3.70	81	54.00	173	53.23
	Otherwise	82	98.80	1	1.20	83	47.43	69	100.00	0	0.00	69	46.00	152	46.77
ALD	No	15	88.24	2	11.76	17	9.71	38	100.00	0	0.00	38	25.33	55	16.92
	Yes	154	97.47	4	2.53	158	90.29	109	97.32	3	2.68	112	74.67	270	83.08
Assistant ILWM	No	128	97.71	3	0.29	131	74.86	88	97.78	2	2.22	90	60.00	221	68.00
	Yes	41	93.18	3	6.82	44	25.14	59	98.33	1	1.67	60	40.00	104	32.00
Training	No	116	96.67	4	3.33	120	68.57	80	98.77	1	1.23	81	54.00	201	61.85
	Yes	53	96.36	2	3.64	55	31.43	67	97.10	2	2.90	69	46.00	124	38.15
Access to credit	No	88	94.62	5	5.38	93	53.14	75	98.68	1	1.32	76	50.67	169	52.00
	Yes	81	98.78	1	1.22	82	46.86	72	97.30	2	2.70	74	49.33	156	48.00
Slope of the parcel	Otherwise	36	97.30	1	2.70	37	21.14	3	100.00	0	0.00	3	2.00	40	12.31
	Flat	133	96.38	5	3.62	138	78.86	144	97.96	3	2.04	147	98.00	285	87.69
Responsibility	No	114	97.44	3	2.56	117	66.86	102	97.14	3	2.86	105	70.00	222	68.31
	Yes	55	94.83	3	5.17	58	33.14	45	100.00	0	0.00	45	30.00	103	31.69

ILWM is for improved land and water management; ALD is for awareness of land degradation

Source: the survey result

Session V: Minutes Summary, List of Posters and Annexes

Minutes summary

Session I. Opening and General Session

Opening Remarks

The upstream-downstream project workshop is aimed at bringing together key stakeholders and present and validate the intermediate results of the project. The project leader, Dr. Seleshi Bekele Awulachew welcomed participants and expressed his appreciation for traveling to participate in this workshop. He invited Prof. Gamal Abdo to facilitate the session.

The facilitator requested the participants to introduce themselves. After the introduction of the participants, he kindly requested Dr. Akissa Bahri, Africa Regional Director to give an opening remark. In her opening statement, Dr. Bahri said the project is meant to fill a knowledge gap regarding the run-off, sedimentation, erosion, hydrological, hydraulic and institutional processes in the Blue Nile watersheds, and is now presenting its interim findings. The facilitator invited Dr. Kim Geheb who is the challenge program (CP) regional coordinator. Dr. Kim in his statement said that CP is happy to support the project whose objective is very much in line with the overall objective of CP-19 and congratulated the research team on the progress made to date.

General papers presentation

1. The CPWF and the CP19 Project Objectives (Dr. Seleshi Bekele Awulachew)

The presenter outlined the CPWF and CP19 project objectives. He presented the USDS in brief with highlight of the following:

- USDS project broad goals, objectives and stated that the major one is to identify major water, land and livestock management opportunities, constraints and impact interventions in the catchments.
- About the key research questions that the project will address
- Major outputs of the project
- Project progress with respect to; watershed management, water allocation simulation modeling, policy and institutions, capacity building, and knowledge sharing and publications. There were no questions, comments and suggestions on this presentation.

2. Characteristics of Blue Nile and GIS Database of Blue Nile (Aster et al.)

The second presenter was W/t Aster who presented on Characteristics of Blue Nile and GIS Database of Blue Nile. She introduced the following:

- Brief introduction of the project
- Data sources (in Ethiopia as well as in Sudan)
- Key basin information (geographic, DEM, climate, geology, land cover, population density, etc)

Minutes summary

- In depth information on selected sub-basins in Ethiopia (Gumera, Gilgel Abbay, Koga) and in Sudan (Dindir and Rehad)
- Availability of documents and data on CD (ready for distribution to participants)

Question: Does the GIS information include groundwater (GW) and water quality information?

Answer: Effort has been made to create baseline information based on secondary data. If there is additional information on GW and water quality the project is ready to include them.

Question: What kind of resolution are you using? 90 m resolution was used for the whole of the Blue Nile Basin

Question: How do you make the information available?

Answer: It will be distributed with CD containing sharable information and in addition it will be posted on the IWMI web-site.

Question: Did you produce soil erosion map? How did you calculate Potential Evapotranspiration (PET)? What quality assurance measures are used? How do you validate the data available? Furthermore, other source of information needs to be exploited to avoid duplication of effort (example FRIEND NILE).

Answer: The information is gathered from IWMI IDIS kit processed under IWMI GIS unit and others are acquired from National Meteorological Service Agency (NMSA) which is the sole source of relevant information in Ethiopia including those obtained from ENTRO. Other source of information will be further explored and it will be added into the data base.

3. Impacts of improving water management of small holder agriculture in the Upper Blue Nile Basin (Teklu et al.)

The presenter structured his presentation as follows: as introduction to the Abbay Basin and the key challenges of the basin (topography, biophysical variations, etc), objectives of the component and preliminary results. Accordingly, nine farming systems were identified, in which cereal based farming system is the dominant one (about 70%). The major soils areas are identified and Leptosols and Nitosols are found to be the dominant ones. Average productivity of the basin was less than one tone a hectare. The low productivity was related to soil erosion, rainfall variation and others. Multifaceted interventions recommended and technological interventions (integrated watershed management, AWMT, etc.) were proposed. Possible impacts of AWMT such as shallow well; RWH, WSM and SSI are outlined. The remaining tasks include estimating the impacts of selected AWMT based on different scenarios.

Question: One of the reasons low productivity was mentioned to be soil erosion. What is the recommended measure?

Answer: The best approach adopted in this country is an integrated watershed management intervention. Unless the catchment is well treated we shall be harvesting sediments. In order to reverse this situation; there are physical, biological and water management interventions.

Question: Among identified farming system perennial farming system is one of them why are farming systems such as livestock missed?

Answer: The data was obtained from river basin master plans which do not include other farming systems other than those mentioned in this study. Effort will be made to include others depending on availability of information.

Question: What are the proposed climate variability interventions? ENTRO has already identified hot spots of soil erosion in Blue Nile Basin. Why not to do an integrated farming approach where there is ample experience in Sudan?

Answer: Description of ongoing activities has been done but during the next phases the comments will be taken up.

Suggestions: Water quality concern is becoming a serious issue in the basin and therefore it highly recommended that this aspect is included in the study. Prioritize list of issues contributing to decreased productivity were presented. However, integrated approach of the various interventions can only alleviate the decrease of productivity. The issues of supply of water, nutrients are critical to increasing productivity and needs to be addressed sufficiently

Session II – Water Allocation Simulation Modeling

1. The Water Allocation Modeling Framework; Mathew

Dr. Mathew has provided an overview of the water allocation modeling and the presentations of this session.

2. Simulation of Lake Tana with Environmental Flows in Lake Tana Sub-basin (Tadesse and Mathew)

The study applied WEAP model for assessing the impact of environmental flow on Lake Tana water level and the reliability of water resource projects planned in the Lake Tana Sub-basin. It was outlined that the study adopted four development scenarios; including the baseline scenarios. It was pointed out that the reliability of navigation deteriorates with development scenarios and with consideration of environmental flow. Climate change assessment and economic analysis are recommended as future enhancement to the current study.

Question: Which of the presented alternatives (scenarios) is the best to maximize the benefit to irrigation and hydropower at the same time?

Answer: The study has only simulated the reliability of Lake Tana water level and proposed development projects for the four development scenarios. Optimization of the development scenarios in terms of maximizing irrigation, hydropower, environmental and social benefits is not conducted. Rather it is recommended as one of the future works. Therefore, the study hasn't identified an optimum scenario.

3. Regionalization, Performance of Rainfall-Runoff Model and Optimization of Water Allocation of Blue Nile (Aemayehu and Seleshi)

The primary focuses of the study were regionalization of rainfall-runoff relationships of unguaged catchments, and derivation of operation policy for multi-reservoir systems using multi-objective optimization methods. Kohonen Neural Network was applied to identify homogenous hydrological regions; and WaSiM-ETH model was used for rainfall-runoff modeling. The optimization (modified single-objective) and simulation (HEC5) modules were coupled to optimize water allocation in multi-reservoir systems.

Question: Future scenarios of water allocation should consider other production system components, including enterprise choice, water management interventions, local capacity, etc. Is it not important to include other scenarios beyond water allocation for practical policy recommendation?

Answer: Operating rules are always changing whenever there is change in demand. Our operation rule curves were derived based on the current and future water resources development extracted from the Master Plan document. It was tested with 50 years generated flow. Moreover, it is possible to update the ruling curve.

Question: What are the chances or plans to collect more water in Abbay basin through studying groundwater and studying the opportunities for water harvesting to secure sustainability of proposed development plans without affecting the water allocation for Egypt and Sudan?

Answer: Groundwater assessment is beyond the scope of the current study. But, water harvesting options are being considered in Dr. Teklu's presentation.

4. Water Balance Assessment of the Roseires Reservoir (Sudan) (Bashar and Mustafa)

The contributions of the intervening catchments and the direct rainfall over the reservoir were not considered in the water balance computation as they are assumed insignificant. It was pointed out that the water balance has performed better in wet season than in dry season. This may be attributed to leakage from dam.

Question: The water balance during dry season has some discrepancies. This might be rectified by including base flow in the water balance.

Answer: Comment noted.

Question: Is there any mitigation measures to reduce the sedimentation process in the Roseires dam reservoir?

Answer: Watershed and land management in the upper Blue Nile and provision of extra storage for sedimentation in the reservoir are some of the measures that can reduce the sedimentation process in the Rosieres reservoir.

Question: The reported volume of the Roseires reservoir after heightening (10 Bm^3) is too much. According to latest studies the total storage capacity after heightening is expected to be about 6 Bm^3.

Answer: The figure is obtained from previous presentation. We will check that.

5. Improving Water Management Practices in the Rahad Scheme (Sudan) (Sulieman and Yosif)

Sedimentation is the major problem in the Rahad irrigation scheme. The major objective of the study is to develop water management tools for Rahad irrigation system; which previously relied upon the experience of operation staff. The total annual amount of water supplied is enough for the scheme. The water scarcity during some months (August – November) is due to problems in the timing of releases and management of the scheme. The study has proposed operation rules.

Question: Rather than using Flow Duration Curves, why the study didn't apply frequency analysis to estimate yield from Rahad seasonal river at different reliability?
Answer: We fully agree that fitting statistical distribution would be more accurate. However, we are dealing with daily flows of longer period records and, hence, the discrepancy caused by using FDC is anticipated to be minimum.

6. Water Allocation Simulation of Upper Blue Nile using HEC-ResSIM (Ethiopia); (Yilma et al.)

The study has considered detailed reservoir operation through HEC-ResSIM in the process of performing water allocation simulation in the Upper Blue Nile. Flow estimation for tributaries of ungauged catchments was the greatest challenge faced by this study.

Question: Why do we talk about Border Dam where you found higher actual and potential evapotranspiration when there are other dams (Karadobi, etc.)?
Answer: The study has considered all dams in the upper Blue Nile.

7. Analysis of Water Uses on Large River Basin using MIKEBASIN Model (A Case Study of Abbay River Basin, Ethiopia) (Fasikaw and Seleshi)

The study has simulated water allocation for the production systems (both existing and planned) in the Abbay River Basin. It has adopted three development scenarios, including the reference scenario, in the simulation of water allocation for the production systems. About 3% of reduction in the annual flow volume at Sudan boarder is estimated as a result of implementing projects in the Abbay Basin.

8. A Water Simulation Model for the Blue Nile River Basin in Sudan using HEC-ResSIM (Sudan) (Yosif and Abdalla)

A Water Simulation Modeling framework was developed for the Sudan part of the Blue Nile. Evaluation of development scenarios using the developed WSM and integration of the modeling system with that of Ethiopian study is recommended.

Question: You said the required amount of water in Sudan is 20 BCM. This amount is higher that the 18.5 BCM allocated to Sudan in the controversial 1959 agreement. Where does the extra water come from unless a new volumetric allocation takes place in the Nile?

Answer: According to the 1959 agreement between Sudan and Egypt, the share of Sudan measured at Aswan is 18.5 BCM annually while it is 20.5 BCM measured as Sennar Dam. The figure shown in the presentation (20 BCM) is based on the current irrigation water demand obtained from crop water requirement computation. However, the actual current consumption of Sudan, as announced officially, is 14.5 BCM at Aswan and 16.5 BCM calculated at Sennar Dam.

9. Integrated Simulation of Blue Nile Water using WEAP under Current and Future Scenario (Ethiopia-Sudan) (Mathew et al)

The study has preliminarily evaluated two basic scenarios (current and year 2015), considering both existing and planned schemes. Further, the 2025 scenario is currently being simulated. The simulation results at major gauging stations and reservoirs have fairly reproduced observations. The preliminary results of the simulation exercise are very promising. Environmental flow is not considered in the current simulation. In the future, environmental flow and impact of climate change on supply and demand shall be included.

Other questions rose during the session and their answers

Question: The flow volume reported at Khartoum seems for the Border. Is that true?
Answer: The data sources say the same as reported. This will be revised if better data is obtained.
Question: What is the proposed plan to mitigate sedimentation in the planned dams?
Answer: Some volumes are allocated in the dams for trapping sediment.
Question: The public domain models are developed for different climate conditions. Why you are not developing your own modeling tool rather than depending on existing models?
Answer: We are not developing models; rather we use or customize existing models to our conditions.
Question: The crop water requirement and base flow estimation models should be used. The crop water requirement should consider different cropping patterns expected in future planned schemes.
Answer: Comment well taken.
Question: What is the purpose of using different models unless one is to select an appropriate model? What if MIKEBASIN is used for lower basin and HEC-ResSIM for upper or both are applied instead of WEAP?
Answer: The purpose of using different models was to experiment with different models.

Session III- Watershed modeling

1. Problems of erosion and sediment transport and modeling framework of the Blue Nile (Seleshi and Tammo)

Overview of sediment transport has been given. The causes, degree, extent and impacts of land degradation on hydrologic structures, productivity, and livelihood both upstream and downstream were highlighted. Emphasis was given to the effects sediment deposition on the downstream sites and the problems of data quality and availability.

Question: Is it not possible to use seasonal curve development? If not what do you suggest?
*Answer***:** Seasonal based type possibly based on monthly bases can be used, but not one curve for all the seasons.

Question: It is known that data shortage and quality is a problem in the Nile system, especially in Ethiopia. How come that your calibration results based on the same data is said to be good?

Answer: The low efficiency obtained by the model can be explained by the data quality.

2. Impact WSM Interventions in Gumera Watershed (Mekuannint and Seleshi)

Mekuanint explained that land degradation is a series threat in Gumara watershed as reflected in the form of soil erosion, which lead to significant loss of soil productivity and reduced life time of reservoirs. Used SWAT model to quantify sediment loss, identify vulnerable areas, and study impact of filter strip on sediment loss.

Question: As mentioned by Dr. Seleshi, Gumera and Ribb catchments are characterized by high flood, especially during the rains season. This results in missing of records from the gauging stations. How did you account for this in your analysis?
Answer: we developed sediment-discharge rating curve for Gumera River, and we estimate the missing data from this rating curve.
Question: How did you consider the land use land cover for future application of your model?
Answer: for future application of the model, we need to use recent satellite images to determine the land use/land cover data for an area of interest.
Question: What are the main factors governing the filter strips? Reduction of erosion by 72% is difficult to believe.
Answer: In the universal soil loss equation, one of the factors is conservation practice (P). After we calibrated and validated the model, we changed the P-factor instead of the existing conservation practice and we run the model. The result was a reduction in sediment yield by 58% to 74%. These results are consistent with soil and water conservation research plots in the basin.

3. Development of Rainfall-Runoff –sediment Discharge relationship in Blue Nile Basin, Ethiopia (Fekadu et al.)

Fekadu explained that the quantification of components of the hydrologic cycle is a crucial step in integrated watershed management. However, data scarcity, accurate methods to estimate the components are challenging that advanced tools are required to overcome the problem. The study suggested that SWAT model simulates well both streamflow and sediment yield for Blue Nile basin.

Question: From your topic, we expect some relationship between rainfall-sediment-runoff, if there is any and if not your point of view. So, what is the relationship? Is it exponential, linear…?

Answer: I missed the last slide which shows the rainfall-runoff-sediment relationship. But as Dr. Seleshi mentioned, rainfall or runoff do not have direct relation with sediment. The peak of sediment comes before that of rainfall and runoff.

Q*uestion*: In discussing the relation between processes like rainfall, runoff and sediment, scale is one of the basic issues that should be considered. So at what scale does your model perform well?

Answer: I did not compare different scales, but it is better with small resolution DEM (only obtained 90 m resolution).

Question: How is groundwater 65% of Blue Nile and 80% of flow occurs in flood season- during the four months (July –October only)?

Answer: I did not say groundwater contributes 65% of Blue Nile, but I said that rainfall contribute 65% of GW that can be base flow and can be runoff at downstream basin.

4. **Integrated sediment transport modeling using SWAT-SoBEK Models: the case of Blue Nile River Basin (Getnet and Yasir)**

Getnet explained sediment transport as a process involving soil erosion, transport and deposition. He also explained the impacts of sediment transport. The study attempted to identify sensitive regions for erosion and deposition in the basin. It was explained that SWAT model can be used for Ethiopian Watersheds, but as it does not recognize storages/reservoirs, it was linked with SOBEK to simulate the downstream situation. SWAT estimation good- under data scarce situation. SOBEK for the lower part estimated with good accuracy.

*Question***:** SWAT results are present on monthly time step. Does it also perform well on daily basis?

Answer: Yes, the daily time step simulation calibration showed that it gives good estimates.

Q*uestion*: Sediment transport is passive. Did you try to model the surface processes?

Answer: Yes, SWAT incorporates land use, soil and topography and management practices in addition to rainfall and runoff volume.

Question: It was presented by Bashar and Eltayeb that the annual rte of sedimentation in Roseries Reservoir is 34Mm3/year but your estimate is about 19Mm3/year. Why this discrepancy?

Answer: From the report that Roseries dam has lost one third of its capacity (3000Mm3), and if you divide the original volume by 50 and multiply by 1/3, you would get20Mm3. Therefore, 19Mm3 is comparable with 20Mm3 loss.

Question: You are using sedimentation and erosion interchangeably. But sediment delivery is affected by different catchments factors. How do you relate that?

Answer: Sediment delivery ratio- the previous version of SWAT uses USLE and hence requires sediment delivery ratio, but the latest version uses MUSLE takes care of the sediment delivery ratio that we should not worry about it.

Question: Is wash load difficult to model?

Answer: if there is data to calibrate such as bed load, one can use transport formula that is based on concentration such as Delft 3D.

5. **Predicting Discharge and Erosion for the Abay with simple Model (Tammo S. Steenhuis et al)**

The presenter explained that subsurface flow is an important component in the hydrological flows in the landscape. Including this surface flows improves simulation models prediction of both river flows and locations of discharges.

Question: About the erosion intensity at different slopes, is it possible that we see higher erosion in the flat lands because of higher cropping intensity and degree of land management? Have you tested it on non-agricultural lands? Does it relate to high kinetic energy due to cumulative effects of water in the flat lands?

Answer: Erosion requires overland flow. There is less overland flow on the hillsides than in the bottom lands. Amount of overland flow is related exponentially to kinetic energy. Certain flow can carry a maximum amount of sediment for a specific velocity. If this maximum is reached depends on the erodability of the soil.

Question: Pipe flow dominates gully formation. You are studying groundwater development (rising). Have you included the data to justify the formation of gully erosion?

Answer: There are many pipes in the Debra mewi watersheds. High water tables are required for pipes to be formed. Gully formation by slumping banks is also caused by high water tables. It is my hypothesis that gully initiation is due to a pipe. Once formed, both mechanisms take place.

Question: Predicting discharge and erosion from the Abbay river with a simple model – the result of your presentation are very challenging; like the infiltration of water on steep slopes is higher than on moderate slopes. Is this for localized conditions or can be generalized?

Answer: In the watershed, we examined near Woldea Sekota and the SCRP watersheds at Maybar and AnditTid had all high infiltration rates on the hill sides. Especially, if some small furrows are built, most water will infiltrate. The Anjeni case was exception. Water infiltration rates were less because the lands were cultivated.

6. **Modeling Rainfall-Runoff and Erosion in the Blue Nile Using A Modified Soil and Water Assessment Tool Model (Zakary M. Easton et al)**

The presenter explained that the famous curve number developed for USA does not reflect the situation in monsoonal rainfall as it under estimates runoff. This shortcoming can be overcome if longer periods are considered. Integrating water balance into SWAT provides reasonable estimates of runoff and sediment.

Question: What are the main factors affection the results of the outputs of SWAT Model? Is it the quality of data, or the way the data are prepared for the model or the experience of the user?

Answer: The out put of SWAT depends on data quality, data preparation, data calibration and experience of the modeler.

7. **Assessment of hydrological controls on gully formation and upland erosion near Lake Tana BDU Students/Advisors (BDU Students and Advisors)**

It was reported that soil loss was severe at the beginning of the rainy season, decreases with time and finally negative loss (deposition). The rate of soil loss increased down the slope. Prediction based on USLE correlates very well with observed data for the upland erosion, for rill and inter rill erosion. But, there is a strong correlation between water table above gully bottom and the amount of gully erosion due to gully erosion. Gully erosion is caused mostly by the sub surface flow.

Session IV- Policy and Institutions

1. Overview of Policy and Institutions Component [Dr. Amare]

This presentation gave an overview of the policy and institution component of the Upstream-Downstream project. The presentation outline the processes involved in this component which included Rapid Appraisal, stakeholder workshop, and in-depth policy and institutional studies. The presentation also highlighted the outputs that this component is producing including working papers, proceedings, MSc theses, and Research reports.

2. Assessment of Local Land and water institutions in the Blue Nile" [Dr. Fitsum]

This presentation looked at broad institutional issues in the Blue Nile, particularly in the Tana Sub-Basin. The presenter began with an explanation of institutions as being the 'rules of the game' and organizations as being the social entities established to make sure these rules are followed. In carrying out an analysis of institutional arrangement issues, Dr. Fitsum presented a framework that was developed for this exercise. This involved the following criteria to look for:

1. Clear objective
2. Linkage between formal and informal institutions
3. Adaptiveness
4. Appropriateness of scale
5. Compliance capacity

The presentation highlighted the methods that were used in this analysis which included a literature review, stakeholder analysis, focus group discussions and institutional analysis. The results at this stage were then presented in the categories of institutional arrangements, problems in institutional arrangement, scale and enforcement capacity.

<u>Question:</u> As you said on of the problems in dealing with institutions is the issue of informal institutions which would take over the mandate of the formal institutions. What are these informal institutions that you have in mind?

Answer: There are unwritten institutions which substitute the role of formal (written) institutions. For example lack of IWRM and EIAs, although the policy advocates for them.

Question: Your presentation was very general. Many irrigation schemes are not sustainable due to institutional failures. To what extent has your study looked at irrigation schemes which are failing due to institutional issues? Also land tenure is a problem in this area. To what extent is this a gap in institutional arrangements?

Answer: There are documented cases of successful and failing irrigation schemes which we did look at. What we see is that traditional schemes have been more successful. For example Water User Associations have had stronger capacity to enforce the 'rules'. In terms of land tenure we have found that this is an incentive-based policy tool.

3. Benefit sharing framework in Transboundary River Basins: The Case of Eastern Nile [Tesfaye]

This presentation gave a background to increasing demand for water which has lead to, in many places, a water crisis. The main point that was highlighted early on was that 'forging cooperation is key'. This presentation pointed out that there should be a stronger emphasis on sharing of benefits rather than just sharing of water. It was at this point that the concept of benefit sharing was introduced. Despite many agreements over the years for the Nile Basin effective transboundary relations still have not been achieved. What the presenter indicated is needed is for a 'basket of benefits' to be identified both water and non-water and to see how these can be achieved by all in question. The presenter advocated for 1) a benefit sharing treaty and 2) a sound financial framework in order to make this possible. A word of caution was also given in that the perception of benefits alter over time so there is a need to revisit these benefit sharing agreements and terms at certain time intervals.

Question: Dr. Abdalla pointed out that river basin management is a way of taking the river as one unit and learning how to mange it as a whole. He asked whether this option had been considered.

Answer: The Nile is considered as a whole, and as we look at the Eastern Nile we also look at this as a whole part. The Cooperative Framework is stuck currently but once it is resolved it can give a better opportunity to look at benefit sharing for the whole Nile.

Comment: This is what we are doing at ENTRO now. We are looking at the whole system by removing the borders and studying how the basin works and then putting the borders back to see where the benefits are being gained and where they should be going.

4. Transboundary Water Governance Institutional Architecture: Reflections from Ethiopia and Sudan [Everisto Mapedza et al.]

Everisto began his presentation with the main message that whatever arrangements are made it 'has to bring benefits to all stakeholders'. The presentation pointed out that if sharing of water is to happen along the Nile then there has to be some form of cross-border cooperation. The presenter outline a number of steps which have occurred over the years towards cooperation, listing agreements, surveys, the Cooperative Framework and also the formation of the NBI. The presentation highlighted also the Shared Vision and Strategic Action Program which have been developed. In terms of institutional architecture, the presentation listed key components which need to be established. These include transparency (data), fairness (gain legitimacy), meaningful powers (with accountability to US and DS), participation as a process, nested institutional arrangements, transboundary institution should be connected to other institutions, and others.

Question: You have stated that "securitizing' water is one of the impediments that would inhibit a basin wide cooperation. Then, what would be, in your opinion, the way out to "de-securitize water"?

Answer: De-securitization of water can be achieved through broader regional economic integration which goes beyond water alone as what is being done within the SADC region.

5. Prospect of Payment for Environmental Service in the Blue Nile Basin: Example from Koga and Gumera Watersheds, Ethiopia [Amare et al]

The presenter opened by saying that there is a lot of scope for institutionalizing PES, however fully-fledged user financed PES may not be viable and that user and state co-financing would have to take place. The presentation highlighted the problems occurring between the upstream and downstream and showcased some of the onsite and offsite impacts. The question posed was 'How to internalize these effects?" The premise that PES will work on is that by improving water and land management in the upstream part of the basin can provide ecosystem services to the downstream. The role of PES would then be to internalize benefits and channel to the upstream as an incentive to pursue conservation practices. In order to arrange PES it is necessary to see what the Willingness to Pay (WTP) and Willingness to Compensate (WTC) are amongst people who would eventually be part of a PES scheme. These were established through a household survey. The results indicated that while there was willingness to pay and willingness to compensate, the amounts were not enough to make the scheme feasible. The presentation also showed what some of the key determinants of WTP and WTC were. For WTP the key determinants were asset holdings, household factors and institutional factors. For WTC, the determinants were asset holdings, household factors, and institutional factors as well as access to credit and access to extension.

Question: Are there any experiences in applying this concept? I noticed that your study relies completely on results of the questionnaire, but will people actually pay? What is the sample size and how representative is it-if we are to rely on the survey results then we make sure these are good.

Answer: PES is a relatively new concept. It is being implemented around the world, and also in Africa in Tanzania, Uganda and South Africa. PES is about understanding US-DS issues and linkages. It requires cooperation of US and DS land users to alleviate the issues. You have to take a sample as cannot survey the whole Nile. This is a nested approach-you can derive implications from this scale to other scales.

Question: You gave a new meaning to US-DS in your presentation than what we have been generally using in the project. What is the role of the government institutions in PES?

Answer: Currently it is mainly the Government that finances sediment management. The Government mist support institutionally as well as financially the communities involved in such a scheme.

6. Determinants of adoption of improved land and water management practices in the Blue Nile: exploring strategies for outscaling of promising technologies [Solomon et al]

This presentation showed that this study had three main objectives including 1) identifying agricultural water management technologies, 2) to find out the determinants of adoption, and 3) to understand how these could be upscaled. The methods used in this study involved the use of a stratified random sampling technique which identified 325 households to be surveyed. A number of variables were identified to a total of 27 which covered aspects such as institutional and policy variables, farm level attributes and plot level attributes. The results of the study were derived by using two main methods: 1) Logit and 2) Tobit and truncated models. The first method- Logit- was used to derive the probability of adopting conservation technologies. This founds that the following variables were very influential: plot size, land registration, fertility, soil depth and land affected by erosion. Other variables which meant that farmers were less likely to adopt conservation techniques were: tenure (rented in), tenure (sharecropping) and slope of plot (flat). The Tobit and truncated models were used to understand the intensity of use of conservation techniques. The main variables affecting this were: plot distance, plot area tenure and soil type. In conclusion the presentation showed that security of tenure affected both adoption and intensity of use of technologies.

Question: Clarification of why adoption of conservation of soil and water conservation technologies is positively correlated to plot size?

Answer: Farmers with bigger plot size are more likely to adopt conservation technologies than those with smaller plots. This is because they think that these technologies occupy space which reduces land for cultivation.

7. Lessons from Upstream Soil Conservation Measures to Mitigate Soil Erosion and its Impact on Upstream and Downstream Users of the Nile River [Yihnew G/Sellassie et al]

The overall premise and conclusion of this presentation was that by using certain soil and water conservation measures it can increase productivity. This presentation outlined a study which ahs been going on to test a number of key soil and water conservation techniques and to evaluate them.

8. Impact and rehabilitation of floods downstream high Aswan Dam [Lady from Egypt]

This presentation showed how the upstream situation of the Blue Nile has direct impact on the Nile River in Egpyt, as seen at the High Aswan Dam.

Comments from Dr. Anne

1. As an important indicator of the validity of a CVM study, the price of the good should significantly and negatively impact upon the WTC/WTP upstream users for improved

land and water management. This is because start bid is an essential variable to determine mean and aggregate WTP/WTC. However, your result completely contradicts this assumption, and under this condition, I am not clear how you are able to compute mean and aggregate WTC/WTP.

2. The other problem is associated with aggregation of differently located environmental services; this may create an issue of implementation of PES projects. As the watershed dummy indicates that the probability of a household WTP/WTC for Koga watershed is greater then Gumara watershed. And this specification greatly affects (reduce) WTP in Gumara watershed by over estimating the mean WTP during implementation.
3. The finding of watershed dummy variable also suggests that there may be a possibility to have a variation in the determined factors between the two watersheds? Because with a similar study, Koga watershed we find that different result between the start bid and WTP variable.
4. Generally, I suggest that disaggregation of specification may show many of the problem associated with CV study.

Presentation of Group Works

In this session, four groups presented their group work.

Group I: Policy and Institutions in the Blue Nile

The group outlined key lessons learned, identified gaps in: institutions, policies and knowledge; identified stakeholders and suggested the way forward. Among the key lessons awareness of relation on downstream & impacts, the roles and responsibilities of organizations & problems in institutional assessments, local community commitment etc. were mentioned. Lack of mechanisms for promoting restricted livestock management, (e.g. Zero grazing), was mentioned as one of the institution and policy related gaps.

Group II: Water Allocation Simulation Model

The group reported on key lessons learned, strength, key gaps, mechanism for data sharing, key stakeholders, and the way forward. Among the strength outlined was "basin scale results prepared jointly by researchers from across the basin", but there is still discrepancy in estimates current water use and even flow. Lack of linkage with other components was also mentioned as a problem. Thus, it was suggested that focus will be made on linkage between watershed, water allocation and policy. It was also suggested to add constraints to model at the downstream end to take into account downstream water requirements

Group III: Watershed Modeling

The group summarized the lessons learned by stating that subsurface flow is an important component in the hydrology of the watershed, especially for determining the location of runoff areas and type of erosion. It was learned that other models can be combined with SWAT to simulate channel processes. SWAT can be parameterized to predict monthly discharges and sediment loads in rivers. As a gap, it watershed modeling should be integrated with livelihood issues on the landscape. Distributed outputs are validated only at the outlet of the watershed at monthly time step, which may not be valid at watershed scale. It was suggested that more models are needed to simulate the watershed process.

Group IV: Knowledge sharing and Impact Pathway

This group identified target groups/stakeholders for knowledge sharing like policy makers, research community including: researchers, scientific societies, higher education institutions, Implementers, including: extension system, NGOs; Nile region, including: other riparian countries and regional organizations (e.g NBI, etc) and farmers. Also, they outlined what knowledge to share with the stakeholders, what knowledge activity to use to share for the different stakeholders and the "how and who-operational details". Finally, the group requested participants to suggest "Top 3 to do". Accordingly, the following prioritized additional dissemination activities were suggested:

- Producing videos
- Regional workshop/training for young researchers from three countries to come together to learn how to use models and analyze own data.
- Training/workshops for those in the Ministries
- Use NBI network to help in dissemination
- Researchers working together- NB capacity building unit—building platform for researchers to share knowledge

General Discussion

A lengthy and heated debate was conducted on issues related to data quality and sharing, linkage and integration between the components of the project, the project lifetime and the gap to be addressed.

Data quality and sharing

The issue of contradiction free information bases/data has been raised by most of the groups. Consequently, there was a heated debate on the same issue during the plenary session. It was suggested to get data from the source of the data, but that has been difficult so far. Data sharing is a dilemma, which is forcing people to use secondary data, which leads to high discrepancy. There was an understanding that the real problem is not the absence of data but its availability is hindered by the historical hydro politics. This is believed to be related to lack of enough confidence building. In line with this, Dr. Seleshi appealed to the decision makers participating in the workshop to help in ensuring the sharing of available data.

Others argued that the only way out is the data protocol which is under development by ENTRO. It was explained that the process has been completed, but has to be signed by higher officials. It was also suggested that attempt be made to generate primary data like sediment/wash data by having gauging stations, but it was reminded that institutions like IWMI do not have the mandate to take measurements. Others argued that the presentations of the previous day were based on SCRP data, collected by the project, which imply that there should be a strategy for projects to be able to collect primary data. Currently, a lot of projects are running in the basin and ENTRO can develop a mega project for data collection by adopting a standardized data protocol. Besides, it was strongly suggested to include gauging/data collection in the next phase of the project, as it is difficult to continue to count on scanty data. In the mean time, the following suggestions were made:

- Link Research Institutes/Universities with development efforts in the basin like with Tana basin development
- Also link with national institutions working in the basin;
  - IWMI has linkage with NBI and Universities
  - IWMI is facilitating research in Nile basin- and this can be strengthened
- Institutions like IWMI can do capacity building in terms of training and facilities for the government institutions which can do the recording

Linkage and Integration between the components of the Project

The link between the first two components is not difficult- but to link with institutions and policy is an important issue. One way to integrate the components is to assess certain watersheds taking the basin as its entirety than country by country basis.

It was also suggested that we follow a two steps- gap filling approach; like understanding the economic implication of land degradation, and economic impact of water allocation and synthesis the results into reports. If there are viable technologies coming up from the model, it is possible to follow-up to see the economic, policy and institutions aspects.

It was recommended to change the term “water allocation” to “water utilization or water budgeting” since the term has connotations beyond the mandate of scientists.

About the projects life time and the gap to be addressed

- There are several research questions to be answered. We should sort out those which can be addressed within the time left
- Mean while there was a strong notion that the project be extended

Summary and conclusion (by the facilitator)

- Thread- off between being focused and covering the issues
- Climate change scenarios should be considered in the future studies
- Communication to the stakeholders is important aspect which should be done in a realistic manner
- When extending the project, the impact downstream should be considered up to Egypt
- About data sharing- we should start from ourselves, if we can make it available before demanding the policy makers or others
- The fact that young molders are emerging from within the basin is encouraging output of the project
- The progress so far is quite optimistic

List of Posters

These are the titles and the authors of the posters displayed during the workshop (for details refer to CD):

Determinants of Household Willingness to Pay for Water to Boost Sustainability of Water Supply Sources: Achefer, Amhara Region, Ethiopia

Aschalew Demeke, Tammo Steenhuis, Charles Nicholson, Amy Collick and Robert Blake

Assessment of Hydrological Controls on Gully Formation near Lake Tana, Northern Highlands of Ethiopia
By: Tigist Y. Tebebu, Anteneh Z. Abiy, Helen E. Dahlke, Eric D. White, Amy S. Collick, Zachary M. Easton, and Tammo S. Steenhuis

Assessment of adoption behavior of soil and water conservation practices in Koga Watershed, Highland of Ethiopia
Fikru A. Mengstie, Amy S. Collick, Fistum H, Tammo S. steenhuis

SWAT based Runoff and sediment yield modeling of Gumara Watershed
Meqaunint Tenaw, Seleshi B. Awulachew

Payment for Environmental Service to Enhance Environmental Productivity in the Blue Nile Basin
Habtamu T. Kassahun, David R. Lee, Charles F. Nicholson, Gregory L. Poe, Amy S. Collick, and Tammo S. Steenhuis

Modeling Rainfall and Runoff Relationships Atmaybar Research Unit, Wollo, Ethiopia
Haimanote K. Bayabil Tammo S. Steenhuis, Seleshi B. Awulachew, Amy S. Collick

Assessment of Upland Erosion Processes and Farmers' Perception of Land Conservation near Lake Tana, Ethiopia
Assefa D. Zegeye, Tammo S. Steenhuis, Robert W. Blake, Amy S.Collick, Selamyihun Kidanu

Application of the SWAT Model in the Ethiopian Highlands
Biniam Biruk, Eric D. White, Zachary M. Easton, Matthew McCartney & Tammo Steenhuis

Modified Soil and Water Assessment Tool (SWAT) for Modeling Rainfall/Runoff in Monsoonal Climates
Eric D. White, Zachary M. Easton, Daniel R. Fuka, and Tammo S. Steenhuis

Rainfall, Runoff and Soil Loss Relationships for Northern Highlands of Ethiopia
Tegenu A. Engda, Tammo S. Steenhuis, Amy S. Collick, Zachary M. Easton, Seleshi B. Awulachew

Assessment of Sustainable Watershed Management Approach Case Study Lenche Dima, Tsegure Eyesus and Dijjil Watershed

Tesfaye Habtamu, Tammo Steenhuis, Amy S. Collick

Assessment of hydrological controls on gully formation near Lake Tana, Northern Highlands of Ethiopia

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