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Sedimentation and Sustainability of Hydropower Reservoirs: Cases of Grand Ethiopian Renaissance Dam on the Blue Nile River in Ethiopia

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Hydropower Development
Submission date: June 2013
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MASTER OF SCIENCE IN HYDROPOWER DEVELOPMENT
SPECIALISATION: HYDROPOWER HYDRAULICS

Candidate: **Tadesse Tufa Borji**

Title: **SEDIMENTATION AND SUSTAINABILITY OF HYDROPOWER RESERVOIRS: CASES OF GRAND ETHIOPIAN RENAISSANCE DAM ON THE BLUE NILE RIVER IN ETHIOPIA**

1 BACKGROUND

Ethiopia has a vast hydropower potential, estimated to be about 30 000 MW with a total potential of 159 TWh/year. Compared to its hydropower potential, the country has not made significant progress in the field of hydropower development. The country is still one of the lowest per capita electric energy consumption in the world. In recent years, the Government has made a determination and commitments to develop and utilize the water resources potential, improve the water and energy security and thus bring economic growth to the country. Accordingly, Ethiopia is undertaking massive hydropower development activities in different river systems within the country. A start has already been made to construct 6000 MW Grand Ethiopian Renaissance Dam (GERD) hydropower project in the Blue Nile river system. The GERD project is located near to the border between Ethiopia and Sudan. The 151 m high RCC dam will create a reservoir with a storage capacity of 74 billion m^3.

The Blue Nile River system is the second largest drainage area in Ethiopia; it has the highest runoff, estimated to be 51 km^3/yr. The basin accounts for 50 percent of water runoff in Ethiopia. It also comprises 62 percent of the Nile discharge into Lake Nasser/Nubia and 72 % of the total Ethiopian contribution to the Nile waters. The river system has a channel length of 922 km and falls 1,295 m from Lake Tana (1,785 masl) to the Sudan border (490 masl). Within the Blue Nile River system, there are existing hydropower projects (Tis Abay I and II, Tana Beles), the Grand Ethiopian Renaissance Dam (GERD) which is under construction and Karadobi, Bako Abo and Mandaya are projects under planning.

Sedimentation is a large problem in reservoirs in the river system within Ethiopia, existing condition of previously constructed reservoirs shows that significant portion of their storage capacities are lost to sedimentation every year. There are even cases where reservoir capacities were filled with sediment within less than five years of operation. Downstream inside Sudan in the Roseires reservoir, the average annual sedimentation rate at Roseires was 1.8% between 1966 and 1985. In other words, 33% of the initial capacity was lost over 19 years of operation. The risk of losing storage capacity in the long term due to reservoir sedimentation is a series and crucial issue for the hydropower projects in the area. This is the main issue with respect to sustainability of the reservoir. The realization of the project objectives will be highly affected, unless impacts of sedimentation and possible mitigation measures are studied and considered during planning, construction and operation of the projects.

2 MAIN QUESTIONS FOR THE THESIS

The thesis shall cover, though not necessarily be limited to the main questions listed below.

2.1 Sediment Transport and Hydropower Reservoirs in Blue Nile River

The presentation of the project shall be as brief as possible, but sufficiently detailed to give the reader, who has no other information on this project, a good understanding and basis for assessing the work carried out by the Candidate without having to go to the reference material. The Candidate shall:

- Give an overall presentation of the hydropower projects in the Blue Nile Basin based on the available Feasibility Reports or other sources.

- Present, review and discuss all the available data, reports and design (pre-feasibility, feasibility and detailed design) with respect to sediment transport, sediment yield, and sedimentation and sediment measurements in the Blue Nile river basin. This includes the Roseires Reservoir in Sudan which is located further downstream on the Blue Nile River.

- Present, review and discuss the adopted sediment management regime for the projects.

2.2 Sedimentation Rate for GERD

Most of the time sediment transport into reservoirs is underestimated and reservoirs fill up by sediment more rapidly than expected, as a long term result the reservoir operates at reduced functional efficiency. There are no commonly accepted rates of reservoir sedimentation. For this reason good prediction of the future reservoir sedimentation rate and associated loss in energy production is important to find out the optimal design of mitigation measures and its economic implication. The Candidate shall study and estimate the sedimentation rate of the reservoir which includes:

- Estimate sediment yield based on the available data and based on the review of the reports
- Sediment inflow characteristics and deposition patter in the reservoir
- Storage capacity loss due to sediment every year (sedimentation rate)
- Trap efficiency of the reservoir under consideration
- Annual losses in benefit due to sedimentation
- Assess the impact of possible new upstream reservoirs on the sedimentation rate

2.3 Propose Strategy for Sediment Management at GERD

The ultimate objective of reservoir sedimentation studies should focus to achieve sustainability of the reservoir through a long term optimum sedimentation management programme. The sustainability of water storage reservoirs require a balance to be achieved between the volume of sediment deposited and the volume of sediment removed from the reservoir. In most cases it is difficult to achieve a complete sediment balance as sediment deposit in reservoir is influenced by several factors. But it is possible to optimize the services of the reservoir through different sediment management strategies. The Candidate shall carry out a study to:

- Identify possible sediment management measures and assess their applicability to the reservoir at GERD
- Select the most appropriate management measure and develop modalities for implementation.
- Recommend possible strategy, with respect to sediment management, need to be considered during construction and operation of the reservoir.

3 SUPERVISION, DATA AND INFORMATION INPUT

Professor Haakon Støle and Dr. Kiflom Belete will supervise the thesis work and assist the Candidate to make relevant information available.

Discussion with and input from colleagues and other research or engineering staff at NTNU, SINTEF, EEPCO, Ministry of Water Resources of Ethiopia and others are recommended. Significant inputs from others shall, however, be referenced in a convenient manner.

The research and engineering work carried out by the Candidate in connection with this thesis shall remain within an educational context. The hydropower reservoirs on the Blue Nile are selected and used during the study is a study object. The Candidate and the supervisors are therefore free to introduce assumptions and limitations, which may be considered unrealistic or inappropriate in a contract research or a professional engineering context.

4 REPORT FORMAT AND REFERENCE STATEMENT

The thesis report shall be in the format A4. This signed thesis assignment text shall be placed unedited right after the title page. The thesis shall be typed by a word processor and figures, tables, photos etc. shall be of good report quality. The report shall include a summary, a table of content, lists of figures and tables, a list of literature and other relevant references and a signed statement where the candidate states that the presented work is his own and that significant outside input is identified.

The report shall have a professional structure, assuming professional senior engineers (not in teaching or research) and decision makers as the main target group.

The summary shall not contain more than 450 words it shall be prepared for electronic reporting. The entire thesis may be published on the Internet as full text publishing. The candidate shall provide a copy of the thesis (as complete as possible) on a CD in addition to the A4 paper report for printing. The summary shall be in a separate MS-Word-file.

The thesis shall be submitted no later than 10th June 2013.

Trondheim, 20th January 2013

Professor Haakon Støle
Department of Hydraulic and
Environmental Engineering, NTNU

Foreword

The thesis titled “Sedimentation and Sustainability of Hydropower Reservoirs: Cases of Grand Ethiopian Renaissance Dam on the Blue Nile River in Ethiopia” has been prepared and submitted as a partial fulfilment of the requirement of the MSc. Course in Hydropower Development at the Department of Hydraulic and Environmental Engineering, the Norwegian University of Science and Technology, Trondheim, Norway.

The author hereby declares that the work presented herein is his own work under close direction and instruction by his advisors.

Trondheim, June 10, 2013

Tadesse Tufa

Summary

Sediment accumulation in a reservoir is a serious problem that threatens sustainability of the reservoir and has severe consequence on reservoir productivity during its operation time. In order to predict the reservoir sediment deposition pattern, evaluate its consequences on the reservoir yield and identify appropriate reservoir sediment management strategy, accurate quantification of long term average sediment yield is needed. The accuracy of sediment yield estimate depends on availability of good quality suspended and bed load data for period long enough to account for temporal variability, which however is very limited in the Blue Nile Basin. Thus there should be a means to estimate the sediment yield based on the very limited data. In this study sediment rating curve developed based on available data was used to generate longer sediment concentration data from the discharge history in order to quantify sediment yield at different locations (Kessie, Burie and Tato) in the basin. Sediment yield estimated based on rating curve was compared with sediment yield estimated based on data obtained from secondary sources (bathymetric survey data of Roserires reservoir and average sediment concentration at El-Deim) and delivery ratio. Comparisons of various scenarios were made to finally estimate total sediment load of 245 million t/year at GERD.

Deposition pattern of sediment entering the GERD reservoir was predicted based on Empirical Area Reduction method. The sediment deposition depth in the reservoir increases gradually and fills up the storage below the minimum water level which defines the life of the reservoir. According to the Empirical Area Reduction method, the GERD reservoir will have life of 116 years for the estimated annual sediment load of 245 million tonnes, trap efficiency of 100% and average deposit density 1.12 t/m^3. The reservoir storage capacity will be lost at an average rate of 0.3 % per year. Consequences of storage capacity loss on production capacity were evaluated where the average annual energy loss due to active storage loss amounts 27 GWh. The estimated present value of economic loss indicates that the total economic values forgone due to the live storage loss was found to vary between 0.26% and 0.06% of the original dam cost, 4.33 billion USD when the discount rate varied between 5% and 13% respectively.

Various reservoir sediment management strategies were evaluated with the catchment area, environmental and social considerations, reservoir capacity to inflow ratio and total sediment load as governing parameters. According to the preliminary assessment and further evaluation of management strategies using RESCON model dredging was found appropriate for the GERD reservoir. Based on the RESCON model estimates, 20 dredges capable of removing 11 million m^3 per year each have to be installed in order to keep the reservoir sustainable.

Acknowledgements

Apart from my efforts, the success of the work depends on encouragement and help of many others. I would like to express my very great appreciation to Professor Haakon Støle, my research supervisor, for his guidance and very useful critiques of this study.

Special thanks should be given to my thesis work supervisor Dr. Kiflom Belete for his patient guidance, enthusiastic encouragement and constructive suggestions during the planning and development of this thesis work. His willingness to give his time so generously has been very much appreciated.

My deepest gratitude goes to our excellent department coordinator Hilbjørg Sandvik for her assistance and encouragement during my study in Norway. I would also like to appreciate the State Education Loan Fund (Lånekassen), Norway, for the financial support.

I wish to acknowledge Dr. Mulugeta B., Mr. Yesuf M., Mr. Guta W. and Mr. Dawit A. for their assistance with the data collection and advice provided by them was greatly appreciated. I would also like to thank the EEPCO employees (Mr. Merga and Fufa J.) for their friendly help during the data collection.

I would also like to offer my special thanks to all my friends in Trondheim for their encouragement and for creating a family environment.

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Abbreviations and Symbols

EEPCO ----- Ethiopian Electric Power Corporation
FSL ----- Full Supply Level
g/l ----- unit for sediment concentration, gram per litre
GERD ----- Great Ethiopian Renaissance Dam
HSRS ----- Hydro-suction system for removal of sediment
JICA ----- Japan International Cooperation Agency
RCC ----- Roller Compacted Concrete
kg/s ----- unit of sediment discharge, kilogram per second
USLE ----- Universal Soil Loss Equation
SWAT ----- Soil and Water Assessment Tool
km ----- unit of length, kilometre
km^2 ----- unit of area, square kilometre
kWh/m^3 ----- kilowatt hour per one cubic meter of water volume
m ----- unit of length, meter
ha ----- hectare
m/s ----- unit of velocity, meter per second
m^3 ----- unit of volume, cubic meter
m^3/s ----- unit of discharge, cubic meter per second
m^3/year ----- unit of runoff volume, cubic meters per year
MAR ----- mean annual runoff
masl ----- unit of elevation, meter above sea level
mill. ----- million
MoWRE ----- Ministry of Water Resources of Ethiopia
MW ----- mega watt
MWEE ----- Ministry of Water and Energy of Ethiopia
NA ----- not available
Q ----- symbol for discharge
RESCON ----- Symbol for reservoir conservation
SSL ----- Suspended Sediment Load
SSY ----- Specific Sediment Yield
t ----- Metric tonne
GWh ----- Giga watt hour
t/km^2/yr ----- unit of specific sediment yield, tonnes per year per square kilometre
t/m^3 ----- unit for deposit density, tonne per cubic meter
t/year ----- unit of sediment yield in terms of weight, tonnes per year
TE ----- Trapping efficiency
TL ----- Total Load
ton ----- tonne
USD ----- US dollar
°C ----- Degree Celsius
mm ----- millimetre
FAO ----- Food and Agricultural Organization

ENTRO ----- Eastern Nile Technical Regional Office
USGS ----- United States Geological Survey
NBCBN-RE ----- Nile Basin Capacity Building Network- River Engineering
g ----- Acceleration due to gravity
γ ----- specific weight of water
η ----- Efficiency
ρ ----- density of water

1 INTRODUCTION

1.1 GENERAL BACKGROUND

Reservoir sedimentation is a gradual accumulation of the incoming sediment load from a river. This accumulation is a serious problem in many parts of the world and has severe consequences on water management, flood control and production of energy. In the present situation, the world wide loss of storage capacity in surface water reservoirs due to sedimentation is higher than the increase in storage volume achieved through construction of new reservoirs (White, 2010). The world wide loss in reservoir storage capacity is estimated to be between 0.5% and 1% per annum (Mahmood, 1987; White, 2010).

Lahlou, (1996) based on study of 73 large North African reservoirs has estimated the total annual storage loss of 0.5% for Morocco, 0.7% for Algeria and 1.2% for Tunisia. Reservoirs of Ethiopia, the existing and the new ones, are under similar threat of sedimentation problem (Haregeweyn, et al., 2012; Siyam et al., 2005). The frequent power cuts and rationing based electric power distribution recently experienced in the country are partially attributed to storage loss due to sedimentation (Tamene, et al., 2006).

Nile tributaries, originating from the Ethiopian plateau, carry large quantities of sediment. Reservoirs built on these tributaries are experiencing alarming loss in capacity due to sedimentation. In some reservoirs, the annual rate of capacity loss exceeds 1.0 %. Khashm El-Girba dam reservoir in Sudan for example has lost 50% of its original capacity in less than 40 years which is about 1.25% annual loss (Siyam, et al., 2005; Shahin, 1993). Roseires in the same way has lost its 42% of its original capacity in 41 years, about 1.02% per year from 1966 to 2007. An average storage loss of 1.16% per year was observed for Sennar reservoir which has no more capacity to store considerable amount of water (Siyam, et al., 2005).

Reservoirs have to be considered as irreplaceable resources and have to be managed in accordance with the objective of sustainable utilization. The fundamental objective of reservoir sedimentation studies should focus on achieving sustainability of the reservoir. The sustainability of water storage reservoirs require a balance to be maintained between the volume of sediment deposited and the volume of sediment removed from the reservoir. In most cases it is difficult to achieve a complete sediment balance as sediment deposit in a reservoir is influenced by several factors (Morris and Fan, 1998). But it is possible to optimize services of the reservoirs through different sediment management strategies (Palmieri, et al., 2003).

The Great Ethiopian Renaissance Dam (GERD) reservoir is one of the largest reservoirs planned on the Blue Nile River involving large investment cost. Its huge storage capacity can be lost in a few years of operation if sediment problems are not handled efficiently. Therefore, it is important to predict sediment inflow at GERD and evaluate its consequences on the reservoir and sustain the reservoir through a long term optimum sediment management program.

1.2 OBJECTIVES

This study focuses on assessment of reservoir sedimentation and its sustainability and identification of most appropriate sediment management strategy that can be applied to the reservoir at GERD.

The specific focuses are to:

- Give an overall presentation of the hydropower projects in the Blue Nile Basin
- Present, review and discuss all the available data, reports and design with respect to sediment transport, sediment yield, and sedimentation and sediment measurements in the Blue Nile river basin including the Roseires Reservoir in Sudan.
- Present, review and discuss the adopted sediment management regime for the projects
- Estimate sediment yield at GERD
- Predict sediment inflow characteristics and deposition pattern in the reservoir
- Estimate sedimentation rate of the reservoir
- Estimate annual loss in benefit due to sedimentation
- Identify possible sediment management measures and assess their applicability to the reservoir under consideration
- Select the most appropriate management measure and develop modalities for implementation, including preliminary design.
- Recommend possible strategy with respect to sediment management, need to be considered during construction and operation of the reservoir.

1.3 ORGANIZATION OF THE THESIS

This study was carried out based on literature reviews and available data of the study area. Chapter 1 introduces the background of the study and presents the objectives of the study.

Chapter 2 briefly describes the study area and gives an overall presentation of reservoirs and hydropower projects in the Blue Nile Basin.

Chapter 3 briefly presents the available stream flow data and sediment data in the basin. Examination of the available data quality is also presented in this chapter.

Chapter 4 introduces erosion and sediment transport in the Blue Nile Basin

Chapter 5 briefly presents estimates of sediment yield in the study area to predict the sediment yield at GERD.

Chapter 6 assesses sediment deposition pattern in GERD reservoir. It includes prediction of sedimentation rate and reservoir life and estimates economic loss due to the live storage loss.

Chapter 7 covers assessment of available sediment management strategies and selection of most appropriate strategy for the GERD reservoir.

Chapter 8 summarizes conclusions and recommendations

2 THE STUDY AREA

2.1 DESCRIPTION OF THE STUDY AREA

2.1.1 LOCATION

The Blue Nile and its tributaries start from the Ethiopian highlands. It originates from Lake Tana, the largest lake in Ethiopia and joins the White Nile at Khartoum, the capital of Sudan. The Blue Nile is located between longitudes 33°26’55’’ and 39°49’12’’ E and latitudes 7°39’28’’ and 13°50’7’’N covering about 210,000 km^2 area and is as shown in **Figure 2.1**. Along the way from Lake Tana to Sudan the Blue Nile River is joined by rivers Beshlo, Derma, Jemma, Muger, Guder, Fincha, Didessa, and Dabus from the left bank and Beles, Birr, and other smaller tributaries from the right bank.

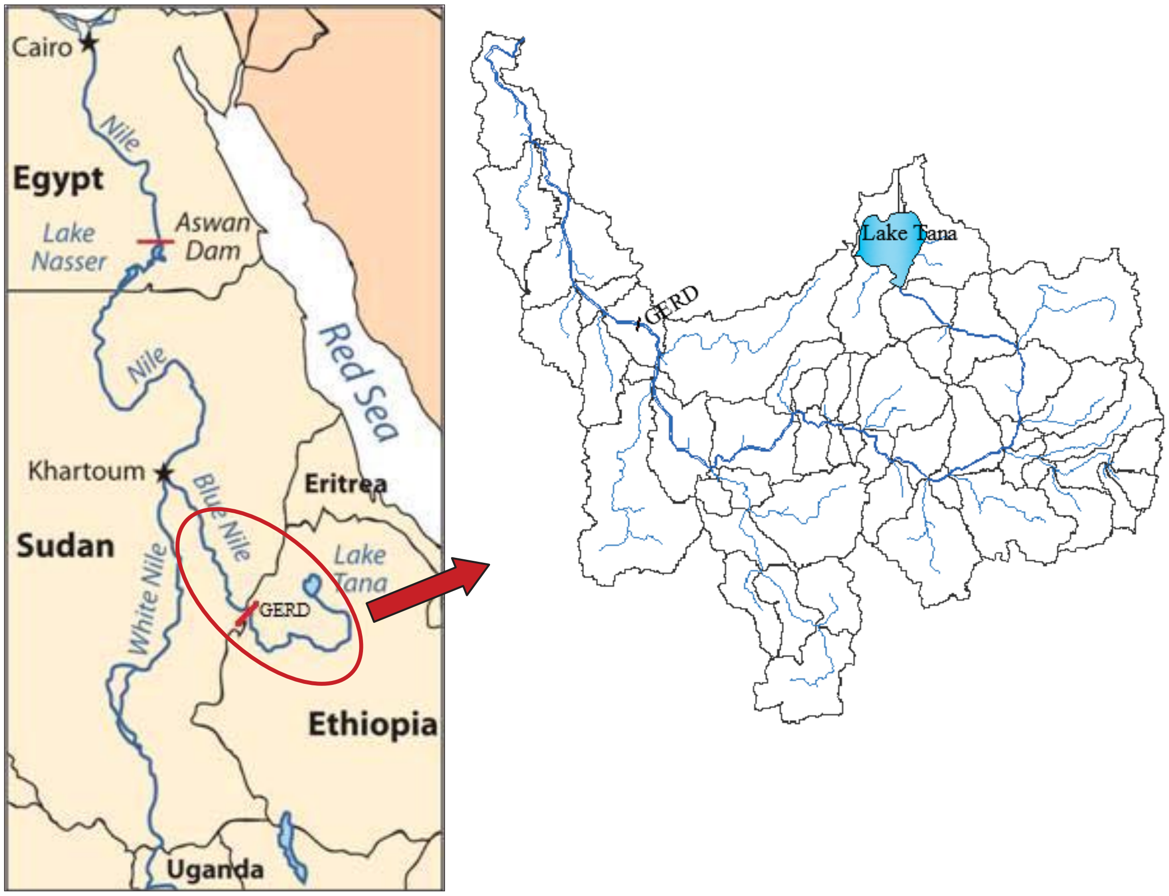

Figure 2.1 Location of the study area

2.1.2 PHYSIOGRAPHY

The Blue Nile Basin is characterized by very broken and hilly plateau with grassy uplands, swamp valleys and scattered trees (Sutcliffe and Parks, 1999). The highland plateau has been deeply incised by the Blue Nile and its tributaries and has the general slope to the northwest (Conway, 1997). The slope of the catchment ranges from as steep as 45% in the Eastern part of the area to 0% in Sudan with an average of about 4%. The elevation of the basin ranges from less than 400 masl in Sudan to 4260 masl at the top of highlands.

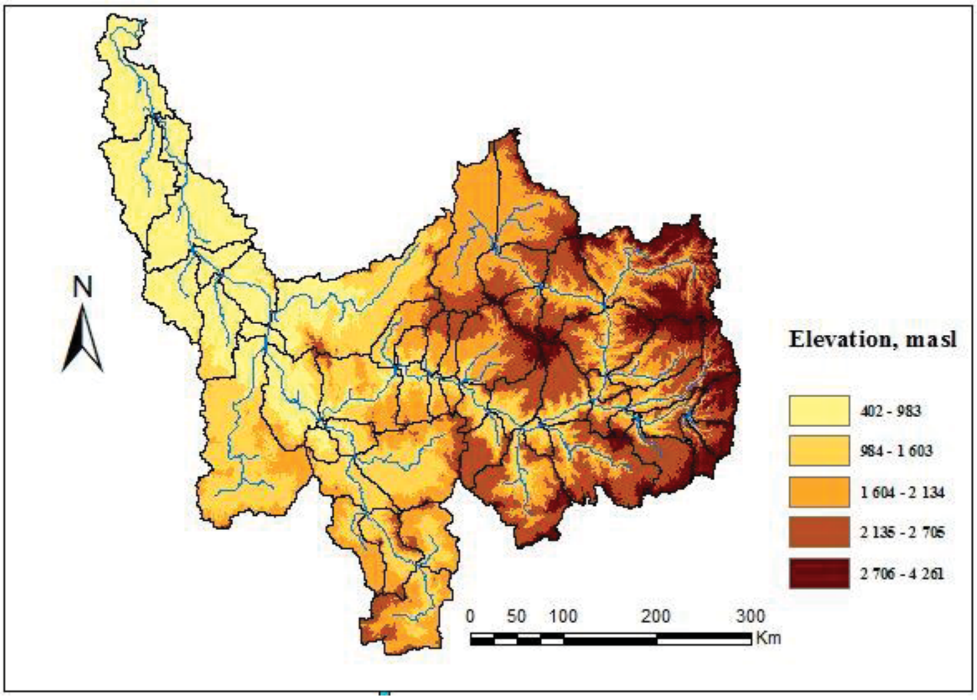

Figure 2.2 Blue Nile Basin relief and drainage

2.1.3 CLIMATE

The climate in the Blue Nile is governed by the seasonal migration of Inter Tropical Convergence Zone from south to north and back. Mean annual precipitation ranges from about 2000 mm in Ethiopian highlands to less than 200 mm in Sudan (Hydrosult, et al., 2007). Within the highlands of Ethiopia the wet season lasts four months from June to September with the maximum rainfall in August. East of Blue Nile, the rainfall pattern is characterized by two wet seasons, the short rainy season and the main rainy season. The short rainy season occurs from mid of February to mid of May and the main rainy season occurs from June to September.

The mean annual temperature in part of the study area located in Sudan is 28.73 °C with maximum daily temperature of 44 °C in May and minimum daily temperature of 14 °C in January. The spatial distribution of temperature highly depends on altitude. In the Ethiopian highlands the mean annual temperature ranges from 6 to 9 °C and 23 to 26 °C in the low lands of the area, near the border (FAO data base, Hydrosult, et al., 2007).

2.1.4 HYDROLOGY

The average annual runoff volume is about 50.6 billion m^3 which equates 241 mm over the catchment area of 209,780 km^2. Flow distribution is reflected to great extent by the rainfall seasons (**Figure 2.3**) but with time-lag and attenuation through which the high-flow season commences first in July and persists until October-November as the high flows gradually recede until low flow condition prevail between December and June. The highest flow months July to October yield about 80% of the annual runoff. Variation in specific runoff of the Blue Nile River at El-deim, Mandaya, Karadobi, Kessie and at the outlet of Lake Tana is given in **Figure 2.3**.

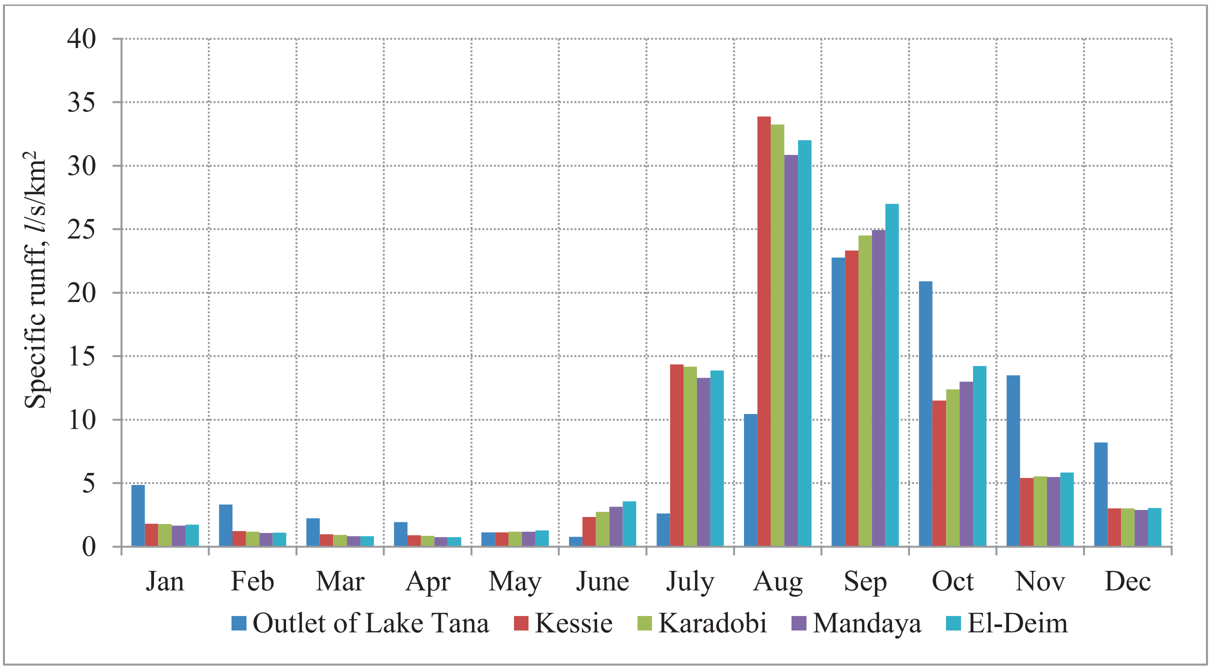

Figure 2.3 Specific runoff at different locations along the Blue Nile River

(Data source: Tefferi, 2012 and Awulachew, et al., 2008)

2.1.5 LAND USE AND LAND COVER

According to USGS (2003), savannah land occupied 69.8% of the total Blue Nile Basin without Dinder and Rahad river basins, forest covered land about 2.17%, grassland 2.31% of the total area, and crop land, dry land and pasture about one fifth (21.61%) of the area, while built up and artificial areas accounted for 0.03% of the total area. The remaining 4.08% being water body, barren and sparsely vegetated land. Though land cover changes from time to time there is no comprehensive data to show change in land use and land cover of the basin.

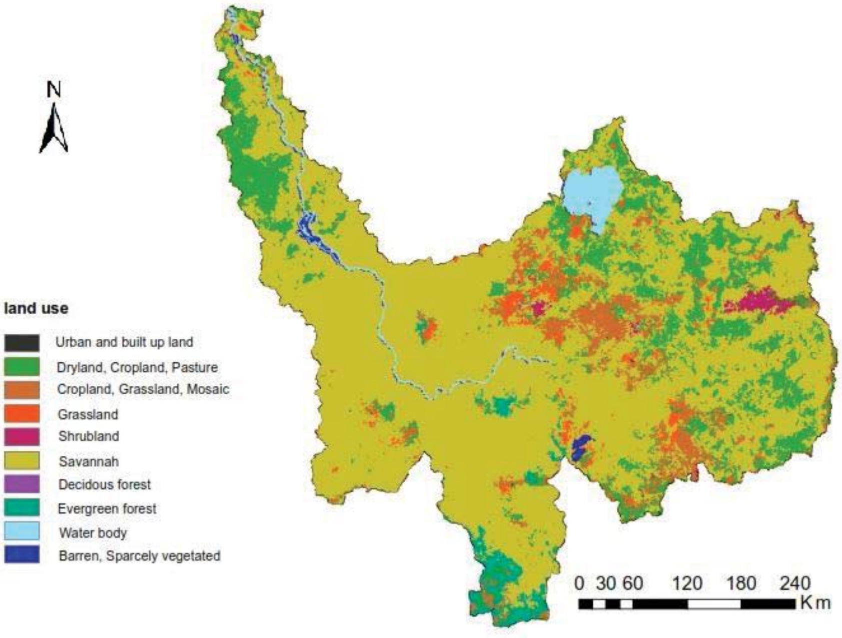

Figure 2.4 Land cover map (Data source: USGS, 2003)

2.1.6 SOIL

The predominant soils are generally characterized as vertisols, luvisols, and leptisols (Easton, et al. 2010). Soil profiles in the highlands are characterized by permeable soils, underlain by bedrock at depth. Soils are generally deeper at lower reaches of the basin while soil depth is less in the steeper slopes. Based on the FAO soil classification, part of the basin in Sudan is dominated by the Eutric Vertisols. The part of the basin in Ethiopia is mainly dominated by Umbric Nitosols in the south eastern part and Lithic Leptisols in the north eastern part (Awulachew and Yilma, 2009).

2.1.7 GEOLOGY

The geology of the basin signifies different formations such as Basalt, Alluvium, Lacustrine deposit, Sand stone, Granite and Marble. The highlands of the basin are composed of basic rocks, mainly basalts and the lowlands composed basement complex rocks as well as metamorphic rocks, such as gneiss and marble (Awulachew, et al. 2008).

2.2 RESERVOIRS IN THE BLUE NILE BASIN

Reservoirs are built either as single or multipurpose reservoirs. Multipurpose reservoirs are schemes combining two or more of the following requirements: irrigation, hydropower, water supply, flood control, navigation, fishery, recreation, environmental issues. In the Blue Nile Basin, Fincha, Tana Beles project taking its water from Lake Tana, Karadobi, Roseires and Sennar reservoirs were intended to supply irrigation schemes in addition to hydropower generation. Tis Abay I and II hydropower projects supplied from Lake Tana, GERD (Grand Ethiopian Renaissance Dam), Bako Abo and Mandaya are planned primarily for hydropower generation.

2.2.1 EXISTING RESERVOIRS

2.2.1.1 Lake Tana

Lake Tana is a natural reservoir located in the country’s north-west highlands at 12°10’0’’ N, and 37°20’0’’ E. The lake covers an area of about 3,000 km^2 at an average elevation of 1800 masl. It has a volume of about 28 billion cubic meters, which makes it the largest lake in Ethiopia. The lake is shallow with an average depth of about 9 m and maximum 14 m (Ligdi, et al., 2010). The climate of Lake Tana basin is characterized by a major rainy season with heavy rain during June to October. The mean annual rainfall over the catchment is 1,326 mm and the average annual runoff volume entering the lake is about 5 billion m^3 (SMEC, 2008). The lake drains a catchment area of 14,500 km^2 which is about 8% of the total catchment area at GERD. Lake Tana supplies Tis Abbay I and II hydropower projects located just downstream of the outlet of the lake and Beles multipurpose project located on the western side of the lake.

Tis Abay I hydroelectric power plant is located on the Blue Nile River some 32 km downstream of Lake Tana at a site where the river bed suddenly drops by approximately 45 meters, thus creating the well known Tiss Issat Water Falls. The head naturally created by the falls has already been used to generate electricity since 1964. The installed capacity of the power plant was 11.4 MW (AECE, 2000).

The low weir named Chara Chara was constructed in 1995-1997, across the Blue Nile River at the outlet of Lake Tana, to enable regulation of the outflow from the lake. This created a hydropower plant named Tis Abay II with an approximate gross head of 53 m and 73 MW installed capacity producing a firm energy of 359 GWh annually (AECE, 2000). The contribution of the intermediate catchment (between Lake Tana and Tis Abay) to the discharge of the Blue Nile River is about 12 m^3/s, which is only 10% of the average annual flow at Tis Abbay, 120 m^3/s.

Being located only 32 km downstream of Lake Tana, the sediment inflow to the Chara Chara weir may be very low. The suspended sediment concentration at the Chara Chara weir can be approximately 10% of the suspended sediment concentration of intermediate area assuming the erosion rates and sediment delivery are the same for the intermediate area and the Lake Tana basin. This assumption is valid considering no sediment outflow from Lake Tana.

The Tana Beles project, put in operation in 2010, also transfers water from Lake Tana by a 12 km tunnel through Beles basin. The transferred water after 130 m drop with vertical pressure shaft generates 123 GWh annually. The water after generating hydropower is diverted to canal system to irrigate an area of about 140,000 ha in the Beles basin.

Sediment inflow to Lake Tana has been estimated, by JICA (1977) to be 10 million m^3 per year and predicted that the lake will lose 6% its storage within 100 years with trap efficiency of 50%. Based on bathymetric surveying study, WRDA (1990) stated that the trap efficiency of the lake is 97% (as sited in Ligdi, et al., 2010).

2.2.1.2 Fincha reservoir

The Fincha River drains Fincha basin located in the South Eastern part of the Blue Nile Basin. Fincha Dam is constructed on this river in 1971 for power generation and Irrigation. The mean annual runoff volume from the Fincha catchment is about 1,720 million m^3 which was harnessed to supply 134 MW capacity power plant and 8,145 ha agricultural area. The climate of the Fincha watershed is ‘Tropical Highland monsoon’ with an average annual rainfall of 1604 mm (Bezuayehu, 2006). Land use of the area is dominated by agriculture which covers about 53% of the Fincha catchment (Awulachew and Yilma, 2009).

The enormous expansion of cropland, especially on the higher and steeper parts of the watershed has made the land more vulnerable to erosion (Bezuayehu and Sterk, 2008). According Bezuayehu and Sterk, (2008), the proportion of the watershed exposed to possible maximum soil loss is cropland amounting 31% in 1957, 36% in 1980, and 46% in 2001.

2.2.1.3 Roseires

Roseires dam is located about 110 km from the Ethio-Sudan border along the Blue Nile River. In addition to generation of 280 MW hydroelectric power, the Roseires reservoir supplies the Gezira plain with irrigation water. The storage capacity of Roseires reservoir during its first filling in 1966 was 3.3 billion m^3 (Siyam, et al., 2005). The mean annual runoff volume at Roseires is about 48.5 billion m^3 (Tefferi, 2012).

The reservoir was equipped with deep sluices in the dam body to help flush the sediments deposited in the reservoir. However, the problem is not entirely solved and the live storage at full reservoir level has been reduced by 20% in the period 1966-1981. According to bathymetric surveying data, the total capacity of Roseires reservoir showed reduction from 3,329 million m^3 to 1,921million m^3 within forty one years of operation (1966-2007) (Bashar and Eltayeb, 2010), which is about 42% capacity loss.

According to the Roseires reservoir operation rules, the reservoir filling starts in September after flood peak has passed. The filling period flood carries significant amount of sediment (Ahmed, 2008) which tends to drop its sediment load when its sediment transport capacity falls due to reservoir water.

2.2.1.4 Sennar

Sennar dam was the first reservoir to be constructed on the Blue Nile in Sudan (1925) about 260 km downstream Roseires dam along the river, with a storage capacity of 0.93 billion m^3. The main purpose of the dam was to irrigate the Gezira Scheme and secure drinking water supply. According to Ahmed (2003), the rate of sedimentation of Sennar reservoir in the period (1925 – 1981) had never exceeded ½ % per year with respect to the original capacity, which is about 28% storage loss in 56 years of operation. On the other side, the followed period (1981-1986) sedimentation increased drastically with a rate of 80 million m^3 per year (9½ %) i.e. a reduction of 400 million m^3 (43%) in only 5 years leading to about 71% of capacity loss in 61 years (Awulachew, et al., 2008).

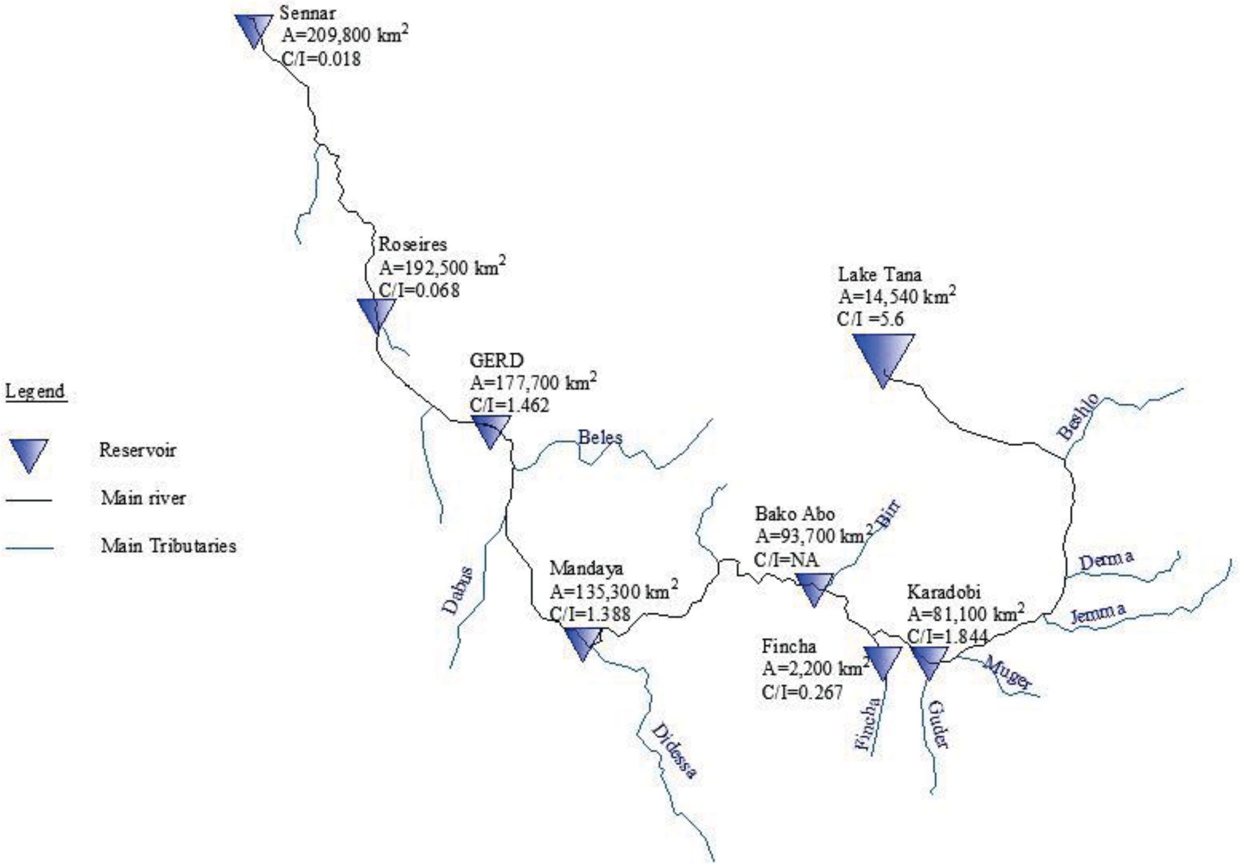

Figure 2.5 Reservoirs in the Blue Nile Basin, their catchment area and main tributaries of the Blue Nile River

2.2.2 RESERVOIRS UNDER PLANNING AND CONSTRUCTION

2.2.2.1 Karadobi HPP

The Karadobi hydropower project is located on the Blue Nile River about 1.7 km downstream of its confluence with Guder River at about 385 km downstream of Lake Tana (Ahmed, 2008). The project comprises a 260 m high RCC dam with an underground power plant in the immediate vicinity of the dam (MoWEE, 2010). Four 9 m diameter headrace tunnels convey a total of 800 m^3/s to the eight 200 MW units in the power cavern for a total 1600 MW capacity (Norconsult).

The mean annual runoff volume at Karadobi is about 21.8 billion m^3 and the gross storage capacity of Karadobi reservoir is 40.2 billion m^3 (MoWEE, 2010). According to the feasibility study the specific sediment yield at Karadobi ranges from 720 to 1150 $t/km^2/yr$ and total sediment load was estimated to be with in 71 and 113 million t/year (Ahmed, 2008). The feasibility study outcomes summarized by Ahmed indicates that the dead storage is allocated for sediment deposition.

2.2.2.2 Beko Abo

Beko Abo is one of the biggest proposed hydropower projects on the Blue Nile River located 106 km downstream Karadobi dam site (Tefferi, 2012). Beko Abo dam is expected to be roller compacted concrete (RCC) dam, with 285 metre height, making the highest of its type in the world. The planned project will have an installed capacity of 2100 MW and an annual energy output of about 12000 GWh (Multiconsult, 2010). The pre-feasibility study indicates that the live storage capacity of the reservoir amounts 17.5 million m^3 (Multiconsult, 2010).

2.2.2.3 Mandaya

The proposed Mandaya dam is located 200 km upstream of GERD. The topography at the site is well suited for the development of a major dam. According to more recent studies the Mandaya site is capable of accommodating a dam of up to 200 metres in height (FSL 800 mals), with the reservoir extending upstream close to the Karadobi site (Ahmed, 2008).

The gross storage capacity of the reservoir was estimated to be 49.2 billion m^3 (Ahmed, 2008) and the live storage amounts 13 million m^3 according to preliminary estimate (Multiconsult, 2010). The mean annual runoff volume at Mandaya is about 35 billion m^3 (MoWEE, 2010) which is approximately 60% greater than annual runoff volume at Karadobi. The installed capacity of the Mandaya project was preliminarily estimated as some 2400 to 2800 MW with potential energy generation in a range of 16,000 to 18,000 GWh/year (MoWEE, 2010). The average annual sediment yield at Mandaya was estimated to be 285 million t/year (Ahmed, 2008).

2.2.3 GRAND ETHIOPIAN RENAISSANCE DAM (GERD)

The Grand Ethiopian Renaissance Dam (GERD), also known as Millennium dam and locally referred to as 'Hidase Dam', is an under construction gravity dam. The GERD project is located approximately 750 km northwest of Addis Ababa and 40 km East of Sudan. The dam is a single purpose hydroelectric facility which controls about 177,700 km^2 of the Blue Nile Basin. The reservoir at 74 billion m^3 storage capacity will be one of the continent's largest manmade reservoirs. The project has envisaged a power plant with an installed capacity of 6,000 MW and 15,692 GWh annual energy.

The major components of the project (EEPCO, 2013) are:

- Main Dam of length 1,780m and 151m height
- Saddle Dam of length 4,800m and height 45m.
- Two power houses with 3,750 and 2,250 MW installed capacity containing 10 and 6 generating units respectively each with a capacity of 375MW.

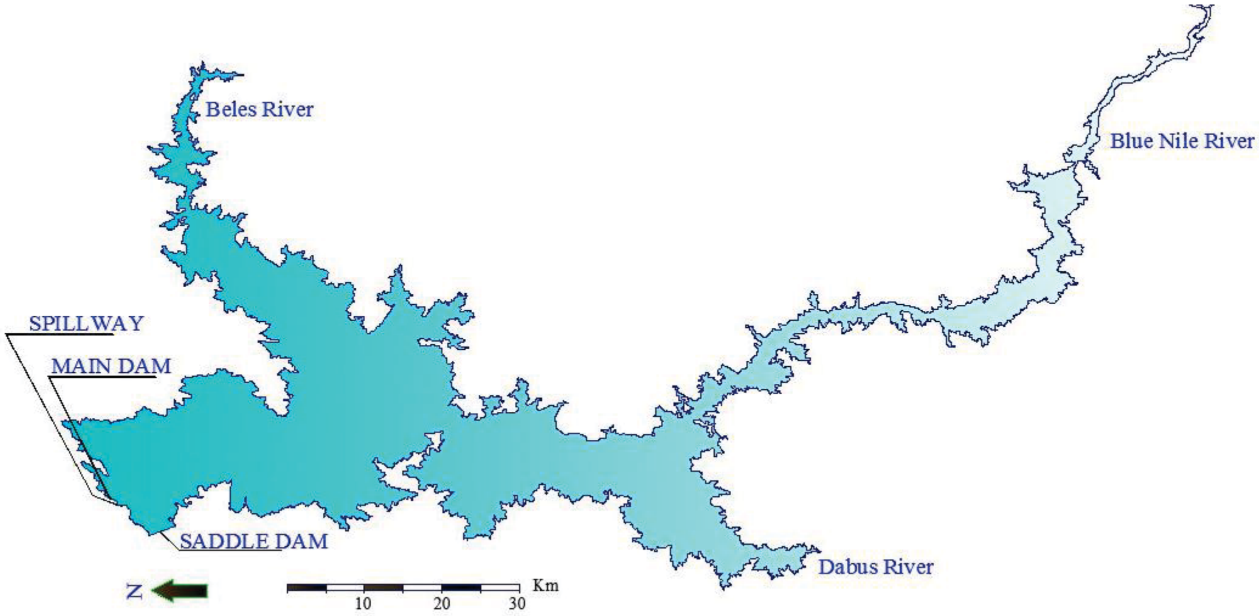

Figure 2.6 Water spread area of the GERD reservoir at FSL.

Both Main Dam and Saddle Dam will create 74 billion m^3 impounding capacity reservoirs of which 59 billion m^3 is live storage. The dam shall create a surface area of 1,900 km^2 at Full Supply Level (FSL) (Semegnew, et al., 2013). The normal and minimum operating water levels will be 646 and 596 masl respectively. The mean annual runoff volume at GERD is about 50.6 billion m^3 (EEPCO, 2013).

Table 2.1 Summary of Capacity - Water Inflow Ratio (CIR) of existing and planned reservoirs in the Blue Nile Basin

Reservoir name	Catchment Area (km^2)	Location (Decimal Degrees)		Runoff Volume $*10^6$ (m^3/year)	Storage Capacity$*10^6$ (m^3)	CIR
		Longitude	Latitude			
Lake Tana	14,540	37.361	11.776	5,000	28,000	5.6
Karadobi	81,100	37.690	9.859	21,800	40,200	1.844
Fincha	2,200	37.412	9.899	1,720	460	0.267
Bako Abo	93,700	37.037	10.284	22,400	17.5**	-
Mandaya	135,300	35.713	9.963	35,440	49,200	1.388
GERD	177,700	35.093	11.212	50,600	74,000	1.462
Roseires	192,500	34.372	11.831	48,433	3,300	0.068
Sennar	209,800	33.629	13.534	50,940	930	0.018

** refers to live storage

Reservoirs on the Blue Nile River, especially those under planning are very huge in capacity. Pre-feasibility and feasibility studies of these reservoirs indicate that large amount of sediment load will be expected at the reservoirs; nevertheless no information was available on planned sediment management programs. On the basis of available information, the reservoirs are designed to allow sediment storage, where the reservoir functions until its storage capacity is lost, and the sediment filled reservoir is left to the coming generations or decommissioned.

3 DATA AVAILABILITY AND QUALITY

3.1 HYDROLOGICAL DATA

3.1.1 DATA AVAILABILITY

River flow data in Ethiopia is generally limited due to remoteness of many of the catchments and lack of economic resource and infrastructure to build and maintain monitoring sites (Awulachew, et al, 2008). However, what has been considered by Awulachew and his partners as a reason for data scarcity may not be main limiting factor in Ethiopia. Economic and infrastructure constraints can limit number of gauging stations, but can have lesser influence on data generation of established stations.

A very few gauging stations cover catchments bigger than 1,000 km^2 and very few gauging stations are located on the main stem of the Blue Nile River or on the major tributaries close to their confluence with the river. There are 12 major river basins in Ethiopia. The hydrological network for both stream and lake consists of 560 gauging stations in the 12 river basins. Out of these, 454 are at present operational throughout the country. As a result of its large area share, 131 operational stream flow gauging stations are located in the Blue Nile Basin according to Ministry of Water and Energy of Ethiopia (MoWEE).

Adequate number of gauging stations might have been established in the Blue Nile Basin. However, long records are not available at most of the stations and the reliability of available data is also questionable. The number of operational stream flow gauging stations has increased from 338 in 1997 (Kidane, 1997) to 454 in 2010 (MoWEE, 2010). This might have been recorded as good change which may only be increase in number rather than quality oriented improvement.

The Hydrological Department under the Ministry of Water Resources is responsible for hydrological and sediment data collection, processing and distribution to the data users. Gauging stations were selected based on their relevance for the study. Nevertheless, daily stream flow data for only six gauging stations were obtained from the Hydrology Department of the Ministry of Water Resources. Locations of these six gauging stations are as in the **Figure 3.1**.

Figure 3.1 Location map of flow gauging stations

These stream flow gauging stations cover a very small catchment area except Kessie station which represents 36% of the total catchment area at GERD. The distribution of the stations is more or less concentrated to small area of the catchment. A single station with a long data can replace the data from four of these stations (Anger, Tato, Didessa nr Dembi and Didessa nr Arjo) for sediment yield estimation at GERD. Table 3.1 summarizes the extent of available recordings in each station.

Table 3.1 Hydrological data stations

Station Name (No.)	Area (km^2)	% of area at GERD	Location		Data period (Year)	Average runoff (mill. m^3)
			Longitude	Latitude		
Kessie (112001)	64,100	36.07	38.18	10.07	1963-2009	18,740
Anger (114002)	4,674	2.63	36.52	9.43	1982-2004	755
Guder (113005)	524	0.29	37.75	8.95	1960-2002	402
Didessa nr. Dembi (114001)	9,981	5.62	36.42	8.68	1960-2002	4,068
Tato (114010)	43	0.02	36.65	9.03	1996-2004	25
Didessa nr. Arjo (114014)	1,806	1.02	36.45	8.05	1985-2002	1,322

3.1.2 DATA QUALITY

In order to provide the stream flow data that meet the needs of most types of hydrological evaluations currently and for the future, a stream gauging network must be able generate data for an extended period of time. For most evaluations in general, discharge data must be available for a period of time that is long enough to account for temporal hydrologic variations.

As a first step in analyzing the data, the record completeness was calculated as follows for each gauging stations:

$$\text{Completeness \%} = \frac{\text{Number of days with data}}{\text{Number of days in the recors}} * 100$$

Table 3.2 summarizes the completeness of data from the stations

Table 3.2 Inventory of the Hydrometric stations

Station name	Station number	Data period	Number of complete years (% of total)	Years with Completeness >80% (% of total)	Years with no data (% of total)
Kessie	112001	1963-2009	26 (79)	31(94)	2 (6)
Anger	114002	1982-2004	12 (52)	18 (78)	5 (22)
Guder	113005	1960- 2002	31 (74)	42 (100)	0 (0)
Didessa nr. Dembi	114001	1960- 2002	15 (60)	22 (88)	3 (12)
Tato	114010	1996- 2004	7 (78)	9 (100)	0 (0)
Didessa nr. Arjo	114014	1985- 2002	9 (64)	14 (100)	0 (0)

The recorded data series for the Blue Nile River at Kessie was examined with particular care owing to its importance as having the longest period of recorded data on the main stem of the Blue Nile River. The flow data from this station along with sediment data can give a basis for sediment yield estimation at GERD. To estimate sediment load at GERD, only one station located on the most downstream reach of a river can replace most of these stations. A single station at the confluence of Didessa River with the Blue Nile River for instance can replace four of these stations. In terms of the importance of the data from these stations, those located on the upstream are less important that those located on most downstream reach in the same catchment.

Guder and Tato stations cover very small catchment, 0.29 and 0.02% of the total catchment area at GERD respectively. The data from these stations has no missing data. Nevertheless, it is less important when compared to stations covering larger area.

Table 3.3 Flow data completeness at Kessie station

year	Completeness (%)	year	Completeness%	year	Completeness%	year	Completeness%
1973	100	1983	100	1993	100	2003	100
1974	100	1984	100	1994	100	2004	93
1975	100	1985	94	1995	100	2005	100
1976	100	1986	95	1996	100	2006	68
1977	100	1987	100	1997	0	2007	33
1978	100	1988	100	1998	100	2008	0
1979	89	1989	100	1999	100	2009	57
1980	100	1990	100	2000	100		
1981	83	1991	15	2001	100		
1982	100	1992	100	2002	100		

3.1.3 QUALITY CONTROL

About 20% of the flow data period (year), obtained at Kessie station, is with more than 20% of its data missing which is similar for other stations. Thus synthesis of the missing stream flow record based on climatic data may be preferable to have long time data coverage. However, climatic data such as precipitation and temperature was not available to use with models such as HBV (Hydrologiska Byråns Vattenbalansavdelning) model which can be used for this purpose. Therefore, months with few days of missing data were filled by averaging from neighbouring year data of the same month and periods with no or very few data (1991, 1997, 2007 and 2008) were omitted. Stream flow data for year 2009 with 43% of its data missing was not omitted as its complete wet season data is usable. To fill gaps with few days missing, different weighting factors were assigned to days of neighbouring years as follows.

$Q_m = Q_1*f_1 + Q_2*f_2$

Where, Q_m is computed flow on day *m* of year *n* with missing data, Q_1 is flow on day *m* of year *n-1*, Q_2 is flow on day *m* of year *n+1*, and f_1 and f_2 are weighting factors.

The weighting factors were determined in a way that the difference between measured and computed data is minimum for a period with measured data. However, due to non linear variability of the stream flow from time to time single weighing factor cannot be used to generate data for long missing data (**Figure 3.2**). Therefore, data filling were applied only to months with few days of missing data.

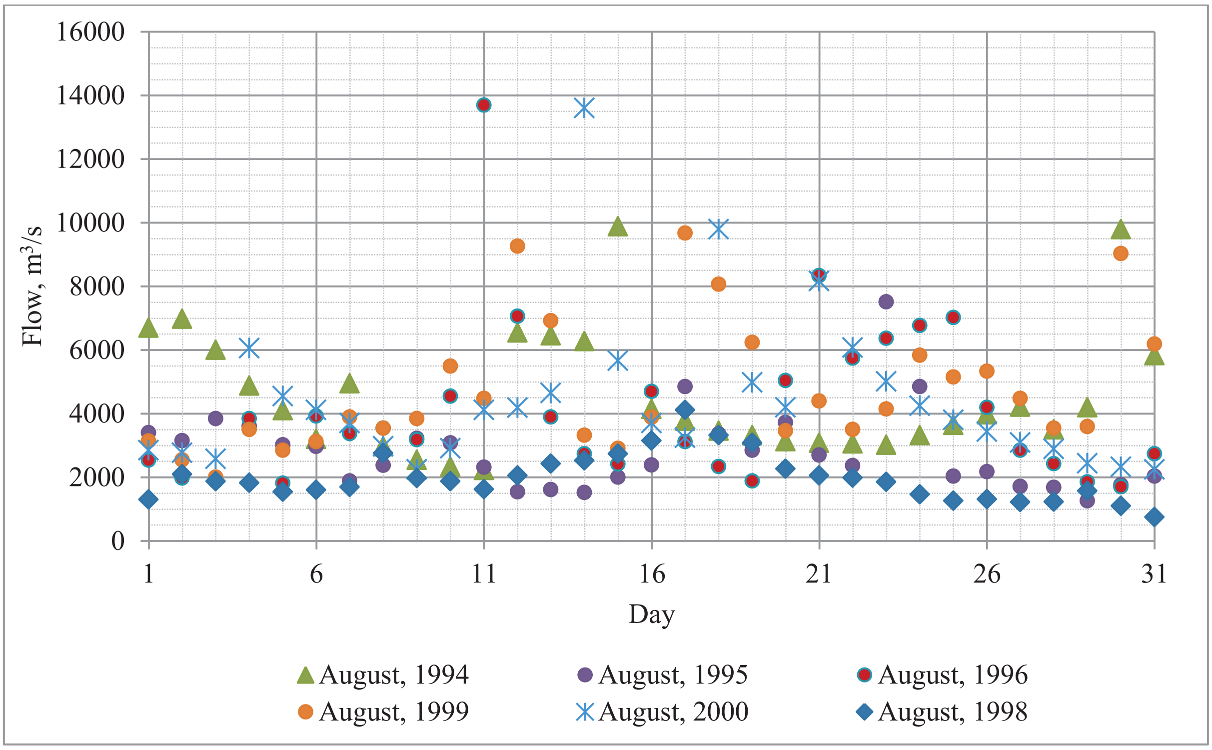

Figure 3.2 Stream flow variability at Kessie in August for chosen successive years

Outliers can be caused by measurement and recording errors which have to be identified before using a data. The flow data available at Kessie shows maximum discharge of 13,700 m^3/s in August of 1996 and minimum of 0.23 m^3/s in June of 1981. These extremes were checked against the neighboring records which show that the maximum observed discharge is about two times larger than observed discharge of the following day. The minimum discharge observed in June 1981, however increases gradually from 0.23 m^3/s followed by 0.943 m^3/s near the beginning of June to 257 m^3/s at the end of June.

The maximum discharge in the data was also compared with maximum discharges in August for different periods. The observed maximum discharge was found to be 2.4 times the average of maximum discharges in August for a period of measurement. Though this discharge is significantly different from the neighboring data it may not be error and can be an extreme event. This peak discharge if used with sediment concentration data may give the representation of flood events that could occur with longer recurrence interval. Therefore, the data was not excluded.

Data at Tato (114010) was also subject to some quality check which included visual identification of errors, comparison of maxima, and correction of mistyped numbers. The maximum observed flow at this station is 25.51 m^3/s followed by 14.14 m^3/s in the first week of September, 2001. Relatively high river flows have been observed during this period in which most of the flow data are more than 4 times river flow recorded in the same month of the following year. Thus, it can be concluded that high flood has occurred during this period.

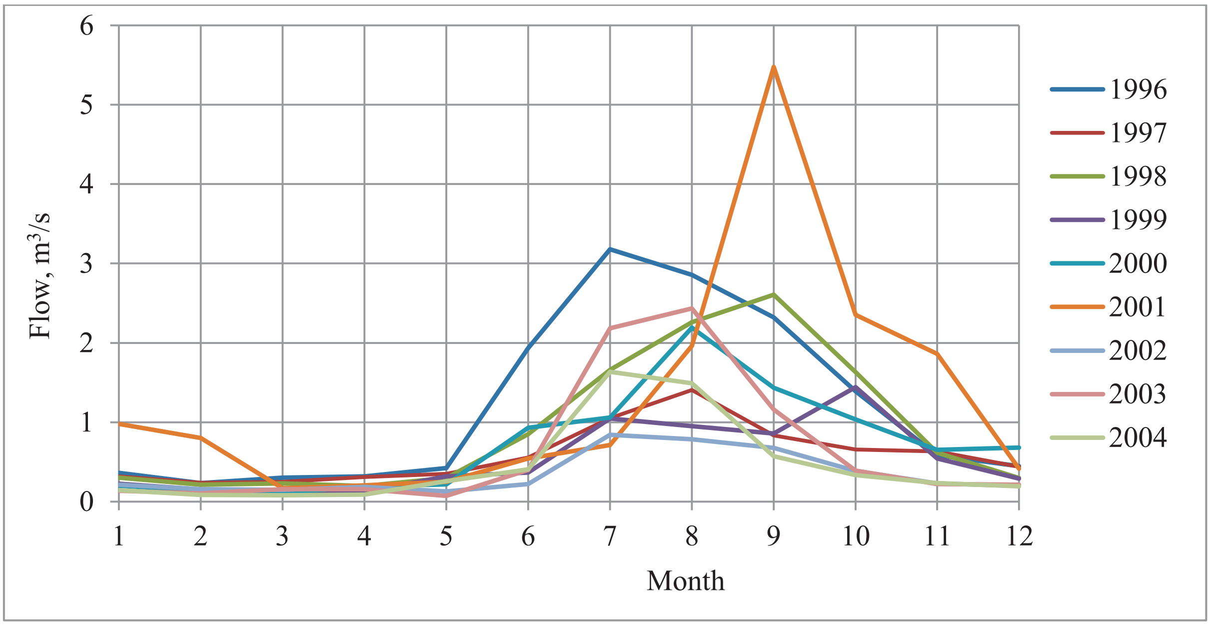

Figure 3.3 Mean monthly flow at Tato station

Stream flow data at Guder (113005) was also checked against possible errors through simple visual identification and comparison of extremes with neighboring data. Data from other stations were not evaluated as no valuable sediment data has been obtained for these stations.

Generally, the available data from the six stations, Kessie, Anger, Guder, Didessa near Dembi, Didessa near Arjo and Tato, were screened based on their importance to this study. The stations, Anger, Didessa near Dembi and Didessa near Arjo were excluded due to lacking sediment data and the stream flow data at Kessie, Tato and Guder were evaluated against some quality test.. The data series for the Kessie station was examined with particular care owing to its importance as having longest period of recorded data and its location on the main river.

3.2 SEDIMENT DATA

Data regarding sediment transport of the Blue Nile are limited in their spatial and temporal resolution compared to the available discharge data. Sediment gauging is much more comprehensive than stream flow gauging. Many activities must be carried out in order to obtain reliable sediment data, while water discharge may be retrieved by single staff gauge reading (Støle, 2007).

Sediment concentration data originating from stations in the Blue Nile Basin were obtained from the Hydrology Department of the Ministry of Water Resources. The data indicate that there are total of 47 operational sediment flow gauging stations in the Blue Nile Basin. However, most of them have a very few measurements. The stations for which location data is available are as shown in the **Figure 3.4**.

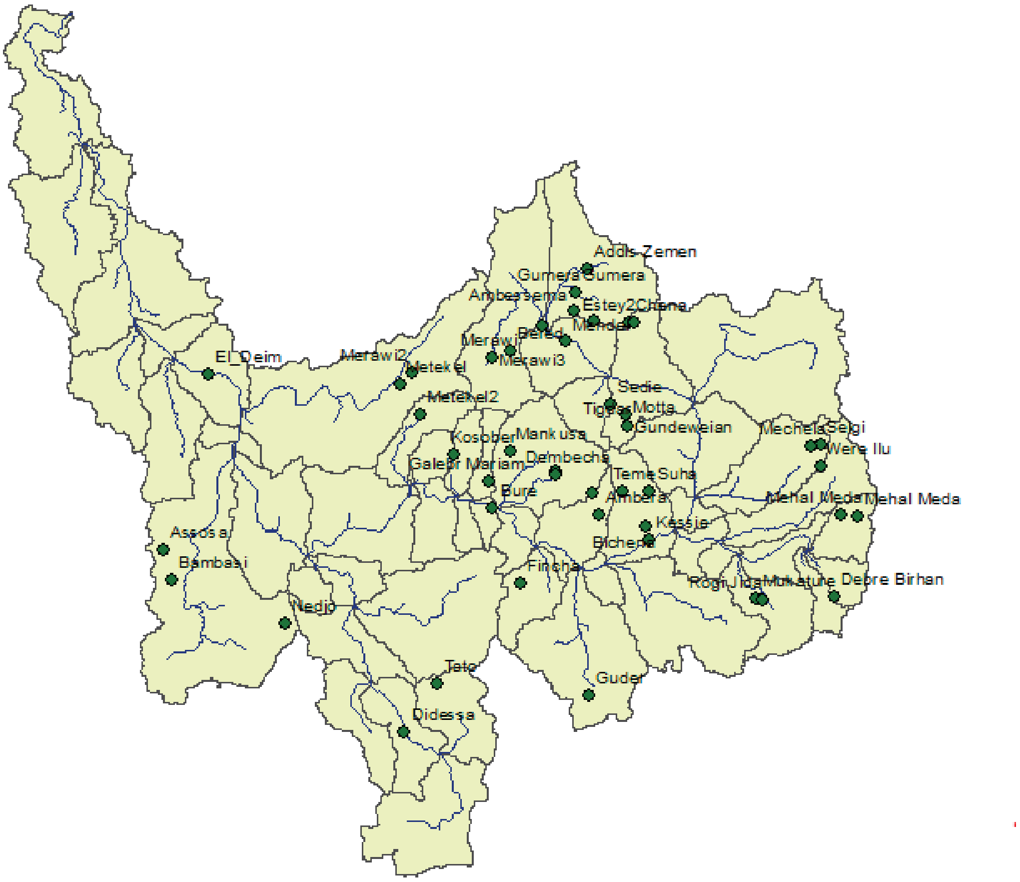

Figure 3.4 Locations of sediment sampling stations (Location data source: Awulachew, et al., 2008)

3.2.1 AVAILABLE DATA AND ITS QUALITY

Suspended sediment concentration: Measurements of suspended sediment concentration at few gauging stations were available, but no bed load measurements. Samples from the suspended sediment sampling stations were taken with point integrating sampler to analyze its sediment content. The available sediment data indicates that the samples were taken from certain point over sampling duration.

Figure 3.5 (a) suspended sediment sampling at Burie bridge, (b) stream flow gauging and sediment sampling station at Kessie Bridge (Photo by: Dr. Kiflom Belete)

Similar to stream flow gauging stations, the suspended sediment sampling stations are located on small tributaries with small catchment area coverage with the exception of Kessie, Burie and El-Deim stations which covers an area of about 64,100 km^2, 94,500 km^2 and 178,200 km^2 catchment area respectively. Suspended sediment measurements, in the form of flow rates and corresponding concentrations, from 47 stations were obtained from Hydrological department of MoWR. A summary of the data stations is given in **Table 3.4**.

Table 3.4 Suspended sediment station data

Station Number	Station Name	Data Year (number of data points)	Station Number	Station Name	Data Year (number of data points)
112001	**Kessie**	**2008-2010 (212)**	112019	Tigdar	1983-1993 (58)
******	**Burie**	**2008-2010 (143)**	**114010**	**Tato (Guti)**	**1988-1996 (42)**
112003	Bahir Dar	1961-1966 (28)	112022	Selgi	1985-1989 (5)
112017	Bichena	1983-1995 (51)	112021	Mechela	1985-1989 (8)
112018	Motta	1985-1996 (53)	113035	Kosober	1986-1993 (14)
112027	Mukature	1985-1996 (47)	111006	Gumera	1964-1996 (37)
112028	Rogi Jida	1985-1996 (43)	113039	Lumame	1993-1995 (5)
112030	Teme	1985-1995 (58)	113020	Mankusa	1968-1994 (6)
112031	Suha	1985-1995 (48)	112011	Mehal Meda	1989-1998 (13)
112037	Sedie	1987-1995 (40)	112009	Mehal Meda	1998 (2)
113005	**Guder**	**1968-1996 (28)**	112036	Mendel	1987-1996 (13)
111005	Addis Zemen	1960-1996 (32)	111020	Bered	1988-1996 (11)
****	Addis Zemen	1960-1968 (4)	116005	Merawi2	1995 (8)
113043	Amanual	1989-1994 (7)	111002	Merawi3	1968-1996 (17)
112038	Ambera	1988- 1995 (29)	116004	Metekel	1995 (9)
111014	Ambessema	1983-1996 (19)	113029	Metekel2	1977- 1995 (55)
115005	Assosa	1989-1996 (7)	115009	Nedjo	1985-1995 (15)
115011	Bambasi	1988-1990 (3)	112024	Were Ilu	1985 (4)
112007	Debre Birhan	1968-2002 (28)	112040	Estey 2	1987-1996 (9)
113041	Debre Markos	1989-1995 (18)	113026	Fincha	1968-1996 (37)
113030	Debre Zeit	1988-1993 (22)	111017	Arb Gebeya	1985-1996 (9)
113012	Dembecha	1960-1995 (54)	113036	Galebr	1986-1989 (12)
113014	Dembecha	1968-1993 (49)	*****	Didessa	2010 (11)
112039	Chena	1985-1996 (12)	116002	El-Deim	1993 (29)

**** Station number not available

(Data source: For El-deim, Ndorimana, et al., 2005 and for other stations, MoWR)

As summarized in the **Table 3.4** most of the data if distributed over the period of measurement are less than 1 data per year. This indicates that some intermediate periods have no data. Except for Kessie (112001), Guder (113005) and Tato (114010) stations, stream flow data was not available at all other stations which limits use of even very few available data. Therefore, for the present study these key sediment measuring stations including Burie station were selected.

The largest number of data point was observed at Kessie and Burie stations. The sampling however was made for flood season only. The sediment concentration data for Kessie station is given in Appendix A.

Table 3.5 Sediment data chronograms for Kessie stations

		Month											
		1	2	3	4	5	6	7	8	9	10	11	12
Year	2008						2	2	10	6	3		
	2009							20	61	50			
	2010	1	1	1	▨	1	1	13	15	21			

☐ month with no data

▨ n month with 'n' number of data

Table 3.6 Sediment data chronograms for Bure station

		Month											
		1	2	3	4	5	6	7	8	9	10	11	12
Year	2008							3	6	7	2		
	2009							4	29	29			
	2010	1	1		1	2	1	5	23	29			

☐ month with no data

▨ n month with 'n' number of data

Guder station (113005) is located on Guder River covering only small fraction, about 6.3%, of Guder catchment. The sediment concentration data at this station besides being few is sparsely distributed over long period as summarized in the **Table 3.7**.

Table 3.7 Sediment data chronograms for Guder station

		Month											
		1	2	3	4	5	6	7	8	9	10	11	12
Year	1968						1	1	2	1	1	1	
	1988												1
	1989	1	1	1	1	1					1		1
	1990	1	1	1	1					1	1		
	1991								1		1		
	1992								1	2			
	1995	1											
	1996												1

☐ month with no data

▨ n month with 'n' number of data

Table 3.8 Sediment data chronograms for Tato station

		Month											
		1	2	3	4	5	6	7	8	9	10	11	12
Year	1988	1			1		1	1	10		1	1	1
	1989	2	1	1	1	1	1			1			1
	1990	1	1	1	1		1	1			1		
	1991									1			
	1992								1	2			
	1995	1							1				
	1996						1		1	1			

☐ month with no data

▨ n month with 'n' number of data

Sediment data at these stations was revised and some possible limitations were identified. Some of the factors that can affect the quality of the sediment data collected at the selected stations include the following:

- The suspended sediment concentration data may not be taken in a way that it represents daily average. The discharge corresponding to measured sediment concentration was compared with the average daily river flow of the same period which in all cases doesn't show agreement. The sediment concentration data therefore, cannot represent the average.
- Errors arising from laboratory analysis and data recording: Magnitude of such errors depends on experience of personnel. Some sediment concentration data at Kessie on a given cross section shows large difference in magnitude between measurements from different verticals. Data with magnitude 5 times bigger than concentration in adjacent vertical have been observed on the same section of the river.
- Errors arising from sampling method and sampling time: choice of sediment sampling mode may have effect on the representativeness of the data. The data representing the average daily value should be taken on appropriate time to be able to represent the average. Number of data taken at different time of a day can be averaged to obtain more accurate daily average data which however may be difficult for sediment data as it involves many laboratory works.
- Effects of irregularity of the data: it's common for sediment measuring stations in Ethiopia to have data for few days of a given month or no data at all. The measured data are not collected on equally spaced time step basis which may have its own consequence on the accuracy of computations where these data are input.
- The suspended sediment concentration distribution was assumed symmetrical about centreline of the river cross section and concentration data was collected for half of the section only. This assumption may lead to erroneous data collection for Kessie and Burie stations because of (1) unsymmetrical velocity distribution, the effect of which can be seen as unsymmetrical deposition/erosion of material (2) the tributary joining the Blue Nile River just upstream of the station (3) geometrically unsymmetrical cross sections about vertical bisection line.

3.2.2 QUALITY CONTROL

The sediment concentration data was subject to few quality control checks. Visual screening showed some mistyped discharge with misplaced decimal points. These were marked in the data set (Appendix A) and then corrected. Some of the flow data field were filled with numbers less than one and no remarks were given with the data. The flow data in such cases may be written as an increment on the data it is next to on the data record (For example, 0.4 m^3/s on 23rd of February 2010 written as an increment on 104.81 m^3/s measured on the previous sampling time, 23rd of January 2010). However, some of them were not consistent and therefore, replaced by discharge calculated based on flow rating curve. Data with both discharge and gage height missing was omitted and the remaining data was tabulated. The flow rating curve (gage height-river flow relationship) was developed based on 70 numbers of discharge and gage height data pairs collected from the original data. Table of data sets used for flow rating curve construction is given in Appendix B.

The suspended sediment concentration varies from time to time across at given section and sampling point. Landslides and armour layer break-up due to high discharges can occur and result in extremely high concentration observations. However the ratios of suspended sediment concentrations in different verticals of the river section measured at time t_1 should not deviate much from ratios of concentrations measured at time t_2 if: (a) the discharge measured at time t_1 and time t_2 are almost equal (b) the geometry of the channel doesn't vary between the two measuring times (c) the effect of difference in density of flow on sediment transport is negligible and (d) proportion of different sizes of the sediment particles are similar.

The maximum ratio of sediment concentrations in different verticals of a section can be expected for maximum discharge in the river, because of water level rise to flood plain where flow velocity is relatively low. The maximum concentration ratio of different verticals at Kessie was observed on September 25, 2009 with discharge of 282.75 m^3/s which is smaller than 96% of the measured discharge. Since the discharge is within the possible range of values, concentration data may be error for this and similar cases.

Therefore to remove faulty sediment data, outliers were identified based on quartile method. The quartile method was not directly applied to concentration data as the method doesn't give sound means to prove that the data is incorrect. Therefore, maximum concentration ratios were calculated as below for all data periods, then outliers were identified and the concentrations corresponding to these outliers were removed accordingly.

$$\text{Ratio max} = \frac{C_{max}}{C_{min}}$$

Where, C_{max} is maximum concentration measured on day n at any vertical, C_{min} is minimum concentration measured on the same measuring time at another vertical of the same river section. The identified outliers along with the data are given in Appendix B.

Reservoir survey data: One of the available sediment data of the basin is bathymetric surveying data of Roseires reservoir. Siltation rate and observed trap efficiency of the Roseires reservoir for the period from year 1966 to 2007 was obtained from Nile Basin Capacity Building Network (NBCBN) study report, Siyam, et al. 2005. The data however have some limitations:

The documented observed trap efficiency was obtained based on the sediment inflow to the reservoir and storage loss of the reservoir over the period from year1966. This may not take the flushed sediment into account.

Soil loss data: Soil loss data of the basin and sub basins was obtained from Ethiopian Highlands Reclamation Study (EHRS, 2010). The soil loss was estimated using SWAT with verification by plot measurements. This data was used for comparison of delivery ratio from the sub catchments.

Other sources of sediment data:

Literatures and study reports on sediment transport in the Blue Nile were also considered mainly for comparison with sediment yield estimate made based on the available data.

3.3 CONCLUSIONS

Stream flow data in the basin is generally poor due to limited data from a very few gauging stations. The available data from the six stations, Kessie, Anger, Guder, Didessa near Dembi, Didessa near Arjo and Tato, were screened based on their importance to the study. The stations, Anger, Didessa near Dembi and Didessa near Arjo were excluded due to lacking sediment data and the stream flow data at Kessie, Tato and Guder were evaluated against some quality test before use. The data series for the Kessie station was examined with particular care owing to its importance as having longest period of recorded data and its location on the main river. The stream flow data at Kessie, Tato and Guder covers a length of 31, 9 and 42 years respectively excluding the period with data completeness smaller than 80%. Generally, the stream flow data at Kessie and Guder can be considered satisfactory in terms of data length and quality for use with sediment yield estimation. The stream flow data at Tato though complete, doesn’t cover long period of time which may not give a picture of temporal variability of runoff. However, it can be considered good data for short term sediment yield estimate when used with sediment rating curve at the station.

The available sediment data station in the basin is far from being adequate to make a best estimate of sediment load in different parts of the basin. However, sediment data at Kessie station can be a benchmark for sediment load estimation in the basin due to availability of relatively better stream flow data and its location on the outlet of steep and high sediment supplying catchment. The sediment data at Kessie station covers the wet season during which transport of large quantity of sediment is expected and the sediment concentration was relatively frequently measured during this period. It was therefore considered good data for sediment yield estimation at the sampling station. Sediment data from Burie station is also of similar quality and quantity as that of Kessie, but is less important due to lacking stream flow data. The two stations, Guder and Tato, cover very small fraction of the total Blue Nile Basin and therefore may only be used for comparison.

The following factors have to be taken into consideration to improve the quality of stream flow and sediment data in the basin:

- Establishment of new stations: Establishment of new stations on tributaries as close as possible to their confluence with the main river can complement the existing gauging network, but it may not be simple due to financial constraint. However, the value of reliable sediment data to design of expensive structures on the sediment laden rivers should not be underestimated.
- Defining sampling, laboratory analysis and data documentation methodology. Guidelines conforming to common standards are necessary for data sampling process, laboratory analysis as well as documentation to obtain reliable, good quality and easily understandable data. The sediment concentration data at Kessie was measured based on equal width increment method, which is one of the

generally accepted methods for measuring suspended sediment concentration. For the Kessie station some measurement locations show equal width increment while others indicate horizontal distance of measuring point from river bank.

- Establishment of benchmark from which distance to sediment sampling section is measured. The available data shows that the distance to sediment sampling point was measured from zero water depth point which varies highly even within a day and is difficult to monitor changes in geometry of the channel. In addition to this the measured distance-water depth data is not reliable which in some cases show unrealistic bed level change within a day.
- Working on continuity and quality of data from existing gauging stations can improve the data problem to large extent. It may be better to have few stations of a good quality data than many stations with very poor data. Therefore, involvement of trained personnel and well organized work is necessary to obtain good quality data at established stations.
- Monitoring the bed level changes due to sediment deposition and calibrating flow rating curve periodically. The river cross section at gauge location can change due to aggradation or degradation.
- Minimizing errors while documenting. Some flow data are recorded as an increment on the fully written value above it (i.e. 0.4 m^3/s as increment on previously measured 104.81 m^3/s). This may be confusing to the data user when there is no remark on how the data is documented.
- Installation of automatic gauges: frequent sampling including high flood events can be achieved through installation of automatic gauges.

4 SOIL EROSION AND SEDIMENT TRANSPORT IN BLUE NILE BASIN

4.1 GENERAL

Soil erosion is the process whereby the earth or rock material is loosened or dissolved and removed from any part of the earth's surface (Morris and Fan, 1998). Gross erosion is the sum of all types of erosion rill, gully, channel erosion, and mass wasting. The relative importance of each type of erosion varies from area to area. Sheet and rill erosion occurs particularly in grazing and cultivated areas of mild slope where runoff is not concentrated in well-defined channel (Morris and Fan, 1998; Vanoni, 2006).

4.2 SOIL EROSION IN THE BLUE NILE BASIN

Sediment in the Nile is mainly originating from the Ethiopian Highlands (Ndorimana, et al., 2005). With the fast growing population and high density live stocks in the Blue Nile Basin, replacement of forest lands by agricultural lands is a common practice. The basin is steep and the vegetation is relatively sparse because of the short rainfall season. The mountainous and steep slopes are cultivated without effective protective measures against soil erosion which with high intensity rainfall speeds up soil loss in the basin.

Blue Nile Basin is characterized by high runoff when compared to the White Nile though the catchment area of the White Nile Basin is about three times that of the Blue Nile Basin (Ahmed, 2008). Blue Nile River which accounts for about 86% of the flood season runoff volume is the main source of flow for the Nile River. The sediment supplied by the river is also of similar proportion. Ahmed, 2008 estimated that contribution of the White Nile River to the Nile River sediment load is less than 5%. Runoff from highlands of Ethiopia makes its way to the Blue Nile through dense gullies formed during intense storm season and tributaries. These gullies and tributaries are the main carriers of eroded sediment too.

Agriculturally based population growth can have significant contribution to the sediment erosion in the basin. The increasing population expands to forest areas and clear forests in order to prepare more area for farming. The agricultural lands prepared during the first arrival of rainfall can be easily detached by precipitation and then transported by surface runoff in to the drainage system.

In addition to erosivity of the rainfall, erodibility of the soil affects soil erosion rate. Erosivity is a characteristic of rainfall which defines its detaching ability while erodibility defines the ease with which the soil material is detached and transported by rain. The Blue Nile Basin soils are erodible and poorly structured (Zaitchik, et al., 2012). High drainage density and steep ground surfaces of the basin assist delivery of eroded material in the river.

Construction activities can also supply significant amount of sediment. Road constructions and site excavations for construction materials loosen the natural and covered soil, and remove protective vegetations. The soil when subject to erosive rainfall and runoff on steep slopes can easily be taken to gullies and streams.

Figure 4.1 Soil exposure due to construction activities

(Source: http://www.eepco.gov.et/gallery)

Construction of reservoirs on the Blue Nile River in addition to having soil disturbing effect during construction activities will have indirect implication on soil erosion and sediment yield. Due to construction of the reservoirs, large numbers of households, most of which are farmers are expected to be relocated to undisturbed areas within the watershed. The relocated farmers undoubtedly will clear forests and cause disturbance to the land in order to prepare cropping fields.

Generally, high soil erosion can be expected from the basin as it includes combinations of the following parameters:

- Presence of steep and long slopes is among the major factors for intensive erosion.
- High rainfall intensity: rainfall in the basin is characterized by short and intense storms.
- High soil formation rate can be expected due to the climatic factors of the region.
- Poor vegetation over much of the area of the basin including steeper areas and land management practices which are poorly adapted for soil and water conservation.

In predicting soil erosion many erosion models have been developed and used over many years (Tesfahunegn, et al., 2012). The most widely used empirical equation for erosion estimation is universal soil loss equation (USLE). Few case studies (e.g., Chekol, 2006; Setegn et al., 2008; Tibebe and Bewket, 2010) have already shown that SWAT model was evaluated with adequate level of accuracy in gauged catchments in some parts of Ethiopia. Soil loss in the Blue Nile Basin has been estimated by EHRS, 2010 using SWAT model along with field plot measurements. The soil loss map (**Figure 4.1**) and summary of the soil loss estimated by EHRS are given below.

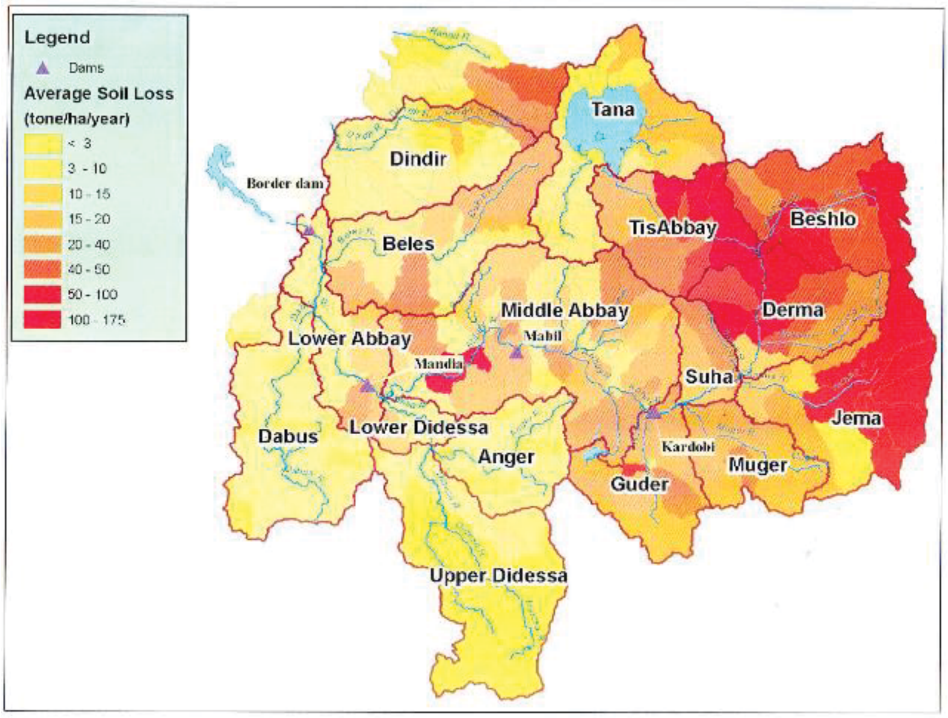

Figure 4.2 Soil loss variability in the Blue Nile Basin (EHRS, 2010)

Table 4.1 Total soil loss and total load for major watersheds of the Blue Nile Basin (EHRS, 2010)

Catchment	Area, km^2	Total soil loss (t/km^2/yr)	Specific sediment yield (t/km^2/year)		
			45%	25%	10%
Tana	14,540	NA	-	-	-
Tis Abbay	9,900	4187	1884.10	1046.72	418.69
Beshlo	11,976	6077	2734.64	1519.24	607.70
Derma	10,769	4764	2143.77	1190.99	476.39
Jema	15,205	4990	2245.50	1247.50	499.00
Muger	7,200	2972	1337.50	743.06	297.22
Suha	3,493	2095	942.86	523.81	209.52
Guder	8,657	3259	1466.41	814.67	325.87
Middle Abbay	27,413	1672	752.48	418.05	167.22
Upper Didessa	17,665	554	249.50	138.61	55.44
Anger	7,822	417	187.92	104.40	41.76
Lower Didessa	2,284	674	303.48	168.60	67.44
Beles	13,605	1238	557.25	309.59	123.83
Dabus	14,637	274	123.10	68.39	27.35
Lower Abbay	7,580	638	286.98	159.43	63.77
Upper Blue Nile	33,950	NA			

4.3 SEDIMENT TRANSPORT

Sediment transport involves a complex interaction between numbers of interrelated variables. However, theoretical approaches in the study of sediment transport are based on simplified and idealized assumptions (Morris and Fan, 1998). It has been common practice to relate sediment transport to some dominant variables such as particle size, discharge, flow velocity, shear stress, energy gradient, etc.

Sediment after joining streams based on its transport mechanism can be classified as bed load or suspended load. Bed load is the transport of sediment that frequently maintains contact with the bed and Suspended load is transport of finer particles which are held in suspension by eddy currents in the flowing stream. The relative quantities of materials transported in suspension and as a bed load varies greatly. In areas where the sediment is coming from a fine grained soil such as wind deposited material, or alluvial clay, the sediment may be transported almost entirely in suspension. On the other hand, a fast flowing clear mountain stream may have negligible amounts of suspended matter and almost all sediment transports by rolling on the stream bed (Hudson, 1993)

Not all eroded sediment join the river due to filtration by vegetation and sediment transport capacity loss of the runoff before it joins the river. The part of eroded sediment that joins the river starts making some deposition pattern. Finer particles keep in suspension until the flow velocity falls below threshold while course sands and boulders start deposition near the river banks.

(a) (b)

Figure 4.2 Sediment flow pattern in the Blue Nile River near Kessie Bridge (a) September 10, 2011(Source: Dr. Kiflom Belete) and (b) June 20, 2009.

The river banks together with the gorge represent the overall rainy season river. The river transporting course sands and boulders from steep areas of the Kessie catchment drops its load as it joins the gentle slope of the river bed. The wide and shallow sand deposits (**Figure 4.2** a) that appear on these banks during the falling stage of flood are the result of the seasonal sedimentation that took place when the progressively decreasing discharge and the consequent drop in flow velocity reduced the river transport capacity. This indicates that considerable amount of sediment can be transported in the form of bed load.

5 SEDIMENT YIELD OF THE BLUE NILE RIVER

5.1 GENERAL

Sediment yield refers to the amount of eroded sediment discharged by a stream at any given point over a period of time, which is also the amount which will enter a reservoir located at the downstream limit of its tributary watershed (Vanoni, 2006). The most common unit for sediment yield is tonnes/year. The *specific sediment yield* is the yield per unit of land area which is most commonly given in tonnes/km^2/year.

Long-term sediment yield estimates have been used for sizing storage reservoirs and estimating reservoir life (Morris and Fan, 1998). However, these estimates may be inaccurate due to limited data, complex interactions of governing parameters and uncertainties involved. In most cases sediment is exported from watersheds during relatively short periods of flood discharge, and these events must be accurately monitored to provide information on the long-term yield (Morris and Fan, 1998). Accurate estimation of sediment yield is very important in order to plan a reservoir and efficiently manage its sediment so that the reservoir can meet its requirements.

Sediment yield is affected by geology, slope, climate, drainage density and patterns of human disturbance and therefore, no single parameter or simple combination of parameters explains the wide variability in sediment yields (Morris and Fan, 1998; Vanoni, 2006; Lustig, 1965). Some relationships between these parameters and sediment yield are highly generalized and do not reflect the wide range of spatial variability of the parameters, and they can’t be extended to other geographic areas. Sediment yield from drier areas tends to be limited because of low runoff and yield in wetter areas is limited by the protective soil cover and reduced erodibility of humid zone soils (Vanoni, 2006).

5.2 SEDIMENT YIELD ESTIMATION METHODS

5.2.1 SEDIMENT RATING CURVE

Sediment rating curve describes the average relation between water discharge and suspended sediment concentration. A relationship between discharge and concentration can be developed which, although exhibiting scatter, will allow the mean sediment yield to be determined on the basis of discharge history (Morris and Fan, 1998). Although apparently simple in concept, critical evaluation of the data, careful application of the technique, and appreciation of its limitations are required if the approach is to be used effectively (Walling, 1977). Most river loads estimated by this method have been underestimated and the degree of underestimation increases with the degree of scatter about the rating curve and can reach 50% (Ferguson, 1986; Walling, 1977). Walling, 1977, has outlined some common sources of errors in applying sediment rating curve:

- An instantaneous sediment rating curve is theoretically not applicable to the direct computation of daily sediment discharges from daily average water discharges except for days on which the rate of water discharge is about constant throughout the day (Colby, 1956 cited in Walling, 1977). Walling, 1977 has compared annual suspended sediment loads using daily mean and instantaneous discharge data for three rivers in England. The result showed about 50% underestimation errors of load with the daily mean data.

- Errors could also result from inaccuracies in stream flow data and/or in the techniques of sediment sampling and subsequent laboratory analysis.
- Mathematically fitted curve is a potentially poor fit at the high extreme, which will be represented by few data points (Morris and Fan, 1998).

There is no standard method for rating curve construction, and in some cases visual curve fitting give better result than mathematical curve fitting (Morris and Fan, 1998). The most commonly used mathematical rating curve is power function (Walling, 1978; Morris and Fan, 1998).

$$Cs = aQ^b$$

Cs is sediment concentration in *mg/l*, Q is water discharge in m^3/s, *a* and *b* are coefficients.

A suspended sediment rating curve is usually presented in one form of the two basic forms, either as a suspended sediment concentration/stream flow or a suspended sediment discharge/stream flow relationship (Walling, 1977; Morris and Fan, 1998). The later is the product of both concentration and discharge and it produces a better fit than the original data set. A logarithmic plot is commonly used in both cases (Walling, 1977). A regression equation minimizes the sum of squared deviation from log transformed data, which introduces bias that underestimates the concentration or load at any discharge (Morris and Fan, 1998).

The relationship between discharge and sediment concentration or discharge and sediment load for a particular stream is not a fixed parameter but can considerably vary from one storm to another depending on factors including the intensity and areal distribution of the rainfall, and changes in the sediment supply (Morris and Fan, 1998). To avoid poor relationship between water discharge and sediment discharge separate curves may be developed for winter and summer, fine and course, falling and rising stages of discharge and different ranges of discharge (Morris and Fan, 1998; Walling, 1977).

5.2.2 SURVEY OF DEPOSITED SEDIMENT IN RESERVOIRS

Survey of sediment deposition rate in reservoirs can give accurate estimate of sediment yield from upstream the reservoir if trap efficiency is known. Considering reservoir sediment problem, reservoir surveys are necessary to get more realistic 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 (Bashar and Khalifa, 2010). Sediment surveys not only determine the volumetric loss but also provide other valuable information such as sediment distribution in a reservoir and changes in the stream channel in relation to transport and deposition. (Vanoni, 2006).

Generally, reservoir survey can be the most accurate means of estimating total sediment yield at a reservoir provided that reservoirs within the study area are monitored frequently. Frequency of monitoring however is determined by amount of annual sediment deposition and budget availability.

5.2.3 SEDIMENT DELIVERY RATIO

Sediment yield from a drainage basin is commonly substantially less than the gross erosion with in the basin, due to depositional losses during the conveyance of sediment from its source to the basin outlet (Walling, 1982; Vanoni, 2006). Erosion computations result in an estimate of soil movement with no indication of how far it moves (Awulachew et al., 2008). Sediment delivery ratios are means of using computed erosion data to predict sediment yields at desired points within a watershed. A sediment delivery ratio is the percentage relationship between the sediment yield at a specified measuring point in a watershed and the total erosion occurring in the watershed upstream from that point (Walling, 1988).

Sediment delivery Ratio (SDR) for a particular basin is influenced by a wide range of geomorphological and environmental factors including the nature, extent and location of the sediment sources, relief and slope characteristics, the drainage pattern and channel conditions, vegetation cover, land use and soil texture (USDA, 1971; Walling, 1988; Morris and Fan, 1997; Vanoni, 2006; Roehl, 1962).

- Drainage Area: Large watersheds will generally have a lower SDR than small watersheds due to increased probability of having lesser sediment transport capacity in the former case (Walling, 1982; Mutua et.al, 2006). However, huge increase in sediment yield in the downstream part of the catchment may reverse this relationship.
- Land Use: Land use can change both the cover condition and the permeability of a watershed. A watershed with poor cover will have a high SDR because of increased surface runoff.
- Texture of eroded material: Clay and silt sized soil particles are much more readily moved through a watershed than sand or gravel particles. Courser particles deposit upstream wherever the velocity of flow is lower that the threshold.
- Drainage Density: Channels are very efficient at transporting sediment. A high drainage density (total length of channel/drainage area) means that the distance from eroding areas to a channel is short. There is less chance for soil particles to deposit when moving a short distance so a high channel density indicates a high SDR. Shape of the watershed also affects SDR by changing distance from erosion source to a channel.
- Topography: Topography of a watershed affects it delivery ratio. Short and steep slopes will deliver more sediment to a channel than a watershed with long and gentle slopes. Whenever changes in slope occur, deposition may also occur. Relief/Length ratio (R/L ratio) often corresponds to delivery ratio.
- Sediment Source: Sediment from stream bank and gully erosion has a much higher chance of being delivered than does sediment from sheet and rill erosion due to the

high transport capacity of gullies and streams. Watersheds with a high percentage of channel erosion will have a higher SDR than a watershed with predominantly sheet and rill erosion.

5.2.3.1 SDR–Area relationship

Values of DR for an area are found to be affected by catchment physiography, sediment sources, transport system, texture of eroded material, land cover etc. (Walling, 1983, 1988). However, variables such as catchment area, land slope and relief length ratio have been mainly used as parameters in empirical equations for DR (Roehl, 1962). Where sufficient sediment yield and stream flow and/or reservoir survey data is available, SDR can be determined from measured sediment yield and soil loss. However such methods are not suitable to determine spatial distribution of sediment yield for large basin as required measurements are rarely available for each sub catchment (Lu, et al., 2004).

The delivery ratio usually decreases with increasing drainage area in the basin that is relatively homogenous with respect to soils; climate and topography, but large downstream increases in erosion rate may increase the delivery ratio (Vanoni, 2006). The inverse relationship of the trend is normally accounted for in terms of the increased opportunity for deposition of transported sediment as it moves into areas with reduced slope gradients and well developed flood plains (Walling and Webb; 1996).

The most common relationship is a SDR- Area power function (Lu, et al., 2004):

$$SDR = \alpha A^{\beta}$$

Where, A is the catchment area (km^2), α and β are empirical parameters. This relationship despite its simplicity carries no description on mechanisms of transport and all physical processes that underlie the sediment transport (Lu, et al., 2004)

5.3 SEDIMENT YIELD ESTIMATION USING RATING CURVE

5.3.1 SEDIMENT YIELD AT KESSIE

Kessie station is located at Kessie Bridge some 295 km downstream of outlet of Lake Tana measured along the Blue Nile River, draining the steepest part of the catchment. Due to the physiography of the catchment upstream of the Kessie station, high sediment load can be contributed by this area.

Sediment rating curve was developed using sediment concentration and discharge data for the period 2008, 2009 and 2010 to estimate sediment load at Kessie. **Figure 5.1** shows the variability of sediment discharge with stream flow discharge at Kessie and El-Deim.

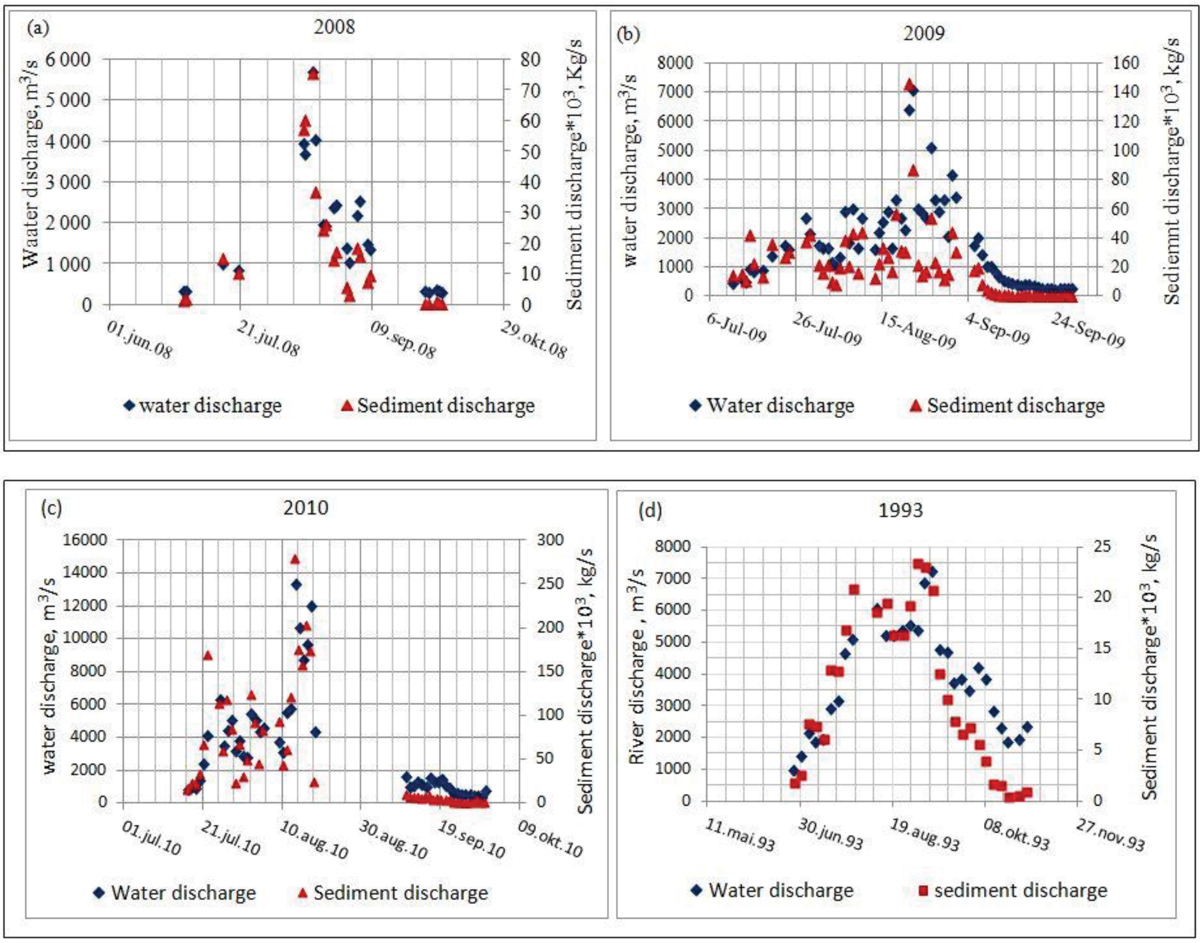

Figure 5.1 Sediment discharge and runoff hydrograph (a), (b) and (c) for year 2008, 2009 and 2010 respectively at Kessie gauging station and (d) is Hydrograph and sediment discharge at El-deim gauging station.

Inter annual variability of sediment load is higher than discharge variability. The above hydrograph shows that water discharge is increased by 25% from year 2008 to 2009 while sediment discharge increment is about 50%. The peak sediment concentration in year 2009 is 2.6 times that of 2008. However, this increase may not be the true increase due to possible unmeasured peak flows.

The sediment and water discharge graph for a period of record as in the **Figure 5.1** shows that the sediment discharge is lower during the falling stage than rising stage of river flow. This may be due to high sediment supply available from the loosened land during the dry period which is less available to the falling stage flood. This less availability during falling stage results from several factors which include removal of loose material during flood rise, less storm power and grown vegetation cover which affect sediment delivery, less rainfall intensity and more ground water runoff rather than surface flow. The rising stage of the hydrograph extends to 17th of August in all the cases. Therefore, different rating curves for rising (June to 17th August) and falling stage (August 19th to December) can give a better result and applied accordingly to minimize the errors that could occur if single rating curve is used.

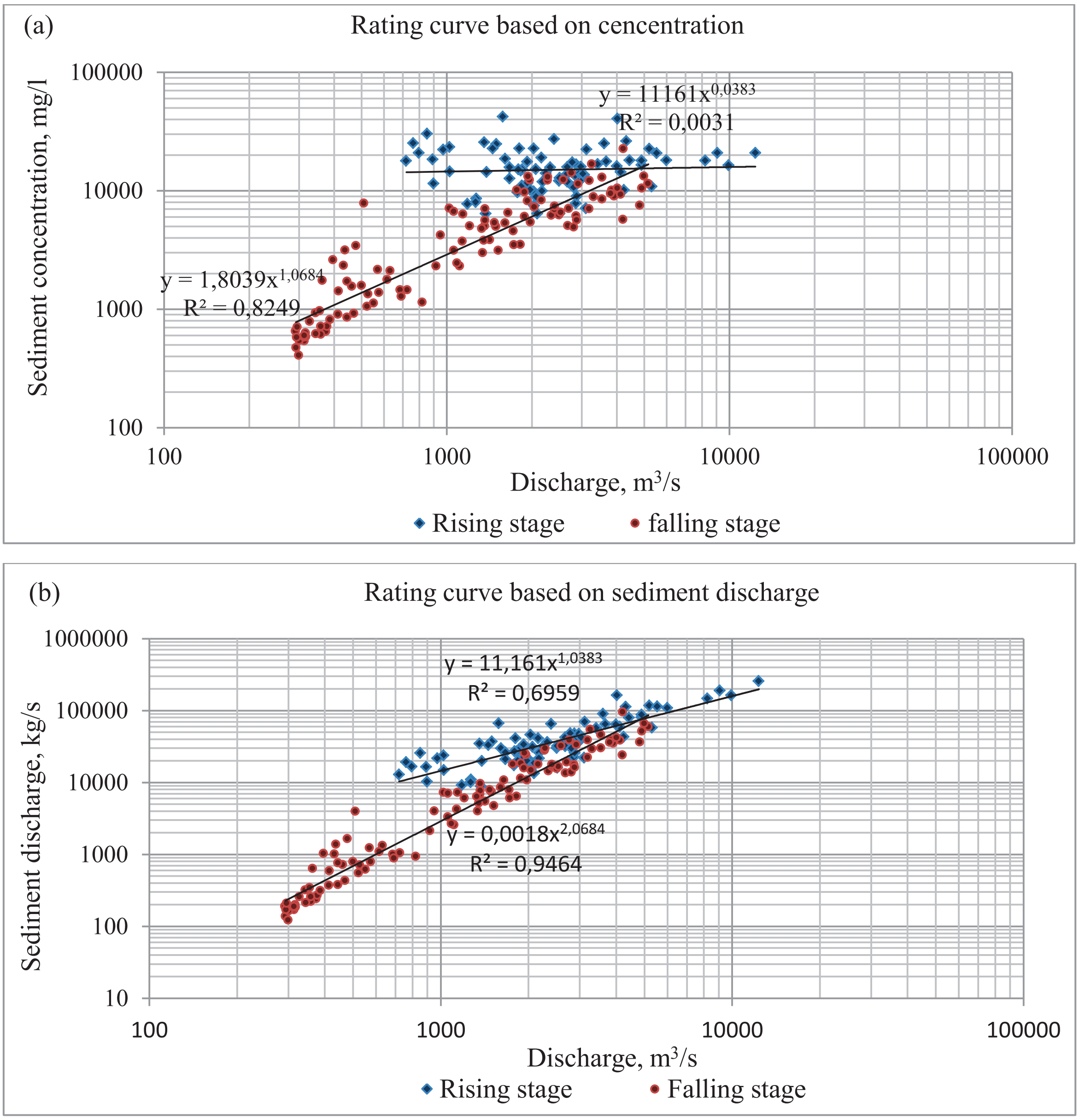

Figure 5.2 The sediment rating curve developed based on (a) sediment concentration-water discharge and (b) sediment discharge-water discharge for falling and rising stages of flood at Kessie station

The fitted line in the **Figure 5.2** shows good correlation of sediment and water discharge. However, good fit doesn’t imply an accurate representation of the process as the data doesn’t cover the entire range of discharges and the data covers few points for peak events.

Discharge and sediment concentration data at Kessie gauging station are available only for flood season (from June to October), which is limiting the application of the developed curve to low flow season. The sediment load estimated for year 2008, 2009 and 2010 based on fitted curve was checked against the measured data which shows that the best fit rating curve for rising stage underestimates the sediment load by about 9% and the rating curve for falling stage overestimates by about 4%. Sum of difference of the estimated and calculated sediment discharge for the whole wet season also confirms that the rating curve underestimated the sediment load i.e. $\sum$ (Measured-Calculated) > 0. However the evaluation of the rating curve for separate years of measurement indicates that the rating curve overestimated the sediment load for year 2009 and underestimated the load for year 2008 and 2010. The summary of the comparison of measured and computed sediment load is in the **Table 5.1**. The measured and computed sediment load for the whole data period is given in Appendix C.

Table 5.1 Comparison between measured and computed sediment load

year	Sum of difference (SOD) (kg/s) (Measured - Calculated)			Number of data	Number of SOD >0	% of SOD >0
	Rising stage	Falling stage	Sum (Rising + Falling)			
2008	-6,786	14,645	7,859	21	9	43
2009	-64,007	-68,258	-132,265	122	45	37
2010	420,069	-11,086	408,983	48	37	77
Total	349,276	-64,699	284,577	191	91	48

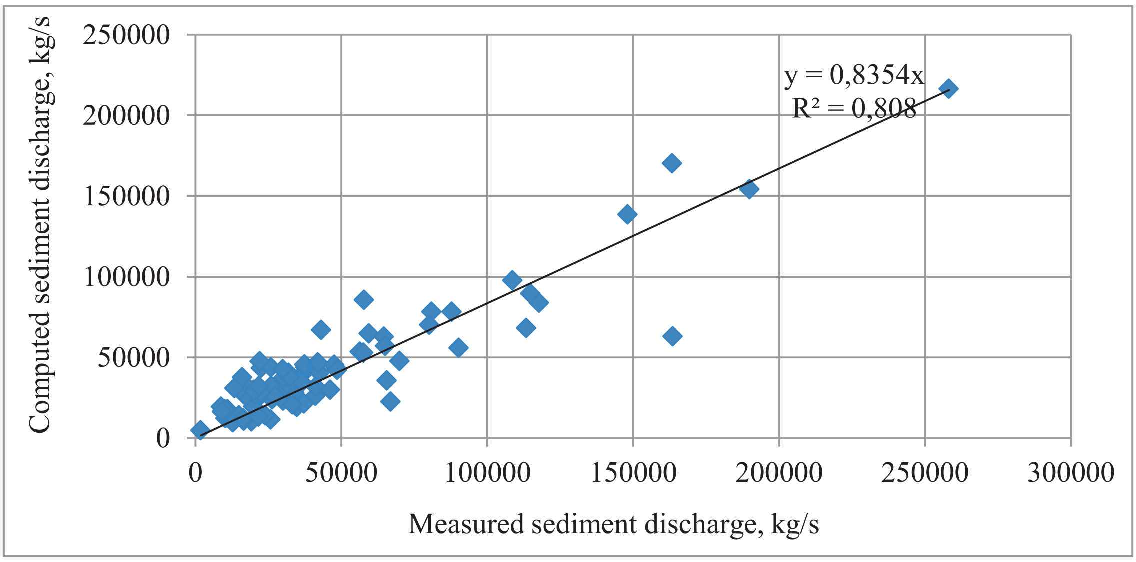

Figure 5.3 Computed vs. measured sediment discharge at Kessie for rising flood stage

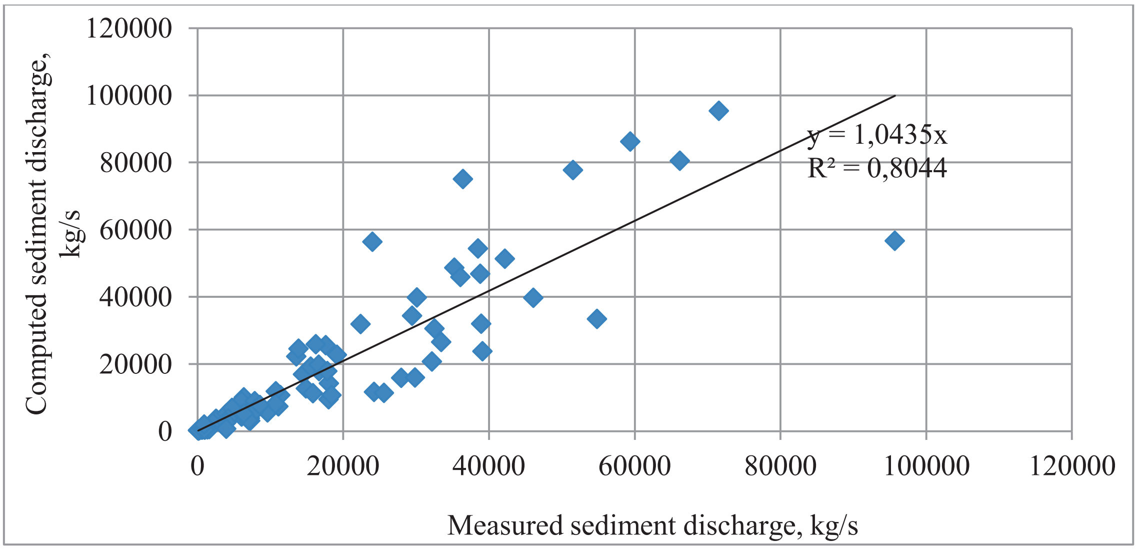

Figure 5.4 Computed vs. measured sediment discharge at Kessie for falling flood stage

The rating curve was used with daily flow data for a period from 1973 to 2009 (the flow data quality and its completeness is covered in previous section) to estimate suspended sediment load. In order to adjust for underestimation, correction coefficients determined based on computed and measured load were applied to the computed load. The estimated sediment load at Kessie for the wet season equals 165 million tones and the specific load equals 2578 t/km^2 without any correction to underestimation. Introducing a correction factor of 1.09 for rising stage and 0.96 for falling flood stage the long term average annual suspended sediment load and specific sediment yield for the 'wet season' was estimated to be 171 million tonnes and 3,460 t/km^2 respectively. The general trend of the estimated sediment yield is as in the figure below.

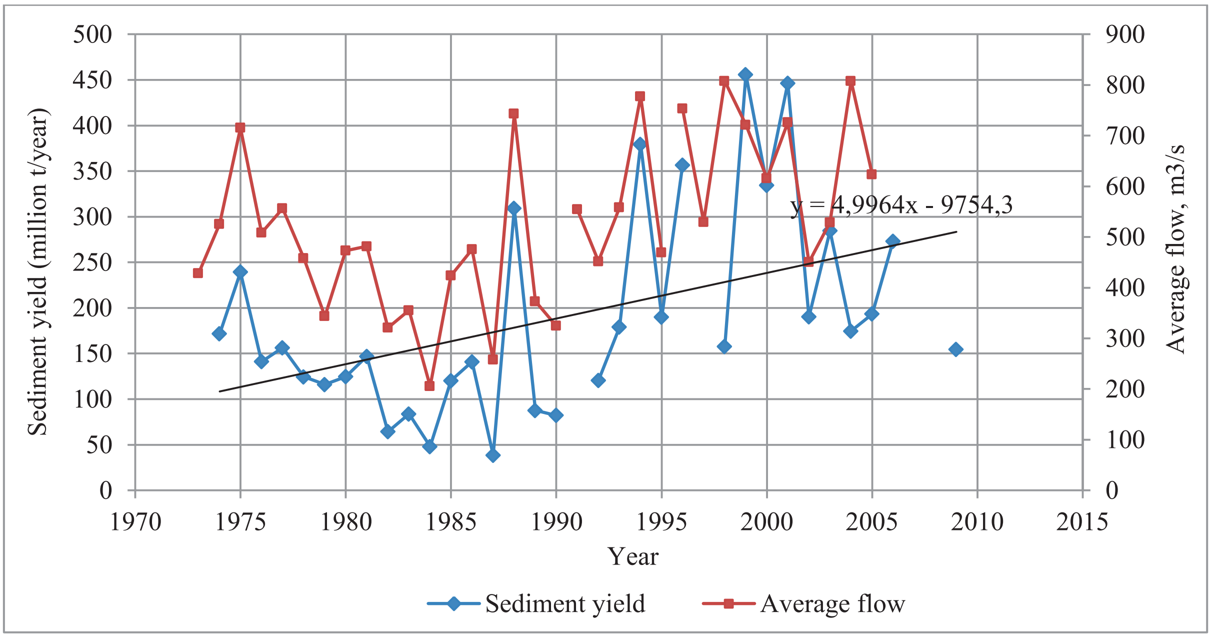

Figure 5.5 Inter-annual variability of average river flow and estimated sediment yield

Several other estimates of sediment yield also show that the sediment yield at El-deim ranges from 60 to 180 million tonnes per year. For example, 136 million t/year with 45% delivery ratio estimated by Awulachew, et al., 2008; 88.96 million tonnes estimated by Fetene et al., 2009, 62 million tons by Betrie, et al., 2009; 140 million tons estimated by Siyam et al., 2005; and 160 -180 million tons stated by Ahmed, 2008 which indicate that the estimate at Kessie may be overestimated. On the other side the average sediment load estimated at Mandaya was 285 million t/year (Ahmed, 2008) which is located some 200 km upstream GERD.

The average sediment concentration for the period of measured data was also used to make sediment yield estimate. The average sediment concentration for wet season is 8997 mg/l which with the wet season runoff volume, 14,516 million m^3 gives sediment yield of 131 million tonnes. This is about 6% smaller than 140 million tonnes estimated using the rating curve with daily data for year 2009. More than 75% of the sediment concentration data during rising stage (June and August) were taken where river discharge exceeds average daily discharge (**Figure 5.6**) which results in overestimation of average concentration leading to overestimation of sediment load. This indicates that the sediment yield based on rating curve is highly overestimated which should have been smaller than the estimate based on overestimated average concentration. This conclusion however is based on the assumption that the mean daily flow reported as stream flow data is better representative of daily average than discharge measured along with the sediment concentration.

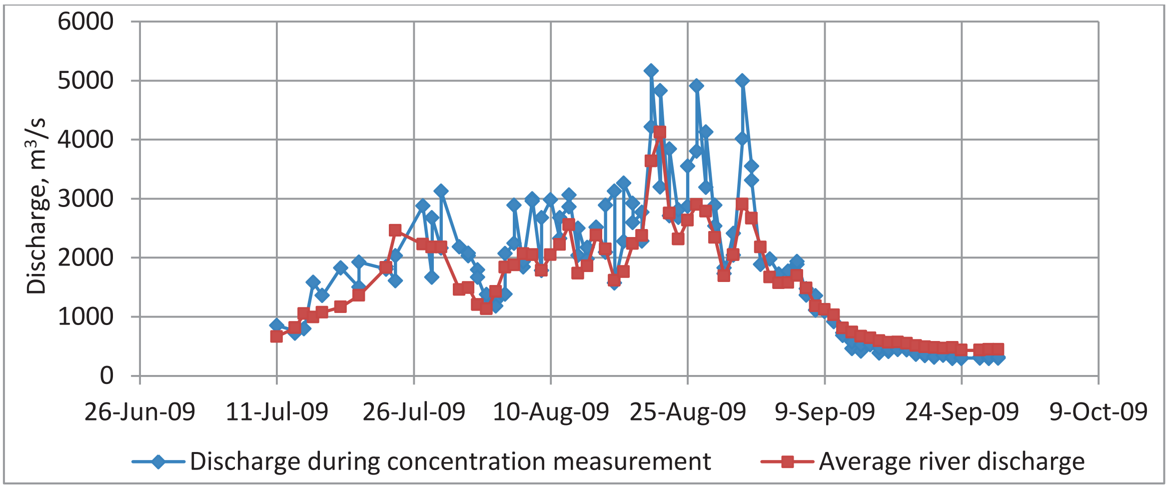

Figure 5.6 Daily average discharge and discharge measured along with concentration.

During the rainy season high sediment concentrations are observed in the basin and relatively sediment free water is observed after the surface runoff has ended (Easton, et.al, 2010). Based on measured flow for a period from 1902 to 2003, river flow during the flood season (June to October) accounts for more than 80% of the annual flow at Kessie station. The low flow season is characterized by very low erosive and transport power and sediment source during this period is limited to the river channel only. This shows that steep drop in water discharge results in steeper drop in sediment load. Therefore, sediment load during the wet season may account for more than 80% of the total annual sediment load. The sediment yield at Kessie was also estimated by extrapolating the rating curve to the low flow period which gives an average annual sediment yield of 182 million tonnes. The estimate for wet season, 171 million tonnes, when increased by 10% gives 188 million tonnes. The cumulative plot of sediment discharge also confirms that large percentage of the annual load is delivered during flood periods (Figure 5.5, 5.6 and 5.7). Therefore, 10% of wet season sediment yield was considered as the low flow season sediment yield to estimate average annual sediment load in the basin.

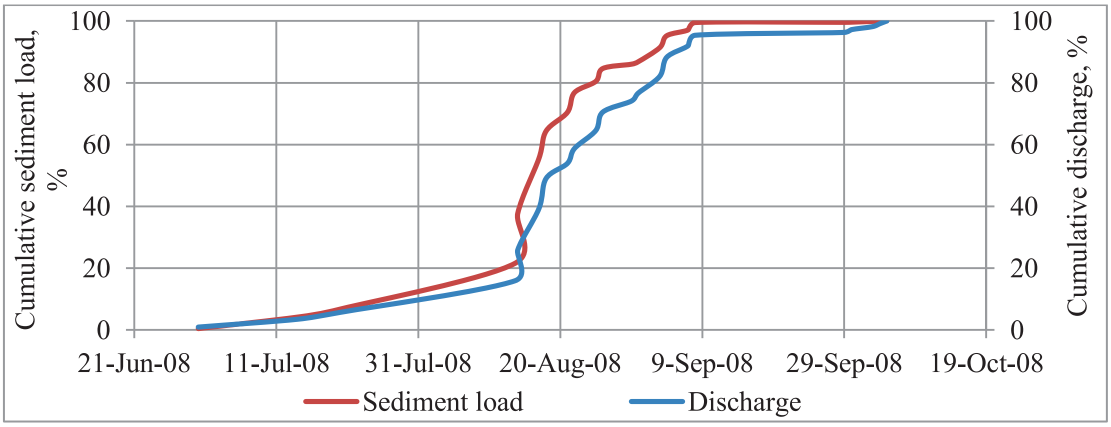

Figure 5.7 Cumulative sediment load and cumulative discharge at Kessie for year 2008

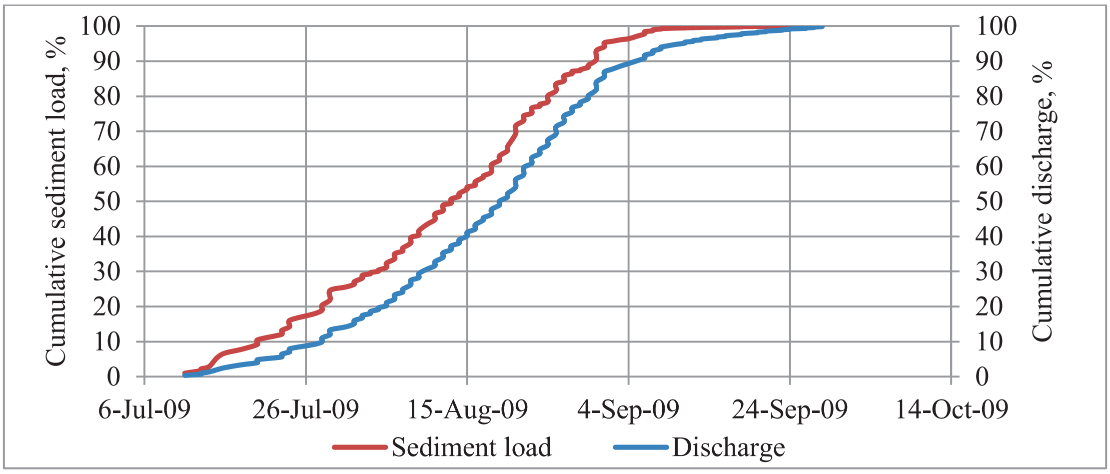

Figure 5.8 Cumulative sediment load and cumulative discharge at Kessie for year 2009

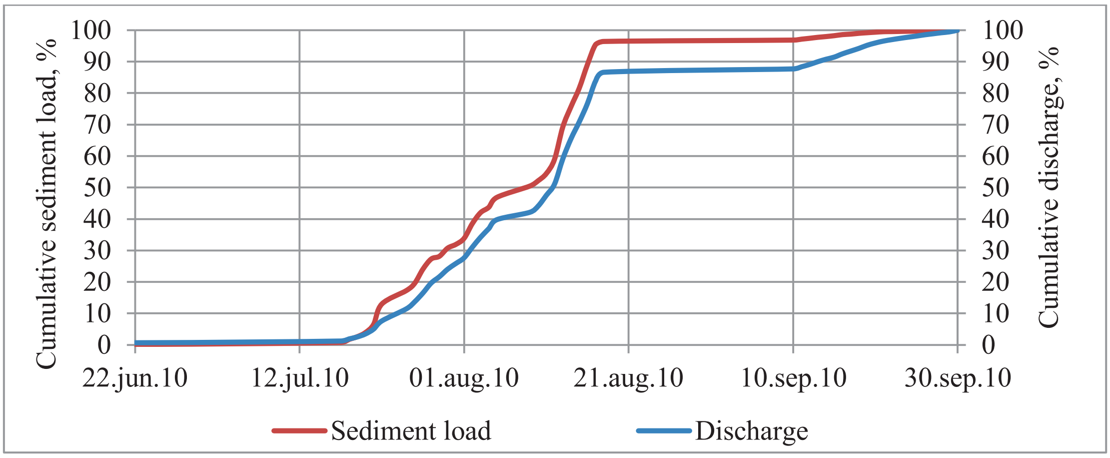

Figure 5.9 Cumulative sediment load and cumulative discharge at Kessie for year 2010

5.3.2 SEDIMENT YIELD AT BURIE

Burie station is located about 170 km downstream of Kessie station controlling about 95,000 km^2 catchment area of the Blue Nile. Unlike Kessie station no daily flow data was available for Burie station to develop rating curve. Therefore, average suspended sediment concentration data at Burie for period year 2008, 2009 and 2010 was used to estimate the suspended sediment yield of 198 million tonnes and specific sediment yield of 2095 t/km^2 for wet season.

Table 5.2 Suspended sediment load estimated based on average concentration

month	Average concentration	RO volume, million m^3	SSL, million tonnes	SSY, t/km^2
Jun	12585	662	8	88
Jul	19316	3540	68	724
Aug	9387	8301	78	825
Sept	4782	5920	28	300
Oct	4881	3090	15	160
Total			198.	2096

5.3.3 SEDIMENT YIELD AT EL- DEIM

The suspended sediment concentration at El-Deim gauging station for year 1993 was obtained from NBCBN (Siyam, 2005) study report. As daily flow data was not available for this station sediment yield was estimated based on average concentration for wet season of year 1993 and the runoff volume of the same period (June to October). The average concentration is 2496 mg/l which with the average runoff volume of 42,810 billion m^3 gives sediment yield of 107 million tonnes. Considering 10% of this as dry period suspended sediment load, the annual suspended load for year 1993 was estimated to be 118 million tonnes. The annual suspended load estimated for year 1993 at Kessie was 179 million tonnes which is about 52% bigger than the estimate at El-deim using average concentration.

The 10 day average sediment concentration determined from measured data for years 1970, 1973, 1975, 1993, and 1994 at El-Deim station was also used to make a long term average sediment yield at El-Deim. The monthly average runoff data at El-deim for period from year 1902 to 2003 was used to determine long term monthly average. The average runoff volume for each one-third of a month is not equal, thus assuming equal distribution may lead to erroneous estimate. Therefore, the daily flow data at Kessie station was used to represent the distribution of runoff in each one-third of each month as in the **Table 5.3**.

Table 5.3 10-days mean suspended sediment concentration at El-deim and average suspended load.

Month	Period	Mean sediment concentration (ppm)	Average RO volume (mill m^3/month)	% of total RO volume of a month	Average RO volume (mill m^3/10 days)	Suspended load (mill. ton)
June	I	NA		26	427.96	NA
	II	NA	1646	27	444.42	NA
	III	1956		47	773.62	1.74
July	I	3361		12	794.40	3.07
	II	3895	6620	28	1853.60	8.30
	III	4335		60	3972.00	19.80
Aug	I	5660		31	4737.11	30.83
	II	3095	15281	36	5501.16	19.58
	III	2948		33	5042.73	17.10
Sept	I	3589		46	5735.74	23.67
	II	2305	12469	31	3865.39	10.25
	III	1755		23	2867.87	5.79
Oct	I	1294		38	2581.72	3.84
	II	591	6794	32	2174.08	1.48
	III	317		30	2038.20	0.74
Total			42,810		42810.00	146.19

Data source: 10-day mean sediment concentration (Ndorimana, et al., 2005) and average monthly discharge at El-deim (Tefferi, 2012)

The relative density of the sediment, 1.15 t/m^3 determined as an average of relative density measured at El-Deim station was used in this estimate. Assuming the mean sediment concentration in the last ten days of June to be the same for the first and second ten days of the month, the suspended sediment yield for wet season at El-Deim equals 148 million tonnes.

5.3.4 SEDIMENT YIELD AT GUDER

Using the very sparse and few data at this station rating curve was developed (**Figure 5.10**). The best fit rating curve gives the average sediment load of 154 t/day for the data period and the measured sediment load is 143 t/day which is about 7% smaller than the computed. On the basis of this rating curve average suspended sediment load was estimated to be 0.441 million t/year and the corresponding specific yield is 84.12 t/km^2/year.

This estimate however, in addition to errors arising from use of rating curve with a very few data has some limitations. No representative data has been obtained for period after1990, thus changes after this period may be significant to deviate the estimated average sediment yield.

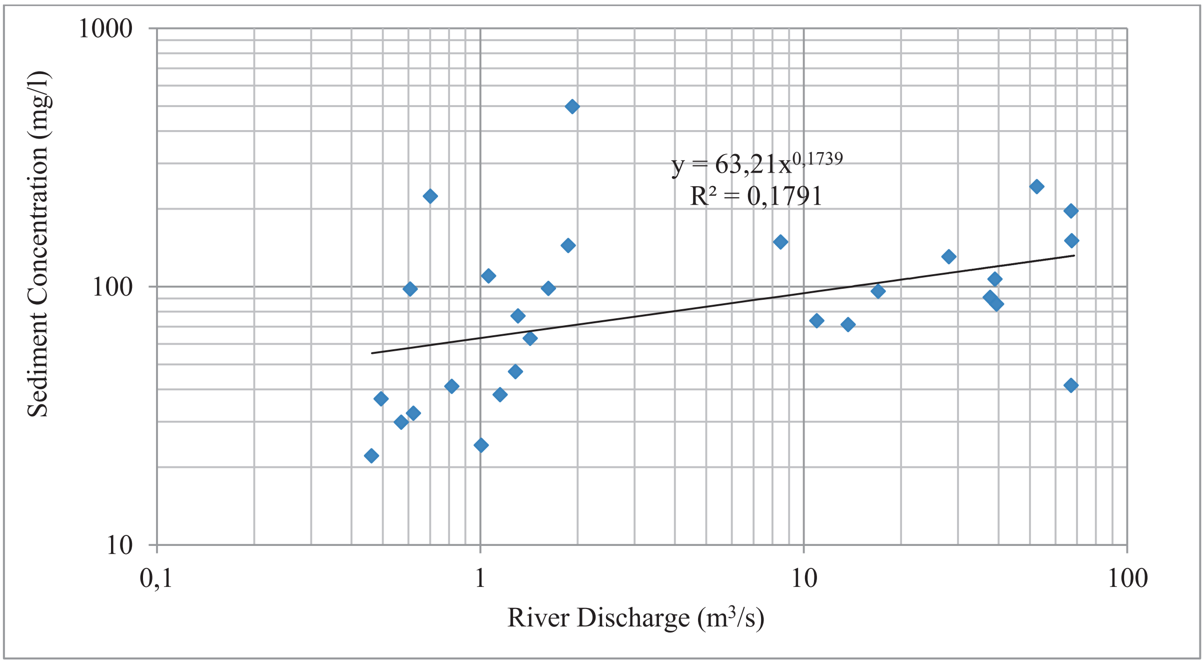

Figure 5.10 Sediment rating curve at Guder

5.3.5 SEDIMENT YIELD AT TATO

Tato is station covering only 42.5 km^2 area of Upper Didessa catchment. The measured sediment discharge was compared with computed sediment discharge which indicates that the underestimated error amounts 24% of the measured load when rating curve is used. The correction factor of 1.24 was therefore applied to the load estimated by rating curve. On this basis the average annual suspended sediment load and specific load at this station was estimated to be 9.13*10^3 t/year and 215 t/km^2/year respectively.

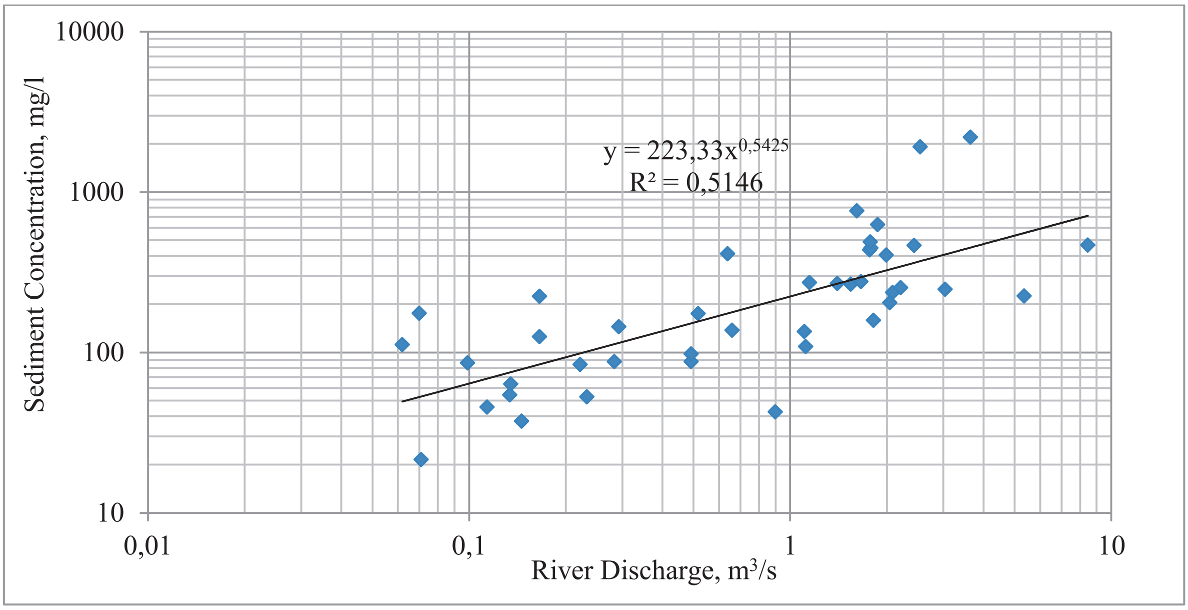

Figure 5.11 Sediment rating curve at Tato

5.4 SEDIMENT YIELD BASED ON RESERVOIR SURVEY

5.4.1 ROSEIRES RESERVOIR

The storage capacity of Roseires reservoir during its first filling in 1966 was 3.3 billion m^3. Based on bathymetric observations the drop in capacity during the first 10 years was 550 million m^3 with an average rate of 55 million m^3 per year. In the period 1976 to 1981, the reduction in the capacity was 100 million m^3 with a rate of 20 million m^3 per year. In the period 1981 to 1985, the reduction in the capacity was 100 million m^3 with a rate of 30 million m^3 per year. A drastic increase occurred in the period 1985 to 1992 with a rate of 60 million m^3 per year and a total reduction of 127 million m^3.

Variation in storage loss and silt deposition with in different elevations of the reservoir is obtained from the bathymetric surveying carried out in years, 1976, 1981, 1985, 1992, 2005 and 2007 which is summarized in the table below.

Table 5.4 Accumulated sediment volume for different periods of survey in million m^3 (Data source: Bashar and Eltayeb, 2010)

R.L(masl)	Time of observation (year)					
	1976	1981	1985	1992	2005	2007
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

Table 5.5 Storage capacity of the Roseires reservoir for different periods of survey in million m^3 (Data source: Bashar and Eltayeb, 2010)

R.L(masl)	1966	1976	1981	1985	1992	2005	2007
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

Annual sediment load can be determined based on the observed trap efficiency and siltation rate of the reservoir. Information on grain size distribution of deposited sediment was obtained from the results of a laboratory test which was done for some sediment samples in the year 1977 (Gibbs, A. & Partners, 1978). The grain types, sizes and percentages of the samples are as below:

(a) Sand (0.02-0.2 mm) ~22% (b) Silt (0.002-0.02 mm) ~ 38% (c) Clay (< 0.002 mm) ~ 40%

The average density of all sediment deposited during *t* years of consolidation may be calculated by equation given by Milller (1953) (Morris and Fan, 1997).

$$W_t = W_1 + 0.4343B\left[\frac{t}{t-1}(\ln t) - 1\right]$$

Where, W_t = average specific weight after *t* years of consolidation, W_1 = initial specific weight and B = constant given as a function of operation condition and texture of the deposit as given in the Table 5.6. Initial bulk density of the deposit is determined by Lara Pamberton method.

Table 5.6 Coefficient values for consolidation calculation

Operation condition	B in kg/m^3		
	Sand	Silt	Clay
Continuously submerged	0	91	256
Periodic draw down	0	29	135
Normally empty reservoir	0	0	0

Assuming similar particle size composition for the period of deposition of sediment in the Roseires reservoir, average specific weight of deposit was estimated to be 1.01 t/m^3. According to the U.S. Natural Resources Conservation Service the specific weight of reservoir deposit with clay-silt mixture sediment dominating and submerged reservoir operation ranges from 0.64 to 1.04 t/m^3. Siyam and his partners (2005) also estimated specific unit weight of 1.118 t/m^3 for assumed composition of deposited sediment. From this information the average specific weight of the deposit was assumed to be within 1 and 1.2 t/m^3.

Sedimentation rate varies highly from time to time which is not only due to decreasing trapping efficiency of the reservoir, but also sediment load variability. Thus, averaging the sediment inflow over the long period can shade the temporal variability of the sediment load. However, it can give good estimate of long term sediment load. The estimated sediment load at Roseires is as summarized in the **Table 5.7**.

Table 5.7 Sediment yield (in million t/year) at Roseires for different deposit density averaged over the period from 1966.

year	Specific weight (t/m^3)				
	1	1.05	1.1	1.15	1.2
1976	122	128	134	140	146
1981	116	122	127	133	139
1985	177	186	195	204	213
1992	169	177	186	194	203
2005	157	165	173	181	189
2007	155	163	170	178	186

The accuracy of this estimate depends on how reliable the measured trap efficiency and reservoir siltation rate are. The observed trap efficiency data available may not take unmeasured sediment in to account. Therefore, consideration of possible unmeasured sediment during flushing may be necessary. Estimated average sediment yield for deposit density of 1.01 t/m^3 considering different percentages for possible unmeasured sediment during flushing is as in the **Table 5.8**. The percentage of unmeasured sediment varies from year to year which is difficult to assign as no data on sediment release and/or sediment inflow to the reservoir is available.

Table 5.8 Average annual sediment yield in million tonnes averaged over the period from year 1966 for different percentage of unmeasured sediment

%	Year					
	1976	1981	1985	1992	2005	2007
0	123	117	179	171	159	157
5	129	123	188	179	167	164
10	135	129	197	188	175	172
15	141	134	206	196	183	180
20	148	140	215	205	191	188

5.4.1.1 Conclusions

- Reservoir surveying is one of the accurate ways of estimating sediment yield of the catchment draining to a given outlet or reservoir. However, inaccuracies or errors can occur which varies in magnitude depending on the surveying method, number of range lines, methods of data collection and analysis. The estimate was made assuming the observed trap efficiency and surveyed deposited volume of sediment are of good quality.
- The density of the deposit was determined based on sediment particle size obtained from laboratory analysis of deposit in 1977 which may not be the same for the period different from time of measurement. Significant deviations in specific weight of deposit from empirically estimated value can affect the estimated sediment yield at this station. Considering the upper and lower limits of deposit density 1 and 1.2, average sediment yield at Roseires range from 155 to 186 million t/year.

5.5 SEDIMENT YIELD BASED ON DELIVERY RATIO

Most of the eroded sediment in the Blue Nile Basin is deposited on the foot slope of the hills and doesn't enter the drainage system. However, those streams which do reach the stream during the rainy season carry heavy sediment loads (Awulachew et al., 2008). According to Awulachew et al., 2008, the estimated sediment delivery ratio (SDR) for the Blue Nile Basin, indicates that approximately 55% of sediment remains in the landscape and does not reach the stream system.

Sediment Delivery Ratio - Area relationships was developed for the Blue Nile based on the above estimates of sediment yield and soil loss estimates by EHRS, 2010. Specific soil loss between the GERD and El-deim as well as between GERD and Roseires was assumed to be equal to the specific soil loss in the west most part of Lower Abbay basin (Figure 4.2). The sediment yield estimates are summarized in the Table 5.9. Estimates at Guder and Tato were excluded because of very small area coverage of the stations which cannot be used with soil loss estimate averaged over large area.

Table 5.9 Estimated sediment delivery ratio

Location	Kesse	Burie	El-Deim	Roseires
Catchment Area, km^2	64063	94493	178200	195000
total load, t/km^2/yr	3384	2645	1040	805
Avg. soil loss, t/yr	2.4E+08	3.0 E+08	3.8E+08	3.9E+08
Specific soil loss t/km^2/yr	3.8E+03	3.2E+03	2.2E+03	2.0E+03
Delivery Ratio, %	88.5 %	83.8 %	48.2 %	40.7 %

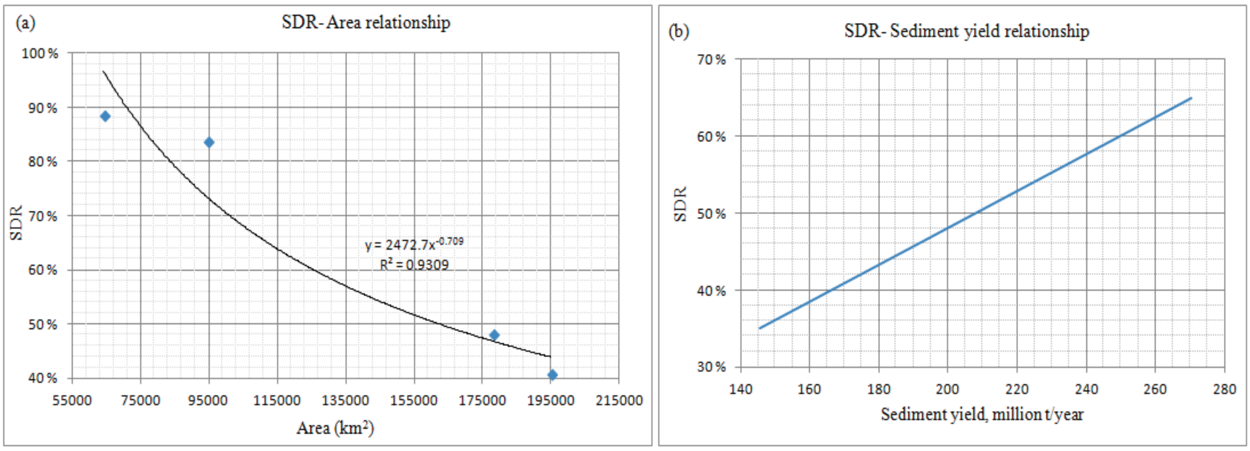

Figure 5.12 SDR- Area relationship and SDR- Sediment yield relationship at GERD

Sediment Delivery Ratio decreases with decreasing slope of the catchment. This trend cannot be reflected using the SDR-Area relationship. According to SDR-Area relationship catchments of equal area will have equal proportion of sediment delivered to river draining the catchment. SDR-Area relationship developed for high yielding catchment lead to over estimation of total yield while relationship developed for low sediment yielding catchments lead to underestimation of total load in a given basin. Taking this into account delivery of sediment from high yielding catchment is of importance. The part of the Blue Nile Basin upstream the Kessie station delivers large proportion of sediment in the basin. Therefore, considering the delivery ratio of 45%, total load at GERD was estimated as 187 million t/year.

5.6 TOTAL SEDIMENT LOAD

Total load is often estimated by measuring suspended load, while the bed load fraction is either ignored or taken to be a fixed fraction of the suspended load. Numbers that are found frequently used are 10% to 20% bed load fraction of the total or suspended load in general (Turowski, et al., 2010; Støle, 2007). Though, it may be in a range of 20% to 40% for mountain rivers (Vanoni, 2006).

There is no reliable means of bed load information in the Nile River, which is believed to be negligible. However, Hurst et al, (1978) estimated the bed load to be 25% of the total sediment load. Ahmed, 2008 stated that what has been reported by Hurst et al (1978) is exaggerated and concluded that suspended sediment commonly accounts for approximately 90% of the total sediment load. According to Hussein et al, 2005 the suspended load was estimated to account for more than 85% of the total sediment load in the Blue Nile River.

In the absence of any data regarding bed load transport in the basin it is common to account for as a percentage of total or suspended load. The Eastern part of the Blue Nile River in Ethiopia is steep in which bed load may exceed 10% of sediment load. Therefore, 15% of the suspended load was considered as bed load in estimation of total load.

Table 5.10 Summary of estimated sediment yield at different locations in the Blue Nile Basin

Station	Area (km2)	SSL (million t/year)	Total load (million t/year)	Specific Sediment yield (t/km^2)	Method	Year
Kessie	64,060	188	217	3384	Rating curve	1973-2009
		143	165	2576	Rating curve	1973-1994
		154	177	2774	Rating curve	2009
		154	177	2774	Average concentration	2008-2010
		147	169	2640	Average concentration	2009
		-	134	2100	SDR (55%)	
Burie	94,490	218	250	2645	Average concentration	2008-2010
Guder	524	0.044	0.05	97	Rating Curve	1960- 2001
Tato	43	0.009	0.01	247	Rating Curve	1996- 2004
GERD	177,700	-	187	1052	SDR (45%)	
El-deim	178,200	161	187	1050	Average concentration	1970-1994
		130	150	839	Average concentration	1993
Roseires	195,000	-	155	795	Bathymetric survey (deposit density=1 t/m^3)	1966-2007
		-	186	954	Bathymetric survey (deposit density=1.2 t/m^3)	1966-2007

5.7 DISCUSSIONS

Average sediment concentration data can be used to estimate an average sediment yield from a catchment if good quality data is available. The suspended sediment concentration data for Kessie station may not be taken in a way that it represents the daily average. The discharge corresponding to measured sediment concentration was compared with the average daily river flow at Kessie station for the same period which shows that 80% of the discharge measured along with sediment concentration is higher than the average daily discharge of the same day in August, 2009. The discharge measured along with sediment concentration in September however consists of 80% of the data smaller than the mean daily discharge of the same period. This indicates that the sediment concentration samples were taken randomly where sediment concentration may be higher or lower than daily average. Therefore, sediment yield estimates made on the basis of averaged sediment concentration at Kessie and Burie stations may not be reliable.

The sediment yield estimated based on the average concentration at Kessie is smaller in magnitude than the estimated load using rating curve for year 2009. Though the measured sediment concentration was taken where river discharge exceeds the average, it cannot indicate that the measured sediment concentration is higher than the average daily concentration. This is because of non linear relationship between discharge and sediment concentration.

The 10-day average sediment concentration at El-deim may give good long term sediment yield estimate as it was obtained from long record covering year 1970 to 1994. The total sediment yield estimated at El-deim using the 10-day average concentration equals 187 million t/year and the annual sediment yield estimated based on rating curve was 165 million tonnes at Kessie station, averaged over year 1973 to 1994. With this information the intermediate catchment was estimated to have a total load of 22 million tonnes which is equivalent to specific sediment yield of 193 tonnes/km^2. The very low specific sediment yield can be related to the topography which is dominated by flat area with an average slope less than 1.8% and relatively good land use and land cover condition.

Considering the average specific sediment yield between Kessie and El-deim to be equal to estimate at Guder, 96.75 t/km^2, total load contribution of this area was estimated to be 11milion tonnes/year. This with the estimate at Kessie for 1973-1994 gives a total load of 176 million tonnes/year, which is equal to the total load estimated based on bathymetric surveying of Roseires reservoir for deposit density of 1.13 t/m^3. The 11 million t/year contribution of the intermediate catchment when combined with the soil loss from the area (140 million t/year) gives a delivery ratio of 7.9% which is very small.

The specific and total load from the intermediate catchment between Kessie and GERD was estimated to be 482 t/km^2 and 54.8 million t/year respectively considering the delivery ratio of 45% with the soil loss estimated by EHRS, 2010. Considering the 165 million t/year at Kessie, total load at GERD becomes 220 million t/year. This corresponds to the specific sediment yield of 1238 t/km^2/year.

Considering the sediment yield at El-Deim based on average concentration of year 1993 with the sediment yield at Kessie estimated based on rating curve for the period 1973-1994, the sediment load from an intermediate catchment will be 4 million t/year. This with the soil loss estimated by EHRS gives SDR of 2.86%.

If specific sediment yield between Kessie and El-Deim is assumed equal to that of Tato, 247 t/km^2/year, the total sediment load at El-Deim will be 193 million t/year with yield at Kessie equal to 165 million t/year. For the specific sediment yield of the intermediate area, 247 t/km^2/year, the delivery ratio of the area was estimated to be 20.45%. The average soil loss from the catchment draining into Tato is approximately equal to the average soil loss from the intermediate catchment between Kessie and El-Deim. If the delivery ratio for both catchments is assumed equal, the specific sediment yield at Tato can represent the intermediate catchment.

Sediment yield estimated based on rating curve for the period after 1995 shows high increase in sediment yield which has resulted from increase in runoff during this period. The specific sediment yield including the period after year 1995 is 3384 t/ km^2/year. Assuming the specific sediment yield of intermediate catchment to be equal to that of Tato, 247 t/km^2/year, the total sediment load and specific sediment yield at GERD will be 245 million t/year and 1380 t/km^2/year respectively. Specific sediment yield map for this scenario is given in the figure below.

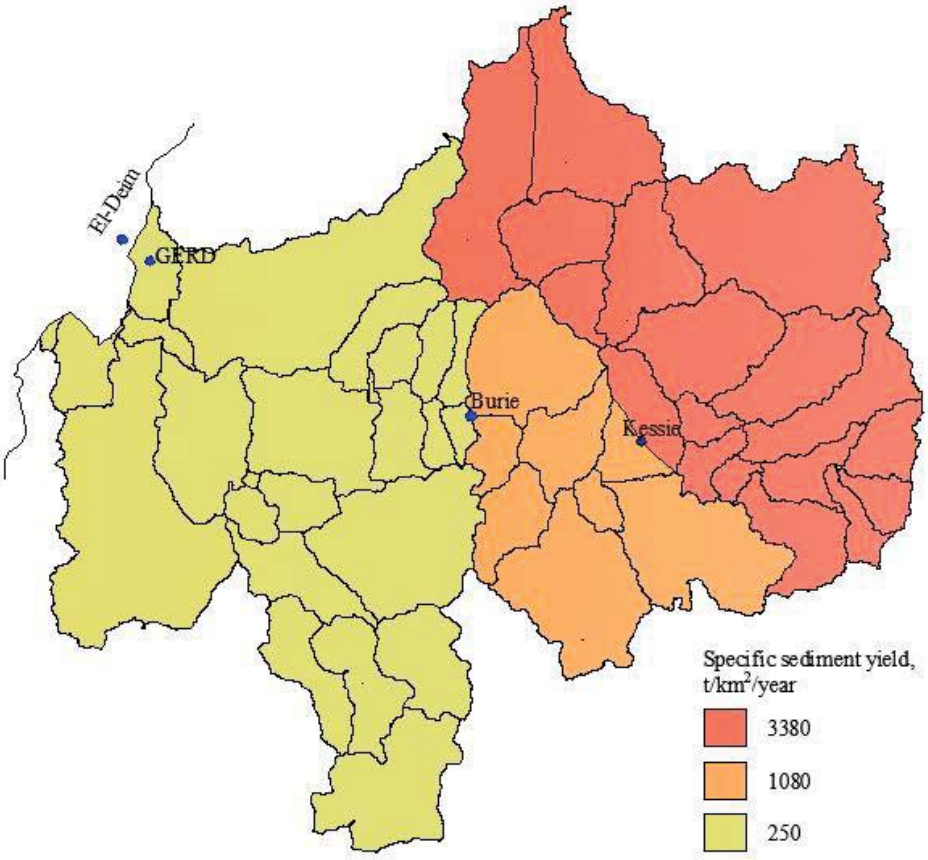

Figure 5.13 Estimated specific sediment yield for the Blue Nile Basin

5.8 CONCLUSION

The sediment yield estimate based on rating curve was considered as the basis for the sediment yield estimate because all other estimates are dependent on secondary data. However, it should be noted that the sediment yield estimated by using rating curve developed for year 2008, 2009, and 2010 with stream flow data of year 1973-2009 may have limitations due to variability in concentration-discharge relationship from time to time.

On the basis of what we have, it may be difficult to conclude that a single estimate is true, as all the estimates involve major uncertainties. However, the total load at GERD, when estimated as a sum of the long term average sediment load at Kessie, 202 million t/ year (3384 t/km^2/year) and the 32 million t/ year (247 t/km^2/year) estimated for intermediate catchment, which equals 245 million t/ year was considered better estimate of the sediment yield. This is equivalent to 1378 t/km^2/year when averaged over the total area. The ranges of values can better represent the sediment load at GERD reservoir than a single value due to uncertainties. The sediment load estimated using the rating curve for year 2009 is of a reasonable quality as it is based on the data measured in the same year. Assuming zero sediment load from the intermediate catchment between Kessie and GERD the total load at GERD for year 2009 will be 177 million t/year which is about 75% of the estimated 245 million t/year. Therefore, the sediment yield at GERD was considered to fall in the range of $\pm 25\%$ of the estimated 245 million t/year.

6 SEDIMENTATION RATE OF GERD RESERVOIR

6.1 GENERAL

One of the main objectives of this study is to determine the sedimentation rate and deposition pattern of sediment in GERD reservoir as a basis for selection of appropriate management method to evacuate incoming sediment in order to improve service life of the reservoir with respect to sedimentation. Uncertainties arising from estimated sediment yield were taken in to account and the consequences of these uncertainties were evaluated.

There are no commonly accepted rates of reservoir sedimentation as each reservoir has its own particularity. Some reservoirs are filled up very rapidly with an annual storage loss rate of more than 1%, while others are hardly affected by sedimentation. For example: sedimentation rate for Roseires reservoir based on reservoir surveying data was 1.02% (Bashar and Eltayeb, 2010). Kashim Elgibra, is one of the oldest reservoirs on the blue Nile with estimated sedimentation rate of 1.25% (Shahin, 1993). Similarly, Koka reservoir has lost large part of its storage capacity at an average annual rate of 1 % (Siyam, 2005) and Angereb reservoir in Northern Ethiopia at annual rate of 0.3% to 0.4 % (Haregeweyn, et al., 2012). The reservoir sedimentation rates depend on its storage capacity, sediment input and trap efficiency which varies from reservoir to reservoir being dependent on many other variables.

Though the ultimate destiny of most reservoirs is to become filled with sediment, the length of time that it takes depends on the sedimentation rate and how well the problem is addressed both during the planning stage and while reservoir sedimentation is occurring (Xiaoqing, 2003). There are always uncertainties in estimating reservoir sedimentation and sediment deposition pattern due to number of governing factors. These are related to quantity of stream flow, sediment load, sediment particle size, and specific weight, trap efficiency and reservoir operation.

6.2 DEPOSITION PATTERN OF SEDIMENT

Sediment loads are discharged into the reservoir by the river in two modes: (i) bed load, and (ii) suspended load. The type and amount of the loads delivered to the reservoir are dependent on the hydraulics of the river, source of the sediment, the geometry of the reservoir, the width to depth ratio at the entrance to the reservoir, detention storage time and the operating procedure (Dargahi, 2012).

As soon as the river flows in to a reservoir the retarding effect of the reservoir limits the sediment carrying capacity of the river resulting in aggradation effect that can travel several kilometers upstream of the entrance to the reservoir (Annandale, 1987). The aggradation effect of the reservoir allows the coarser material to deposit at the inlet to the reservoir, while silt and clay materials deposit in the mid and outlet section of the reservoir. A typical distribution of the sediment types is given in

Table 6.1.

Table 6.1 A typical example of distribution of deposited sediment in a reservoir (USACE, 1987 cited in Dargahi, 2012)

Particle size	Inlet (%)	Mid-reservoir (%)	Outlet (%)
Sand	5	<1	0
Silt	76	61	51
Clay	19	38	49

6.2.1 RESERVOIR OPERATION PROCEDURE

Reservoir operation has significant effect on rate of sedimentation, sediment distribution and trapping efficiency of the reservoir. It is therefore important to examine effects of operation strategy on sedimentation of the reservoir.

6.2.1.1 Staged filling of the reservoir

The staged filling may start prior to completion of the construction to allow the project to begin generation sooner than the case if the reservoir impoundment starts after the completion of the entire dam. If the reservoir is planned to retain 10% of the annual runoff during the filling period, the minimum water level will be reached in 3 years after which the power plant can start operation. During this 3 year filling period, almost all the incoming sediment will deposit in the deepest part of the reservoir (dead storage) just behind the dam. After these three years of filling the course sediment starts depositing at the inlet to the reservoir, while the dominant fine sediment transports close to the dam where it settles. With the staged filling, minimum deposition can be attained if the filling takes place during falling stage of the river runoff from October to December provided that all incoming sediment and runoff is bypassed during rising stage of flood. This filling strategy may however be conflicting with that of Roseires reservoir in which filling starts in September.

The filling of the reservoir may continue with retention of 10 to 20% of annual runoff until the full reservoir capacity is reached. This takes about 14 years with 10% retention and 7.25 years with 20% retention.

6.2.1.2 Filling in one season

Other filling option is to retain all incoming water until the reservoir fills up to minimum water level. In this case the total runoff volume just downstream the GERD reservoir will be reduced by 29.4% for the first operation year which will be consumed to fill up the storage below the minimum water level. Filling in one season may not be preferable in view point of the downstream water users. However, the shared benefits may be maximized with this option. After the minimum water level is reached the complete filling may be staged retaining small part of the annual runoff to raise the water level. During the longer operation time after filling of the reservoir, the water level of the reservoir varies between 608 masl and 646 masl. The water will be withdrawn until minimum water level is reached when portion of live storage is filled with sediment. If no remedial measure is taken all total load of the filling period can deposit close to the dam. This discussion only highlights the effect of operation strategy on sedimentation of the reservoir. Detailed operation optimization is out of the scope of the study.

To predict the deposition pattern of the incoming sediment after filling the GERD reservoir can be divided into 3 sections as in the **Figure 6.1**. Reservoir sediment deposition and deposition pattern depends on operational rules of the reservoir. The reservoir operation for GERD after filling was assumed similar to Karadobi reservoir as no data on reservoir operation strategy was obtained for this reservoir. According to pre-feasibility study, Karadobi reservoir is gradually emptied from January to June and filling starts in early July. The reservoir fills at the end of September and then draw down takes place to 60% in early January of the following year.

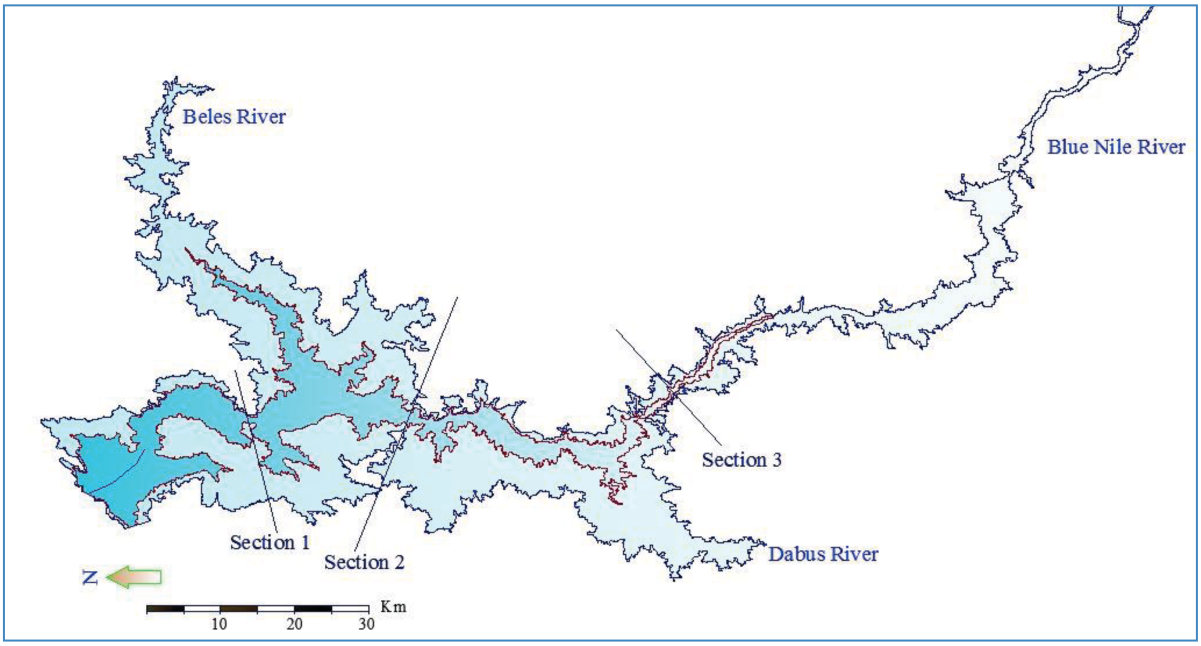

Figure 6.1 Water spread area for minimum and full supply reservoir level

The reservoir upstream section 3 is narrow section with an average top width of about 3 km at FSL. From the geometry of the section uniform longitudinal distribution of course sediment deposit can be expected. However due to dominancy of fine sediment in the river, most of the load will be transported farther downstream section 3 and course sediment deposit just downstream section 3 due to expansion of wetted area. The sediment deposited and delta formed at this section will be flushed during the first flood when reservoir water level is low (July to August). Drainage from Dabus sub basin joins the Blue Nile from the left bank just downstream section 3 and some 80km upstream of GERD. Dabus catchment in terms of sediment load contribution to the main river may be insignificant which however can have turbulence effect.

The reservoir has larger water spread area in between section 2 and 3 at FSL allowing settling of fine sediment when reservoir is full. As the stage of a reservoir recedes, sediment deposited when the water level was above the current elevation will be eroded and transported in to the existing pool. The deposit when the seasonal flood occurs will be transported downstream section 2 where most of it is expected to settle.

The suspended sediment which passes section 2 will get longer residence time and lower transit velocity because of wider section of the reservoir. If through flow velocities are high enough the material deposited in between section 1 and 2 may be re-entrained by flows and transported further downstream of section 1 or out of the reservoir. However, large area of this section in addition to constriction at section 1 allows most of the incoming sediment to deposit in between section 1 and 2. A part of incoming suspended sediment transport further to section 1 with finer sediment deposition focusing on the deepest part of the section. Local sediment inflow from Beles river which joins the Blue Nile about 40 km upstream of GERD from the right bank may also be insignificant thus affecting only the deposition surface where it joins the river. After certain period of operation exposed delta will be covered with vegetation which allows more sediment deposition leading to formation of flood plain.

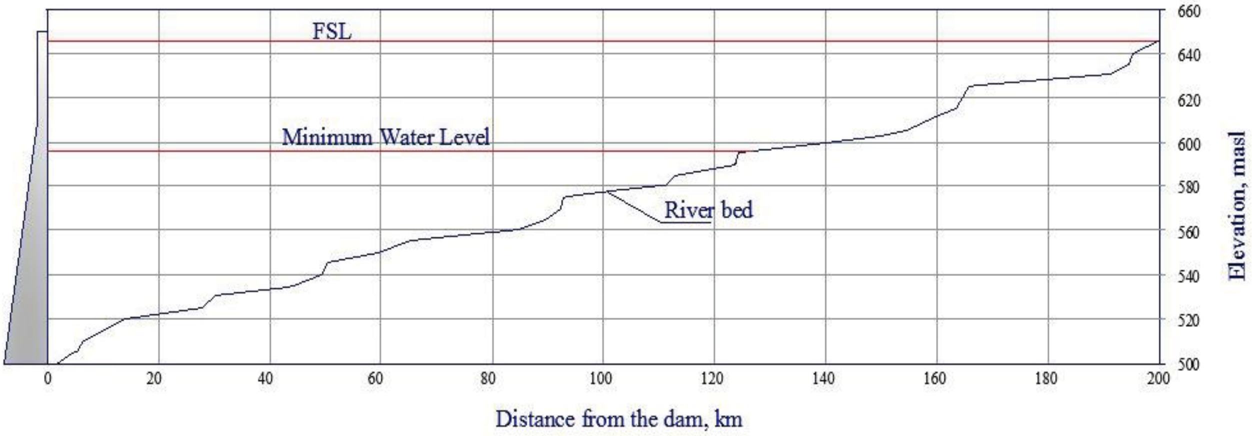

Figure 6.2 The longitudinal profile of the GERD reservoir along the thalweg (Determined from DEM of the basin)

6.3 TRAP EFFICIENCY

Reservoir trap efficiency is defined as a ratio of deposited sediment to the total sediment inflow for a given period. Trap efficiency is influenced by many factors of which primary factors are: the sediment fall velocity, velocity field through the reservoir and reservoir operation rules (Ahmed, 2008).

The main factors influencing trap efficiency can be categorized as hydraulic characteristics of the reservoir and sediment characteristics. Hydraulic characteristics of the reservoir such as the capacity inflow ratio, reservoir shape, type of outlet and reservoir operation affect trap efficiency of a reservoir. Sediment characteristics include particle size, particle shape and behavior of fine sediment under varying fluid and hydraulic properties (USACE, 1989).

Trap efficiency estimates are empirically based up on measurements of deposited sediment in a large number of reservoirs mainly in the USA. Brune’s and Churchil’s empirical relationships have been widely used and found to provide reasonable estimates for long term release and trapping efficiency (Morris and Fan, 1998). Both methods are based on reservoir capacity to inflow ratio referred to as capacity inflow ratio (CIR) and neither method specifically considers effect of sediment characteristics.

6.3.1 CAPACITY-INFLOW METHOD (BRUNE'S CURVE)

Brune's curve which equates capacity to inflow ratio requires little input data, is simple to apply and has been very widely used to estimate reservoir trap efficiency.

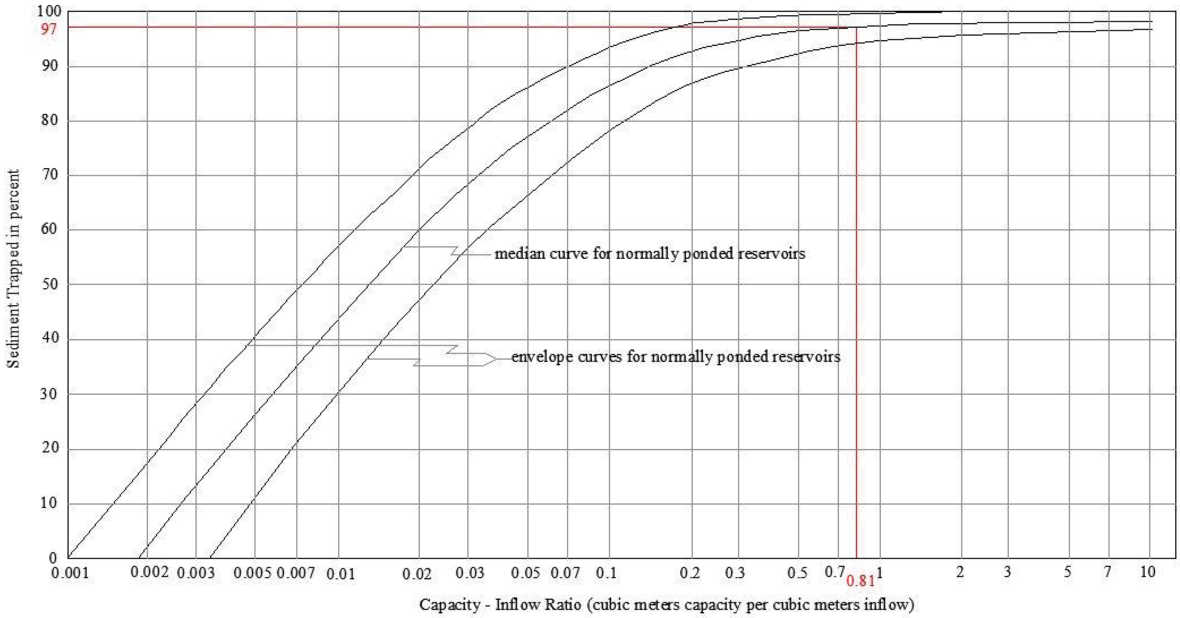

Figure 6.3 Brune's curve (redrawn from Brune, 1953)

6.3.2 SEDIMENT INDEX METHOD (CHURCHILL'S CURVE)

The sedimentation Index of a reservoir is the period of retention divided the reservoir mean velocity. The retention time or mean velocity cannot be approximated by assuming effective retention time to be equal to the retention time as computed by using the C/I' ratio (USCE, 1989). The retention period (R, in seconds) can then be computed by obtaining the capacity (C, in cubic meters) of the reservoir at the mean operating pool elevation and dividing by the average daily inflow rate (I', in cubic meter per second). The mean velocity (V, in meter per second) is obtained by dividing the average daily inflow rate by the average cross sectional area (A, in meter squared) in which the average cross sectional area is obtained by dividing the capacity by the reservoir length (L, in meter at the mean operating pool elevation). This can be written numerically as:

$S.I. = CA/I'^{2} = (C/I')^{2}/L$

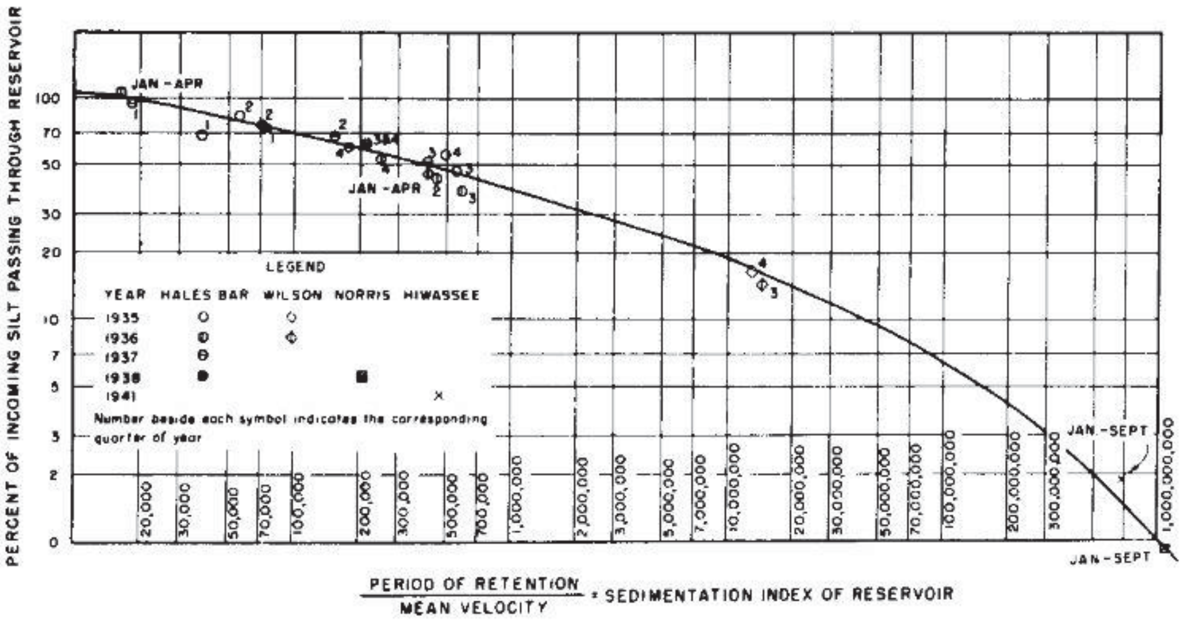

Figure 6.4 Sediment release efficiency by Churchill. (Brune, 1953)

6.3.3 TRAP EFFICIENCY OF GERD RESERVOIR

Trap efficiency is affected by reservoir operation which has to be examined to make judgment on its effects. Reservoir operation for GERD was assumed similar to that of Karadibi reservoir for which filling starts in early July up to September. Due to gradually rising water level and high sediment load, significant sediment deposition is expected during this period. Taking this into consideration, reservoir operation during filling is of importance in estimating trap efficiency of the reservoir. After filling period the reservoir operates between 608 and 646 masl up till the time the reservoir looses about 9 billion of its live storage capacity. The average storage above minimum water level during the operation of the reservoir was assumed equal to 10% of the live storage volume which corresponds to reduced level 604.6 masl and FSL is at 646 masl. A storage volume at the mean reduced level of 625 masl was used for estimating trap efficiency using Brune's and Churchill's method.

- Full supply level = 646 masl
- Reservoir level at the beginning of filling period = 625 masl
- Average annual runoff volume at GERD (I) = 50.60 billion m^3
- Storage capacity of the reservoir at FSL = 74 billion m^3
- Storage capacity at mean water level (C) = 41.22 billion m^3
- Average daily inflow rate (I') = 1543 m^3/s
- Reservoir length at FSL = 200 km
- Reservoir length at mean water level = 174 km

With these information trap efficiency of GERD was estimated to be 97% (Figure 6.3) and 100% (**Figure 6.4**) based on Brune's and Churchil's method respectively.

The trap efficiencies estimated based on these methods might have overestimated sediment trapping efficiency of the reservoir. It must be noted that none of these methods indicate an analysis of sediment characteristics. Trap efficiency progressively drops due to decreasing storage capacity which can be accounted for using the general trap efficiency function (Siyam, et al., 2005), but it needs calibration data. Therefore, constant trap efficiency of 100%, which assumes that all incoming sediment deposits within the reservoir, was considered for sedimentation rate prediction. Effects of uncertainties in this estimate were also presented in the following sections.

6.4 SPECIFIC WEIGHT OF SEDIMENT DEPOSIT

Deposit density is used to convert sediment mass to volume in predicting storage depletion. Specific weight is determined by grain size, deposit thickness, and whether the deposit has been exposed to the air and allowed to dry. Consolidation is a time-dependent process which increases specific weight, and reservoir sediments may consolidate for decades because of self-weight plus overburden from additional loads.

Lara and Pemberton (1963) developed an empirical method for estimating the initial specific weight of sediment deposits taking grain size distribution and reservoir operation into account. Lara-Pamberton equation is given as:

$$W = WcPc + WmPm + WsPs$$

Where, W is the deposit specific weight in kg/m^3; Wc, Wm and Ws are initial weights for clay, silt and sand respectively; Pc, Pm and Ps are percentages of clay, silt and sand.

Operational condition	Initial weight kg/m^3		
	Wc	Wm	Ws
Continuously submerged	416	1120	1154
Periodic draw down	561	1140	1154
Normally empty reservoir	641	1150	1154
Riverbed sediment	961	1170	1154

The average density of all sediment deposited during *t* years of consolidation may be calculated by equation given by Milller (1953) (Morris and Fan, 1997).

$$\mathrm{W1} = \mathrm{W} + 0.4343\mathrm{B}\left(\frac{t}{t-1}\ln t - 1\right)$$

Where, W1 is specific weight of a deposit with an age of t years, W is initial specific weight and B is constant which depends on particle size and reservoir operation.

Operational condition	B in kg/m^3		
	Sand	Silt	Clay
Continuously submerged	0	91	256
Periodic draw down	0	29	135
Normally empty reservoir	0	0	0

For the composition of sediment in the Blue Nile; Sand (0.02-0.2 mm) ~22%, Silt (0.002-0.02 mm) ~ 38% and Clay (< 0.002 mm) ~ 40%, and continuously submerged reservoir, initial specific weight can be estimated as 0.846 t/m^3. According to the U.S. Natural Resources Conservation Service the specific weight of deposit with clay-silt mixture sediment dominating and submerged reservoir ranges from 0.64 to 1.04 t/m^3.

Different density of deposited sediment has been used by different Authors. For example, Elsheikh and Kaikai, 1991 considered 1.13 t/m^3 for Roseires reservoir; ENTRO, 2007 based their calculation by assuming density of sediment deposit as 1.5 t/m^3 and Ahmed, 2008 stated that the most common density is 1.12 t/m^3 which was used for Mandaya reservoir sedimentation study. The average deposit density of sediment deposit in GERD equals 1.12 t/m^3 in about 250 years according to Miller, 1953. This however may lead to overestimation of sedimentation rate thus constant specific weight of 1.12 t/m^3 was assumed for sedimentation rate calculations.

6.5 SEDIMENTATION RATE

The problem of reservoir sedimentation on its useful life is complex. Several methods based on empirical, physical and arithmetic models have been formulated and applied to simulate sediment deposition processes in lakes and reservoirs. The most common of them are described below.

6.5.1 EMPIRICAL MODELS

6.5.1.1 Area-Increment method

Cristofano (1953) was the first researcher who proposed a very simple method called ‘area increment method’ to take into account the sediment distribution throughout the reservoir (Annandale, 1987). This method uses the assumption that an equal volume of sediment will be deposited within each depth increment in the reservoir (Morris and Fan, 1998; Annandale, 1987).

The method involves iteration with the aim to balance the calculated volume of sediment and expected volume of deposit in the reservoir. The total estimated sediment deposited is given by;

$Vs = \sum A_o(h-h_o)+V_o$

$H \geq h \geq h_o$

Where Vs is total volume of sediment, A_o is water surface area of the original reservoir at height h_o, H is maximum reservoir depth at dam wall measured from original zero elevation, h_o is assumed depth of sediment at dam wall, V_o is volume of sediment accumulated under depth h_o and h is variable depth above original zero elevation.

6.5.1.2 Empirical area reduction method

The most common empirical method is called area reduction method. This method was developed by Boreland and Miller (1958) based on survey of 30 reservoirs in USA to establish volume-surface area-depth relationship of reservoirs after deposition of sediment (Morris and Fan, 1998). This method includes four main steps as outlined in Morris and Fan, 1998:

- Determine the amount of sediment to be distributed.
- On the basis of the site characteristics, select the appropriate empirical curve for sediment distribution.
- Determine the height of sediment accumulation at the dam, termed the *new zero-capacity elevation.*
- Use the selected empirical curve to distribute sediment as a function of depth above the new zero-capacity elevation. These values are then subtracted from the original stage-area and stage-capacity curves to produce the adjusted curves.

Limitations:

- Similar to Area Increment method the distribution of sediment as a function of longitudinal distance cannot be calculated using Empirical Area Reduction method.
- Annandale, 1987 based on comparison of empirically calculated and observed volume-area-depth relationships of 14 reservoirs in South Africa has found out that the general applicability of the method is limited.
- This method was developed based on field survey data gathered from reservoirs in the USA with capacities ranging from 49 million m^3 to 36.9 billion m^3 (Annandale, 1987). The method may not predict deposition pattern well for reservoirs with capacity out of the range.

6.5.2 ANALYTICAL MODELS

A variety of analytical models have been applied for computation of sediment deposition and delta formation. The majority of these models are developed based on sediment transport theory. These models consist of two coupled partial models; one for a computation of the water level in the reservoir based on the energy conservation equation in non uniform flow and the second model for the computation of sediment deposition in the reservoir based on the sediment continuity equation (Annadale, 1987).

6.5.2.1 HEC-6

HEC-6 which is probably the most widely used model in the United States for simulation of scour and deposition of sediment in rivers and reservoirs was developed by William Thomas (1977) (Morris and Fan, 1998). HEC-6 allows for simultaneous erosion and deposition to occur depending on the competency of the stream to transport suspended sediment and bed load. However, HEC-6 doesn’t allow bank erosion and lateral channel migration (USACE, 1993).

The model limitations:

- Accuracy of the model output depends on input data used for model calibration.
- It contains many simplifying assumptions such as 1D flow, steady flow, gradually varied flow and sediment transport.

6.5.3 DISCUSSION

The concept introduced by Cristofano oversimplifies the problem and often leads to an underestimation of the compensation that must be made to accommodate deposited sediment (Simons et al., 1982; Annandale, 1987). Empirical area reduction method provides four different type curves to model the sediment distribution in reservoir. One of these curves is very similar to an Area Increment curve, thus excluding an Area-Increment method.

One of the possible errors in using Area Reduction method for GERD reservoir can be attributed to the larger capacity of the reservoir. The maximum reservoir capacity for which the method was developed is 36.9 billion m^3, while the reservoir capacity of GERD reservoir is 74 billion m^3.

Analytical models can be most promising method to simulate reservoir sedimentation for GERD reservoir. However, these models were not considered for this study due to unavailability of model verification data, limited availability of the models and time constraint. Therefore, Empirical Area Reduction method was used for prediction of reservoir sedimentation in the GERD reservoir.

6.5.4 SEDIMENT DISTRIBUTION IN GERD RESERVOIR

In order to evaluate the sediment distribution within the reservoir, the Empirical Area Reduction method, developed by Borland and Miller (1958) with revisions by Lara (1962) and Pamberton (1978), was used. This method as briefly described in the previous section predicts deposition by taking into account the reservoir shape, the total amount of deposited sediment, on the size and texture of sediment particles as well as on the type of reservoir operation.

The shape of the reservoir characterized by the depth to capacity relationship is considered the major factor in determining the sediment distribution within the reservoir. The adopted classification of reservoir shape depends on m-values which is the reciprocal of the slope of the depth (as ordinate) versus the reservoir capacity (as abscissa) curve on log-log plot. The m-value for GERD reservoir was found to be 3.7 which according to this method categorize the reservoir as type I (Lake). For considerable draw down of reservoir water, the reservoir falls under class III. In type I category reservoirs sediment deposition takes place in a form of delta deposit where most of the incoming sediment deposit in the upper 50% of the reservoir depth. This type of distribution may not represent the pattern in reservoirs like GERD reservoir where fine sediment dominates. Most of the sediment particles in GERD reservoir are expected to settle in the reservoir section between section 1 and 2 (**Figure 6.1**) which is within the lower 40% of the reservoir depth. Therefore, the type III distribution was adopted for GERD reservoir.

The Elevation-Area-Storage relationship was developed from Digital Elevation Model (DEM) of resolution 110 m x 110 m. The elevation-storage capacity-area data for minimum water level and full supply level obtained from Semegnew, et al., 2013 was used for verification of the developed Elevation- Area-Storage relationship. The Elevation-Area-Storage data for 5 m elevation interval is given in Appendix D.

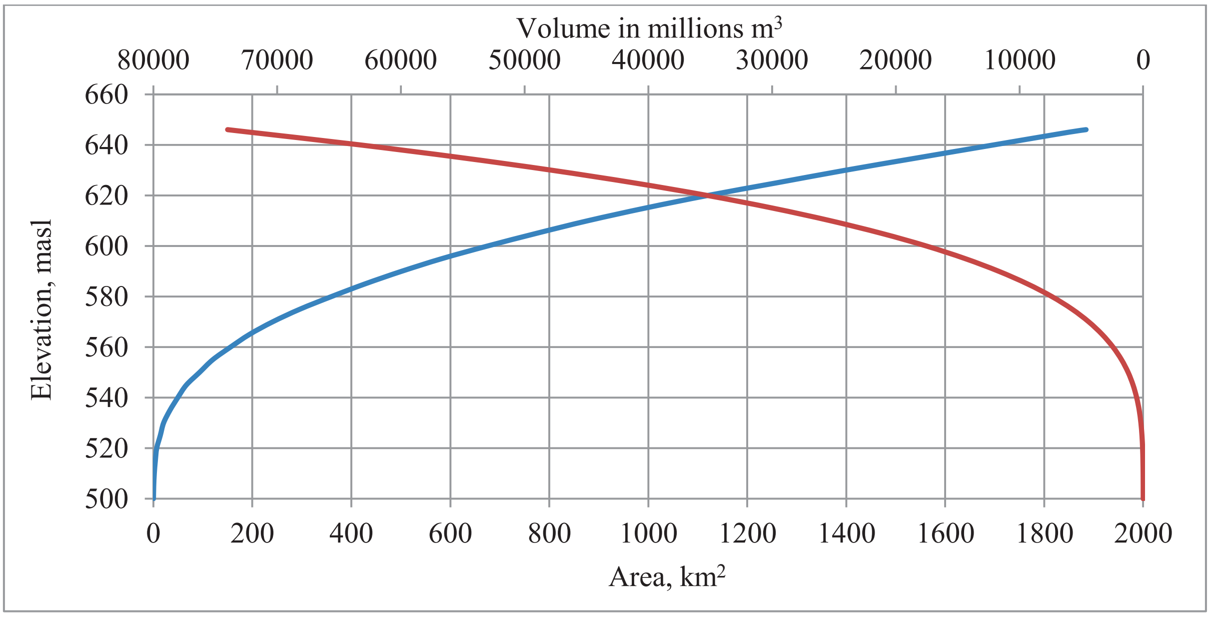

Figure 6.5 Elevation- Area-Capacity relationship curve before sedimentation

Due to deposition of sediments in the reservoir, the water-spread area at an elevation keeps on decreasing. Using the Empirical Area Reduction method, the water-spread area and storage capacity at different reservoir levels was determined. By comparing the original and revised elevation-capacity curves, the amount of capacity lost to sedimentation was assessed.

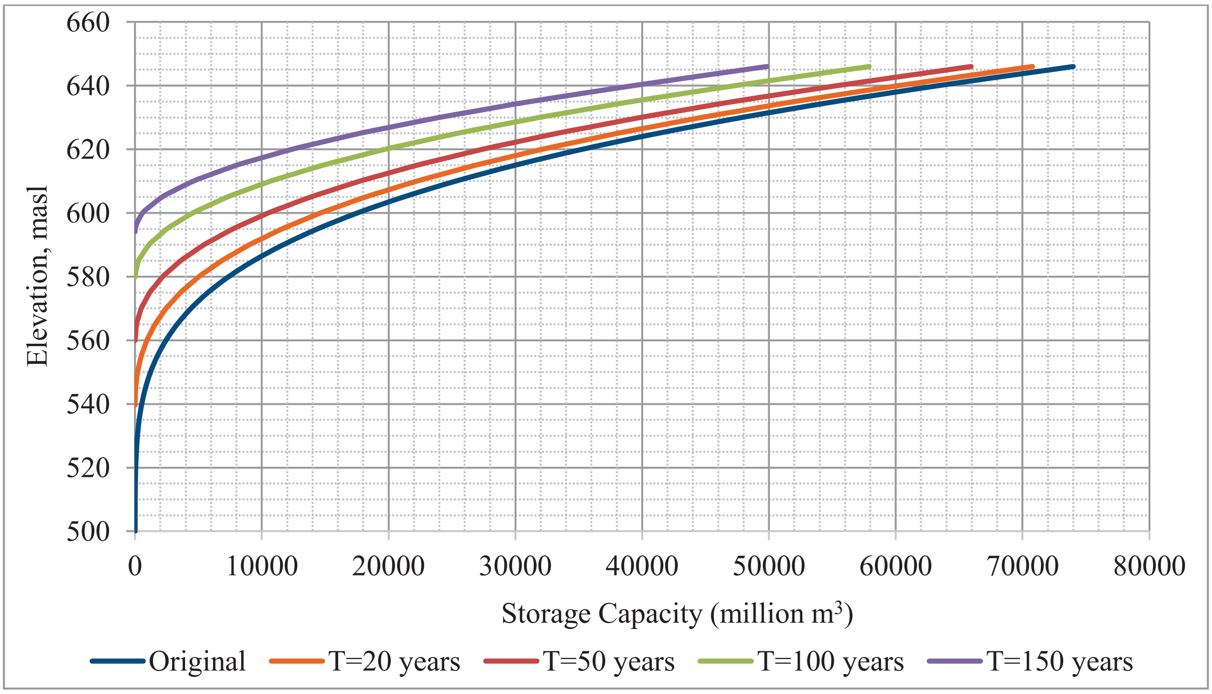

Figure 6.6 The original and adjusted Elevation-Capacity curves for GERD reservoir

The live storage of this reservoir was estimated to be 59 billion m^3 (Semegnew, et al., 2013) which is normally storage above intake level. With the gradual deposition of sediment both in live and dead storage, the plant operates with reduced production until the dead storage is completely filled with sediment. According to the Empirical Area Reduction method, the GERD reservoir will have life of **116** years for the estimated annual sediment load of 245 million tonnes, trap efficiency of 100% and average deposit density 1.12 t/m^3. The reservoir storage capacity will be lost at an average rate of 0.3 % per year.

6.5.5 SENSITIVITY ANALYSIS

In estimating reservoir sedimentation number of uncertainties arise. These are related to sediment load, deposit density, trap efficiency and reservoir operation. The total amount sediment inflow estimated at GERD as presented in Chapter 5 includes uncertainties, because it was obtained from a limited number of data and the rating curve is only an approximation of the actual sediment transported by the river. To analyze the sensitivity of deposition pattern to uncertainties in sediment yield, the sediment yield in a range of 30% lower and 30% higher than the estimated (245 million t/ year) were considered. Considering these values of sediment yield, the life of the reservoir ranges from 90 to 166 years.

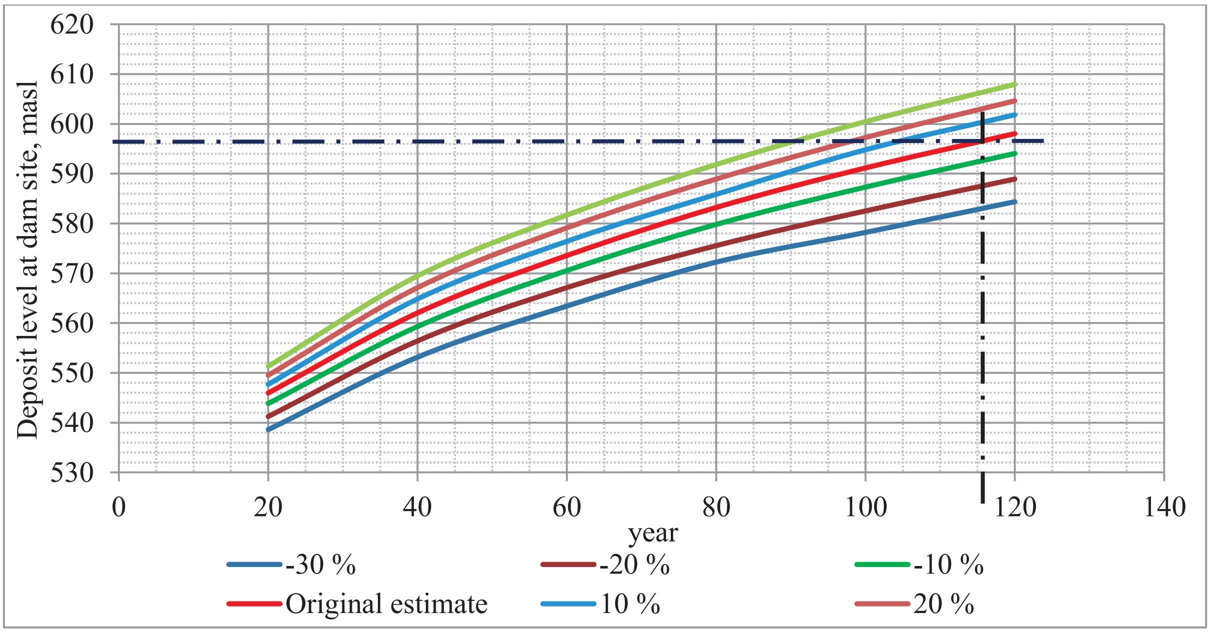

Figure 6.7 Sensitivity of reservoir life to uncertainties sediment yield

Deposit level at the dam determines service life the reservoir. The reservoir operates with gradually declining storage capacity until the deposit level at the dam reaches minimum water level. After 80 years of operation the deposit level at the dam reaches 592 masl for the sediment yield 30% larger and 572 masl for sediment yield 30% smaller than the estimated.

The assumption that considers all the incoming sediment deposit in the reservoir may be different on the ground as a result of deviation of governing parameters from assumed while estimating trap efficiency. The governing parameters which may cause uncertainties in trapping efficiency include sediment particle size and its properties, and reservoir operation condition. With the trap efficiency of 90% the reservoir is expected to have a life of 126 years. An uncertainty in deposit density was of a similar magnitude of effect on reservoir life. The life of the reservoir was estimated to be 104 and 128 years respectively for 10% lower deposit density and 10% higher deposit density than assumed 1.12 t/m^3.

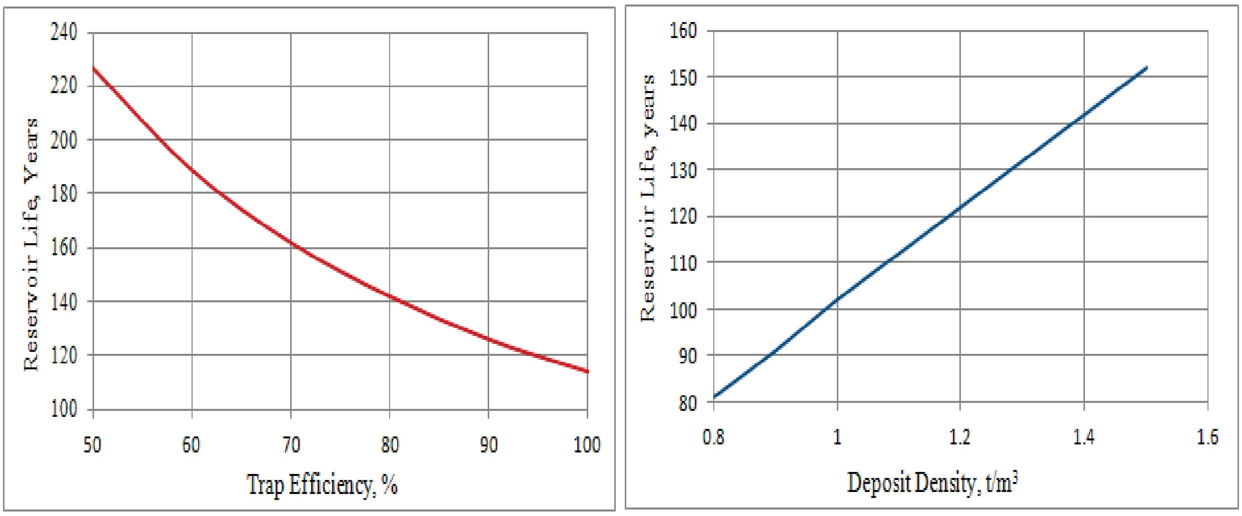

Figure 6.8 Effect of uncertainties in trap efficiency and deposit density on reservoir life

Sensitivity of storage loss to uncertainties in sediment yield was also evaluated. Increase in sediment yield by 10% (with respect to the estimated) increased annual gross storage loss rate from 0.3% to 0.33%. Unlike the gross storage loss rate, the live storage loss rate increases with time as in the **Figure 6.10**. Increase in sediment yield from 245 million t/year to 270 million t/year increased the live storage capacity loss from 600 to 674 million m^3 in the first 20 years of operation.

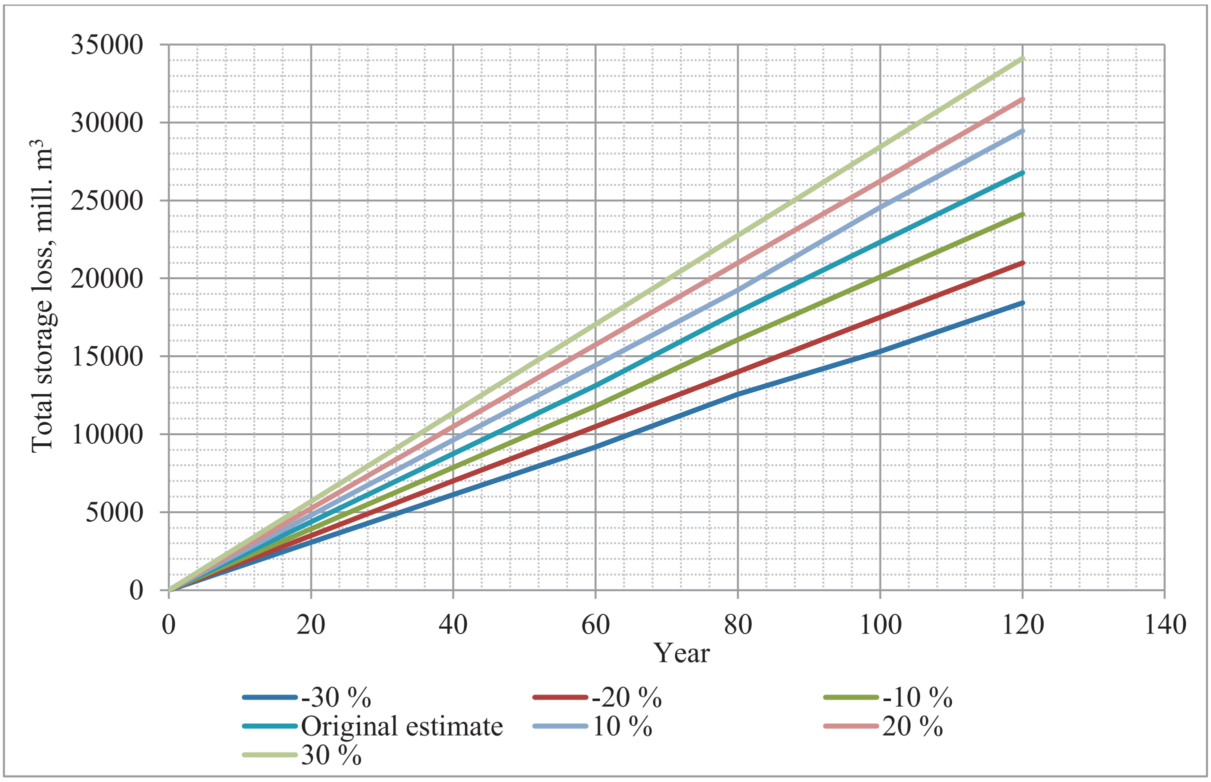

Figure 6.9 Sensitivity of gross storage loss to uncertainties in sediment yield

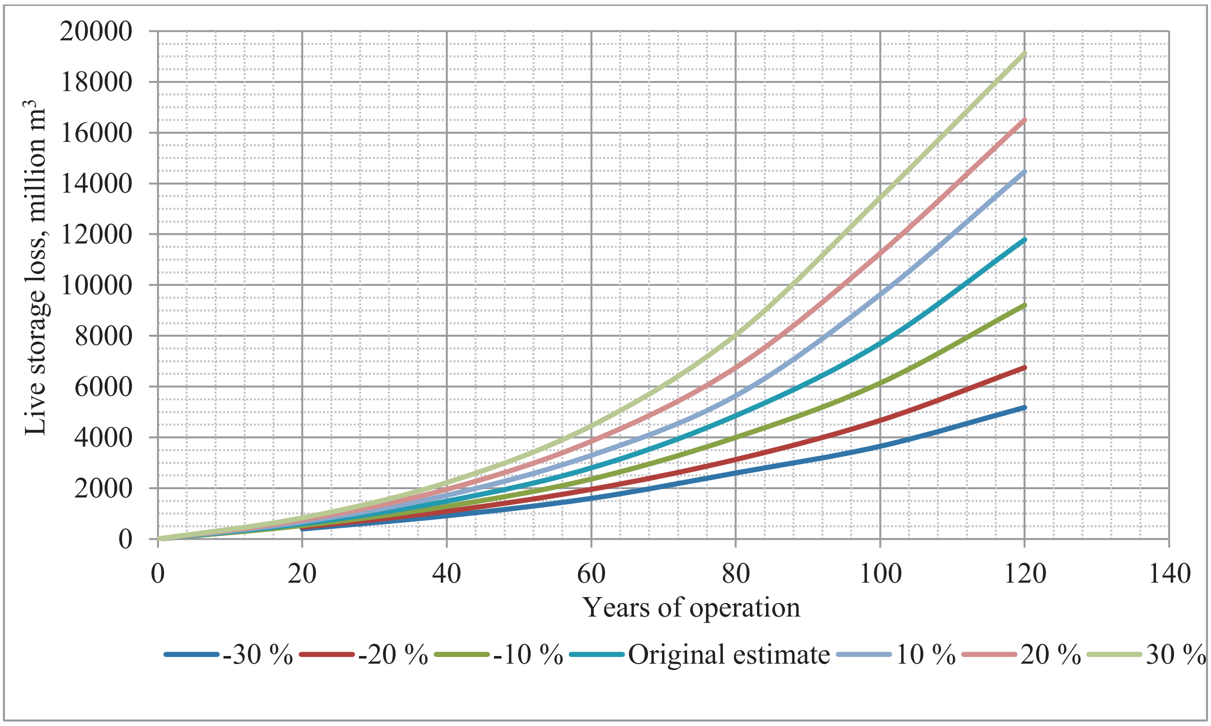

Figure 6.10 Sensitivity of live storage loss to uncertainties in sediment yield

The live storage loss rate increases with operation time of the reservoir. The inflowing sediment normally starts deposition at the entrance to the reservoir in live storage due to effects of reservoir water and part of it the makes its way to the dead storage. The gradually accumulating sediment in both dead and live storage fills up certain elevation completely in some years of operation. The deposition in dead storage decreases the bed slope of the channel, thus reducing of transport capacity of incoming sediment laden water. This allows deposition of more sediment in live storage as the reservoir operation time increases.

6.6 ECONOMIC LOSS DUE TO SEDIMENTATION

Reservoir sedimentation has tremendous economic and environmental impacts (Annadale, 1987). Some of the experienced impacts include:

- Consequence of storage loss on production loss
- Downstream effects of reservoirs on the river bed
- Reduction in efficiency of power generation due to sedimentation
- Contamination due to sediment

Sedimentation leads to reservoir storage capacity depletion over time reducing available water for production of electricity. This effect of sedimentation is addressed in this section to give the general overview of economic loss resulting from storage loss due to sedimentation with so many assumptions.

The GERD hydropower project comprise 16 Francis units each with 375 MW capacity, maximum net head of 123 m and design nominal discharge of 320 m^3/s (Semegnew, et al., 2013). The live storage of the reservoir is 59 billion m^3 and mean annual runoff at GERD is about 50.6 billion m^3. The reservoir capacity deteriorates day by day and if remedial measure is not taken, the generation capacity is likely to be reduced. The live storage capacity is 16.6% larger than the mean annual runoff volume. The effect of sedimentation on the runoff volume released for production is insignificant until this 16.6% of the live storage is lost. It however affects production potential reducing the net head as the reservoir starts operating down to minimum operating water level when some part of the live storage is lost. It was assumed that every litre of water lost from the live storage have equal economic value.

To get the economic loss due to sedimentation the volume of live storage replaced by sediment was converted to energy (kWh) using energy equivalent of 0.302 kWh/m^3 obtained from the site information i.e. Net Head (Hn) = 123 m and assumed overall efficiency (η) of the power plant, 90%. The energy equivalent is the amount of energy produced from each m^3 and is computed as:

$$EE = \eta * \rho * g * \frac{Hn}{3600}, \text{ in kWh/m}^3$$

Total storage loss was determined as a difference between the original (before sedimentation) and revised storage capacity of the reservoir. Revised storage capacity refers to a new storage capacity after deposition has taken place. Live storage capacity on year N after start of operation was determined as a difference between the new total storage capacity at FSL on year N and the revised storage capacity at minimum water level, 596 masl on the same year. The total storage lost in the first 20 years was estimated to be 4,464 million m^3 as a difference between original total storage capacity of 74,000 million m^3 and the revised total storage capacity of 69,536 million m^3. Similarly the live storage lost in the first 20 years was computed as a difference between the original live storage capacity, 59,000 million m^3 and the revised live storage capacity, 58,384 million m^3.

To calculate annual economic loss, the live storage loss per year was estimated as the total live storage lost in each 20 years interval divided by 20 years. This assumes that the live storage loss rate in each consecutive 20 years is equal. However, the live storage loss rate increases from time to time in reality which can be represented more accurately if shorter time step is used. The Empirical model used is generally an approximation thus 20 years interval may be adequate. The annual live storage loss is converted into energy loss which when multiplied by the unit price gives the value of lost live storage at the end of a year.

In order to predict economic loss from sedimentation accurately it is necessary to specify firm and surplus power price which defines water value variation with time. Firm power is the supply which can be guaranteed at all times or a large percentage of time. Firm power consumption and price varies with the seasons mainly in line with air temperature variations. However, to make such analysis accurate estimate of seasonal storage loss must be obtained which is not possible with available sediment data and data on seasonal variation of power price is also not available. Therefore, an average energy price of 0.6 birr/kWh which is equivalent to 3.21 USC/kWh according to current rate was assumed.

There is always electricity price escalation from time to time which may result from increase in maintenance cost, increase in demand and some other factors. With the price increase rate of 1% per year and discount rate of 12% per year Net Present Value (NPV) of the lost revenue can be estimated as in the **Table 6.2**.

The Present Value (PV) of the economic loss was calculated by discounting each annual economic loss (A).

$$\mathrm{PV} = \mathrm{A} * \left(\frac{(1+\mathrm{i})^{\mathrm{n}} - 1}{\mathrm{i} * (1+\mathrm{i})^{\mathrm{n}}}\right)$$

Where, i is discount rate and n is discounting period

The NPV that takes electricity price increase into account was calculated based on the geometric increment equations.

$$\mathrm{PV} = \mathrm{A} * \begin{cases} \dfrac{1 - \left(\dfrac{1+\mathrm{g}}{1+i}\right)^{n}}{i - \mathrm{g}}, & \mathrm{g} \neq i \\ \dfrac{n}{1+i}, & \mathrm{g} = i \end{cases}$$

Where, PV is the present value of annual economic loss, A is uniform annual economic loss, i is discount rate, n is discounting period, g is price increase rate.

The cash flow diagram of the annual economic loss (in millions USD), for the first 20 years of operation, is given in the figure below.

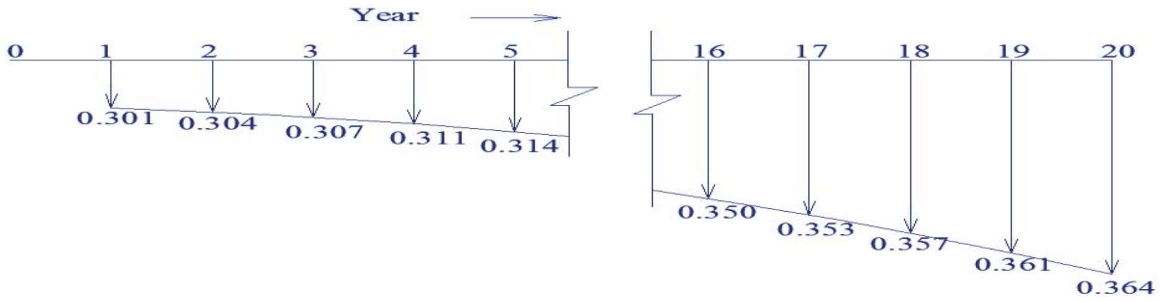

Figure 6.11 Cash flow diagram of annual economic loss for the first 20 years of operation

Table 6.2 Sediment deposition and economic loss at an average sedimentation rate

No. of years of operation	Total storage loss, (million m^3)	Live storage loss (million m^3)	Energy equivalent, GWh/yr	NPV of lost water value (million USD)
20	4375.00	601.23	9.08	2.337
40	8750.00	1490.04	11.25	2.774
60	13125.00	2799.04	14.09	2.856
80	17857.14	4854.84	18.33	2.872
100	22321.43	7703.77	23.27	2.875
116	25379.05	10379.05	27.02	2.875

For the original estimate of sediment yield, present value of the annual economic loss resulting from sedimentation of the active storage was calculated for different discount rates as shown in the Figure 6.12. The total economic values forgone due to the live storage loss was found to vary non-linearly between 0.26% and 0.06% of the dam cost, 4.33 billion USD when the discount rate varied between 5% and 13% respectively for price increase rate of 1% per year.

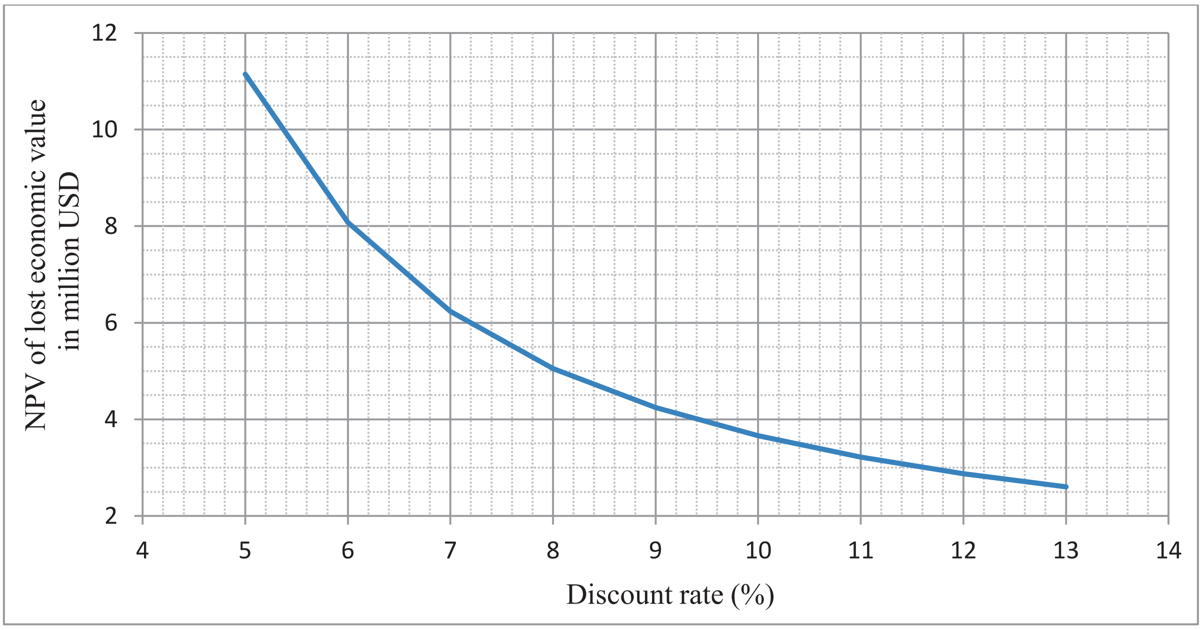

Figure 6.12 PV of economic value forgone for various discount rates

The total value of lost active storage during the 116 years of operation varies from 1.84 to 4.05 million USD for sediment yield 30% smaller and 30% larger than estimated 245 million t/year respectively.

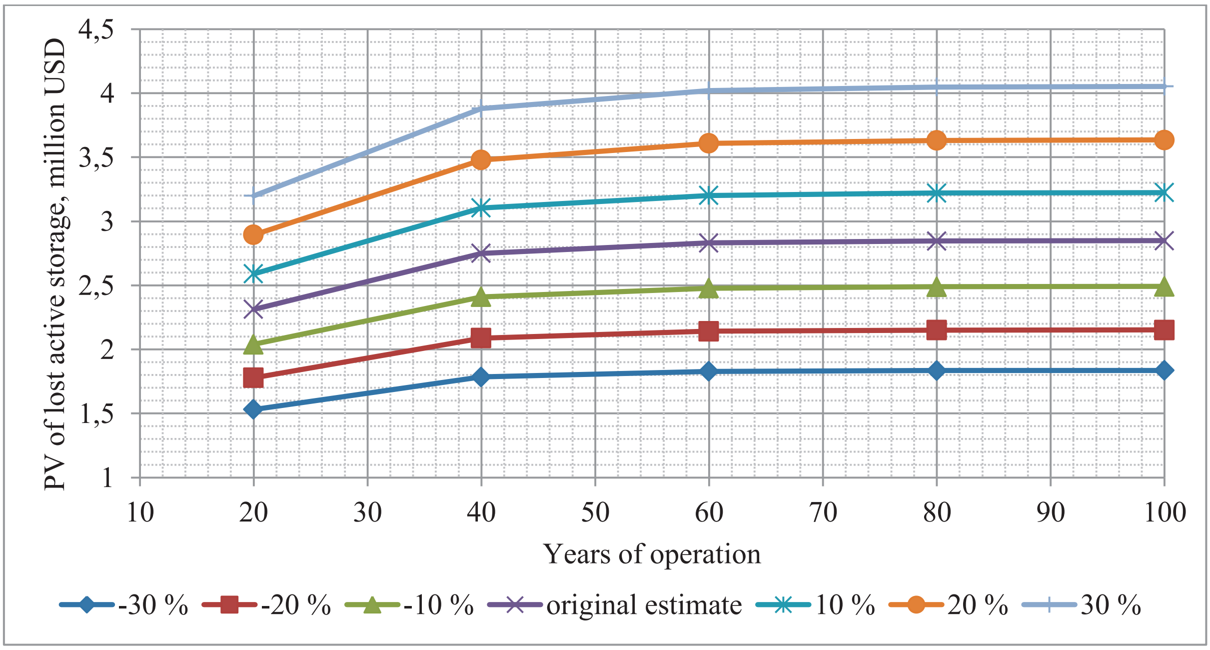

Figure 6.13 Present value of economic loss due to sedimentation for various magnitudes of sediment yield

6.7 CONCLUSIONS

The reservoir life estimated depends on how fast the dead storage is completely filled with sediment. The empirical area reduction method which was used to estimate the storage capacity reduction over time depends on the chosen reservoir type, which may change over time and/or can be different from what was chosen. The reservoir life of GERD was estimated to be 215, 177, and 116 years for type I, II and III respectively. Based on currently available data, type III curve looks the most probable for GERD reservoir. With type III reservoir, the average annual storage loss of the GERD reservoir will be 0.3%.

In estimating reservoir sedimentation number of uncertainties arise. These are related to sediment load, deposit density, trap efficiency and reservoir operation. With the sediment yield of 30% lower and 30% higher than the estimated (245 million t/ year), the estimated reservoir life equals 166 and 90 years respectively. Analysis of sensitivity of storage loss to uncertainties in sediment yield shows that increase in sediment yield by 10% (with respect to the estimated) increased annual gross storage loss rate from 0.3% to 0.33%.

For different ranges of values of sediment yield, present value of the annual economic loss resulting from sedimentation of the active storage was evaluated. For the original estimate of sediment yield the total economic values forgone due to the live storage loss was found to vary non-linearly between 0.26% and 0.06% of the dam cost, 4.33 billion USD when the discount rate varied between 5% and 13% respectively for price increase rate of 1% per year.

7 SUSTAINABILITY OF THE GERD RESERVOIR

One of the objectives of this study is to evaluate reservoir sediment management alternatives and identify suitable strategy that can prolong the service life of the GERD reservoir. The identification of environmentally, economically and technically feasible management strategy requires in-depth study of characteristics of management options at the given site. This section of the study presents a very general evaluation of technical feasibility of several reservoir sediment management alternatives.

7.1 RESERVOIR SEDIMENTATION MANAGEMENT METHODS

Reservoir sedimentation affects the long term sustainability of dams. Sediment deposition in reservoirs causes mainly loss of water storage capacity, risk of blockage of intake structures, sediment entrainment in power intakes and turbines. Sedimentation reduces flood absorption capacity of reservoirs thus increasing risks of dam overtopping during flood events.

Therefore, systematic and thorough consideration of technical, social and environmental and economic factors should be made to address reservoir sedimentation and prolong the useful life of reservoirs. There are number of ways of managing reservoir sedimentation problems. These include:

- Reducing sediment inflow to the reservoir
- Reducing sediment deposition
- Removing deposited sediment
- Replacing lost storage

7.1.1 REDUCING SEDIMENT INFLOW TO RESERVOIRS

In the upstream watershed of a reservoir, three basic patterns of soil conservation measures are commonly taken to reduce sediment load entering reservoir: structural measures, vegetative measures, and operational measures (Morris and Fan, 1998).

Structural measures include structural terraces, flood interception and diversion works, channel protection and stabilization works, bank protection works, check dams and silt trapping dams. Vegetative measures include growing soil and water conservation forests, reforestation. Operational measures include strategies such as scheduling construction and timber harvest activities. Some of these measures are discussed below.

7.1.1.1 Structural measures

Structural terraces

Terraces are broad channels across the slope which if well designed can control sheet and gully erosion. Runoff water from above the terrace follows these broad channels to an outlet. Terraces reduce slope length and deliver surface runoff through terrace channels that are designed to be non erodible and to prevent deposition of sediment.

Reservoir bank protection works

Bank erosion occurs at some extents almost at each dam reservoir as a result of wave and wind action (Jandora, et al., 2002). Material eroded and flushed in to a reservoir from the reservoir banks can have a significant role in reservoir sedimentation diminishing live storage of the reservoir. The methods of bank stabilization can be made of natural materials like riprap of quarry stone completed by appropriate vegetation in order to minimize cost of the protective measure.

Check dams

Check dams are small structures designed to trap bed load to prevent bed degradation and gully erosion. Check dams reduce the stream slope by letting the inflowing sediment deposit, on the bed of the valley which also reduces flow velocity and its sediment transporting potential. As these structures have limited capacity inspection and removal of sediment deposit is necessary to attain extended service time of the structure.

Debris basin

Debris dams may be constructed as conventional dams with spillways (Morris and Fan, 1998). These structures can extend the life of the dam it is protecting by stopping the sediment inflow to the main dam, but the debris basin itself requires sediment management to extend its life. Debris basins are designed to catch the course sediments and prevent their transport downstream onto the reservoir they are protecting. However, most of the fine silt and clay will pass to the main reservoir depending on the operation of the debris basin.

Sediment deposited in the debris basins can be removed through dredging or periodic excavation which requires disposal site for excavated material. With the objective to insure sustainability of the reservoir, debris basins need to be sustainable. This can be achieved through dredging and/or sediment bypass techniques with which it may not meet the economic feasibility criteria.

Disadvantages of structural measures

Under favourable condition, sediment trapping before it enters the reservoir can be a highly effective measure for sediment yield reduction. However, there are several disadvantages of structural measures (Morris and Fan, 1989).

- All structural measures are very costly to construct.
- With the exception of check dams, which are located within the gully floor, a sediment detention pool will occupy a significant amount of land area which may be costly to acquire.
- The long-term integrity of sediment detention structures is a critical issue, because when a structure fails the trapped sediment will be exposed to erosive forces and may be released.

7.1.1.2 Vegetative measures

Planting and establishment of quick growing vegetation can provide temporary and/or permanent stabilization of exposed areas. Using grasses, brush and trees on small land parcels can offer ground cover, and soil protection with inexpensive and aesthetic natural vegetation.

Limitations of vegetative measures:

- Erosion cannot be reduced to zero. Therefore, vegetative measures alone cannot be a sustainable measure against reservoir sedimentation which can only be achieved by balancing sediment across the reservoir.
- For a large watershed with poor natural condition, soil conservation can hardly be effective. However, vegetative measures can help reduce the cost of other management options if implemented jointly.
- It may be costly and difficult to implement the vegetative measure on large catchments with thousands of land users.

7.1.2 REDUCTION OF SEDIMENT DEPOSITION IN THE RESERVOIR

Reduction of sediment deposition in reservoirs by facilitating sediment-laden flows to pass through reservoirs, as quickly as possible, before deposition of sediments is one of the most effective and economic ways to preserve the storage capacity (Morris and Fan, 1989). An approach which can be followed to limit sediment deposition in a reservoir is to attempt to control sediment deposition once it has been discharged into the reservoir. This can only be achieved if the sediment carrying capacity of the stream flowing through the reservoir is kept as close to the original carrying capacity of the river as possible (Annadale, 1987). Some of the most commonly used methods of sediment deposition reduction are presented below.

7.1.2.1 Sediment routing

Sediment routing is the method to use reservoir hydraulics and/or geometry to pass the incoming sediment with the objective of minimizing deposition. Sediment routing techniques can be classified into two main categories (Morris and Fan, 1998): (a) Sediment pass through: this is where the incoming sediment is discharged through deep sluice mainly during high sediment concentration season in the river. (b) Sediment bypass: is the technique in which the incoming sediment is diverted from the main storage area upstream the reservoir area. As the main process involved in sediment routing is to pass sediment laden flood and store water from less sediment carrying flow, it partially preserves natural sediment transport process in the river. It can be considered environmentally friendly management strategy when compared with other approaches.

Limitations of this method:

- It is not able to remove the previously deposited sediment or pass part of the coarsest part of inflowing load.
- Significant amount of water must be released to transport sediment

- Sediment routing is most applicable to small reservoirs where water discharged by large sediment transporting floods exceeds the reservoir capacity, making water available for sediment without negative effect on beneficial uses.
- Drawdown may be necessary in order to maintain the sediment transport capacity of the incoming sediment laden flood.

7.1.2.2 Venting of turbidity currents

Stratified flow occurs in a reservoir frequently because of density differences between inflowing sediment laden water and stored water caused by differences in turbidity, temperature, and dissolved solids. Density of sediment laden water at a time of flood may be high and the sediment laden water enters an impoundment beneath clear water along the bottom of the reservoir. The density current can be vented through outlets without draw downing the water level if it has potential to travel the distance greater than the length of reservoir. This technique has similar limitations as for sediment routing.

7.1.3 REMOVING DEPOSITED SEDIMENT

7.1.3.1 Flushing

Sediment flushing involves reservoir draw down by opening lower level gates in order to create flow capable of eroding and transporting the deposited sediment through the outlet. Unlike sediment routing which attempt to prevent deposition of sediment during flood, flushing uses draw downed water to erode the sediment after it has been deposited. The efficiency of drawdown flushing depends on the geometry of the reservoir, the characteristics of the outlet, the incoming and outgoing discharges, sediment concentrations, and other factors.

Limitations of flushing

- Large flushing discharge is required to preserve long term storage capacity. Flushing is suitable where annul runoff volume is large when compared to the reservoir capacity.
- Effective flushing requires draw downing or emptying the reservoir. This limits the applicability of flushing to hydrologically small reservoirs.
- An extreme concentration can create unacceptable impacts downstream.
- Flushing efficiency depends on the reservoir shape. Flushing scours the deposition in the main channel while depositions on flood plains stay unaffected by flushing operation.

7.1.3.2 Conventional dredging

Mechanical dredging systems

Mechanical dredging systems use buckets to excavate submerged sediment. There are several types of mechanical dredgers used most commonly (Vlasblom, 2005). These include: dipper and backhoe dredge, bucket ladder dredge and grab dredge. Almost all types of materials can be removed through mechanical dredging systems. The maximum dredging depth for Dipper and backhoe dredge is about 20m and more than 100 m is possible with Grab dredge.

Hydraulic dredging systems

In hydraulic dredging system the sediment is mixed with water and transported from point of excavation to point of disposal as sediment-water slurry. Hydraulic dredgers can be categorized based on their operation method as plain suction dredger, cutter dredger and trailing suction hopper dredger. The maximum dredging depth for all types of hydraulic dredging systems is limited to 70 m (Vlasblom, 2005).

Limitations of dredging methods:

- Mechanical excavation methods may be costly where the large volume of material has to be moved.
- Limitation in maximum dredging depth
- Need for suitable disposal sites at a reasonable distance.

7.1.3.3 Dry Excavation (Trucking)

Dry excavation which is also known as trucking uses conventional earth moving equipment on emptied reservoir to excavate the deposited material. The difference between dry excavation and conventional dredging is that the conventional dredging can operate from the water surface without necessarily emptying of the reservoir.

Limitations of Trucking:

- High excavation and disposal costs
- Need for emptying the reservoir

7.1.3.4 Hydrosuction Sediment Removal System (HSRS)

Hydrosuction sediment removal system removes deposited or incoming sediment using the energy from head difference between water levels in the reservoir and discharging end (Hotchkiss and Huang, 1995). One of the main advantages of the HSRS is that it operates without interrupting operation of the reservoir.

Hydrosuction sediment removal system can be categorized in to two types as hydrosuction dredging and hydrosuction bypassing (Hotchkiss and Huang, 1995). Hydrosuction dredging uses pump to loosen the deposit and it removes the material using head difference between water upstream and downstream from the dam. The Saxophone Sediment Sluicer (SSS) is one of the hydrosuction dredging type techniques of sediment removal. The Saxophone Sediment Sluicer consists of saxophone shaped suction head mounted on a pipeline. Hydrosuction bypassing is another type of the Hydrosuction sediment removal technique in which sediment from permanent inlet station upstream a reservoir is collected into a pipe and bypassed without deposition.

Limitations of HSRS:

- Significant amount of water may be needed where sediment inflow is large
- Production of the HSRS is very low for low suction head which may necessitate pumps to assist suction.
- It is limited to small reservoirs due to its low production

7.1.4 REPLACING LOST STORAGE

Replacement of lost storage through heightening the dam and/or construction of new dam is one of the possible strategies.

Limitations of replacing lost storage

- Replacing lost storage through dam heightening results in inundation of land and may necessitate resettlement.
- Construction of new storage dam may be very expensive

7.2 PRELIMINARY ASSESSMENT OF RESERVOIR MANAGEMENT

Pelmieri, et al., 2003 recommends preliminary assessment of reservoir management options to be carried out based on the preliminary screening criteria given in the **Figure 7.1** before applying RESCON approach to currently available alternatives. The limitations and possibilities of sediment management options were evaluated for two cases: (1) management options for GERD reservoir and (2) management options for joint operation the GERD reservoir with the reservoirs located upstream.

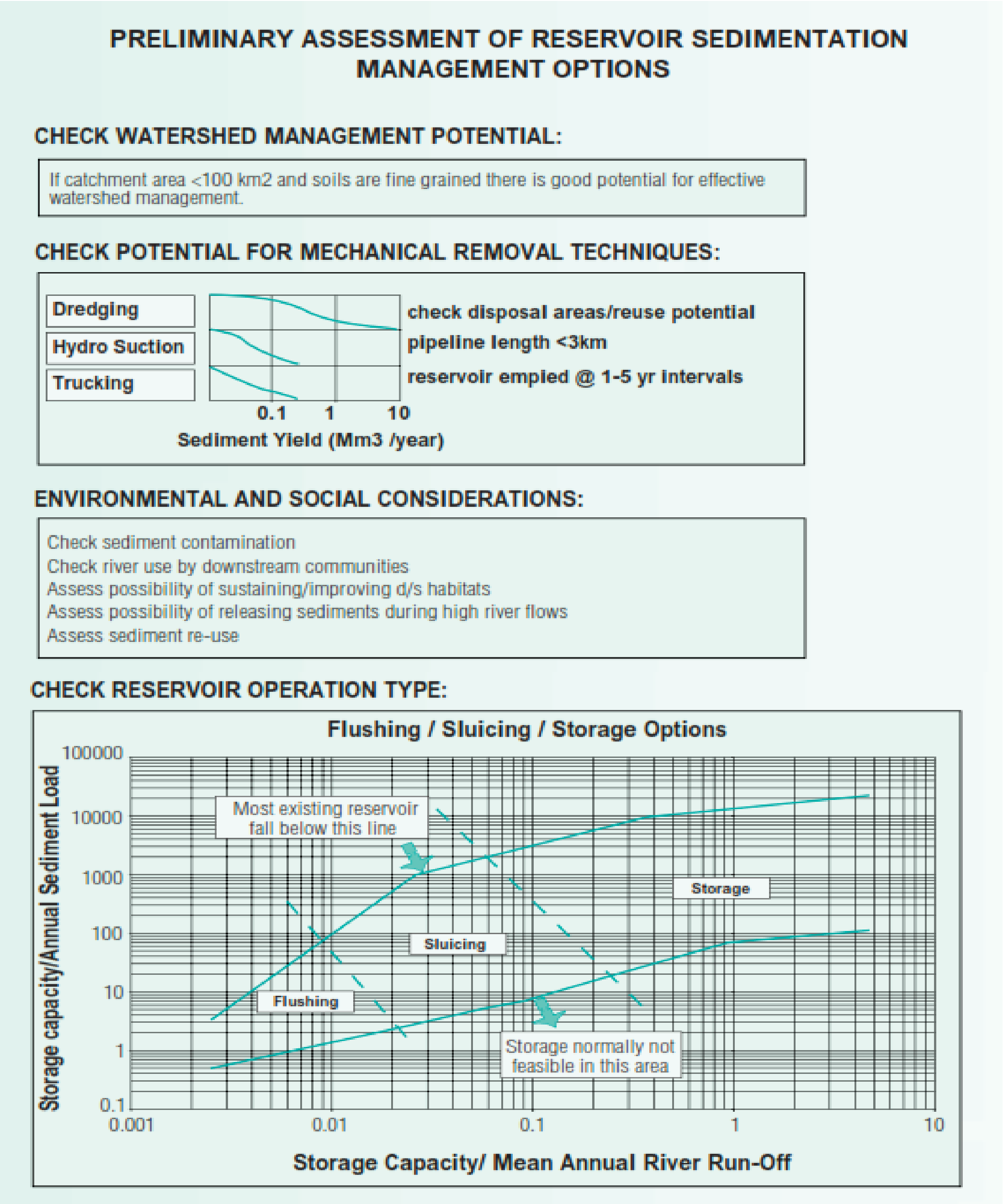

Figure 7.1 Preliminary assessment of reservoir sediment management option (Palmieri, et al., 2003)

7.2.1 THE GERD RESERVOIR

The GERD reservoir controls Blue Nile Basin, the largest river basin in Ethiopia, covering an area of about 177,700 km^2. The most important part of the catchment in terms of sediment supply is however, less than 50% of the total area.

Watershed management options have been recommended and applied to small catchments in Gibe-Omo Basin (PHE, 2011) and smaller catchments in the Fincha Basin, covering less than 1000 km^2 (Bezuayehu and Sterk, 2008). However, the attained result was poor due to poor follow up of the undertaken watershed management intervention (PHE, 2011, Bezuayehu and Sterk, 2008). The Blue Nile Basin is large in size and shared by thousands of land users which can make attainment of effective of watershed management difficult. In Ethiopia in general, the conservation activities are structured as top-down approach, where involvement of farmers is limited to labour contribution (Bewket, 2003). Bewket, 2003 briefly presented that the IWM (Integrated Water Management), where all affected parties are involved to achieve effective and sustainable resource management, is lacking in Ethiopia. Vegetative measures can be applied to bare lands and sensitive areas, which however cannot control the natural process of erosion and can only reduce sediment yield by small fraction. Structural measures on the other side can be effective enough to control sediment inflow to the reservoir if managed properly. The structural measures however need frequent monitoring and maintenance which adds up to its huge investment cost. Extensive soil and water conservation activity is needed in the basin at least to reduce the course sediment coming to the live storage of the reservoir. However the fine sediment will continue to be transported into the reservoir as it is a natural process. This means soil and water conservation alone may not address the problem of reservoir sedimentation, but it may be important strategy when combined with other methods.

Dredging is one of the sediment removal techniques, which can be used to evacuate sediment without draw downing the reservoir if disposal site is available at a reasonable distance. However, the limitation lies on the quantity of sediment that can be removed per year while maximizing the benefit from sediment management. As briefly discussed in previous sections, maximum dredging depth of more than 100 m can be achieved with grab type dredgers. Dredging option regardless of its huge investment cost may be sustainable option if multiple dredgers are used to completely remove annual sediment inflow.

Trucking needs the reservoir to be emptied in order to excavate the deposit. It however will not be economically preferable to empty the huge capacity reservoir (C/I = 1.46) which takes long time to refill. Generally, the need for reservoir emptying, excluded Trucking option from possible alternatives.

Sluicing, venting turbidity current and flushing when properly operated can extend the reservoir life though their efficiency depends on factors such as reservoir size, its geometry and operation, and sediment material property. However, the alteration to the runoff hydrograph and sediment release due to construction of GERD reservoir may seek adjustment of operation strategy of the downstream reservoirs in order to achieve optimum mutual benefit. Considering the original operation strategy to be maintained for downstream reservoirs (i.e. Roseires), management options such as sluicing, flushing and hydrosuction cannot be implemented at GERD to completely evacuate the annual sediment load.

In general, on the basis of the preliminary assessment, measures which do not have considerable impact on the downstream uses can only be implemented. The possible management strategies include construction of debris basins and check dams to control the sediment inflow, and dredging, to remove deposited sediment without emptying the reservoir, provided that disposal site is available at reasonable cost. These can be coupled with vegetative measures in a way that optimal measure can be established. Sediment removal with hydrosuction systems and through flushing will also be evaluated for technical feasibility.

7.2.2 JOINT OPERATION OF RESERVOIRS

Numbers of reservoirs are planned as a cascade development on the Blue Nile River. These reservoirs can operate jointly with an objective of minimizing storage loss due to sedimentation and maximizing the net benefit from the project's operation. Upstream reservoirs can operate in a way that all incoming sediment deposits in them without release to the GERD reservoir or release some part of the incoming sediment thus optimizing the benefits from the projects involved. Both operation options conflict with the sustainability issues as all the reservoirs gradually fill up within certain periods of operation.

One of the important benefits from joint operation of the reservoirs is increased number of possible management alternatives. For instance possibility to obtain the cheapest possible location for excavated material disposal site. The size of the reservoirs under planning can also be optimized in a way that management options can be implemented efficiently. The reservoirs located upstream can serve like detention dam/ debris basin for the downstream reservoir thus protecting the downstream reservoir from sedimentation, but the protecting reservoir itself has to be sustained through effective management measures.

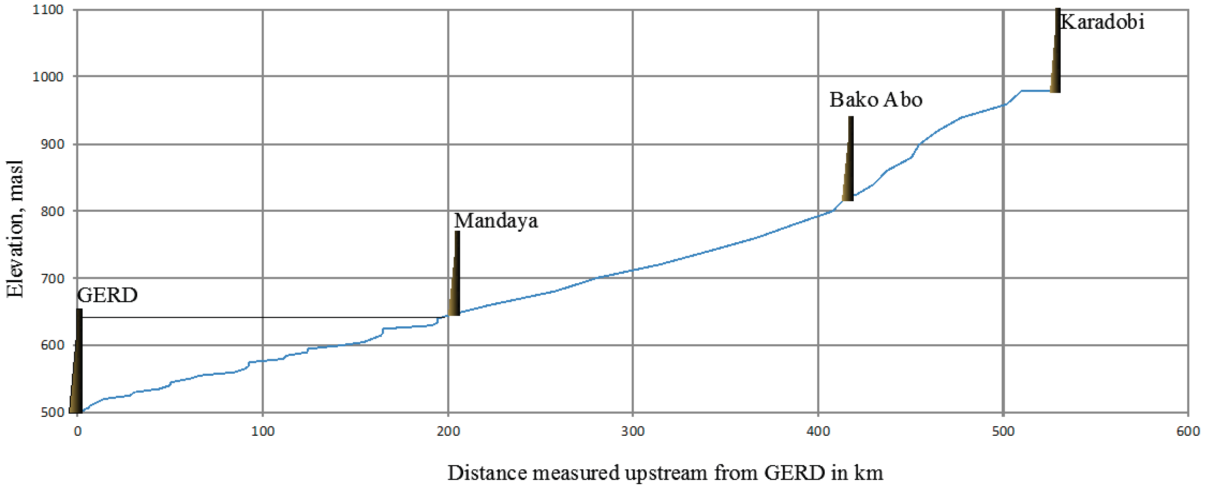

Figure 7.2 The cascade arrangement of the reservoirs on the Blue Nile River

As long as the sediment entering GERD reservoir cannot be released to the downstream environment, large portion of the sediment load in the river must be trapped by the upstream reservoirs in order to perpetuate the life of GERD reservoir in view point of sedimentation.

The amount of sediment that should be trapped by each reservoir depends on the reservoir depth and its length, location of disposal site and location of major sediment source in the basin. Thorough analysis of these all alternatives cannot be made in this study due to unavailability of detailed map and finalized components of the projects. Therefore, joint operation of Mandaya and GERD reservoirs was only considered for analysis of reservoir management strategies.

The Mandaya site is a mountainous valley with its river banks more than 310 m height above the river bed (Ahmed, 2008). This indicates that there is huge potential for hydropower development at this location. In view point of reservoir sediment management, shallow reservoirs provide good efficiency when conventional dredging is used, and small sized and narrow reservoirs provide good condition for effective flushing. In order to attain the efficient management goal, it is necessary to take management options in to account during planning of the reservoir. This however, involves a major trade off between the benefit from large reservoir generating large income for some decades and the benefit from perpetuated or longer life reservoir but lower annual revenue. In depth evaluation of opportunity cost however has to be made to come to conclusion on the size of the reservoir.

The estimated annual sediment load at GERD reservoir was 245 million t/year which is equivalent to 1380 t/km^2/year over an area of 177,700 km^2 and the catchment between Kessie and GERD was estimated to yield specific sediment of 250 t/km^2/year. With this estimates total sediment load at Mandaya will be 234 million t/ year which equals an average specific sediment yield of 1732 t/km^2/year over a catchment of 135,300 km^2. The total sediment load at Mandaya which is about 95% of the total sediment load at GERD, if stopped at Mandaya dam, can increase economic life time of the GERD reservoir. However, the water value in Mandaya reservoir may be higher than that of GERD in which damaging Mandaya to save GERD will have no benefit.

In general, in order to achieve sustainable reservoir and inter-generational equity, off-site disposal may be the only alternative for the reservoirs on the Blue Nile River unless total decommissioning cost is paid by the generation using the dam. From the preliminary analysis, Mandaya reservoir is as large as the GERD reservoir and may not create better management conditions than what can be applied to the GERD reservoir. However, management alternatives like discharging sediment in Mandaya reservoir in to the dead storage of GERD reservoir may maximize benefits from maintained high production capacity of the projects.

7.3 SELECTION OF MANAGEMENT STRATEGY

According to the preliminary evaluation of management strategies, dredging was found appropriate to sustain the reservoirs. In addition to the outcomes from the preliminary assessment, reservoir sediment management alternatives have to be evaluated further considering three cases:

i. The entire sediment load in the Blue Nile River is managed at GERD

ii. The Mandaya reservoir is resized in a way that it takes efficiency of management alternatives in to account and

iii. The incoming sediment load is controlled at Mandaya reservoir and safely released to the GERD reservoir's dead storage

In the first two cases offsite disposal of material removed through dredging and/or trucking will be the possible sediment management strategies in order to develop sustainable reservoirs. Detailed assessment of dredging at both sites was not made in this study mainly because of limited site information and time limitations. Alternatives like flushing and HSRS, although environmentally infeasible, were also evaluated further with RESCON model for GERD reservoir.

The third case however, aims at maximizing the benefits from the reservoirs. In this case the initial energy production capacity of the projects will be maintained for certain period of operation until the reservoir completely loses its dead storage capacity. This scenario is dealt with in the following section.

7.3.1 RESCON APPROACH FOR GERD RESERVOIR

RESCON research project was initiated by World Bank in 1999 to develop an approach to the assessment and promotion of sustainable reservoir management. As an outcome of the research a RESCON model was developed in order to make evaluation of principal reservoir management options (i.e flushing, hydrosuction, traditional dredging and trucking) at prefeasibility level with respect to technical feasibility and economic benefits (Palmieri, et al., 2003).

In the RESCON model flushing and hydrosuction are checked for technical feasibility. Traditional dredging and trucking are assumed technically feasible. If based on the input data, flushing and hydrosuction fulfil technical feasibility criteria; their economic returns are computed and compared with those of traditional dredging, trucking and no intervention scenarios. The main steps involved in the process are summarized in the figure below.

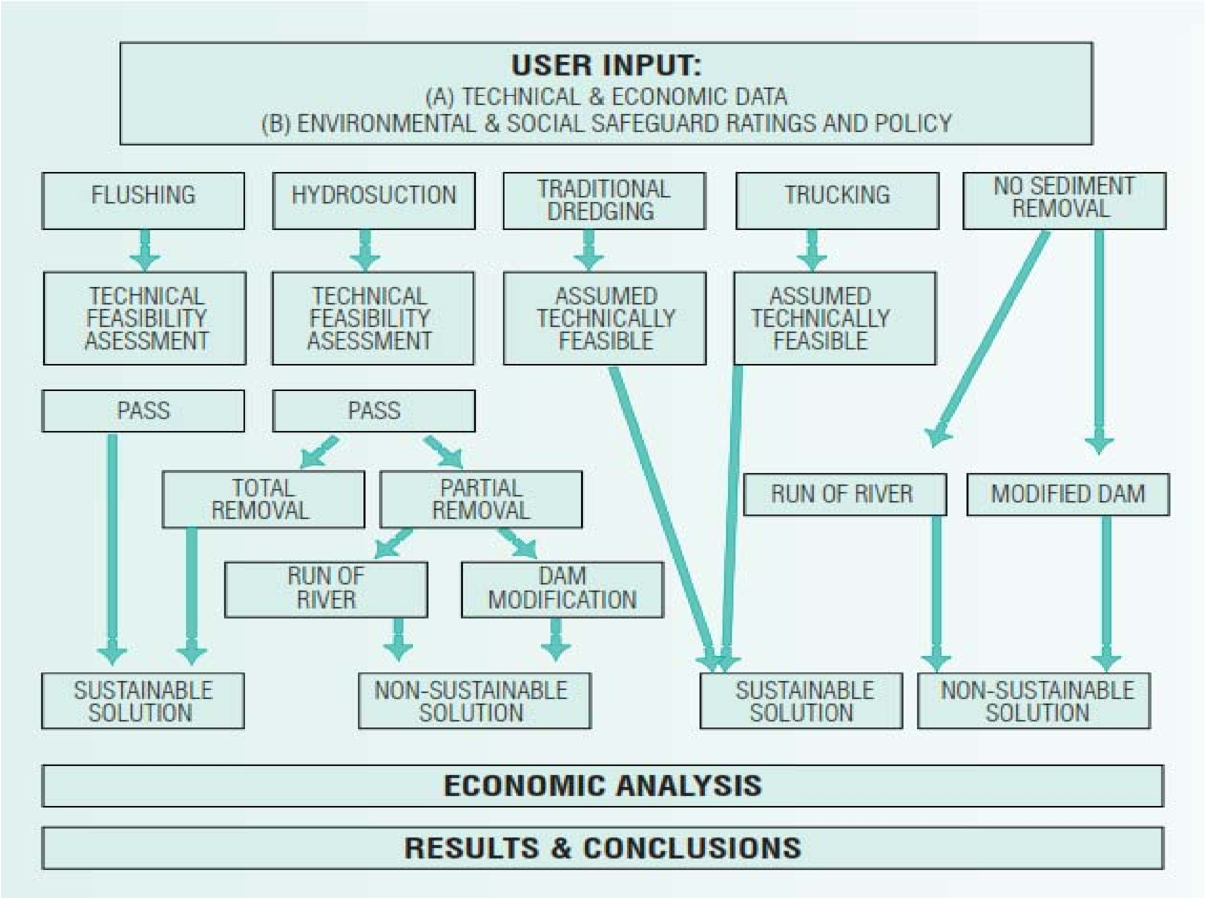

Figure 7.3 RESCON program structure (Palmieri, et al., 2003)

7.3.1.1 Input parameters

Most of the reservoir geometry parameters were determined based contour map generated from Digital Elevation Model (DEM) of the basin. The representative bottom width of the reservoir was measured from Google earth digital map, and the coefficient of variation of annual runoff was determined from mean monthly stream flow data at El-Deim obtained from Tefferi, (2012).

No data on size and capacity of sluices were available. Though flushing as an alternative is not environmentally feasible, the flushing discharge was chosen based on the annual inflow to evaluate its technical feasibility. As has been discussed previously Roseires reservoir filling commences in September after peak flood passage. Considering flushing of GERD reservoir to be carried out during the rising flood stage in July, before Roseires reservoir impoundment starts, the mean monthly flow in July was assumed as the flushing discharge. The mean monthly flow at El-deim in July is 2,472 m^3/s. Duration of flushing for initial evaluation was assumed 20 days every year. For the assumed flushing period of 20 days about 9% of the total annual runoff will be lost.

Unit price of reservoir yield (USD/m^3) was calculated as a product of energy equivalent (kWh/m^3) and unit price of electricity (USD/kWh). Energy equivalent for the GERD reservoir as presented in 0 is 0.302 kWh/m^3 and the unit price of electricity was taken as 3.21 USC/kWh according to current rate. The unit price of reservoir water is therefore 0.096

USD/m^3. Annual operation and maintenance cost and sediment removal cost was accounted for as a percentage of unit price of reservoir yield. Considering 10% of this for operation, maintenance and sediment removal cost, net unit price of reservoir yield, 0.086 USD/m^3 was used with RESCON model.

Table 7.1 summarizes important input parameters. Other model input parameters are assumed similar to the default values given in the model.

Table 7.1 RESCON model input parameters

Parameter	**Units**	**Description**	**Value**
Reservoir Geometry			
S_o	(m^3)	Original (pre-impoundment) capacity of the reservoir	74E+09
S_e	(m^3)	Existing storage capacity of the reservoir	74E+09
W_{bot}	(m)	Representative bottom width for the reservoir	100.0
SS_{res}		Representative side slope for the reservoir. 1 Vertical to SSres Horizontal.	50.0
EL_{max}	(m)	Elevation of top water level in reservoir	646.0
EL_{min}	(m)	Minimum bed elevation	500.0
EL_f	(m)	Water elevation at dam during flushing	610
L	(m)	Reservoir length at the normal pool elevation.	200,000
h	(m)	Available head	146.0
Water Characteristics			
V_{in}	(m^3)	Mean annual reservoir inflow (mean annual runoff)	50.6E+09
Cv	(m^3)	Coefficient of Variation of Annual Run-off volume.	0.193
Sediment Characteristics			
ρ_d	(tonnes/m^3)	Density of in-situ reservoir sediment. Typical values range between 0.9 - 1.35.	1.12
M_{in}	(metric tonnes)	Mean annual sediment inflow mass.	245E+06
Removal Parameters			
Q_f	(m^3/s)	Representative flushing discharge.	2, 500
T_f	(days)	Duration of flushing after complete drawdown.	20
N	(years)	Frequency of flushing events (whole number of years between flushing events)	1
D	(feet)	Assume a trial pipe diameter for hydrosuction. Should be between 1 - 4 feet.	3.0

Economic Parameters			
Parameter	**Units**	**Description**	**Value**
C2	($)	Total Cost of Dam Construction.	4,330,000,000
r	decimal	Discount rate	0.06
Mr	decimal	Market interest rate that is used to calculate annual retirement fund.	0.06
P1	($/m^3)	Unit Benefit of Reservoir Yield.	0.086

7.3.1.2 RESCON results

Flushing results

With the above input it is not technically feasible to have sustainable flushing as annual volume of sediment which can be flushed is less than the average annual sediment inflow.

Table 7.2 RESCON model Flushing technical results

Criterion	Required	Calculated	Notes
SBR	> 1	0.86	Can be flushed if > 1, otherwise not.
LTCR	preferably > 0.35	0.02	Use caution if < 0.35.

HSRS results

HSRS with 1 pipe of 3 ft diameter cannot remove total incoming sediment and therefore is not technically feasible to have sustainable HSRS.

Table 7.3 RESCON model HSRS technical results

Sediment Transport Rate, Qs =	3.94E-06	(m^3/s)	= 127.4618	(metric tons/yr)
Reservoir Volume Restored =	3.40E-01	(m^3/day)	= 124.1511	(m^3/year)
Mixture Velocity, Vm =	0.8	(m/s)		
Mixture Flow rate, Qm =	0.51	(m^3/s)		
Sediment Concentration through Hydrosuction Pipe, C =	8.74E+00	(ppm)		

HSRS is generally technically infeasible for large reservoirs like GERD. It was also evaluated with increased number of pipes to remove only 10% of the total sediment load at GERD. The results indicate that only 382 metric tonnes can be removed annually with 3 pipes of 3 ft diameter.

Economic Results

The aggregate net present value calculated for all alternatives are almost equal and may not give strong support to decision making. However, the result when combined with environmental and social impact assessment can give guide to selection of better management strategy.

Table 7.4 RESCON model Economic results

Possible Strategies	Technique	Aggregate Net Present Value, $
Do nothing	N/A	6.1429E+10
Non sustainable (Decommissioning) with Partial Removal	HSRS	6.1428E+10
Non sustainable (Run-of-River) with No Removal	N/A	6.1429E+10
Non sustainable (Run-of-River) with Partial Removal	HSRS	6.1428E+10
Sustainable	Flushing	Flushing is technically infeasible
Sustainable	HSRS	Total Removal with HSRS is technically infeasible
Sustainable	Dredging	6.1429E+10
Sustainable	Trucking	6.1429E+10
Conclusion		
Strategy yielding the highest aggregate net benefit:		Sustainable
Technique yielding the highest aggregate net benefit:		Dredging
The highest aggregate net benefit is: $		6.143E+10

Sustainability

The long term capacity of the reservoir for different alternatives calculated by the model is given in the Table 7.5. The highest long term reservoir capacity is maintained through dredging which is 4.43 billion m^3. This long term capacity is only 7.5% of the live storage capacity before sedimentation.

Table 7.5 Long term reservoir capacity for different management techniques

Long term reservoir capacity for Flushing	N/A	
Long term reservoir capacity for HSRS	Not applicable	
Long term reservoir capacity for Dredging	4.43	billion m^3
Long term reservoir capacity for Trucking	1.88	billion m3

According to RESCON results dredging is technically feasible for sustainable reservoir and it can also maintain the highest long term reservoir capacity. In view point environmental restrictions, dredging may have lesser environmental and social impacts when compared with flushing and HSRS. Therefore, dredging was found the best strategy to extend the operation life of the GERD reservoir.

7.3.1.3 Sensitivity Analysis

The input data used for the evaluation of available management alternatives is subject to many assumptions and approximations, thus creating uncertainties in the result. The main parameters subject to uncertainties include annual sediment load, unit benefit of the reservoir yield, flushing discharge, duration of flushing and the discount rate. The obtained result can be considered sound if uncertainties in these parameters create insignificant effect on the feasibility of the management alternative. Therefore, uncertainty analysis was carried out to evaluate effect of these uncertainties on the technical and economic feasibility and rankings of the considered alternatives.

Annual sediment load

The sediment load at a given catchment outlet varies from time to time which can be due to combination of parameters like hydrologic variability, land use/ land cover changes, changes in ground condition, changes in sediment source and climatic variables. The estimated long-term average annual sediment load at GERD reservoir as briefly presented in chapter 5 amounts 245 million t/year. The model results were evaluated for annual sediment load of 220, 230, 260 and 270 million t/year.

The result shows that the uncertainty has no significant effect on the ranking and feasibility of the alternatives. The result shows that the maximum Aggregate Net Present Value is retained by Dredging for all examined annual sediment load ranges. Increase in sediment yield from 245 to 270 million t/year decreased the NPV by very small fraction.

Unit benefit of the reservoir yield

One of the important optimization parameter is the value of dammed water. The estimated unit value of the reservoir water was 0.086 USD/m^3. The sensitivity of economic results was evaluated for unit price ranging from 0.05 to 0.12 USD/m^3. The remaining parameters are assumed independent and the same as initial estimate as given in **Table 7.1**.

The result shows that increase in unit price from 0.05 to 0.086 USD/m^3 increases the net present value from 32.14 to 61.43 billion USD and the increase in unit price from 0.086 to 1 USD/m^3 increased the net present value to 72.82 billion USD. This indicates that the present value is sensitive to changes in unit benefit of the reservoir yield. However, the maximum aggregate net present value is maintained by dredging.

Flushing discharge and duration of flushing

Sensitivity of technical and economic results to changes in flushing discharge was also evaluated keeping other initial inputs unchanged. Variation in SBR (Sediment Balance Ratio) for different flushing discharges and flushing durations is given in the **Table 7.6**. The result shows that the sustainable flushing can be achieved with minimum flushing discharge of 2000 m^3/s and 35 days of flushing. For this flushing discharge and duration the volume of water lost to flushing will be 6.048 billion m^3/year, which is about 12% of the total annual runoff volume at GERD.

Table 7.6 SBR for different flushing discharges and duration of flushing

		Flushing discharge, m^3/s				
		1000	1500	2000	2500	3000
Duration of flushing, days	15	0.20	0.33	0.48	0.64	0.81
	20	0.26	0.44	0.64	0.86	1.09
	25	0.33	0.55	0.80	1.07	1.36
	30	0.39	0.66	0.96	1.28	1.63
	35	0.46	0.77	1.12	1.50	1.90
	40	0.52	0.88	1.28	1.71	2.17

7.3.2 JOINT OPERATION OF MANDAYA WITH GERD RESERVOIR

The Mandaya reservoir, as discussed in Section 7.2.2 accounts for 95% of the total sediment load at GERD. This sediment load can be trapped at Mandaya reservoir and safely released to the dead storage of the GERD reservoir in order to maintain the maximum production of the reservoirs. Filling the dead storage of the reservoir and maintaining the live storage allows maximum production of the reservoir to continue until the dead storage fills up relatively in shorter time than where the sediment is distributed both in the live and dead storage. If the total sediment load at GERD deposits in its dead storage, it will fill up with sediment in 68 years assuming 100% trap efficiency and 1.12 t/m^3 deposit density.

The reservoir life where portion of the sediment deposits in the live storage was estimated to be 116 years as briefly presented in section 6.6. In this case the sedimentation of reservoir causes consequent reduction in live storage loss, thus reducing production capacity of the reservoir from time to time. However, it allows production for a longer period than where all sediment is sent to dead storage.

A very rough economic comparison of the above two cases, (1) transporting deposit to dead storage and (2) no action alternative, were made in order to indentify economically better alternative.

The GERD project has a potential for production of 15692 GWh energy annually. Considering the utilization factor of 0.7, the annual energy produced will be 10984 GWh. Some cost parameters were not included in NPV calculation and they were assumed equal for both alternatives. Cost of transporting the sediment to dead storage was also not considered in this case. Table 7.7 summarizes the economic comparison of the two alternatives.

Table 7.7 Comparison of no action alternative and transporting deposit to dead storage

Parameters	**Unit**	**Alternatives**	
		Transporting deposit to dead storage	**No action alternative**
Reservoir life, years	Years	68	116
Investment cost	Million USD	4330	4330
Annual energy production	GWh	10984	10984
Price of Electricity	USC/kWh	3.21	3.21
NPV of lost live storage over the useful life of the reservoir	Million USD	0	4.99
Annual operation and maintenance cost (assumed 0.01% of the dam cost)	Million USD	0.433	0.433
Discount rate	%	7	7
NPV	Million USD	**656**	**700**

The table result indicates that the gradual filling of live storage is preferable to the maintenance of live storage by moving it to the dead storage. The NPV of the no action alternative is 6.7% bigger than the NPV of maintaining live storage alternative.

7.4 CONCLUSION

Preliminary evaluation of various reservoir sediment management strategies were carried out with the catchment area, environmental and social considerations, reservoir capacity to inflow ratio and total sediment load as governing parameters. In addition to their environmental limitations flushing and sluicing will not be economically feasible alternatives due to need for complete drawdown in order to achieve worthwhile result. Of the available alternatives dredging was found appropriate because of its application without affecting the reservoir operation. Soil and water conservation measures have to be considered in order to minimize cost of sediment management at the dam.

The management strategies were assessed further with RESCON model. Removing a portion of sediment at GERD for the downstream river reach maintenance was considered, but because of small head available for hydrosuction it was found practically impossible to achieve a worthwhile result in removing sediment through HSRS. Sediment removal through flushing was found technically infeasible for flushing discharge lower than 2000 m^3/s and duration of flushing of 35 days. In addition to its technical infeasibility it is not possible to completely flush the deposit due to its impacts on the downstream users. Amongst available alternatives dredging was found technically feasible and it retains maximum long term capacity. Based on the RESCON model estimates, 20 dredges capable of removing 11 million m^3 per year each have to be installed in order to keep the reservoir sustainable. However, detailed assessment of all cost components which include cost of disposal site, operation and maintenance costs and environmental costs has to be carried out in order to confirm its feasibility.

The Mandaya reservoir, located upstream of GERD was also considered to examine potential for joint operation and sediment management in order to maximize benefits from the projects. The Mandaya and GERD reservoirs according to current data are similar in size, thus managing sediment at Mandaya may not be better than managing from the GERD reservoir. Sediment removal through dredging from one of the reservoirs located upstream of GERD may be economically and environmentally better than removal from GERD. Therefore, thorough evaluation of alternative disposal sites has to be made to select the best site which minimizes cost of disposal and environmental impacts.

As a possible alternative, trapping all incoming sediment at Mandaya reservoir and releasing the deposit in to the dead storage of the reservoir was also considered. The alternative however, was not better than the case in which the storage capacity is lost gradually decreasing its live storage. The NPV of the two cases were calculated where the NPV for the later was found to be 6.7% bigger than that of transporting sediment from Mandaya to dead storage of GERD reservoir.

8 CONCLUSIONS AND RECOMMENDATIONS

The study goes through sediment yield estimate deposition pattern prediction and finally identification of better reservoir sediment management strategy. Conclusions and recommendations are given for each chapter and this only summarizes main pats of each conclusions.

The river flow and sediment data available for this study was generally far from being adequate, to make a best estimate of sediment load in different parts of the basin. The available data from 3 locations (Kessie, Guder and Tato) in the basin were checked for quality and considered for use in sediment yield estimation. To meet the need for flow and sediment data in the basin, improvement of data quality at existing stations and establishment of new gauging stations is necessary. Capacity building, installation of automatic gauges and periodic monitoring of the stations have to be considered.

Sediment yield in different parts of the basin was estimated based on sediment rating curve, survey data of Roseires reservoir, average concentration at El-deim and average concentration at Burie. The sediment yield estimate based on rating curve at Kessie was considered as the basis for the sediment yield estimate as all other estimates are dependent on secondary data. On the basis of rating curve, total sediment load and specific sediment yield at GERD was estimated to be 245 million t/year and 1378 t/km^2/year respectively.

Sediment deposition pattern of the GERD reservoir was predicted based on Empirical Area Reduction method. According to the Empirical Area Reduction method, the GERD reservoir will have life of 116 years for the estimated annual sediment load of 245 million tonnes, trap efficiency of 100% and average deposit density 1.12 t/m^3. The reservoir storage capacity will be lost at an average rate of 0.3 % per year. The estimated present value of economic loss indicates that the total economic values forgone due to the live storage loss was found to vary between 0.26% and 0.06% of the original dam cost, 4.33 billion USD when the discount rate varied between 5% and 13% respectively.

Various reservoir sediment management strategies were evaluated with the catchment area, environmental and social considerations, reservoir capacity to inflow ratio and total sediment load as governing parameters. According to the preliminary assessment and further evaluation of management strategies using RESCON model dredging was found appropriate for the GERD reservoir. Based on the RESCON model estimates, 20 dredges capable of removing 11 million m^3 per year each have to be installed in order to keep the reservoir sustainable. However, detailed assessment of all cost components which include cost of disposal site, operation and maintenance costs and environmental costs has to be carried out in order to confirm its feasibility.

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Appendix A. Sediment concentration data

Table A.1 Original suspended sediment concentration data at Kessie

No.	Field Sample No.	Date & time of Sampling	Gage height (m)	Flow (m^3/s)	Depth (m)	Direction of measurement	Width (m)	Sediment Conc. (mg/l)
1	1 of 3	29.jun.08	3.02		4.08		14.00	2076.12
	2 of 3	29.jun.08	3.02		4.45		28.00	7902.19
	3 of 3	29.jun.08	3.02		4.63		42.00	1990.82
2	1 of 3	30.jun.08	3.06		3.96		16.25	5126.30
	2 of 3	30.jun.08	3.06		4.57		32.50	6414.81
	3 of 3	30.jun.08	3.06		5.49		48.75	2948.72
3	1 of 3	14.jul.08	4.28	1025.13	3.96		17.25	15981.54
	2 of 3	14.jul.08	4.28		7.01		34.50	13522.50
	3 of 3	14.jul.08	4.28		8.69		51.75	14195.91
4	1 of 3	20.jul.08	4.07			R		11596.50
	2 of 3	20.jul.08	4.07					10496.58
	3 of 3	20.jul.08	4.07			L		12436.21
5	1 of 5	13-Aug-08	6.92		10.00		11.25	14940.71
	2 of 5	13-Aug-08			15.00		33.75	15895.46
	3 of 5	13-Aug-08		56.25	12.00			14258.33
	4 of 5	13-Aug-08			15.00		78.75	13097.07
	5 of 5	13-Aug-08	6.59		21.00		101.25	13901.41
6	1 of 5	14-Aug-08	6.45		21.00		11.20	13104.60
	2 of 5	14-Aug-08	6.60		20.00		33.60	16522.38
	3 of 5	14-Aug-08	6.72		15.00		56.20	15341.69
	4 of 5	14-Aug-08	6.82		15.00		78.40	16090.12
	5 of 5	14-Aug-08	6.85		15.00		100.80	19640.24
7	1 of 5	17-Aug-08	7.40				11.50	11599.19
	2 of 5	17-Aug-08	7.40				33.50	12037.38
	3 of 5	17-Aug-08	7.40				56.50	13440.25
	4 of 5	17-Aug-08	7.40				79.50	14166.22
	5 of 5	17-Aug-08	7.40				102.50	14742.20
8	1 of 5	18-Aug-08	6.64				11.25	9130.72
	2 of 5	18-Aug-08	6.64				34.75	8788.50
	3 of 5	18-Aug-08	6.64				58.25	8655.75
	4 of 5	18-Aug-08	6.64				71.75	7910.89
	5 of 5	18-Aug-08	6.64				95.25	10562.30
9	1 of 5	21-Aug-08	5.28				11.00	13232.16
	2 of 5	21-Aug-08	5.28				33.00	12840.79
	3 of 5	21-Aug-08	5.28				55.00	12392.06
	4 of 5	21-Aug-08	5.28				77.00	12055.13
	5 of 5	21-Aug-08	5.28				99.00	11259.47

No.	Field Sample No.	Date & time of Sampling	Gage height (m)	Flow (m3/s)	Depth (m)	Direction of measurement	Width (m)	Sediment Conc. (mg/l)
10	1 of 5	22-Aug-08	5.26				11.00	13831.43
	2 of 5	22-Aug-08	5.29				33.00	13556.80
	3 of 5	22-Aug-08	5.33				55.00	13297.78
	4 of 5	22-Aug-08	5.36				77.00	13072.05
	5 of 5	22-Aug-08	5.40				99.00	12231.86
11	1 of 5	25-Aug-08	5.60				11.00	5460.26
	2 of 5	25-Aug-08	5.65				33.00	6163.25
	3 of 5	25-Aug-08	5.70				55.00	6277.81
	4 of 5	25-Aug-08	5.75				77.00	6681.69
	5 of 5	25-Aug-08	5.80				99.00	6355.56
12	1 of 5	26-Aug-08	5.65				11.00	6726.00
	2 of 5	26-Aug-08	5.65				33.00	8440.58
	3 of 5	26-Aug-08	5.65				55.00	6855.26
	4 of 5	26-Aug-08	5.65				77.00	6858.95
	5 of 5	26-Aug-08	5.65				99.00	5826.84
13	1 of 5	30-Aug-08	4.74		9.30		10.00	3991.16
	2 of 5	30-Aug-08	4.74		6.50		30.00	3614.19
	3 of 5	30-Aug-08	4.74		5.00		50.00	4297.80
	4 of 5	30-Aug-08	4.74		4.20		70.00	3956.81
	5 of 5	30-Aug-08	4.74		4.80		90.00	3462.40
14	1 of 5	31-Aug-08	4.30		8.00		10.00	2843.46
	2 of 5	31-Aug-08	4.30		6.00		30.00	3105.35
	3 of 5	31-Aug-08	4.30		5.00		50.00	3076.87
	4 of 5	31-Aug-08	4.30		5.00		70.00	3544.27
	5 of 5	31-Aug-08	4.30		5.00		90.00	3150.42
15	1 of 5	3-Sep-08	5.45		7.00		9.40	8523.21
	2 of 5	3-Sep-08	5.49		5.00		33.00	8506.36
	3 of 5	3-Sep-08	5.53		5.00		55.00	8484.52
	4 of 5	3-Sep-08	5.60		5.00			8295.65
	5 of 5	3-Sep-08	5.60		5.00		99.00	7985.76
16	1 of 5	4-Sep-08	5.72		5.00		11.00	6869.29
	2 of 5	4-Sep-08	5.72		7.00		33.00	6297.03
	3 of 5	4-Sep-08	5.70		4.50		55.00	6347.23
	4 of 5	4-Sep-08	5.68		4.50		77.00	6116.94
	5 of 5	4-Sep-08	5.66		4.50		99.00	5526.27
17	1 of 5	7-Sep-08	4.82		4.50		13.00	5303.17
	2 of 5	7-Sep-08	4.82		6.50		33.00	5144.94
	3 of 5	7-Sep-08	4.82		5.00		55.00	4480.35
	4 of 5	7-Sep-08	4.82		5.00		77.00	5127.95
	5 of 5	7-Sep-08	4.82		5.00		99.00	4824.33

No.	Field Sample No.	Date & time of Sampling	Gage height (m)	Flow (m3/s)	Depth (m)	Direction of measurement	Width (m)	Sediment Conc. (mg/l)
18	1 of 5	8-Sep-08	4.68		5.00		13.00	7105.19
	2 of 5	8-Sep-08	4.68		5.00		33.00	7389.52
	3 of 5	8-Sep-08	4.68		5.00		55.00	6714.57
	4 of 5	8-Sep-08	4.68		5.00		77.00	6973.78
	5 of 5	8-Sep-08	4.68		5.00		99.00	7097.62
19	1 of 5	29-Sep-08	3.04				8.46	587.89
	2 of 5	29-Sep-08	3.04				25.38	807.95
	3 of 5	29-Sep-08	3.04				42.30	605.45
	4 of 5	29-Sep-08	3.04				59.22	651.67
	5 of 5	29-Sep-08	3.04				76.14	588.00
20	1 of 5	30-Sep-08	3.00				8.46	490.26
	2 of 5	30-Sep-08	3.00				25.38	610.67
	3 of 5	30-Sep-08	3.00					782.09
	4 of 5	30-Sep-08	3.00				59.22	623.56
	5 of 5	30-Sep-08	3.00				76.14	567.08
21	1 of 5	3-Oct-08	3.10				8.38	2418.54
	2 of 5	3-Oct-08	3.10				25.14	2530.71
	3 of 5	3-Oct-08	3.10				41.90	2755.85
	4 of 5	3-Oct-08	3.10				58.66	2715.58
	5 of 5	3-Oct-08	3.10				75.42	2617.91
22	1 of 5	4-Oct-08	3.05				8.32	727.58
	2 of 5	4-Oct-08	3.05				24.96	731.73
	3 of 5	4-Oct-08	3.05				41.60	741.46
	4 of 5	4-Oct-08	3.05				58.24	694.69
	5 of 5	4-Oct-08	3.05				74.88	686.04
23	1 of 5	5-Oct-08	3.00				8.30	632.08
	2 of 5	5-Oct-08	3.00				24.90	751.86
	3 of 5	5-Oct-08	3.00				41.50	753.41
	4 of 5	5-Oct-08	3.00				58.10	767.19
	5 of 5	5-Oct-08	3.00				74.70	674.41
24	1 of 5	11-Jul-09	3.33	852.08	18.00		10.00	24753.33
	2 of 5	11-Jul-09	3.10-3.44	852.08				31810.30
	3 of 5	11-Jul-09	3.44-3.5	852.08	18.80		34.00	30561.98
	4 of 5	11-Jul-09	3.5-3.59	852.08	16.10		46.00	34576.74
	5 of 5	11-Jul-09	3.59-3.63	852.08	13.00		58.00	30027.59
25	1 of 5	12-Jul-09						13164.56
	2 of 5	12-Jul-09						18121.58
	3 of 5	12-Jul-09						13780.65
	4 of 5	12-Jul-09						8120.19
	5 of 5	12-Jul-09						15545.89

No.	Field Sample No.	Date & time of Sampling	Gage height (m)	Flow (m3/s)	Depth (m)	Direction of measurement	Width (m)	Sediment Conc. (mg/l)
26	1 of 5	13-Jul-09		761.52				24192.57
	2 of 5	13-Jul-09		761.52				26853.33
	3 of 5	13-Jul-09		761.52				25150.33
	4 of 5	13-Jul-09	3.63-3.64	761.52	16.40		54.00	24592.81
	5 of 5	13-Jul-09		761.52				25441.86
27	1 of 5	13-Jul-09				Right		15367.74
	2 of 5	13-Jul-09	3.69-3.71			Right		16854.67
	3 of 5	13-Jul-09	3.72-3.80			Right		18708.48
	4 of 5	13-Jul-09	3.78			Right		20482.30
	5 of 5	13-Jul-09	3.78			Right		18198.16
28	1 of 5	14-Jul-09	3.46	796.15		Left		22194.74
	2 of 5	14-Jul-09	3.46	796.15		Left		21536.63
	3 of 5	14-Jul-09	3.46	796.15		Left		21238.30
	4 of 5	14-Jul-09	3.46	796.15		Left		18245.28
	5 of 5	14-Jul-09	3.46	796.15		Left		21374.77
29	1 of 5	15-Jul-09	4.22	1580.92		Right		36152.99
	2 of 5	15-Jul-09	4.22	1580.92		Right		38354.48
	3 of 5	15-Jul-09	4.15-4.12	1580.92		Right		64772.06
	4 of 5	15-Jul-09	4.12-4.10	1580.92		Right		36426.52
	5 of 5	15-Jul-09	4.10	1580.92		Right		35923.88
30	1 of 5	16-Jul-09	4.05	1358.97		Right		33489.58
	2 of 5	16-Jul-09	4.04	1358.97		Right		28325.47
	3 of 5	16-Jul-09	4.04	1358.97		Right		25087.34
	4 of 5	16-Jul-09	4.05	1358.97		Right		21480.77
	5 of 5	16-Jul-09	4.05	1358.97		Right		19776.60
31	1 of 5	17-Jul-09		3463.22	22.50	Right	14.03	15496.53
	2 of 5	17-Jul-09		3463.22	22.60	Right	26.00	17195.33
	3 of 5	17-Jul-09		3463.22	27.00	Right	44.00	17781.25
	4 of 5	17-Jul-09		3463.22	19.20	Right	62.00	16838.49
	5 of 5	17-Jul-09		3463.22				14106.67
32	1 of 5	18-Jul-09	4.15	1828.54		Right		17611.32
	2 of 5	18-Jul-09	4.15	1828.54		Right		14994.58
	3 of 5	18-Jul-09	4.15	1828.54		Right		13785.24
	4 of 5	18-Jul-09	4.15	1828.54		Right		14464.29
	5 of 5	18-Jul-09	4.15	1828.54		Right		13403.97
33	1 of 5	20-Jul-09	4.75	1500.23	5.80	Right	26.00	23814.70
	2 of 5	20-Jul-09	4.75	1500.23	19.87	Right	44.00	24699.67
	3 of 5	20-Jul-09	4.75	1500.23	29.60	Right	62.00	23736.66
	4 of 5	20-Jul-09	4.75	1500.23	25.60	Right	80.00	24404.53
	5 of 5	20-Jul-09	4.75	1500.23	25.00	Right	94.00	27322.10

No.	Field Sample No.	Date & time of Sampling	Gage height (m)	Flow (m3/s)	Depth (m)	Direction of measurement	Width (m)	Sediment Conc. (mg/l)
	1 of 5	20-Jul-09	5.35	1926.19	26.80		14.00	17795.04
	2 of 5	20-Jul-09	5.35	1926.19	26.80		26.00	15625.00
	3 of 5	20-Jul-09	5.35	1926.19	30.00		44.00	16983.81
	4 of 5	20-Jul-09	5.35	1926.19	21.80		62.00	17479.93
34	5 of 5	20-Jul-09	5.35	1926.19				20091.86
	1 of 5	23-Jul-09	4.98	1807.02	25.20	Right	16.00	22674.42
	2 of 5	23-Jul-09	4.98	1807.02	28.70	Right	36.00	22636.52
	3 of 5	23-Jul-09	4.98	1807.02		Right	50.00	23190.48
	4 of 5	23-Jul-09	4.98	1807.02		Right	70.00	19823.77
35	5 of 5	23-Jul-09	4.98	1807.02		Right	90.00	25497.91
	1 of 5	23-Jul-09	5.08	1850.25	13.50	Left	16.00	12263.62
	2 of 5	23-Jul-09	5.08	1850.25	20.90	Left	34.00	12841.74
	3 of 5	23-Jul-09	5.08	1850.25	28.60	Left	52.00	15188.26
	4 of 5	23-Jul-09	5.08	1850.25	30.40	Left	70.00	14583.75
36	5 of 5	23-Jul-09	5.08	1850.25	24.60	Left	86.00	21017.96
	1 of 5	24-Jul-09	4.98	1612.15		Right		19448.89
	2 of 5	24-Jul-09	4.98	1612.15		Right		19061.22
	3 of 5	24-Jul-09	4.98	1612.15		Right		19436.17
	4 of 5	24-Jul-09	4.98	1612.15		Right		16692.59
37	5 of 5	24-Jul-09	4.98	1612.15		Right		18538.46
	1 of 5	24-Jul-09	5.48	2033.56		Left		22056.42
	2 of 5	24-Jul-09	5.48	2033.56		Left		22575.19
	3 of 5	24-Jul-09	5.48	2033.56		Left		22882.35
	4 of 5	24-Jul-09	5.48	2033.56		Left		23052.05
38	5 of 5	24-Jul-09	5.48	2033.56		Left		23141.38
	1 of 5	27-Jul-09		2876.05				16469.50
	2 of 5	27-Jul-09		2876.05				15410.53
	3 of 5	27-Jul-09		2876.05				17994.65
	4 of 5	27-Jul-09		2876.05				15989.25
39	5 of 5	27-Jul-09		2876.05				17881.51
	1 of 5	27-Jul-09						14229.34
	2 of 5	27-Jul-09						14649.40
	3 of 5	27-Jul-09						12313.02
	4 of 5	27-Jul-09						14217.20
40	5 of 5	27-Jul-09						14308.33
	1 of 5	28-Jul-09	5.00			Right	14.00	15226.42
	2 of 5	28-Jul-09	5.00			Right	32.00	15936.36
	3 of 5	28-Jul-09	5.00			Right	50.00	15654.94
	4 of 5	28-Jul-09	5.00			Right	68.00	16444.07
41	5 of 5	28-Jul-09	5.00			Right	94.00	15740.17

No.	Field Sample No.	Date & time of Sampling	Gage height (m)	Flow (m3/s)	Depth (m)	Direction of measurement	Width (m)	Sediment Conc. (mg/l)
42	1 of 5	28-Jul-09	5.85			Left	22.00	13433.63
	2 of 5	28-Jul-09	5.85			Left	40.00	12270.10
	3 of 5	28-Jul-09	5.85			Left	58.00	14397.77
	4 of 5	28-Jul-09	5.85			Left	76.00	13582.46
	5 of 5	28-Jul-09	5.85			Left	94.00	15901.19
43	1 of 5	29-Jul-09	5.45			Right	16.00	20384.68
	2 of 5	29-Jul-09	5.45			Right	34.00	20530.47
	3 of 5	29-Jul-09	5.45			Right	52.00	19800.73
	4 of 5	29-Jul-09	5.45			Right	70.00	17794.22
	5 of 5	29-Jul-09	5.45			Right	94.00	16991.34
44	1 of 5	29-Jul-09	6.16			Left	22.00	20708.00
	2 of 5	29-Jul-09	6.16			Left	40.00	24159.91
	3 of 5	29-Jul-09	6.16			Left	58.00	22243.41
	4 of 5	29-Jul-09	6.16			Left	22.00	20439.42
	5 of 5	29-Jul-09	6.16			Left		24500.00
45	1 of 5	31-Jul-09	5.11	2183.88				11833.33
	2 of 5	31-Jul-09	5.11	2183.88				11480.94
	3 of 5	31-Jul-09	5.11	2183.88				12899.64
	4 of 5	31-Jul-09	5.11	2183.88				12814.69
	5 of 5	31-Jul-09	5.11	2183.88				10497.30
46	1 of 5	1-Aug-09	5.00	2031.84	11.00	Left	22.00	10195.12
	2 of 5	1-Aug-09	5.00	2031.84	21.50	Left	40.00	10427.56
	3 of 5	1-Aug-09	5.00	2031.84	31.00	Left	56.00	11391.75
	4 of 5	1-Aug-09	5.00	2031.84	28.20	Left	76.00	7781.99
	5 of 5	1-Aug-09	5.00	2031.84	26.00	Left	94.00	9422.68
47	1 of 5	1-Aug-09	5.10	2073.44		Right	11.00	7027.78
	2 of 5	1-Aug-09	5.10	2073.44		Right	21.50	8564.46
	3 of 5	1-Aug-09	5.10	2073.44		Right	31.00	9935.71
	4 of 5	1-Aug-09	5.10	2073.44		Right	28.20	10270.55
	5 of 5	1-Aug-09	5.10	2073.44		Right	26.00	8696.43
48	1 of 5	2-Aug-09	4.96	1793.89	3.10	Left	22.00	15065.57
	2 of 5	2-Aug-09	4.96	1793.89	21.50	Left	40.00	15723.40
	3 of 5	2-Aug-09	4.96	1793.89	32.10	Left	56.00	16135.65
	4 of 5	2-Aug-09	4.96	1793.89		Left	74.00	15936.57
	5 of 5	2-Aug-09	4.96	1793.89	22.00	Left	94.00	13027.24
49	1 of 5	2-Aug-09	5.00		3.10	Right	22.00	11398.00
	2 of 5	2-Aug-09	5.00			Right		12850.69
	3 of 5	2-Aug-09	5.00			Right		13150.26
	4 of 5	2-Aug-09	5.00			Right		13676.26
	5 of 5	2-Aug-09	50.00			Right		12239.70

No.	Field Sample No.	Date & time of Sampling	Gage height (m)	Flow (m3/s)	Depth (m)	Direction of measurement	Width (m)	Sediment Conc. (mg/l)
50	1 of 5	3-Aug-09	4.48	1272.26	22.90	Right	19.17	7941.44
	2 of 5	3-Aug-09	4.48	1272.26	22.90	Right	36.00	8841.00
	3 of 5	3-Aug-09	4.48	1272.26	24.70	Right	54.00	10562.50
	4 of 5	3-Aug-09	4.48	1272.26	22.00	Right	72.00	8880.17
	5 of 5	3-Aug-09	4.48	1272.26	9.30	Right	90.00	6888.37
51	1 of 5	3-Aug-09	4.35	1374.59	13.30	Left	22.00	6901.29
	2 of 5	3-Aug-09	4.35	1374.59	24.00	Left	40.00	6446.22
	3 of 5	3-Aug-09	4.35	1374.59	26.40	Left	58.00	6450.09
	4 of 5	3-Aug-09	4.35	1374.59	22.90	Left	76.00	6773.05
	5 of 5	3-Aug-09	4.35	1374.59	22.70	Left	96.00	5618.32
52	1 of 5	4-Aug-09	4.15	1268.34	9.30	Right	14.00	7218.15
	2 of 5	4-Aug-09	4.15	1268.34	16.10	Right	32.00	8460.91
	3 of 5	4-Aug-09	4.15	1268.34	23.10	Right	50.00	8609.93
	4 of 5	4-Aug-09	4.15	1268.34	19.20	Right	68.00	8449.20
	5 of 5	4-Aug-09	4.15	1268.34	21.10	Right	86.00	7317.18
53	1 of 5	4-Aug-09	4.34	1183.13	22.70	Left	22.00	7946.94
	2 of 5	4-Aug-09	4.34	1183.13	21.10	Left	40.00	7917.29
	3 of 5	4-Aug-09	4.34	1183.13	25.40	Left	58.00	7920.55
	4 of 5	4-Aug-09	4.34	1183.13	17.50	Left	76.00	8723.40
	5 of 5	4-Aug-09	4.34	1183.13	10.70	Left	94.00	6335.88
54	1 of 5	5-Aug-06	4.71	1384.38	22.60	Right	14.00	10746.00
	2 of 5	5-Aug-06	4.71	1384.38	22.90	Right	32.00	12890.85
	3 of 5	5-Aug-06	4.71	1384.38	25.40	Right	50.00	14105.66
	4 of 5	5-Aug-06	4.71	1384.38	18.90	Right	68.00	17351.26
	5 of 5	5-Aug-06	4.71	1384.38	9.90	Right	86.00	16726.94
55	1 of 5	5-Aug-06	5.23	2068.64	14.40	Left	22.00	15524.27
	2 of 5	5-Aug-06	5.23	2068.64	23.00	Left	40.00	16962.07
	3 of 5	5-Aug-06	5.23	2068.64	29.40	Left	58.00	16876.68
	4 of 5	5-Aug-06	5.23	2068.64	25.20	Left	76.00	14323.74
	5 of 5	5-Aug-06	5.23	2068.64	24.20	Left	94.00	12497.18
56	1 of 5	6-Aug-09	5.38	2241.74	16.00	Right	16.00	13313.60
	2 of 5	6-Aug-09	5.38	2241.74	30.60	Right	34.00	14568.84
	3 of 5	6-Aug-09	5.38	2241.74	31.00	Right	52.00	15044.94
	4 of 5	6-Aug-09	5.38	2241.74	26.00	Right	70.00	13647.94
	5 of 5	6-Aug-09	5.38	2241.74	16.10	Right	88.00	13667.86
57	1 of 5	6-Aug-09	6.00		18.70	Left	22.00	13106.99
	2 of 5	6-Aug-09	6.00		23.10	Left	40.00	16693.97
	3 of 5	6-Aug-09	6.00		35.30	Left	58.00	13264.15
	4 of 5	6-Aug-09	6.00		32.10	Left	76.00	11517.24
	5 of 5	6-Aug-09	6.00		28.00	Left	94.00	10909.01

No.	Field Sample No.	Date & time of Sampling	Gage height (m)	Flow (m3/s)	Depth (m)	Direction of measurement	Width (m)	Sediment Conc. (mg/l)
58	1 of 5	7-Aug-09	5.17		2402.00	Right	16.00	8938.49
	2 of 5	7-Aug-09	5.17		22.00	Right	34.00	9855.63
	3 of 5	7-Aug-09	5.17		29.90	Right	52.00	10777.78
	4 of 5	7-Aug-09	5.17		25.20	Right	70.00	12484.05
	5 of 5	7-Aug-09	5.17		24.20	Right	88.00	13329.92
59	1 of 5	7-Aug-09	5.25		12.00	Left	22.00	14464.15
	2 of 5	7-Aug-09	5.25		23.10	Left	40.00	13154.68
	3 of 5	7-Aug-09	5.25		32.50	Left	58.00	11645.95
	4 of 5	7-Aug-09	5.25		29.40	Left	76.00	9906.90
	5 of 5	7-Aug-09	5.25		28.20	Left	94.00	9001.84
60	1 of 5	8-Aug-09	5.60	2995.39	11.80	Left	22.00	9974.58
	2 of 5	8-Aug-09	5.60	2995.39	24.10	Left	40.00	12174.69
	3 of 5	8-Aug-09	5.60	2995.39	32.30	Left	58.00	12797.20
	4 of 5	8-Aug-09	5.60	2995.39	29.70	Left	76.00	13302.16
	5 of 5	8-Aug-09	5.60	2995.39	26.70	Left	94.00	14207.41
61	1 of 5	8-Aug-09	6.05		16.20	Right	18.00	16426.36
	2 of 5	8-Aug-09	6.05		28.00	Right	36.00	14810.38
	3 of 5	8-Aug-09	6.05		36.70	Right	54.00	14747.63
	4 of 5	8-Aug-09	6.05		32.20	Right	72.00	13351.45
	5 of 5	8-Aug-09	6.05		31.30	Right	90.00	10892.19
62	1 of 5	9-Aug-09	5.02	1783.63	14.40	Right	22.00	9675.37
	2 of 5	9-Aug-09	5.02	1783.63	22.00	Right	40.00	10760.86
	3 of 5	9-Aug-09	5.02	1783.63	29.90	Right	58.00	10205.88
	4 of 5	9-Aug-09	5.02	1783.63	25.20	Right	76.00	6968.75
	5 of 5	9-Aug-09	5.02	1783.63	24.20	Right	94.00	10766.67
63	1 of 5	9-Aug-09	5.85		23.80	Left	22.00	11209.82
	2 of 5	9-Aug-09	5.85		26.50	Left	40.00	9841.99
	3 of 5	9-Aug-09	5.85		31.10	Left	58.00	17443.98
	4 of 5	9-Aug-09	5.85		27.30	Left	76.00	10990.33
	5 of 5	9-Aug-09	5.85		28.80	Left	94.00	10198.33
64	1 of 5	10-Aug-09	5.85	2983.61	19.10	Left	22.00	16158.85
	2 of 5	10-Aug-09	5.85	2983.61	17.20	Left	40.00	16414.94
	3 of 5	10-Aug-09	5.85	2983.61	35.90	Left	58.00	14635.14
	4 of 5	10-Aug-09	5.85	2983.61	16.50	Left	76.00	16620.94
	5 of 5	10-Aug-09	5.85	2983.61	19.10	Left	94.00	16079.14
65	1 of 5	11-Aug-05	5.70	2323.39	17.20	Right	14.00	16583.00
	2 of 5	11-Aug-05	5.70	2323.39	24.60	Right	32.00	17185.92
	3 of 5	11-Aug-05	5.70	2323.39	34.00	Right	50.00	15517.36
	4 of 5	11-Aug-05	5.70	2323.39	30.90	Right	68.00	15445.47
	5 of 5	11-Aug-05	5.70	2323.39	27.40	Right	86.00	14067.93

No.	Field Sample No.	Date & time of Sampling	Gage height (m)	Flow (m3/s)	Depth (m)	Direction of measurement	Width (m)	Sediment Conc. (mg/l)
66	1 of 5	11-Aug-05	5.85		16.20	Left	22.00	14378.91
	2 of 5	11-Aug-05	5.85		23.00	Left	40.00	15481.20
	3 of 5	11-Aug-05	5.85		34.00	Left	58.00	15847.04
	4 of 5	11-Aug-05	5.85		30.00	Left	76.00	16985.82
	5 of 5	11-Aug-05	5.85		27.20	Left	94.00	16820.69
67	1 of 5	12-Aug-05	5.70	2862.86	30.70	Left	22.00	7910.75
	2 of 5	12-Aug-05	5.70	2862.86	32.10	Left	40.00	8320.14
	3 of 5	12-Aug-05	5.70	2862.86	15.40	Left	58.00	8670.31
	4 of 5	12-Aug-05	5.70	2862.86	20.00	Left	76.00	7205.04
	5 of 5	12-Aug-05	5.70	2862.86	20.00	Left	94.00	7205.43
68	1 of 5	12-Aug-05	6.12		29.20	Right	14.00	12677.74
	2 of 5	12-Aug-05	6.12		25.90	Right	32.00	14197.08
	3 of 5	12-Aug-05	6.12		33.70	Right	50.00	14874.32
	4 of 5	12-Aug-05	6.12		27.10	Right	68.00	13813.01
	5 of 5	12-Aug-05	6.12		18.70	Right	86.00	12815.09
69	1 of 5	13-Aug-09	4.99	2038.42	25.70	Right	16.00	6632.91
	2 of 5	13-Aug-09	4.99	2038.42	28.20	Right	34.00	7242.75
	3 of 5	13-Aug-09	4.99	2038.42	29.70	Right	52.00	7259.26
	4 of 5	13-Aug-09	4.99	2038.42	12.40	Right	70.00	8597.40
	5 of 5	13-Aug-09	4.99	2038.42	14.50	Right	88.00	7700.79
70	1 of 5	13-Aug-09	5.72		35.00	Right	16.00	9149.09
	2 of 5	13-Aug-09	5.72		31.30	Right	34.00	10688.17
	3 of 5	13-Aug-09	5.72		30.00	Right	52.00	12007.04
	4 of 5	13-Aug-09	5.72		31.30	Right	70.00	12805.65
	5 of 5	13-Aug-09	5.72		24.00	Right	88.00	16057.35
71	1 of 5	14-Aug-09	5.25	1977.05	27.40	Right	16.00	9380.00
	2 of 5	14-Aug-09	5.25	1977.05	29.70	Right	34.00	10007.14
	3 of 5	14-Aug-09	5.25	1977.05	32.90	Right	52.00	10741.01
	4 of 5	14-Aug-09	5.25	1977.05	24.10	Right	70.00	11087.30
	5 of 5	14-Aug-09	5.25	1977.05	10.90	Right	88.00	9794.96
72	1 of 5	14-Aug-09	5.46		12.00	Left	22.00	10275.00
	2 of 5	14-Aug-09	5.46		24.00	Left	40.00	11401.27
	3 of 5	14-Aug-09	5.46		32.50	Left	58.00	9700.40
	4 of 5	14-Aug-09	5.46		29.40	Left	76.00	10180.00
	5 of 5	14-Aug-09	5.46		28.20	Left	94.00	8426.57
73	1 of 5	15-Aug-09	5.73		13.50	Left	22.00	13274.68
	2 of 5	15-Aug-09	5.73		24.60	Left	40.00	12333.33
	3 of 5	15-Aug-09	5.73		34.00	Left	58.00	13442.03
	4 of 5	15-Aug-09	5.73		34.00	Left	76.00	12750.92
	5 of 5	15-Aug-09	5.73		28.10	Left	94.00	12528.99

No.	Field Sample No.	Date & time of Sampling	Gage height (m)	Flow (m3/s)	Depth (m)	Direction of measurement	Width (m)	Sediment Conc. (mg/l)
74	1 of 5	15-Aug-09	5.73		17.20	Left	22.00	6573.08
	2 of 5	15-Aug-09	5.73		24.60	Left	40.00	6833.65
	3 of 5	15-Aug-09	5.73		34.60	Left	58.00	7028.99
	4 of 5	15-Aug-09	5.73		30.90	Left	76.00	6468.86
	5 of 5	15-Aug-09	5.73		27.40	Left	94.00	5124.55
75	1 of 5	16-Aug-09	5.65	2093.98	11.80	Left	22.00	6531.69
	2 of 5	16-Aug-09	5.65	2093.98	24.10	Left	40.00	7074.62
	3 of 5	16-Aug-09	5.65	2093.98	30.70	Left	58.00	6961.24
	4 of 5	16-Aug-09	5.65	2093.98	30.10	Left	76.00	6135.24
	5 of 5	16-Aug-09	5.65	2093.98	26.70	Left	94.00	5368.03
76	1 of 5	16-Aug-09	6.00		29.10	Right	16.00	9076.05
	2 of 5	16-Aug-09	6.00		32.30	Right	34.00	8906.98
	3 of 5	16-Aug-09	6.00		34.50	Right	52.00	8966.24
	4 of 5	16-Aug-09				Right		
	5 of 5	16-Aug-09				Right		
77	1 of 5	17-Aug-09	5.00	3127.04	35.00	Left	22.00	11969.23
	2 of 5	17-Aug-09	5.00	3127.04	13.00	Left	40.00	10222.22
	3 of 5	17-Aug-09	5.00	3127.04	31.80	Left	58.00	11400.00
	4 of 5	17-Aug-09	5.00	3127.04	27.50	Left	76.00	9470.59
	5 of 5	17-Aug-09	5.00	3127.04	36.00	Left	94.00	9000.00
78	1 of 5	17-Aug-09	4.90		10.90	Right	22.00	6800.00
	2 of 5	17-Aug-09	4.90		12.00	Right	40.00	7280.00
	3 of 5	17-Aug-09	4.90		32.00	Right	58.00	7263.16
	4 of 5	17-Aug-09	4.90		28.00	Right	76.00	7342.11
	5 of 5	17-Aug-09	4.90		26.00	Right	94.00	6764.71
79	1 of 5	18-Aug-09	5.05	2277.38	36.00	Right	16.00	10615.39
	2 of 5	18-Aug-09	5.05	2277.38	29.40	Right	34.00	12447.37
	3 of 5	18-Aug-09	5.05	2277.38	32.50	Right	52.00	13729.73
	4 of 5	18-Aug-09	5.05	2277.38	23.10	Right	70.00	12414.63
	5 of 5	18-Aug-09	5.05	2277.38	12.00	Right	88.00	12256.41
80	1 of 5	18-Aug-09	6.25		31.70	Left	22.00	19352.11
	2 of 5	18-Aug-09	6.25		33.10	Left	34.00	14684.93
	3 of 5	18-Aug-09	6.25		33.70	Left	52.00	17333.33
	4 of 5	18-Aug-09	6.25		27.10	Left	70.00	16169.01
	5 of 5	18-Aug-09	6.25		17.10	Left	88.00	16481.01
81	1 of 5	19-Aug-09	5.85	2923.99	27.40	Right	16.00	12024.69
	2 of 5	19-Aug-09	5.85	2923.99	30.90	Right	34.00	11325.00
	3 of 5	19-Aug-09	5.85	2923.99	34.00	Right	52.00	11818.18
	4 of 5	19-Aug-09	5.85	2923.99	24.60	Right	70.00	12049.38
	5 of 5	19-Aug-09	5.85	2923.99	17.20	Right	88.00	10027.03

No.	Field Sample No.	Date & time of Sampling	Gage height (m)	Flow (m3/s)	Depth (m)	Direction of measurement	Width (m)	Sediment Conc. (mg/l)
82	1 of 5	19-Aug-09	6.18	2593.63	18.70	Left	22.00	13500.00
	2 of 5	19-Aug-09	6.18	2593.63	27.10	Left	40.00	12273.97
	3 of 5	19-Aug-09	6.18	2593.63	35.90	Left	58.00	11617.65
	4 of 5	19-Aug-09	6.18	2593.63	32.20	Left	76.00	12864.87
	5 of 5	19-Aug-09	6.18	2593.63	29.20	Left	94.00	11818.18
83	1 of 5	20-Aug-09	6.04	2767.62	28.60	Right	16.00	12947.37
	2 of 5	20-Aug-09	6.04	2767.62	34.00	Right	34.00	13402.99
	3 of 5	20-Aug-09	6.04	2767.62	34.70	Right	52.00	13797.47
	4 of 5	20-Aug-09	6.04	2767.62	26.50	Right	70.00	14815.79
	5 of 5	20-Aug-09	6.04	2767.62	18.10	Right	88.00	15763.16
84	1 of 5	20-Aug-09	5.55		27.40	Right	16.00	11194.44
	2 of 5	20-Aug-09	5.55		32.10	Right	34.00	13215.19
	3 of 5	20-Aug-09	5.55		32.70	Right	52.00	13225.00
	4 of 5	20-Aug-09	5.55		22.90	Right	70.00	12911.39
	5 of 5	20-Aug-09	5.55		11.80	Right	88.00	14842.11
85	1 of 5	21-Aug-09	7.70	4217.88	24.10	Left	22.00	24200.00
	2 of 5	21-Aug-09	7.70	4217.88	31.30	Left	40.00	23913.04
	3 of 5	21-Aug-09	7.70	4217.88	40.70	Left	58.00	20933.33
	4 of 5	21-Aug-09	7.70	4217.88	37.60	Left	76.00	22914.29
	5 of 5	21-Aug-09	7.70	4217.88	35.30	Left	94.00	21506.49
86	1 of 5	21-Aug-09	7.28		34.40	Right	22.00	9648.65
	2 of 5	21-Aug-09	7.28		37.20	Right	40.00	10029.41
	3 of 5	21-Aug-09	7.28		38.80	Right	58.00	12771.43
	4 of 5	21-Aug-09	7.28		32.20	Right	76.00	12931.51
	5 of 5	21-Aug-09	7.28		23.90	Right	94.00	12151.52
87	1 of 5	22-Aug-09	7.95	3198.50	25.00	Left	22.00	14277.78
	2 of 5	22-Aug-09	7.95	3198.50	32.10	Left	40.00	11294.12
	3 of 5	22-Aug-09	7.95	3198.50	41.30	Left	58.00	12584.62
	4 of 5	22-Aug-09	7.95	3198.50	38.30	Left	76.00	10939.39
	5 of 5	22-Aug-09	7.95	3198.50	36.00	Left	94.00	11855.07
88	1 of 5	22-Aug-09	7.12		33.00	Right	18.00	8169.01
	2 of 5	22-Aug-09	7.12		35.20	Right	36.00	7764.71
	3 of 5	22-Aug-09	7.12		38.20	Right	54.00	7594.94
	4 of 5	22-Aug-09	7.12		25.00	Right	72.00	6400.00
	5 of 5	22-Aug-09	7.12		22.10	Right	90.00	7831.33
89	1 of 5	23-Aug-09	6.04	2707.97	14.10	Left	22.00	6480.00
	2 of 5	23-Aug-09	6.04	2707.97	25.20	Left	40.00	6693.33
	3 of 5	23-Aug-09	6.04	2707.97	35.70	Left	58.00	7578.95
	4 of 5	23-Aug-09	6.04	2707.97	31.50	Left	76.00	6731.71
	5 of 5	23-Aug-09	6.04	2707.97	29.20	Left	94.00	7894.74

No.	Field Sample No.	Date & time of Sampling	Gage height (m)	Flow (m3/s)	Depth (m)	Direction of measurement	Width (m)	Sediment Conc. (mg/l)
90	1 of 5	23-Aug-09	6.60		16.30	Right	18.00	9120.00
	2 of 5	23-Aug-09	6.60		27.30	Right	36.00	7714.29
	3 of 5	23-Aug-09	6.60		37.90	Right	54.00	7743.59
	4 of 5	23-Aug-09	6.60		27.30	Right	72.00	17392.41
	5 of 5	23-Aug-09	6.60		16.20	Right	90.00	8556.96
91	1 of 5	24-Aug-09	5.75	2683.34	26.30	Left	22.00	4756.09
	2 of 5	24-Aug-09	5.75	2683.34	31.70	Left	40.00	5125.00
	3 of 5	24-Aug-09	5.75	2683.34	32.10	Left	58.00	5923.08
	4 of 5	24-Aug-09	5.75	2683.34	18.80	Left	76.00	5164.56
	5 of 5	24-Aug-09	5.75	2683.34	18.20	Left	94.00	4379.75
92	1 of 5	24-Aug-09	5.95		27.10	Right	18.00	5219.51
	2 of 5	24-Aug-09	5.95		30.80	Right	36.00	5414.29
	3 of 5	24-Aug-09	5.95		30.80	Right	54.00	4753.62
	4 of 5	24-Aug-09	5.95		34.10	Right	72.00	5125.00
	5 of 5	24-Aug-09	5.95		25.80	Right	90.00	4169.01
93	1 of 5	25-Aug-09	5.85	2870.04	27.20	Right	16.00	5610.39
	2 of 5	25-Aug-09	5.85	2870.04	30.00	Right	34.00	6628.57
	3 of 5	25-Aug-09	5.85	2870.04	34.00	Right	52.00	5378.38
	4 of 5	25-Aug-09	5.85	2870.04	23.10	Right	70.00	5714.29
	5 of 5	25-Aug-09	5.85	2870.04	16.20	Right	888.00	7402.60
94	1 of 5	25-Aug-09	7.00	3551.08	21.20	Left	22.00	12525.00
	2 of 5	25-Aug-09	7.00	3551.08	29.60	Left	40.00	12647.89
	3 of 5	25-Aug-09	7.00	3551.08	36.20	Left	58.00	11676.47
	4 of 5	25-Aug-09	7.00	3551.08	34.70	Left	76.00	14525.00
	5 of 5	25-Aug-09	7.00	3551.08	31.70	Left	94.00	13585.37
95	1 of 5	26-Aug-09	7.30	3807.32	35.30	Right	22.00	9146.67
	2 of 5	26-Aug-09	7.30	3807.32	37.60	Right	38.00	
	3 of 5	26-Aug-09	7.30	3807.32	40.70	Right	56.00	9714.29
	4 of 5	26-Aug-09	7.30	3807.32	32.50	Right	74.00	7882.35
	5 of 5	26-Aug-09	7.30	3807.32	24.10	Right	92.00	11188.41
96	1 of 5	26-Aug-09	7.16		23.90	Left	22.00	11827.16
	2 of 5	26-Aug-09	7.16		32.00	Left	40.00	11397.26
	3 of 5	26-Aug-09	7.16		40.10	Left	58.00	9923.08
	4 of 5	26-Aug-09	7.16			Left	76.00	9725.00
	5 of 5	26-Aug-09	7.16			Left	94.00	9604.94
97	1 of 5	27-Aug-09	6.25	3194.00	18.80	Left	22.00	6929.82
	2 of 5	27-Aug-09	6.25	3194.00	16.80	Left	40.00	7356.36
	3 of 5	27-Aug-09	6.25	3194.00	35.40	Left	58.00	6955.10
	4 of 5	27-Aug-09	6.25	3194.00	32.30	Left	76.00	7056.22
	5 of 5	27-Aug-09	6.25	3194.00	30.00	Left	94.00	6811.76

No.	Field Sample No.	Date & time of Sampling	Gage height (m)	Flow (m3/s)	Depth (m)	Direction of measurement	Width (m)	Sediment Conc. (mg/l)
98	1 of 5	27-Aug-09	6.76		32.00	Right	18.00	7069.34
	2 of 5	27-Aug-09	6.76		34.30	Right	36.00	8174.27
	3 of 5	27-Aug-09	6.76		38.00	Right	54.00	11008.85
	4 of 5	27-Aug-09	6.76		18.50	Right	72.00	10128.68
	5 of 5	27-Aug-09	6.76		20.80	Right	90.00	10238.49
99	1 of 5	28-Aug-09	6.22	2535.80	29.20	Right	16.00	6264.82
	2 of 5	28-Aug-09	6.22	2535.80	28.00	Right	34.00	6840.00
	3 of 5	28-Aug-09	6.22	2535.80	35.30	Right	52.00	6767.18
	4 of 5	28-Aug-09	6.22	2535.80	27.10	Right	70.00	6238.10
	5 of 5	28-Aug-09	6.22	2535.80	18.70	Right	88.00	6724.64
100	1 of 5	28-Aug-09	6.00		18.00	Left	22.00	5522.73
	2 of 5	28-Aug-09	6.00		25.00	Left	40.00	6197.76
	3 of 5	28-Aug-09	6.00		34.50	Left	58.00	6128.51
	4 of 5	28-Aug-09	6.00		34.00	Left	76.00	5584.03
	5 of 5	28-Aug-09	6.00		28.00	Left	94.00	4786.67
101	1 of 5	29-Aug-09	6.24	1825.08	18.70	Right	22.00	3444.00
	2 of 5	29-Aug-09	6.24	1825.08	25.90	Right	40.00	3655.05
	3 of 5	29-Aug-09	6.24	1825.08	35.30	Right	58.00	3809.52
	4 of 5	29-Aug-09	6.24	1825.08	32.20	Right	76.00	3173.58
	5 of 5	29-Aug-09	6.24	1825.08	29.20	Right	94.00	3501.90
102	1 of 5	29-Aug-09	5.06		26.40	Right	16.00	3173.39
	2 of 5	29-Aug-09	5.06		31.10	Right	37.00	3843.22
	3 of 5	29-Aug-09	5.06		31.80	Right	52.00	3649.82
	4 of 5	29-Aug-09	5.06		23.60	Right	70.00	3542.17
	5 of 5	29-Aug-09	5.06		15.20	Right	94.00	3320.51
103	1 of 5	30-Aug-09	5.50	2412.96	25.50	Right	16.00	7855.37
	2 of 5	30-Aug-09	5.50	2412.96	31.70	Right	34.00	7448.28
	3 of 5	30-Aug-09	5.50	2412.96	31.40	Right	54.00	7419.75
	4 of 5	30-Aug-09	5.50	2412.96	26.40	Right	72.00	7440.61
	5 of 5	30-Aug-09	5.50	2412.96	16.50	Right	90.00	6822.31
104	1 of 5	30-Aug-09	5.35		16.30	Left	22.00	7088.71
	2 of 5	30-Aug-09	5.35		25.80	Left	40.00	7408.92
	3 of 5	30-Aug-09	5.35		29.10	Left	58.00	7617.76
	4 of 5	30-Aug-09	5.35		28.60	Left	76.00	6956.18
	5 of 5	30-Aug-09	5.35		24.20	Left	94.00	7435.68
105	1 of 5	31-Aug-09	6.70	4018.12	20.20	Left	22.00	10315.00
	2 of 5	31-Aug-09	6.70	4018.12	17.30	Left	40.00	10746.32
	3 of 5	31-Aug-09	6.70	4018.12	37.40	Left	58.00	10394.37
	4 of 5	31-Aug-09	6.70	4018.12	34.00	Left	76.00	11216.87
	5 of 5	31-Aug-09	6.70	4018.12	20.00	Left	94.00	9853.21

No.	Field Sample No.	Date & time of Sampling	Gage height (m)	Flow (m3/s)	Depth (m)	Direction of measurement	Width (m)	Sediment Conc. (mg/l)
106	1 of 5	31-Aug-09	7.20		32.20	Left	22.00	13146.62
	2 of 5	31-Aug-09	7.20		45.20	Left	40.00	13654.62
	3 of 5	31-Aug-09	7.20		46.70	Left	58.00	13885.17
	4 of 5	31-Aug-09	7.20		29.60	Left	76.00	12076.60
	5 of 5	31-Aug-09	7.20		21.20	Left	94.00	13543.93
107	1 of 5	1-Sep-09	6.42	3551.81	30.00	Right	18.00	7096.65
	2 of 5	1-Sep-09	6.42	3551.81	32.00	Right	36.00	8444.88
	3 of 5	1-Sep-09	6.42	3551.81	36.00	Right	54.00	9409.45
	4 of 5	1-Sep-09	6.42	3551.81	16.50	Right	72.00	8439.22
	5 of 5	1-Sep-09	6.42	3551.81	18.80	Right	90.00	9029.41
108	1 of 5	1-Sep-09	6.28		28.10	Left	22.00	8790.98
	2 of 5	1-Sep-09	6.28		30.10	Left	40.00	8988.64
	3 of 5	1-Sep-09	6.28		33.70	Left	58.00	9270.16
	4 of 5	1-Sep-09	6.28		29.80	Left	76.00	9162.88
	5 of 5	1-Sep-09	6.28		28.00	Left	94.00	8333.33
109	1 of 5	2-Sep-09		1885.96				5573.33
	2 of 5	2-Sep-09		1885.96				6091.67
	3 of 5	2-Sep-09		1885.96				6079.37
	4 of 5	2-Sep-09		1885.96				6797.79
	5 of 5	2-Sep-09		1885.96				5734.27
110	1 of 5	2-Sep-09						6026.09
	2 of 5	2-Sep-09						6902.22
	3 of 5	2-Sep-09						7968.25
	4 of 5	2-Sep-09						6119.13
	5 of 5	2-Sep-09						5448.15
111	1 of 5	3-Sep-09		1978.48				5027.03
	2 of 5	3-Sep-09		1978.48				4969.16
	3 of 5	3-Sep-09		1978.48				6272.32
	4 of 5	3-Sep-09		1978.48				5969.57
	5 of 5	3-Sep-09		1978.48				5012.05
112	1 of 5	3-Sep-09						4303.03
	2 of 5	3-Sep-09						4109.09
	3 of 5	3-Sep-09						4193.55
	4 of 5	3-Sep-09						4521.19
	5 of 5	3-Sep-09						4413.22
113	1 of 5	4-Sep-09		1722.28				4261.36
	2 of 5	4-Sep-09		1722.28				4734.78
	3 of 5	4-Sep-09		1722.28				4314.39
	4 of 5	4-Sep-09		1722.28				5271.89
	5 of 5	4-Sep-09		1722.28				4362.60

No.	Field Sample No.	Date & time of Sampling	Gage height (m)	Flow (m3/s)	Depth (m)	Direction of measurement	Width (m)	Sediment Conc. (mg/l)
114	1 of 5	5-Sep-09	5.10		13.50	Left	22.00	11806.32
	2 of 5	5-Sep-09	5.10		30.90	Left	40.00	10441.99
	3 of 5	5-Sep-09	5.10		30.90	Left	58.00	9130.91
	4 of 5	5-Sep-09	5.10		27.80	Left	76.00	10239.67
	5 of 5	5-Sep-09	5.10		25.50	Left	94.00	9271.32
115	1 of 5	6-Sep-09	5.33	1886.85	26.70	Right	16.00	9198.16
	2 of 5	6-Sep-09	5.33	1886.85	29.00	Right	34.00	9362.60
	3 of 5	6-Sep-09	5.33	1886.85	32.10	Right	52.00	9492.06
	4 of 5	6-Sep-09	5.33	1886.85	23.90	Right	70.00	9235.77
	5 of 5	6-Sep-09	5.33	1886.85	10.70	Right	88.00	11585.90
116	1 of 5	6-Sep-09	5.25		26.00	Right	14.00	7329.41
	2 of 5	6-Sep-09	5.25			Right	36.00	7644.19
	3 of 5	6-Sep-09	5.25		21.90	Right		8467.92
	4 of 5	6-Sep-09				Right		8883.46
	5 of 5	6-Sep-09	5.25			Right		8745.32
117	1 of 5	7-Sep-09	4.72	1364.84	24.80	Left	22.00	4913.42
	2 of 5	7-Sep-09	4.72	1364.84	24.80	Left	40.00	5026.32
	3 of 5	7-Sep-09	4.72	1364.84	24.80	Left	58.00	5197.58
	4 of 5	7-Sep-09	4.72	1364.84	24.80	Left	76.00	4882.59
	5 of 5	7-Sep-09	4.72	1364.84	24.80	Left	94.00	5211.62
118	1 of 5	7-Sep-09	4.80		28.00	Right	16.00	5276.32
	2 of 5	7-Sep-09	4.80		28.00	Right	34.00	5550.20
	3 of 5	7-Sep-09	4.80		28.00	Right	52.00	5287.50
	4 of 5	7-Sep-09	4.80		28.00	Right	70.00	5182.93
	5 of 5	7-Sep-09	4.80		28.00	Right	88.00	5556.31
119	1 of 5	8-Sep-09	4.35	1354.35	6.80	Left	22.00	2776.19
	2 of 5	8-Sep-09	4.35	1354.35	20.00	Left	40.00	3795.65
	3 of 5	8-Sep-09	4.35	1354.35	28.20	Left	58.00	4125.00
	4 of 5	8-Sep-09	4.35	1354.35	25.50	Left	76.00	3806.28
	5 of 5	8-Sep-09	4.35	1354.35	22.80	Left	94.00	4603.77
120	1 of 5	8-Sep-09	4.37			Left	22.00	1864.63
	2 of 5	8-Sep-09	4.37		27.50	Left	40.00	2043.31
	3 of 5	8-Sep-09	4.37		29.90	Left	58.00	2307.69
	4 of 5	8-Sep-09	4.37		26.80	Left	76.00	2763.39
	5 of 5	8-Sep-09	4.37		24.50	Left	94.00	2618.87
121	1 of 5	9-Sep-09	4.34		24.00	Right	16.00	3491.02
	2 of 5	9-Sep-09	4.34		24.50	Right	34.00	2691.98
	3 of 5	9-Sep-09	4.34			Right	52.00	2093.88
	4 of 5	9-Sep-09	4.34		21.00	Right	70.00	2096.00
	5 of 5	9-Sep-09	4.34		808.00	Right	88.00	1911.89

No.	Field Sample No.	Date & time of Sampling	Gage height (m)	Flow (m3/s)	Depth (m)	Direction of measurement	Width (m)	Sediment Conc. (mg/l)
122	1 of 5	10-Sep-09	4.10		9.80	Left	22.00	2271.49
	2 of 5	10-Sep-09	4.10		22.70	Left	40.00	2270.59
	3 of 5	10-Sep-09	4.10		30.90	Left	58.00	2402.71
	4 of 5	10-Sep-09	4.10		27.80	Left	76.00	2463.20
	5 of 5	10-Sep-09	4.10		28.00	Left	16.00	2155.74
123	1 of 5	11-Sep-09	3.79		21.40	Right	14.00	1400.90
	2 of 5	11-Sep-09	3.79		22.20	Right	32.00	1520.66
	3 of 5	11-Sep-09	3.79		29.60	Right	50.00	1512.40
	4 of 5	11-Sep-09	3.79		21.40	Right	68.00	1475.41
	5 of 5	11-Sep-09	3.79		9.90	Right	80.00	1355.00
124	1 of 5	11-Sep-09	3.72		19.60	Right	16.00	1643.17
	2 of 5	11-Sep-09	3.72		18.90	Right	34.00	1491.23
	3 of 5	11-Sep-09	3.72		20.40	Right	52.00	1531.65
	4 of 5	11-Sep-09	3.72		16.10	Right	70.00	1353.98
	5 of 5	11-Sep-09	3.72			Right	88.00	1272.32
125	1 of 5	12-Sep-09	3.61	461.69	7.70	Left	22.00	1563.88
	2 of 5	12-Sep-09	3.61	461.69	11.90	Left	40.00	1383.62
	3 of 5	12-Sep-09	3.61	461.69	17.40	Left	58.00	1614.17
	4 of 5	12-Sep-09	3.61	461.69	19.30	Left	76.00	1983.19
	5 of 5	12-Sep-09	3.61	461.69	19.20	Left	94.00	1251.05
126	1 of 5	12-Sep-09	3.51		18.70	Right	14.00	1061.40
	2 of 5	12-Sep-09	3.51		19.00	Right	32.00	1833.99
	3 of 5	12-Sep-09	3.51		18.00	Right	50.00	1586.21
	4 of 5	12-Sep-09	3.51		12.80	Right	68.00	1024.00
	5 of 5	12-Sep-09	3.51		9.10	Right	86.00	1400.00
127	1 of 5	13-Sep-09	3.44	415.07	8.40	Right	22.00	1273.50
	2 of 5	13-Sep-09	3.44	415.07	10.90	Right	40.00	2155.46
	3 of 5	13-Sep-09	3.44	415.07	17.70	Right	58.00	1401.57
	4 of 5	13-Sep-09	3.44	415.07	18.70	Right	76.00	1250.00
	5 of 5	13-Sep-09	3.44	415.07		Right	94.00	1043.48
128	1 of 5	13-Sep-09	3.41		18.50	Left	14.00	949.37
	2 of 5	13-Sep-09	3.41		18.50	Left	32.00	1452.26
	3 of 5	13-Sep-09	3.41		17.60	Left	50.00	2158.59
	4 of 5	13-Sep-09	3.41		10.70	Left	68.00	1118.14
	5 of 5	13-Sep-09	3.41		8.00	Left	86.00	1056.03
129	1 of 5	14-Sep-09	3.40	487.20	6.60	Left	26.00	705.13
	2 of 5	14-Sep-09	33.30	487.20	22.10	Left	42.00	1895.65
	3 of 5	14-Sep-09	3.40	487.20	16.20	Left	58.00	948.94
	4 of 5	14-Sep-09	3.40	487.20	26.00	Left	74.00	754.17
	5 of 5	14-Sep-09	33.30	487.20	21.60	Left	94.00	1176.99

No.	Field Sample No.	Date & time of Sampling	Gage height (m)	Flow (m3/s)	Depth (m)	Direction of measurement	Width (m)	Sediment Conc. (mg/l)
130	1 of 5	14-Sep-09	3.40		24.00	Right	18.00	887.55
	2 of 5	14-Sep-09	3.40		25.10	Right	34.00	1080.72
	3 of 5	14-Sep-09	3.40		24.10	Right	50.00	1017.39
	4 of 5	14-Sep-09	3.40		26.20	Right	66.00	1149.19
	5 of 5	14-Sep-09	3.40		11.70	Right	82.00	1145.16
131	1 of 5	15-Sep-09	3.24	386.84	17.50	Right	18.00	652.17
	2 of 5	15-Sep-09	3.24	386.84	16.70	Right	33.00	655.32
	3 of 5	15-Sep-09	3.24	386.84	14.70	Right	48.00	738.10
	4 of 5	15-Sep-09	3.24	386.84	10.30	Right	63.00	1341.01
	5 of 5	15-Sep-09	3.24	386.84	4.10	Right	28.00	684.87
132	1 of 5	15-Sep-09	3.28		4.40	Left	28.00	765.77
	2 of 5	15-Sep-09	3.28		15.00	Left	43.00	732.51
	3 of 5	15-Sep-09	3.28		15.70	Left	58.00	1443.40
	4 of 5	15-Sep-09	3.28		17.00	Left	73.00	783.46
	5 of 5	15-Sep-09	3.28		17.60	Left	88.00	874.07
133	1 of 5	16-Sep-09	3.16	413.31	9.10	Left	34.00	720.52
	2 of 5	16-Sep-09	3.16	413.31	12.40	Left	46.00	1186.13
	3 of 5	16-Sep-09	3.16	413.31	14.70	Left	58.00	873.47
	4 of 5	16-Sep-09	3.16	413.31	18.00	Left	70.00	891.30
	5 of 5	16-Sep-09	3.16	413.31	16.80	Left	82.00	848.71
134	1 of 5	16-Sep-09	3.22		16.00	Right	25.00	811.76
	2 of 5	16-Sep-09	3.22		14.90	Right	37.00	711.38
	3 of 5	16-Sep-09	3.22		10.90	Right	49.00	927.71
	4 of 5	16-Sep-09	3.22		9.70	Right	61.00	873.19
	5 of 5	16-Sep-09	3.22		8.50	Right	73.00	938.05
135	1 of 5	17-Sep-09	3.20	421.77	17.00	Right	25.00	910.11
	2 of 5	17-Sep-09	3.20	421.77		Right	37.00	2341.37
	3 of 5	17-Sep-09	3.20	421.77	14.70	Right	49.00	1274.19
	4 of 5	17-Sep-09	3.20	421.77	12.90	Right	49.00	1674.16
	5 of 5	17-Sep-09	3.20	421.77	9.00	Right	61.00	2066.67
136	1 of 5	17-Sep-09	3.22		9.30	Left	38.00	2466.14
	2 of 5	17-Sep-09	3.22		13.00	Left	50.00	2022.81
	3 of 5	17-Sep-09	3.22		14.80	Left	58.00	1625.47
	4 of 5	17-Sep-09	3.22			Left	70.00	1483.02
	5 of 5	17-Sep-09	3.22		17.00	Left	25.00	1012.50
137	1 of 5	18-Sep-09	3.28	437.70	8.40	Left	34.00	3481.78
	2 of 5	18-Sep-09	3.28	437.70	12.20	Left	46.00	3415.77
	3 of 5	18-Sep-09	3.28	437.70	15.00	Left	58.00	2924.37
	4 of 5	18-Sep-09	3.28	437.70	15.00	Left	70.00	2663.97
	5 of 5	18-Sep-09	3.28	437.70	17.80	Left	82.00	3284.64

No.	Field Sample No.	Date & time of Sampling	Gage height (m)	Flow (m3/s)	Depth (m)	Direction of measurement	Width (m)	Sediment Conc. (mg/l)
138	1 of 5	18-Sep-09	3.30		17.60	Right	25.00	3712.45
	2 of 5	18-Sep-09	3.30		18.00	Right	36.00	3028.69
	3 of 5	18-Sep-09	3.30		13.00	Right	47.00	3431.37
	4 of 5	18-Sep-09	3.30		10.00	Right	58.00	3140.63
	5 of 5	18-Sep-09	3.30		10.00	Right	69.00	3925.78
139	1 of 5	19-Sep-09	3.12	363.41	6.10	Left	34.00	2318.78
	2 of 5	19-Sep-09	3.12	363.41	8.90	Left	46.00	1352.46
	3 of 5	19-Sep-09	3.12	363.41	13.70	Left	58.00	1585.94
	4 of 5	19-Sep-09	3.12	363.41	13.70	Left	70.00	2045.45
	5 of 5	19-Sep-09	3.12	363.41	17.00	Left	82.00	1465.35
140	1 of 5	19-Sep-09	3.09			Right	25.00	1356.86
	2 of 5	19-Sep-09	3.09		17.50	Right	37.00	4419.12
	3 of 5	19-Sep-09	3.09		14.80	Right	61.00	2244.90
	4 of 5	19-Sep-09	3.09			Right	73.00	1345.24
	5 of 5	19-Sep-09	3.09		8.00	Right	85.00	1741.07
141	1 of 5	20-Sep-09	3.00	343.57	8.00	Left	34.00	712.00
	2 of 5	20-Sep-09	3.00	343.57	11.90	Left	46.00	705.26
	3 of 5	20-Sep-09	3.00	343.57	15.00	Left	58.00	1282.79
	4 of 5	20-Sep-09	3.00	343.57	15.80	Left	70.00	887.10
	5 of 5	20-Sep-09	3.00	343.57	16.00	Left	82.00	1060.47
142	1 of 5	20-Sep-09	2.99		16.30	Right	25.00	619.23
	2 of 5	20-Sep-09	2.99		12.80	Right	40.00	1023.53
	3 of 5	20-Sep-09	2.99		13.60	Right	55.00	1145.23
	4 of 5	20-Sep-09	2.99		11.00	Right	70.00	1028.04
	5 of 5	20-Sep-09	2.99		6.20	Right	85.00	1020.75
143	1 of 5	21-Sep-09	2.94	316.92	8.20	Left	34.00	643.15
	2 of 5	21-Sep-09	2.94	316.92	10.90	Left	46.00	605.15
	3 of 5	21-Sep-09	2.94	316.92	13.10	Left	58.00	712.55
	4 of 5	21-Sep-09	2.94	316.92	15.00	Left	70.00	616.86
	5 of 5	21-Sep-09	2.94	316.92	16.00	Left	82.00	581.30
144	1 of 5	21-Sep-09	2.91		15.70	Right	25.00	625.64
	2 of 5	21-Sep-09	2.91		14.60	Right	40.00	744.77
	3 of 5	21-Sep-09	2.91		10.70	Right	55.00	596.08
	4 of 5	21-Sep-09	2.91		11.70	Right	70.00	603.05
	5 of 5	21-Sep-09	2.91		9.20	Right	85.00	1372.09
145	1 of 5	22-Sep-09	2.90	329.39	7.80	Left	34.00	512.20
	2 of 5	22-Sep-09	2.90	329.39	10.60	Left	46.00	759.05
	3 of 5	22-Sep-09	2.90	329.39	12.50	Left	58.00	1217.95
	4 of 5	22-Sep-09	2.90	329.39	14.20	Left	70.00	3760.33
	5 of 5	22-Sep-09	2.90	329.39	15.50	Left	82.00	1148.15

No.	Field Sample No.	Date & time of Sampling	Gage height (m)	Flow (m3/s)	Depth (m)	Direction of measurement	Width (m)	Sediment Conc. (mg/l)
146	1 of 5	22-Sep-09	2.96		15.80	Right	25.00	511.81
	2 of 5	22-Sep-09	2.96		15.10	Right	37.00	801.56
	3 of 5	22-Sep-09	2.96		13.10	Right	49.00	448.00
	4 of 5	22-Sep-09	2.96		11.80	Right	61.00	675.78
	5 of 5	22-Sep-09	2.96		8.00	Right	73.00	662.16
147	1 of 5	23-Sep-09	2.86	292.34	9.00	Left	25.00	486.49
	2 of 5	23-Sep-09	2.86	292.34	11.50	Left	35.00	613.28
	3 of 5	23-Sep-09	2.86	292.34	12.80	Left	47.00	709.16
	4 of 5	23-Sep-09	2.86	292.34	13.50	Left	59.00	762.12
	5 of 5	23-Sep-09	2.86	292.34	16.50	Left	71.00	689.92
148	1 of 5	23-Sep-09	2.87		15.80	Right	24.00	440.48
	2 of 5	23-Sep-09	2.87		14.70	Right	36.00	599.22
	3 of 5	23-Sep-09	2.87		13.60	Right	48.00	683.79
	4 of 5	23-Sep-09	2.87		15.50	Right	60.00	542.97
	5 of 5	23-Sep-09	2.87		14.30	Right	72.00	436.00
149	1 of 5	24-Sep-09	2.82	293.60	15.00	Left	26.00	421.49
	2 of 5	24-Sep-09	2.82	293.60	15.20	Left	36.00	552.85
	3 of 5	24-Sep-09	2.82	293.60	14.40	Left	46.00	505.85
	4 of 5	24-Sep-09	2.82	293.60	12.20	Left	56.00	495.93
	5 of 5	24-Sep-09	2.82	293.60	10.00	Left	66.00	387.45
150	1 of 5	24-Sep-09	2.83		9.80	Right	40.00	421.05
	2 of 5	24-Sep-09	2.83		12.00	Right	50.00	534.14
	3 of 5	24-Sep-09	2.83		14.10	Right	60.00	573.71
	4 of 5	24-Sep-09	2.83		15.50	Right	70.00	687.73
	5 of 5	24-Sep-09	2.83		16.20	Right	80.00	501.87
151	1 of 5	25-Sep-09	2.85	282.75	8.80	Left	40.00	976.19
	2 of 5	25-Sep-09	2.85	282.75	11.50	Left	50.00	1585.06
	3 of 5	25-Sep-09	2.85	282.75	13.10	Left	60.00	801.80
	4 of 5	25-Sep-09	2.85	282.75	14.70	Left	70.00	3254.75
	5 of 5	25-Sep-09	2.85	282.75	15.30	Left	80.00	442.80
152	1 of 5	25-Sep-09	2.86		16.20	Right	26.00	401.61
	2 of 5	25-Sep-09	2.86		15.80	Right	36.00	1845.19
	3 of 5	25-Sep-09	2.86		13.30	Right	46.00	1722.22
	4 of 5	25-Sep-09	2.86		13.80	Right	50.00	1685.95
	5 of 5	25-Sep-09	2.86		8.70	Right	36.00	1221.67
153	1 of 5	26-Sep-09	2.85	300.04	9.30	Left	40.00	351.78
	2 of 5	26-Sep-09	2.85	300.04	11.50	Left	50.00	444.44
	3 of 5	26-Sep-09	2.85	300.04	14.60	Left	60.00	511.81
	4 of 5	26-Sep-09	2.85	300.04	12.50	Left	70.00	385.21
	5 of 5	26-Sep-09	2.85	300.04	15.70	Left	80.00	346.15

No.	Field Sample No.	Date & time of Sampling	Gage height (m)	Flow (m3/s)	Depth (m)	Direction of measurement	Width (m)	Sediment Conc. (mg/l)
154	1 of 5	26-Sep-09	2.87		15.60	Right	26.00	598.46
	2 of 5	26-Sep-09	2.87		15.50	Right	36.00	877.39
	3 of 5	26-Sep-09	2.87		14.20	Right	46.00	426.78
	4 of 5	26-Sep-09	2.87		12.00	Right	56.00	456.00
	5 of 5	26-Sep-09	2.87		10.00	Right	66.00	555.10
155	1 of 5	27-Sep-09	2.91	295.17	9.80	Left	40.00	745.37
	2 of 5	27-Sep-09	2.91	295.17	12.70	Left	50.00	559.36
	3 of 5	27-Sep-09	2.91	295.17	14.00	Left	60.00	665.32
	4 of 5	27-Sep-09	2.91	295.17	15.60	Left	70.00	465.59
	5 of 5	27-Sep-09	2.91	295.17	16.00	Left	80.00	459.59
156	1 of 5	27-Sep-09	2.88		16.20	Right	26.00	466.93
	2 of 5	27-Sep-09	2.88		16.10	Right	36.00	521.91
	3 of 5	27-Sep-09	2.88		15.20	Right	46.00	659.92
	4 of 5	27-Sep-09	2.88		14.60	Right	50.00	654.76
	5 of 5	27-Sep-09	2.88		10.50	Right	60.00	619.43
157	1 of 5	28-Sep-09	2.89	296.13	15.30	Right	26.00	1096.23
	2 of 5	28-Sep-09	2.89	296.13	15.00	Right	36.00	765.96
	3 of 5	28-Sep-09	2.89	296.13	14.10	Right	46.00	640.82
	4 of 5	28-Sep-09	2.89	296.13	11.80	Right	56.00	527.78
	5 of 5	28-Sep-09	2.89	296.13	9.80	Right	66.00	498.04
158	1 of 5	28-Sep-09	2.87		9.80	Left	40.00	574.14
	2 of 5	28-Sep-09	2.87		12.80	Left	50.00	510.12
	3 of 5	28-Sep-09	2.87		15.10	Left	60.00	738.78
	4 of 5	28-Sep-09	2.87		15.20	Left	70.00	564.32
	5 of 5	28-Sep-09	2.87		15.40	Left	80.00	608.51
159	1 of 5	23-Jan-10	2.50	104.81	1.83	Left	15.00	129.82
	2 of 5	23-Jan-10	2.50	104.81	2.50	Left	23.00	128.03
	3 of 5	23-Jan-10	2.50	104.81	3.17	Left	35.00	160.18
	4 of 5	23-Jan-10	2.50	104.81	3.84	Left	43.00	136.62
	5 of 5	23-Jan-10	2.50	104.81	3.84	Left	55.00	137.55

No.	Field Sample No.	Date & time of Sampling	Gage height (m)	Flow (m3/s)	Depth (m)	Direction of measurement	Width (m)	Sediment Conc. (mg/l)
160	1 of 5	23-Feb-10	2.55	0.40	12.00	Right	12.00	130.67
	2 of 5	23-Feb-10	2.55	0.40	12.10	Right	24.00	148.57
	3 of 5	23-Feb-10	2.55	0.40	12.90	Right	36.00	145.79
	4 of 5	23-Feb-10	2.55	0.40	10.00	Right	48.00	134.83
	5 of 5	23-Feb-10	2.55	0.40	8.10	Right	60.00	138.06
161	1 of 5	31-Mar-10	1.88	0.32	11.90	Right	14.00	200.98
	2 of 5	31-Mar-10	1.88	0.32	12.60	Right	28.00	177.12
	3 of 5	31-Mar-10	1.88	0.32	10.10	Right	42.00	195.83
	4 of 5	31-Mar-10	1.88	0.32	7.80	Right	56.00	182.54
	5 of 5	31-Mar-10	1.88	0.32	5.70	Right	70.00	180.56
162	1 of 5	4-May-10	2.18		7.40	Left	18.00	5257.94
	2 of 5	4-May-10	2.18		10.00	Left	30.00	5733.91
	3 of 5	4-May-10	2.18		13.10	Left	42.00	4987.80
	4 of 5	4-May-10	2.18		12.90	Left	54.00	5093.39
	5 of 5	4-May-10	2.18		10.00	Left	66.00	5199.15
163	1 of 5	20-Jun-10	1.96		7.70	Left	22.00	17097.56
	2 of 5	20-Jun-10	2.96		9.70	Left	30.00	19162.79
	3 of 5	20-Jun-10	3.96		11.40	Left	38.00	19384.31
	4 of 5	20-Jun-10	4.96		12.70	Left	46.00	19960.00
	5 of 5	20-Jun-10	5.96		11.00	Left	56.00	19302.68
164	1 of 5	17-Jul-10	4.06	1.65	11.00	Left	14.30	18475.86
	2 of 5	17-Jul-10	4.06	1.65	16.50	Left	28.60	19966.91
	3 of 5	17-Jul-10	4.06	1.65	18.60	Left	42.90	13968.53
	4 of 5	17-Jul-10	4.06	1.65	18.80	Left	57.20	22760.87
	5 of 5	17-Jul-10	4.06	1.65	19.20	Left	71.50	17193.13
165	1 of 5	18-Jul-10	4.25	2.45	16.00	Right	15.00	25076.92
	2 of 5	18-Jul-10	4.25	2.45	16.70	Right	30.00	21504.24
	3 of 5	18-Jul-10	4.25	2.45		Right	45.00	23819.23
	4 of 5	18-Jul-10	4.25	2.45	13.10	Right	60.00	22550.73
	5 of 5	18-Jul-10	4.25	2.45	14.50	Right	75.00	23937.50
166	1 of 5	19-Jul-10	4.18	2.28	7.70	Left	15.00	21882.98
	2 of 5	19-Jul-10	4.18	2.28	11.50	Left	30.00	23316.87
	3 of 5	19-Jul-10	4.18	2.28	15.30	Left	45.00	23265.15
	4 of 5	19-Jul-10	4.18	2.28	15.00	Left	60.00	22114.29
	5 of 5	19-Jul-10	4.18	2.28	14.20	Left	75.00	20801.53
167	1 of 5	20-Jul-10	4.78	2.26	16.50	Left	18.30	30040.16
	2 of 5	20-Jul-10	4.78	2.26	16.60	Left	36.60	25881.89
	3 of 5	20-Jul-10	4.78	2.26	13.90	Left	54.90	19218.39
	4 of 5	20-Jul-10	4.78	2.26	10.90	Left	73.20	18270.27
	5 of 5	20-Jul-10	4.78	2.26	7.90	Left	91.50	20628.69

No.	Field Sample No.	Date & time of Sampling	Gage height (m)	Flow (m3/s)	Depth (m)	Direction of measurement	Width (m)	Sediment Conc. (mg/l)
168	1 of 5	21-Jul-10	5.64	3.18	6.00	Right	18.00	34880.14
	2 of 5	21-Jul-10	5.64	3.18	12.70	Right	36.00	19153.85
	3 of 5	21-Jul-10	5.64	3.18	15.50	Right	54.00	24184.03
	4 of 5	21-Jul-10	5.64	3.18	19.80	Right	72.00	25260.07
	5 of 5	21-Jul-10	5.64	3.18	19.20	Right	90.00	33357.66
169	1 of 5	22-Jul-10	6.70	4.09	10.50	Left	18.70	32333.33
	2 of 5	22-Jul-10	6.70	4.09	24.80	Left	37.40	32833.33
	3 of 5	22-Jul-10	6.70	4.09	19.00	Left	56.10	77520.16
	4 of 5	22-Jul-10	6.70	4.09	18.00	Left	74.80	30215.33
	5 of 5	22-Jul-10	6.70	4.09	11.50	Left	93.50	30399.02
170	1 of 5	25-Jul-10	7.65	4.40	25.80	Right	19.30	17073.80
	2 of 5	25-Jul-10	7.65	4.40	25.70	Right	38.60	16095.94
	3 of 5	25-Jul-10	7.65	4.40	23.40	Right	57.90	17402.34
	4 of 5	25-Jul-10	7.65	4.40	21.30	Right	77.20	17265.63
	5 of 5	25-Jul-10	7.65	4.40	10.70	Right	96.50	22793.72
171	1 of 5	26-Jul-10	6.35	3.18	7.80	Left	19.30	17285.17
	2 of 5	26-Jul-10	6.35	3.18	15.30	Left	38.60	12532.32
	3 of 5	26-Jul-10	6.35	3.18	18.60	Left	57.90	12399.21
	4 of 5	26-Jul-10	6.35	3.18	21.00	Left	77.20	20777.78
	5 of 5	26-Jul-10	6.35	3.18	7.00	Left	96.50	21141.26
172	1 of 5	27-Jul-10	6.86		9.20	Right	18.60	26794.22
	2 of 5	27-Jul-10	6.86			Right	37.30	29098.11
	3 of 5	27-Jul-10	6.86			Right	55.90	27362.21
	4 of 5	27-Jul-10	6.86			Right	74.50	22547.45
	5 of 5	27-Jul-10	6.86			Right	93.10	25483.61
173	1 of 5	28-Jul-10	7.15	4.57	8.20	Left	19.00	13700.00
	2 of 5	28-Jul-10	7.15	4.57	18.40	Left	38.00	17136.53
	3 of 5	28-Jul-10	7.15	4.57	21.30	Left	57.00	14908.43
	4 of 5	28-Jul-10	7.15	4.57	24.00	Left	76.00	17482.52
	5 of 5	28-Jul-10	7.15	4.57	10.00	Left	95.00	19515.46
174	1 of 5	29-Jul-10	6.15			Right	19.00	6791.67
	2 of 5	29-Jul-10	6.15			Right	38.00	7016.26
	3 of 5	29-Jul-10	6.15			Right	57.00	7682.14
	4 of 5	29-Jul-10	6.15			Right	76.00	6648.98
	5 of 5	29-Jul-10	6.15			Right	95.00	7423.08
175	1 of 5	30-Jul-10	6.50	3.89	10.00	Left	19.00	15752.17
	2 of 5	30-Jul-10	6.50	3.89	16.50	Left	38.00	17684.59
	3 of 5	30-Jul-10	6.50	3.89	20.00	Left	57.00	17926.83
	4 of 5	30-Jul-10	6.50	3.89	22.90	Left	76.00	16541.67
	5 of 5	30-Jul-10	6.50	3.89	8.20	Left	95.00	20743.77

No.	Field Sample No.	Date & time of Sampling	Gage height (m)	Flow (m3/s)	Depth (m)	Direction of measurement	Width (m)	Sediment Conc. (mg/l)
176	1 of 5	31-Jul-10	5.95		19.80	Right	19.00	8965.38
	2 of 5	31-Jul-10	5.95		19.40	Right	38.00	10623.69
	3 of 5	31-Jul-10	5.95		16.80	Right	57.00	9204.95
	4 of 5	31-Jul-10	5.95		12.70	Right	76.00	12807.43
	5 of 5	31-Jul-10	5.95		4.70	Right	95.00	11703.45
177	1 of 5	1-Aug-10	5.93		5.50	Left	19.00	16863.12
	2 of 5	1-Aug-10	5.93		13.70	Left	38.00	19188.41
	3 of 5	1-Aug-10	5.93		17.90	Left	57.00	18186.38
	4 of 5	1-Aug-10	5.93		20.40	Left	76.00	15795.14
	5 of 5	1-Aug-10	5.93		6.00	Left	95.00	17114.39
178	1 of 5	2-Aug-10	7.30		10.70	Right	19.00	19301.04
	2 of 5	2-Aug-10	7.30		21.60	Right	38.00	18326.32
	3 of 5	2-Aug-10	7.30		22.00	Right	57.00	27233.05
	4 of 5	2-Aug-10	7.30		18.00	Right	76.00	23059.83
	5 of 5	2-Aug-10	7.30		9.30	Right	95.00	25182.12
179	1 of 5	3-Aug-10	7.15		11.00	Left	19.00	15960.99
	2 of 5	3-Aug-10	7.15		18.30	Left	38.00	17398.41
	3 of 5	3-Aug-10	7.15		21.50	Left		18646.84
	4 of 5	3-Aug-10	7.15		24.00	Left	76.00	18338.93
	5 of 5	3-Aug-10	7.15		9.80	Left	95.00	19512.82
180	1 of 5	4-Aug-10	6.82		8.40	Right	19.00	8607.93
	2 of 5	4-Aug-10	6.82		22.70	Right	38.00	7886.52
	3 of 5	4-Aug-10	6.82		20.10	Right	57.00	11500.00
	4 of 5	4-Aug-10	6.82		16.10	Right	76.00	13468.97
	5 of 5	4-Aug-10	6.82		7.20	Right	95.00	9384.87
181	1 of 5	5-Aug-10	6.92		11.40	Left	19.00	21329.90
	2 of 5	5-Aug-10	6.92		18.00	Left	38.00	16197.03
	3 of 5	5-Aug-10	6.92		20.70	Left	57.00	17361.20
	4 of 5	5-Aug-10	6.92		23.60	Left	76.00	18223.73
	5 of 5	5-Aug-10	6.92		9.70	Left	95.00	17345.73
182	1 of 5	9-Aug-10	6.46		7.00	Right	19.00	25574.63
	2 of 5	9-Aug-10	6.46		21.60	Right	38.00	26722.81
	3 of 5	9-Aug-10	6.46		18.80	Right	57.00	25228.96
	4 of 5	9-Aug-10	6.46		15.00	Right	76.00	24643.10
	5 of 5	9-Aug-10	6.46		6.00	Right	95.00	23011.77
183	1 of 5	10-Aug-10	6.10		10.70	Left	19.00	13186.96
	2 of 5	10-Aug-10	6.10		17.30	Left	38.00	13698.25
	3 of 5	10-Aug-10	6.10		20.40	Left	57.00	14678.45
	4 of 5	10-Aug-10	6.10		23.30	Left	76.00	14273.72
	5 of 5	10-Aug-10	6.10		9.00	Left	95.00	13845.49

No.	Field Sample No.	Date & time of Sampling	Gage height (m)	Flow (m3/s)	Depth (m)	Direction of measurement	Width (m)	Sediment Conc. (mg/l)
184	1 of 5	11-Aug-10	7.35		10.60	Right	19.00	10797.79
	2 of 5	11-Aug-10	7.35		24.90	Right	38.00	10554.35
	3 of 5	11-Aug-10	7.35		20.50	Right	57.00	11099.24
	4 of 5	11-Aug-10	7.35		17.30	Right	76.00	11161.54
	5 of 5	11-Aug-10	7.35		8.20	Right	95.00	10810.81
185	1 of 5	12-Aug-10	7.45		9.60	Left	19.00	21389.96
	2 of 5	12-Aug-10	7.45		19.00	Left	38.00	20467.86
	3 of 5	12-Aug-10	7.45		22.90	Left	57.00	20975.78
	4 of 5	12-Aug-10	7.45		25.00	Left	76.00	20370.11
	5 of 5	12-Aug-10	7.45		11.00	Left	95.00	20545.76
186	1 of 5	13-Aug-10	9.73		16.80	Left	19.00	20828.05
	2 of 5	13-Aug-10	9.73		26.50	Left	38.00	20142.24
	3 of 5	13-Aug-10	9.73		30.00	Left	57.00	20741.94
	4 of 5	13-Aug-10	9.73		33.20	Left	76.00	20768.24
	5 of 5	13-Aug-10	9.73		18.50	Left	95.00	22017.07
187	1 of 5	14-Aug-10	9.05		16.00	Right	19.00	16877.32
	2 of 5	14-Aug-10	9.05		29.00	Right	38.00	17161.62
	3 of 5	14-Aug-10	9.05		27.40	Right	57.00	16304.80
	4 of 5	14-Aug-10	9.05		23.00	Right	76.00	16615.65
	5 of 5	14-Aug-10	9.05		13.50	Right	95.00	15263.16
188	1 of 5	15-Aug-10	8.50		13.00	Left	19.00	20755.03
	2 of 5	15-Aug-10	8.50		21.80	Left	38.00	18573.38
	3 of 5	15-Aug-10	8.50		25.50	Left	57.00	17936.03
	4 of 5	15-Aug-10	8.50		27.30	Left	76.00	17568.11
	5 of 5	15-Aug-10	8.50		15.10	Left	95.00	15168.78
189	1 of 5	16-Aug-10	8.78		14.50	Right	19.00	18333.33
	2 of 5	16-Aug-10	8.78		29.50	Right	38.00	22086.96
	3 of 5	16-Aug-10	8.78		28.40	Right	57.00	21172.66
	4 of 5	16-Aug-10	8.78		24.20	Right	76.00	21723.40
	5 of 5	16-Aug-10	8.78		14.50	Right	95.00	21363.96
190	1 of 5	17-Aug-10	9.40		15.00	Left	19.00	14007.09
	2 of 5	17-Aug-10	9.40		24.90	Left	38.00	14533.10
	3 of 5	17-Aug-10	9.40		28.30	Left	57.00	14305.56
	4 of 5	17-Aug-10	9.40		30.40	Left	76.00	14637.93
	5 of 5	17-Aug-10	9.40		15.50	Left	95.00	14580.99
191	1 of 5	18-Aug-10	6.80		8.80	Right	19.00	5278.88
	2 of 5	18-Aug-10	6.80		23.60	Right	38.00	5818.51
	3 of 5	18-Aug-10	6.80		20.10	Right	57.00	5919.01
	4 of 5	18-Aug-10	6.80		16.00	Right	76.00	5681.36
	5 of 5	18-Aug-10	6.80		8.50	Right	95.00	5889.27

No.	Field Sample No.	Date & time of Sampling	Gage height (m)	Flow (m3/s)	Depth (m)	Direction of measurement	Width (m)	Sediment Conc. (mg/l)
192	1 of 5	10-Sep-10	4.98		15.30	Right	33.00	6071.97
	2 of 5	10-Sep-10	4.98		15.20	Right	44.00	6519.69
	3 of 5	10-Sep-10	4.98		12.50	Right	54.00	6979.92
	4 of 5	10-Sep-10	4.98		15.20	Right	68.00	6785.71
	5 of 5	10-Sep-10	4.98		15.30	Right	81.00	6287.55
193	1 of 5	11-Sep-10	4.25		6.60	Left	28.00	5865.17
	2 of 5	11-Sep-10	4.25		9.90	Left	40.00	6293.44
	3 of 5	11-Sep-10	4.25		11.90	Left	52.00	6029.09
	4 of 5	11-Sep-10	4.75		15.30	Left	68.00	7343.10
	5 of 5	11-Sep-10	4.75		14.60	Left	80.00	10012.40
194	1 of 5	12-Sep-10	4.41		14.10	Right	28.00	6134.83
	2 of 5	12-Sep-10	4.41		14.40	Right	40.00	6312.06
	3 of 5	12-Sep-10	4.41		11.50	Right	52.00	6221.43
	4 of 5	12-Sep-10	4.41		14.40	Right	66.00	7616.94
	5 of 5	12-Sep-10	4.41		14.10	Right	80.00	5390.95
195	1 of 5	13-Sep-10	4.68		7.50	Left	32.00	4780.88
	2 of 5	13-Sep-10	4.68		10.40	Left	44.00	6092.25
	3 of 5	13-Sep-10	4.68		12.50	Left	56.00	5177.94
	4 of 5	13-Sep-10	4.68		15.20	Left	68.00	7334.59
	5 of 5	13-Sep-10	4.68		14.80	Left	80.00	4832.68
196	1 of 5	14-Sep-10	4.49		14.40	Right	28.00	5623.57
	2 of 5	14-Sep-10	4.49		14.60	Right	40.00	4973.38
	3 of 5	14-Sep-10	4.49		11.80	Right	52.00	4875.46
	4 of 5	14-Sep-10	4.49		9.60	Right	66.00	4448.72
	5 of 5	14-Sep-10	4.49		6.80	Right	80.00	5276.60
197	1 of 5	15-Sep-10	4.30		6.20	Left	6.20	7680.93
	2 of 5	15-Sep-10	4.30		9.90	Left	9.90	5992.25
	3 of 5	15-Sep-10	4.30		11.30	Left	11.30	6333.33
	4 of 5	15-Sep-10	4.30		14.10	Left	14.10	5913.21
	5 of 5	15-Sep-10	4.30		13.70	Left	13.70	7414.06
198	1 of 5	16-Sep-10	4.94		15.40	Right	29.00	5324.53
	2 of 5	16-Sep-10	4.94		15.90	Right	41.00	5531.60
	3 of 5	16-Sep-10	4.94		13.10	Right	53.00	5396.36
	4 of 5	16-Sep-10	4.94		10.90	Right	65.00	5354.48
	5 of 5	16-Sep-10	4.94		8.40	Right	77.00	5049.81
199	1 of 5	17-Sep-10	4.65		8.20	Left	32.00	2673.99
	2 of 5	17-Sep-10	4.65		11.10	Left	44.00	2814.81
	3 of 5	17-Sep-10	4.65		13.10	Left	56.00	3059.29
	4 of 5	17-Sep-10	4.65		16.10	Left	68.00	3294.34
	5 of 5	17-Sep-10	4.65		15.80	Left	82.00	3173.29

No.	Field Sample No.	Date & time of Sampling	Gage height (m)	Flow (m3/s)	Depth (m)	Direction of measurement	Width (m)	Sediment Conc. (mg/l)
200	1 of 5	18-Sep-10	4.64		14.50	Right	28.00	4641.79
	2 of 5	18-Sep-10	4.64		15.00	Right	40.00	4981.75
	3 of 5	18-Sep-10	4.64		12.20	Right	52.00	4794.57
	4 of 5	18-Sep-10	4.64		10.20	Right	64.00	4970.59
	5 of 5	18-Sep-10	4.64		7.40	Right	76.00	4607.55
201	1 of 5	19-Sep-10	4.85		9.10	Left	32.00	2815.38
	2 of 5	19-Sep-10	4.85		11.40	Left	44.00	3022.56
	3 of 5	19-Sep-10	4.85		13.70	Left	56.00	3375.00
	4 of 5	19-Sep-10	4.85		16.40	Left	78.00	3046.33
	5 of 5	19-Sep-10	4.85		16.00	Left	90.00	3404.58
202	1 of 5	20-Sep-10	4.40		13.80	Right	30.00	3550.40
	2 of 5	20-Sep-10	4.40		14.20	Right	40.00	3544.75
	3 of 5	20-Sep-10	4.40		11.40	Right	52.00	4381.53
	4 of 5	20-Sep-10	4.40		9.30	Right	64.00	3626.46
	5 of 5	20-Sep-10	4.40		6.60	Right	76.00	3674.24
203	1 of 5	21-Sep-10	4.15		5.60	Left	32.00	4216.31
	2 of 5	21-Sep-10	4.15		8.70	Left	44.00	4097.47
	3 of 5	21-Sep-10	4.15		11.00	Left	56.00	4462.12
	4 of 5	21-Sep-10	4.15		13.80	Left	68.00	4564.29
	5 of 5	21-Sep-10	4.15		12.90	Left	80.00	3730.22
204	1 of 5	22-Sep-10	3.73		11.70	Right	28.00	1358.78
	2 of 5	22-Sep-10	3.73		11.80	Right	40.00	1262.17
	3 of 5	22-Sep-10	3.73		9.30	Right	52.00	1408.24
	4 of 5	22-Sep-10	3.73		7.10	Right	64.00	1315.38
	5 of 5	22-Sep-10	3.73		4.10	Right	76.00	1056.68
205	1 of 5	23-Sep-10	3.62		11.70	Right	20.00	2128.21
	2 of 5	23-Sep-10	3.62		11.30	Right	32.00	2106.06
	3 of 5	23-Sep-10	3.62		10.80	Right	44.00	1865.94
	4 of 5	23-Sep-10	3.62		8.10	Right	56.00	2098.90
	5 of 5	23-Sep-10	3.62		5.90	Right	68.00	2344.44
206	1 of 5	24-Sep-10	3.50		11.50	Right	19.00	2386.03
	2 of 5	24-Sep-10	3.50		10.90	Right	31.00	2194.14
	3 of 5	24-Sep-10	3.50		10.60	Right	43.00	2164.71
	4 of 5	24-Sep-10	3.50		7.70	Right	55.00	1966.79
	5 of 5	24-Sep-10	3.50		5.30	Right	67.00	2078.43
207	1 of 5	25-Sep-10	3.46		11.20	Right	18.00	961.83
	2 of 5	25-Sep-10	3.46		10.80	Right	30.00	1175.37
	3 of 5	25-Sep-10	3.46		10.30	Right	42.00	1081.71
	4 of 5	25-Sep-10	3.46		7.40	Right	54.00	1065.89
	5 of 5	25-Sep-10	3.46		5.50	Right	66.00	1332.09

No.	Field Sample No.	Date & time of Sampling	Gage height (m)	Flow (m3/s)	Depth (m)	Direction of measurement	Width (m)	Sediment Conc. (mg/l)
	1 of 5	26-Sep-10	3.59		11.60	Right	18.00	1833.33
	2 of 5	26-Sep-10	3.59		11.00	Right	30.00	1570.96
	3 of 5	26-Sep-10	3.59		10.70	Right	42.00	1975.00
	4 of 5	26-Sep-10	3.59		7.70	Right	54.00	1813.38
208	5 of 5	26-Sep-10	3.59		5.40	Right	66.00	1685.19
	1 of 5	27-Sep-10	3.35		10.90	Right	19.00	1475.69
	2 of 5	27-Sep-10	3.35		10.50	Right	31.00	1670.94
	3 of 5	27-Sep-10	3.35		10.10	Right	43.00	1463.50
	4 of 5	27-Sep-10	3.35		7.10	Right	55.00	1806.45
209	5 of 5	27-Sep-10	3.35		5.00	Right	67.00	1530.69
	1 of 5	28-Sep-10	3.37		11.10	Right	19.00	7690.97
	2 of 5	28-Sep-10	3.37		10.50	Right	31.00	7982.14
	3 of 5	28-Sep-10	3.37		10.50	Right	43.00	7870.37
	4 of 5	28-Sep-10	3.37		7.10	Right	55.00	7896.91
210	5 of 5	28-Sep-10	3.37		5.00	Right	67.00	7765.52
	1 of 5	29-Sep-10	3.19		10.20	Right	18.00	1705.43
	2 of 5	29-Sep-10	3.19		9.90	Right	30.00	2441.86
	3 of 5	29-Sep-10	3.19		9.30	Right	42.00	1802.16
	4 of 5	29-Sep-10	3.19		6.50	Right	54.00	3855.14
211	5 of 5	29-Sep-10	3.19		4.20	Right	66.00	1893.13
	1 of 5	30-Sep-10	3.95		9.70	Right	18.00	1132.84
	2 of 5	30-Sep-10	3.95		9.20	Right	30.00	1168.54
	3 of 5	30-Sep-10	3.95		8.90	Right	42.00	1085.82
	4 of 5	30-Sep-10	3.95		6.10	Right	54.00	1094.34
212	5 of 5	30-Sep-10	3.95		3.90	Right	66.00	1238.81

Yellow fields: Both gage height and discharge are missing
Red fields: Mistyped and incorrect numbers
Open fields: No data

Appendix B. Sediment data analysis for Kessie gauging station

Table B.1 Flow rating curve data

no	Gage height, H (m)	Discharge, Q (m^3/s)	no	Gage height, H (m)	Discharge, Q (m^3/s)	no	Gage height, H (m)	Discharge, Q (m^3/s)
1	2.50	104.81	25	4.28	1025.13	49	5.48	2033.56
2	2.82	293.60	26	4.34	1183.13	50	5.50	2412.96
3	2.85	282.75	27	4.35	1374.59	51	5.60	2995.39
4	2.85	300.04	28	4.35	1354.35	52	5.65	2093.98
5	2.86	292.34	29	4.48	1272.26	53	5.70	2323.39
6	2.89	296.13	30	4.71	1384.38	54	5.70	2862.86
7	2.90	329.39	31	4.72	1364.84	55	5.75	2683.34
8	2.91	295.17	32	4.75	1500.23	56	5.85	2983.61
9	2.94	316.92	33	4.96	1793.89	57	5.85	2923.99
10	3.00	343.57	34	4.98	1807.02	58	5.85	2870.04
11	3.12	363.41	35	4.98	1612.15	59	6.04	2767.62
12	3.16	413.31	36	4.99	2038.42	60	6.04	2707.97
13	3.20	421.77	37	5.00	2031.84	61	6.18	2593.63
14	3.24	386.84	38	5.00	3127.04	62	6.22	2535.80
15	3.28	437.70	39	5.02	1783.63	63	6.24	1825.08
16	3.40	487.20	40	5.05	2277.38	64	6.25	3194.00
17	3.44	415.07	41	5.08	1850.25	65	6.42	3551.81
18	3.45	852.08	42	5.10	2073.44	66	6.70	4018.12
19	3.46	796.15	43	5.11	2183.88	67	7.00	3551.08
20	3.61	461.69	44	5.23	2068.64	68	7.30	3807.32
21	4.05	1358.97	45	5.25	1977.05	69	7.70	4217.88
22	4.15	1828.54	46	5.33	1886.85	70	7.95	3198.50
23	4.15	1268.34	47	5.35	1926.19			
24	4.22	1580.92	48	5.38	2241.74			

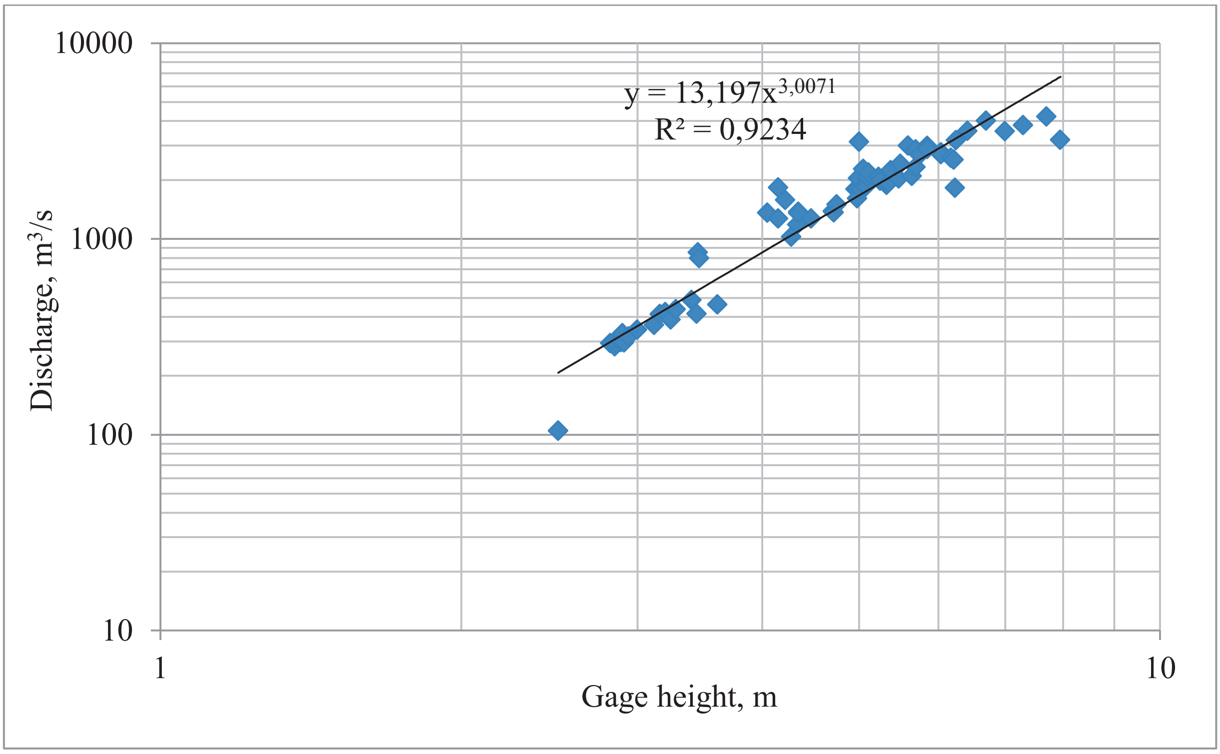

Figure B.1 Flow rating curve development

This rating curve was used to fill missing discharges in the data series. The river discharge - gage height relationship for the period from year 2008 to 2010 is as in the figure below.

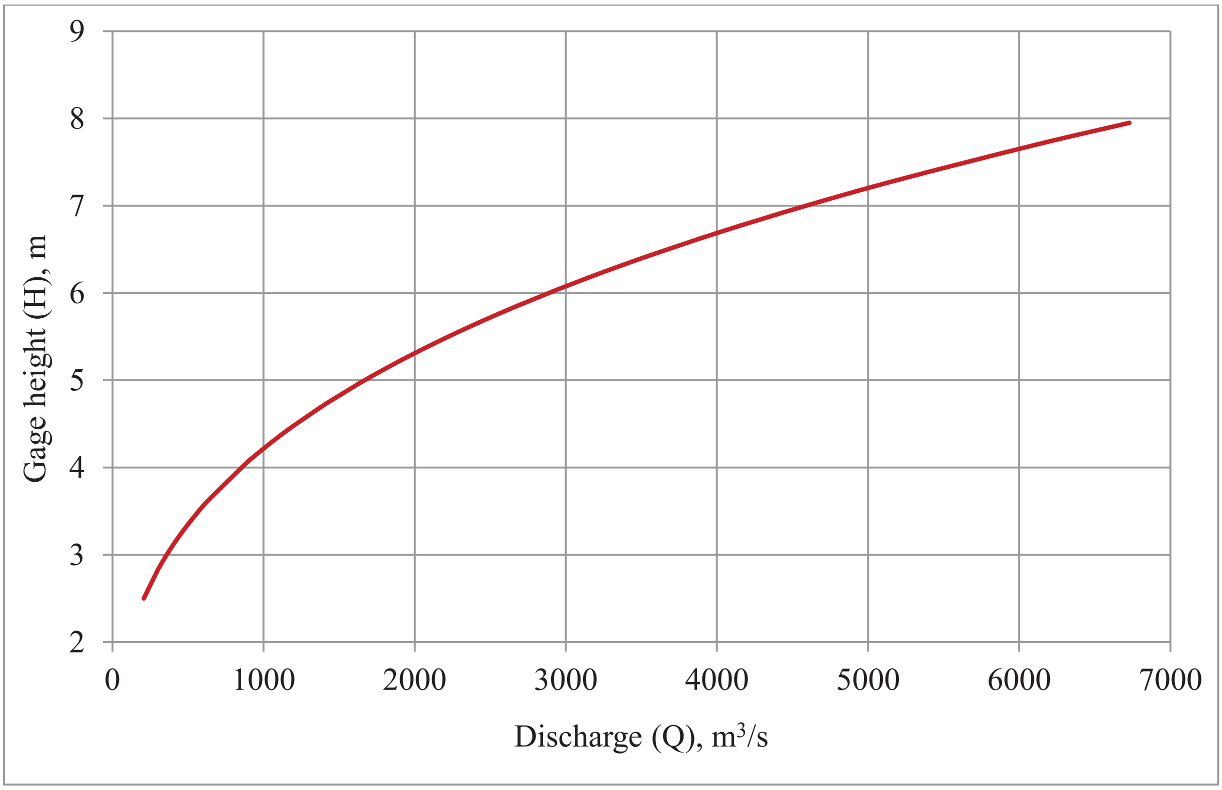

Figure B.2 Stage-Discharge relationship at Kessie gauging station

Table B.2 Analysis of sediment data at Kessie

No.	Date of Sampling	Gage height (m)	Discharge Q (m^3/s)	Average Sed. Conc. (mg/l)	Cmax/Cmin ratio (mg/l/mg/l)
1	29.jun.08	3.02	366.36	3989.71	3.97
2	30.jun.08	3.06	381.14	4829.94	2.18
3	14.jul.08	4.28	1025.13	14566.65	1.18
4	20.jul.08	4.07	898.64	11509.76	1.18
5	13-Aug-08	6.76	4123.27	14418.60	1.21
6	14-Aug-08	6.69	4001.51	16139.81	1.50
7	17-Aug-08	7.40	5424.28	13197.05	1.27
8	18-Aug-08	6.64	3915.77	9009.63	1.34
9	21-Aug-08	5.28	1965.66	12355.92	1.18
10	22-Aug-08	5.33	2019.88	13197.98	1.13
11	25-Aug-08	5.70	2474.38	6187.71	1.22
12	26-Aug-08	5.65	2409.68	6941.53	1.45
13	30-Aug-08	4.74	1421.05	3864.47	1.24
14	31-Aug-08	4.30	1060.18	3144.07	1.25
15	3-Sep-08	5.53	2263.96	8359.10	1.07
16	4-Sep-08	5.70	2467.86	6231.35	1.24
17	7-Sep-08	4.82	1494.40	4976.15	1.18
18	8-Sep-08	4.68	1367.64	7056.14	1.10
19	29-Sep-08	3.04	373.70	648.19	1.37
20	30-Sep-08	3.00	359.11	614.73	1.60
21	3-Oct-08	3.10	396.32	2607.72	1.14
22	4-Oct-08	3.05	377.41	716.30	1.08
23	5-Oct-08	3.00	359.11	715.79	1.21
24	11-Jul-09	3.45	852.08	30345.99	1.40
25	13-Jul-09	3.64	761.52	25246.18	1.11
26	13-Jul-09	3.78	719.53	17922.27	1.33
27	14-Jul-09	3.46	796.15	20917.94	1.22
28	15-Jul-09	4.16	1580.92	42325.99	1.80
29	16-Jul-09	4.05	1358.97	25631.95	1.69
30	17-Jul-09		3463.22	16283.65	1.26
31	18-Jul-09	4.15	1828.54	14851.88	1.31
32	20-Jul-09	4.75	1500.23	24795.53	1.15
33	20-Jul-09	5.35	1926.19	17595.13	1.29
34	23-Jul-09	4.98	1807.02	22764.62	1.29
35	23-Jul-09	5.08	1850.25	15179.07	1.71
36	24-Jul-09	4.98	1612.15	18635.47	1.17
37	24-Jul-09	5.48	2033.56	22741.48	1.05
38	27-Jul-09		2876.05	16749.09	1.17
39	28-Jul-09	5.00	1668.58	15800.39	1.08
40	28-Jul-09	5.85	2675.41	13917.03	1.30

No.	Date of Sampling	Gage height (m)	Discharge Q (m^3/s)	Average Sed. Conc. (mg/l)	Cmax/Cmin ratio (mg/l/mg/l)
41	29-Jul-09	5.45	2162.19	19100.29	1.21
42	29-Jul-09	6.16	3124.81	22410.15	1.20
43	31-Jul-09	5.11	2183.88	11905.18	1.23
44	1-Aug-09	5.00	2031.84	9843.82	1.46
45	1-Aug-09	5.10	2073.44	8898.99	1.46
46	2-Aug-09	4.96	1793.89	15177.69	1.24
47	2-Aug-09	5.00	1668.58	12662.98	1.20
48	3-Aug-09	4.48	1272.26	8622.70	1.53
49	3-Aug-09	4.35	1374.59	6437.79	1.23
50	4-Aug-09	4.15	1268.34	8011.07	1.19
51	4-Aug-09	4.34	1183.13	7768.81	1.38
52	5-Aug-09	4.71	1384.38	14364.14	1.61
53	5-Aug-09	5.23	2068.64	15236.79	1.36
54	6-Aug-09	5.38	2241.74	14048.64	1.13
55	6-Aug-09	6.00	2887.05	13098.27	1.53
56	7-Aug-09	5.17	1845.07	11077.17	1.49
57	7-Aug-09	5.25	1932.26	11634.70	1.61
58	8-Aug-09	5.60	2995.39	12491.21	1.42
59	8-Aug-09	6.05	2960.00	14045.60	1.51
60	9-Aug-09	5.02	1783.63	9675.51	1.54
61	9-Aug-09	5.85	2675.41	11936.89	1.77
62	10-Aug-09	5.85	2983.61	15981.80	1.14
63	11-Aug-09	5.70	2323.39	15759.94	1.22
64	11-Aug-09	5.85	2675.41	15902.73	1.18
65	12-Aug-09	5.70	2862.86	7862.33	1.20
66	12-Aug-09	6.12	3064.19	13675.45	1.17
67	13-Aug-09	4.99	2038.42	7486.62	1.30
68	13-Aug-09	5.72	2500.58	12141.46	1.76
69	14-Aug-09	5.25	1977.05	10202.08	1.18
70	14-Aug-09	5.46	2174.14	9996.65	1.35
71	15-Aug-09	5.73	2513.75	12865.99	1.09
72	15-Aug-09	5.73	2513.75	6405.83	1.37
73	16-Aug-09	5.65	2093.98	6414.16	1.32
74	16-Aug-09	6.00	2887.05	8983.09	1.02
75	17-Aug-09	5.00	3127.04	10412.41	1.33
76	17-Aug-09	4.90	1570.23	7090.00	1.09
77	18-Aug-09	5.05	2277.38	12292.71	1.29
78	18-Aug-09	6.25	3264.12	16804.08	1.32
79	19-Aug-09	5.85	2923.99	11448.86	1.20
80	19-Aug-09	6.18	2593.63	12414.93	1.16

No.	Date of Sampling	Gage height (m)	Discharge Q (m^3/s)	Average Sed. Conc. (mg/l)	Cmax/Cmin ratio (mg/l/mg/l)
81	20-Aug-09	6.04	2767.62	14145.36	1.22
82	20-Aug-09	5.55	2283.70	13077.63	1.33
83	21-Aug-09	7.70	4217.88	22693.43	1.16
84	21-Aug-09	7.28	5164.05	11506.50	1.34
85	22-Aug-09	7.95	3198.50	12190.20	1.31
86	22-Aug-09	7.12	4830.23	7552.00	1.28
87	23-Aug-09	6.04	2707.97	7075.75	1.22
88	23-Aug-09	6.60	3845.26	10105.45	2.25
89	24-Aug-09	5.75	2683.34	5069.70	1.35
90	24-Aug-09	5.95	2815.30	4936.29	1.30
91	25-Aug-09	5.85	2870.04	6146.85	1.38
92	25-Aug-09	7.00	3551.08	12991.95	1.24
93	26-Aug-09	7.30	3807.32	9482.93	1.42
94	26-Aug-09	7.16	4912.29	10495.49	1.23
95	27-Aug-09	6.25	3194.00	7021.85	1.08
96	27-Aug-09	6.76	4132.45	9323.93	1.56
97	28-Aug-09	6.22	2535.80	6566.95	1.10
98	28-Aug-09	6.00	2887.05	5643.94	1.29
99	29-Aug-09	6.24	1825.08	3516.81	1.20
100	29-Aug-09	5.06	1729.52	3505.82	1.21
101	30-Aug-09	5.50	2412.96	7397.26	1.15
102	30-Aug-09	5.35	2045.07	7301.45	1.10
103	31-Aug-09	6.70	4018.12	10505.15	1.14
104	31-Aug-09	7.20	4995.28	13261.39	1.15
105	1-Sep-09	6.42	3551.81	8483.92	1.33
106	1-Sep-09	6.28	3311.46	8909.20	1.11
107	2-Sep-09	0.00	1885.96	6055.29	1.22
108	3-Sep-09	0.00	1978.48	5450.03	1.26
109	4-Sep-09	0.00	1722.28	4589.00	1.24
110	5-Sep-09	5.10	1770.96	10178.04	1.29
111	6-Sep-09	5.33	1886.85	9774.90	1.26
112	6-Sep-09	5.25	1932.26	8214.06	1.21
113	7-Sep-09	4.72	1364.84	5046.31	1.07
114	7-Sep-09	4.80	1475.83	5370.65	1.07
115	8-Sep-09	4.35	1354.35	3821.38	1.66
116	8-Sep-09	4.37	1112.93	2319.58	1.48
117	9-Sep-09	4.34	1090.11	2456.95	1.83
118	10-Sep-09	4.10	918.71	2312.75	1.14
119	11-Sep-09	3.79	725.27	1452.87	1.12
120	11-Sep-09	3.72	685.73	1458.47	1.29

No.	Date of Sampling	Gage height (m)	Discharge Q (m^3/s)	Average Sed. Conc. (mg/l)	Cmax/Cmin ratio (mg/l/mg/l)
121	12-Sep-09	3.61	461.69	1559.18	1.59
122	12-Sep-09	3.51	575.80	1381.12	1.79
123	13-Sep-09	3.44	415.07	1424.80	2.07
124	13-Sep-09	3.41	527.86	1346.88	2.27
125	14-Sep-09	3.37	487.20	1096.18	2.69
126	14-Sep-09	3.40	523.22	1056.00	1.29
127	15-Sep-09	3.24	386.84	814.29	2.06
128	15-Sep-09	3.28	469.63	919.84	1.97
129	16-Sep-09	3.16	413.31	904.03	1.65
130	16-Sep-09	3.22	444.27	852.42	1.32
131	17-Sep-09	3.20	421.77	1653.30	2.57
132	17-Sep-09	3.22	444.27	1721.99	2.44
133	18-Sep-09	3.28	437.70	3154.11	1.31
134	18-Sep-09	3.30	478.30	3447.78	1.30
135	19-Sep-09	3.12	363.41	1753.60	1.71
136	19-Sep-09	3.09	392.49	2221.44	3.29
137	20-Sep-09	3.00	343.57	929.52	1.82
138	20-Sep-09	2.99	355.52	967.36	1.85
139	21-Sep-09	2.94	316.92	631.80	1.23
140	21-Sep-09	2.91	327.68	788.33	2.30
141	22-Sep-09	2.90	329.39	1479.54	7.34
142	22-Sep-09	2.96	344.90	619.86	1.79
143	23-Sep-09	2.86	292.34	652.19	1.57
144	23-Sep-09	2.87	314.32	540.49	1.57
145	24-Sep-09	2.82	293.60	472.71	1.43
146	24-Sep-09	2.83	301.33	543.70	1.63
147	25-Sep-09	2.85	282.75	1412.12	7.35
148	25-Sep-09	2.86	311.04	1375.33	4.59
149	26-Sep-09	2.85	300.04	407.88	1.48
150	26-Sep-09	2.87	314.32	582.75	2.06
151	27-Sep-09	2.91	295.17	579.05	1.62
152	27-Sep-09	2.88	317.62	584.59	1.41
153	28-Sep-09	2.89	296.13	705.77	2.20
154	28-Sep-09	2.87	314.32	599.17	1.45
155	23-Jan-10	2.50	104.81	138.44	1.25
156	23-Feb-10	2.55	220.28	139.58	1.14
157	31-Mar-10	1.88	88.08	187.41	1.13
158	4-May-10	2.18	137.48	5254.44	1.15
159	17-Jul-10	4.06	892.02	18473.06	1.63
160	18-Jul-10	4.25	1023.54	23377.72	1.17

No.	Date of Sampling	Gage height (m)	Discharge Q (m^3/s)	Average Sed. Conc. (mg/l)	Cmax/Cmin ratio (mg/l/mg/l)
161	19-Jul-10	4.18	973.68	22276.16	1.12
162	20-Jul-10	4.78	1457.41	22807.88	1.64
163	21-Jul-10	5.64	2396.88	27367.15	1.82
164	22-Jul-10	6.70	4023.14	40660.23	2.57
165	25-Jul-10	7.65	5994.23	18126.29	1.42
166	26-Jul-10	6.35	3423.70	16827.15	1.71
167	27-Jul-10	6.86	4319.02	26257.12	1.29
168	28-Jul-10	7.15	4891.69	16548.59	1.42
169	29-Jul-10	6.15	3109.58	7112.43	1.16
170	30-Jul-10	6.50	3672.71	17729.81	1.32
171	31-Jul-10	5.95	2815.30	10660.98	1.43
172	1-Aug-10	5.93	2786.94	17429.49	1.21
173	2-Aug-10	7.30	5206.83	22620.47	1.49
174	3-Aug-10	7.15	4891.69	17971.60	1.22
175	4-Aug-10	6.82	4243.73	10169.66	1.71
176	5-Aug-10	6.92	4433.62	18091.52	1.32
177	9-Aug-10	6.46	3605.17	25036.25	1.16
178	10-Aug-10	6.10	3034.17	13936.57	1.11
179	11-Aug-10	7.35	5314.81	10884.75	1.06
180	12-Aug-10	7.45	5535.24	20749.89	1.05
181	13-Aug-10	9.73	12354.62	20899.51	1.09
182	14-Aug-10	9.05	9936.04	16444.51	1.12
183	15-Aug-10	8.50	8228.69	18000.27	1.37
184	16-Aug-10	8.78	9071.05	20936.06	1.20
185	17-Aug-10	9.40	11136.99	14412.93	1.05
186	18-Aug-10	6.80	4206.42	5717.41	1.12
187	10-Sep-10	4.98	1648.59	6528.97	1.15
188	11-Sep-10	4.45	1175.33	7108.64	1.71
189	12-Sep-10	4.41	1143.84	6335.24	1.41
190	13-Sep-10	4.68	1367.64	5643.67	1.53
191	14-Sep-10	4.49	1207.38	5039.55	1.26
192	15-Sep-10	4.30	1060.18	6666.76	1.30
193	16-Sep-10	4.94	1609.09	5331.36	1.10
194	17-Sep-10	4.65	1341.45	3003.14	1.23
195	18-Sep-10	4.64	1332.79	4799.25	1.08
196	19-Sep-10	4.85	1522.54	3132.77	1.21
197	20-Sep-10	4.40	1136.06	3755.48	1.24
198	21-Sep-10	4.15	952.81	4214.08	1.22
199	22-Sep-10	3.73	691.29	1280.25	1.33
200	23-Sep-10	3.62	631.78	2108.71	1.26

No.	Date of Sampling	Gage height (m)	Discharge Q (m^3/s)	Average Sed. Conc. (mg/l)	Cmax/Cmin ratio (mg/l/mg/l)
201	24-Sep-10	3.50	570.88	2158.02	1.21
202	25-Sep-10	3.46	551.48	1123.38	1.38
203	26-Sep-10	3.59	616.17	1775.57	1.26
204	27-Sep-10	3.35	500.42	1589.45	1.23
205	28-Sep-10	3.37	509.46	7841.18	1.04
206	29-Sep-10	3.19	431.94	2339.54	2.26
207	30-Sep-10	3.95	821.30	1144.07	1.14
25% percentile (Q1)			1.18		
75% percentile (Q2)			1.50		
Inter Quartile Range (Q2-Q1)			0.32		
Upper outlier			2.45		
Lower outlier			0.23		

- The upper and lower outliers are marked red in the data sheet
- Missing discharges are filled using the discharge rating curve equation
- The data on 22nd, July 2010 was not omitted because of the high probability that large concentration difference can occur for high discharges.
- Concentration data on January 23rd 2010, February 3rd 2010, March 31st 2010 and May 4th 2010 were excluded to avoid bias from relatively low sediment supply during these periods
- The total number of data used for sediment rating curve development = 195
- The data is used to estimate sediment yield for wet season (June to September)

Appendix C. Sediment Rating Curve

Table C.1 Comparison of measured and computed sediment discharge for Kessie station (Rising flood stage)

No.	Date & time of Sampling	Discharge Q (m^3/s)	Measured		Computed sediment discharge (Qsc) kg/s	Difference (Qsc-Qsm) kg/s
			Sediment Concentration (Cm) mg/l	Sediment discharge (Qsm) kg/s		
1	30-Jun-08	381.14	4829.943	1840.90	4719.724	-3500.40
2	14-Jul-08	1025.13	14566.65	14932.71	14010.3	11.81
3	20-Jul-08	898.64	11509.76	10343.15	12121.41	-2670.88
4	13-Aug-08	4123.27	14418.6	59451.74	64740.37	-3848.95
5	14-Aug-08	4001.51	16139.81	64583.55	62641.09	3222.63
6	11-Jul-09	852.08	30345.99	25857.21	11432.55	13542.59
7	13-Jul-09	761.52	25246.18	19225.47	10103.66	8266.93
8	13-Jul-09	719.53	17922.27	12895.67	9492.766	2563.80
9	14-Jul-09	796.15	20917.94	16653.82	10610.07	5177.41
10	15-Jul-09	1580.92	42325.99	66914.00	22559.8	43518.56
11	16-Jul-09	1358.97	25631.95	34833.05	19102.27	14838.35
12	17-Jul-09	3463.22	16283.65	56393.93	53439.29	3580.34
13	18-Jul-09	1828.54	14851.88	27157.26	26474.65	-53.85
14	20-Jul-09	1500.23	24795.53	37199.00	21296.82	15042.16
15	20-Jul-09	1926.19	17595.13	33891.56	28033.52	5170.12
16	23-Jul-09	1807.02	22764.62	41136.12	26132.21	14257.46
17	23-Jul-09	1850.25	15179.07	28085.07	26820.52	538.44
18	24-Jul-09	1612.15	18635.47	30043.17	23050.36	6167.68
19	24-Jul-09	2033.56	22741.48	46246.16	29756.66	15860.66
20	27-Jul-09	2876.05	16749.09	48171.21	43564.47	4622.89
21	28-Jul-09	1668.58	15800.39	26364.27	23939.22	1620.44
22	28-Jul-09	2675.41	13917.03	37233.70	40234.11	-3164.48
23	29-Jul-09	2162.19	19100.29	41298.38	31832.88	8914.97
24	29-Jul-09	3124.81	22410.15	70027.42	47725.58	22561.90
25	31-Jul-09	2183.88	11905.18	25999.48	32184.28	-6721.35
26	1-Aug-09	2031.84	9843.82	20001.07	29728.98	-10357.75
27	1-Aug-09	2073.44	8898.99	18451.51	30399.02	-12552.92
28	2-Aug-09	1793.89	15177.69	27227.10	25923.48	551.19
29	2-Aug-09	1668.58	12662.98	21129.24	23939.22	-3614.59
30	3-Aug-09	1272.26	8622.70	10970.31	17766.26	-7701.40
31	3-Aug-09	1374.59	6437.79	8849.33	19343.86	-11384.05
32	4-Aug-09	1268.34	8011.07	10160.77	17706.07	-8451.22
33	4-Aug-09	1183.13	7768.81	9191.51	16402.41	-8123.89
34	5-Aug-09	1384.38	14364.14	19885.43	19495.41	-497.59
35	5-Aug-09	2068.64	15236.79	31519.43	30321.64	589.51

No.	Date & time of Sampling	Discharge Q (m^3/s)	Measured		Computed sediment discharge (Qsc) kg/s	Difference (Qsm-Qsc) kg/s
			Sediment Concentration (Cm) mg/l	Sediment discharge (Qsm) kg/s		
36	6-Aug-09	2241.74	14048.64	31493.39	33123.22	-2128.01
37	6-Aug-09	2887.05	13098.27	37815.33	43747.68	-5905.90
38	7-Aug-09	1845.07	11077.17	20438.15	26737.95	-7028.39
39	7-Aug-09	1932.26	11634.70	22481.31	28130.73	-6334.16
40	8-Aug-09	2995.39	12491.21	37416.04	45556.44	-8009.98
41	8-Aug-09	2960.00	14045.60	41574.99	44964.89	-3293.91
42	9-Aug-09	1783.63	9675.51	17257.52	25760.47	-9259.99
43	9-Aug-09	2675.41	11936.89	31936.02	40234.11	-8462.15
44	10-Aug-09	2983.61	15981.80	47683.46	45359.45	2442.92
45	11-Aug-09	2323.39	15759.94	36616.48	34452.32	1722.72
46	11-Aug-09	2675.41	15902.73	42546.26	40234.11	2148.08
47	12-Aug-09	2862.86	7862.33	22508.76	43344.81	-20832.21
48	12-Aug-09	3064.19	13675.45	41904.14	46708.41	-4605.65
49	13-Aug-09	2038.42	7486.62	15260.88	29834.88	-15200.02
50	13-Aug-09	2500.58	12141.46	30360.70	37352.48	-7300.05
51	14-Aug-09	1977.05	10202.08	20170.03	28848.59	-9339.23
52	14-Aug-09	2174.14	9996.65	21734.10	32026.44	-10835.20
53	15-Aug-09	2513.75	12865.99	32341.87	37568.86	-5524.82
54	15-Aug-09	2513.75	6405.83	16102.64	37568.86	-21764.06
55	16-Aug-09	2093.98	6414.16	13431.13	30730.35	-17892.27
56	16-Aug-09	2887.05	8983.09	25934.60	43747.68	-17786.62
57	17.jul.10	892.02	18473.06	16478.31	12023.2	3563.85
58	18.jul.10	1023.54	23377.72	23927.97	13986.37	9031.14
59	19.jul.10	973.68	22276.16	21689.76	13238.94	7545.71
60	20.jul.10	1457.41	22807.88	33240.52	20629.37	11739.89
61	21.jul.10	2396.88	27367.15	65595.82	35652.61	29555.37
62	22.jul.10	4023.14	40660.23	163581.67	63013.54	101876.33
63	25.jul.10	5994.23	18126.29	108653.16	97693.92	15301.11
64	26.jul.10	3423.70	16827.15	57611.16	52769.06	5423.19
65	27.jul.10	4319.02	26257.12	113405.09	68128.27	46981.27
66	28.jul.10	4891.69	16548.59	80950.56	78125.35	5359.87
67	29.jul.10	3109.58	7112.43	22116.65	47469.86	-25108.70
68	30.jul.10	3672.71	17729.81	65116.49	57004.63	8982.09
69	31.jul.10	2815.30	10660.98	30013.89	42553.65	-12579.78
70	01.aug.10	2786.94	17429.49	48574.98	42082.47	6426.73
71	02.aug.10	5206.83	22620.47	117780.95	83677.7	37127.81
72	03.aug.10	4891.69	17971.60	87911.48	78125.35	12320.80
73	04.aug.10	4243.73	10169.66	43157.33	66823.42	-22064.67
74	05.aug.10	4433.62	18091.52	80210.88	70118.73	11956.23

No.	Date & time of Sampling	Discharge Q (m^3/s)	Measured		Computed sediment discharge (Qsc) kg/s	Difference (Qsm-Qsc) kg/s
			Sediment Concentration (Cm) mg/l	Sediment discharge (Qsm) kg/s		
75	09.aug.10	3605.17	25036.25	90259.88	55852.79	35197.02
76	10.aug.10	3034.17	13936.57	42286.00	46205.53	-3750.88
77	11.aug.10	5314.81	10884.75	57850.37	85588.02	-24540.13
78	12.aug.10	5535.24	20749.89	114855.61	89499.59	28914.38
79	13.aug.10	12354.62	20899.51	258205.45	216410.7	60394.87
80	14.aug.10	9936.04	16444.51	163393.24	170305.7	5628.66
81	15.aug.10	8228.69	18000.27	148118.67	138415.1	18403.38
82	16.aug.10	9071.05	20936.06	189912.07	154074.2	46383.30
Sum				3.9E+06	3.6E+06	352,856
Average		2840.17	16,179	47,635	43,933	
% difference		= ((Sum of Qsm) – (Sum of Qsc))/(Sum of Qsm)			9%	

Table C.2 Comparison of measured and computed sediment discharge for Kessie station (Falling flood stage)

No.	Date & time of Sampling	Discharge Q (m^3/s)	Measured		Computed sediment discharge (Qsc) kg/s	Difference (Qsm-Qsc) kg/s
			Sediment Concentration (Cm) mg/l	Sediment discharge (Qsm) kg/s		
1	17.aug.08	5424.28	13197.05	71584.45	95364.19	-23986.36
2	18-Aug-08	3915.77	9009.632	35279.62	48602.08	-13427.77
3	21-Aug-08	1965.66	12355.92	24287.50	11683.25	12578.93
4	22-Aug-08	1943.35	13197.98	25648.33	11410.7	14212.90
5	25-Aug-08	2346.13	6187.714	14517.16	16846.41	-2365.75
6	26-Aug-08	2409.68	6941.526	16726.88	17804.05	-1115.74
7	30-Aug-08	1421.05	3864.472	5491.59	5972.105	-493.45
8	31-Aug-08	1060.18	3144.074	3333.27	3258.103	68.11
9	3-Sep-08	2162.19	8359.1	18073.93	14228.71	3814.40
10	4-Sep-08	2500.58	6231.352	15582.00	19221.18	-3680.83
11	7-Sep-08	1494.40	4976.148	7436.34	6627.319	794.66
12	8-Sep-08	1367.64	7056.136	9650.25	5517.165	4121.13
13	29-Sep-08	373.70	648.192	242.23	376.9484	-135.54
14	30-Sep-08	359.11	614.732	220.76	347.1387	-127.13
15	3-Oct-08	396.32	2607.718	1033.50	425.6739	606.90
16	4-Oct-08	377.41	716.3	270.34	384.7273	-115.22
17	5-Oct-08	359.11	715.79	257.05	347.1387	-90.84
18	17-Aug-09	3127.04	10412.41	32560.02	30521.54	1972.34
19	17-Aug-09	1570.23	7090.00	11132.94	7341.827	3775.21
20	18-Aug-09	2277.38	12292.71	27995.16	15841.35	12119.49
21	18-Aug-09	3264.12	16804.08	54850.51	33353.86	21424.39
22	19-Aug-09	2923.99	11448.86	33476.34	26564.22	6854.57
23	19-Aug-09	2593.63	12414.93	32199.75	20730.03	11424.80
24	20-Aug-09	2767.62	14145.36	39148.97	23709.67	15387.93
25	20-Aug-09	2283.70	13077.63	29865.35	15932.38	13898.45
26	21-Aug-09	4217.88	22693.43	95718.16	56678.37	38916.99
27	21-Aug-09	5164.05	11506.50	59420.17	86143.4	-26909.88
28	22-Aug-09	3198.50	12190.20	38990.34	31981.85	6939.20
29	22-Aug-09	4830.23	7552.00	36477.89	75022.5	-38707.16
30	23-Aug-09	2707.97	7075.75	19160.91	22664.86	-3553.06
31	23-Aug-09	3845.26	10105.45	38858.09	46809.39	-8052.72
32	24-Aug-09	2683.34	5069.70	13603.72	22240.54	-8685.01
33	24-Aug-09	2815.30	4936.29	13897.14	24562.38	-10718.45
34	25-Aug-09	2870.04	6146.85	17641.69	25560.42	-7974.10
35	25-Aug-09	3551.08	12991.95	46135.44	39704.35	6345.07
36	26-Aug-09	3807.32	9482.93	36104.55	45859.11	-9853.92
37	26-Aug-09	4912.29	10495.49	51556.90	77682.76	-26294.18

No.	Date & time of Sampling	Discharge Q (m^3/s)	Measured Sediment Concentration (Cm) mg/l	Measured Sediment discharge (Qsm) kg/s	Computed sediment discharge (Qsc) kg/s	Difference (Qsm-Qsc) kg/s
38	27-Aug-09	3194.00	7021.85	22427.80	31888.85	-9530.15
39	27-Aug-09	4132.45	9323.93	38530.69	54329.66	-15916.69
40	28-Aug-09	2535.80	6566.95	16652.47	19785.36	-3175.76
41	28-Aug-09	2887.05	5643.94	16294.32	25874.69	-9636.44
42	29-Aug-09	1825.08	3516.81	6418.46	10020.93	-3624.18
43	29-Aug-09	1729.52	3505.82	6063.40	8966.008	-2922.04
44	30-Aug-09	2412.96	7397.26	17849.30	17854.15	-43.53
45	30-Aug-09	2045.07	7301.45	14931.97	12680.63	2223.87
46	31-Aug-09	4018.12	10505.15	42210.97	51266.48	-9166.59
47	31-Aug-09	4995.28	13261.39	66244.34	80421.75	-14351.66
48	1-Sep-09	3551.81	8483.92	30133.28	39721.23	-9674.02
49	1-Sep-09	3311.46	8909.20	29502.46	34362.22	-4934.21
50	2-Sep-09	1885.96	6055.29	11420.03	10724.67	672.12
51	3-Sep-09	1978.48	5450.03	10782.77	11841.45	-1084.34
52	4-Sep-09	1722.28	4589.00	7903.55	8888.521	-1004.23
53	5-Sep-09	1770.96	10178.04	18024.94	9416.056	8588.48
54	6-Sep-09	1886.85	9774.90	18443.77	10735.14	7685.37
55	6-Sep-09	1932.26	8214.06	15871.72	11276.44	4570.85
56	7-Sep-09	1364.84	5046.31	6887.40	5493.835	1381.66
57	7-Sep-09	1475.83	5370.65	7926.16	6458.119	1454.05
58	8-Sep-09	1354.35	3821.38	5175.48	5406.855	-243.09
59	8-Sep-09	1112.93	2319.58	2581.52	3602.34	-1028.62
60	9-Sep-09	1090.11	2456.95	2678.35	3451.252	-780.38
61	10-Sep-09	918.71	2312.75	2124.74	2422.752	-303.26
62	11-Sep-09	725.27	1452.87	1053.73	1485.707	-435.20
63	11-Sep-09	685.73	1458.47	1000.12	1323.047	-325.79
64	12-Sep-09	461.69	1559.18	719.86	583.734	134.86
65	12-Sep-09	575.80	1381.12	795.24	921.7462	-128.50
66	13-Sep-09	415.07	1424.80	591.39	468.3761	122.00
67	13-Sep-09	527.86	1346.88	710.97	770.0781	-60.78
68	14-Sep-09	523.22	1056.00	552.52	756.1388	-205.25
69	15-Sep-09	386.84	814.29	315.00	404.8763	-90.75
70	15-Sep-09	469.63	919.84	431.99	604.6997	-174.02
71	16-Sep-09	413.31	904.03	373.64	464.2775	-91.64
72	16-Sep-09	444.27	852.42	378.71	539.0994	-161.56
73	17-Sep-09	444.27	1721.99	765.03	539.0994	224.76
74	18-Sep-09	437.70	3154.11	1380.55	522.7356	856.68
75	18-Sep-09	478.30	3447.78	1649.07	628.0017	1019.71
76	19-Sep-09	363.41	1753.60	637.27	355.793	280.71

No.	Date & time of Sampling	Discharge Q (m^3/s)	Measured		Computed sediment discharge (Qsc) kg/s	Difference (Qsm-Qsc) kg/s
			Sediment Concentration (Cm) mg/l	Sediment discharge (Qsm) kg/s		
77	20-Sep-09	343.57	929.52	319.36	316.7863	1.88
78	20-Sep-09	355.52	967.36	343.92	340.0039	3.18
79	21-Sep-09	316.92	631.80	200.23	268.0629	-68.41
80	21-Sep-09	327.68	788.33	258.32	287.2267	-29.53
81	22-Sep-09	344.90	619.86	213.79	319.3331	-106.23
82	23-Sep-09	292.34	652.19	190.66	226.8348	-36.67
83	23-Sep-09	314.32	540.49	169.89	263.5339	-94.22
84	24-Sep-09	293.60	472.71	138.79	228.8616	-90.57
85	24-Sep-09	301.33	543.70	163.83	241.5035	-78.19
86	26-Sep-09	300.04	407.88	122.38	239.3668	-117.51
87	26-Sep-09	314.32	582.75	183.17	263.5339	-80.94
88	27.sep.09	295.17	579.05	170.92	231.4035	-60.99
89	27.sep.09	317.62	584.59	185.68	269.2974	-84.20
90	28.sep.09	296.13	705.77	209.00	232.9645	-24.47
91	28.sep.09	314.32	599.17	188.33	263.5339	-75.77
92	18.aug.10	4206.42	5717.41	24049.82	56360.35	-32432.64
93	10.sep.10	1648.59	6528.97	10763.61	8119.891	2626.13
94	11.sep.10	1023.54	7108.64	7275.96	3029.498	4239.89
95	12.sep.10	1143.84	6335.24	7246.52	3812.394	3425.87
96	13.sep.10	1367.64	5643.67	7718.50	5517.165	2189.38
97	14.sep.10	1207.38	5039.55	6084.66	4263.449	1811.98
98	15.sep.10	1060.18	6666.76	7067.94	3258.103	3802.78
99	16.sep.10	1609.09	5331.36	8578.66	7722.639	839.28
100	17.sep.10	1341.45	3003.14	4028.55	5300.837	-1283.77
101	18.sep.10	1332.79	4799.25	6396.39	5230.33	1154.73
102	19.sep.10	1522.54	3132.77	4769.77	6888.087	-2133.24
103	20.sep.10	1136.06	3755.48	4266.45	3758.941	499.37
104	21.sep.10	952.81	4214.08	4015.23	2612.474	1397.10
105	22.sep.10	691.29	1280.25	885.03	1345.324	-463.21
106	23.sep.10	631.78	2108.71	1332.25	1116.778	213.05
107	24.sep.10	570.88	2158.02	1231.96	905.5334	324.47
108	25.sep.10	551.48	1123.38	619.52	843.0535	-225.36
109	26.sep.10	616.17	1775.57	1094.05	1060.443	31.31
110	27.sep.10	500.42	1589.45	795.40	689.5759	104.33
111	28.sep.10	509.46	7841.18	3994.78	715.5848	3277.64
112	29.sep.10	431.94	2339.54	1010.54	508.6088	500.83
113	30.sep.10	821.30	1144.07	939.63	1921.45	-985.99
Sum				1.45E+06	1.51E+06	-58,952
Average		1,658	5,277	13,487	14,191	
% difference		= ((Sum of Qsm) – (Sum of Qsc))/(Sum of Qsm)			-3.8%	

Table C.3 Estimated sediment yield at Kessie

year	Suspended load mill. t/year	bed load (mill. t/year)	Total load mill. t/year	Specific sediment yield t/km^2/year
1973	135.8	20.4	156.1	2437.3
1974	171.6	25.7	197.4	3081.0
1975	239.4	35.9	275.3	4297.4
1976	141.1	21.2	162.2	2532.4
1977	156.5	23.5	179.9	2808.9
1978	124.5	18.7	143.2	2235.8
1979	116.0	17.4	133.4	2082.9
1980	124.6	18.7	143.3	2237.6
1981	146.9	22.0	169.0	2638.0
1982	64.3	9.6	73.9	1153.7
1983	83.8	12.6	96.4	1504.3
1984	48.0	7.2	55.2	862.1
1985	120.3	18.0	138.3	2158.8
1986	140.9	21.1	162.1	2530.3
1987	38.5	5.8	44.3	690.9
1988	309.1	46.4	355.5	5549.6
1989	87.6	13.1	100.8	1573.5
1990	82.3	12.3	94.6	1477.4
1992	120.4	18.1	138.5	2161.9
1993	179.0	26.8	205.8	3212.9
1994	379.5	56.9	436.4	6812.7
1995	190.0	28.5	218.5	3410.1
1996	356.4	53.5	409.9	6398.9
1998	157.6	23.6	181.3	2829.9
1999	455.9	68.4	524.3	8184.7
2000	334.5	50.2	384.7	6005.2
2001	446.5	67.0	513.4	8014.7
2002	190.2	28.5	218.7	3413.6
2003	284.6	42.7	327.3	5109.1
2004	174.6	26.2	200.8	3134.8
2005	193.4	29.0	222.4	3471.5
2006	273.1	41.0	314.1	4902.6
2009	154.5	23.2	177.7	2773.6
Average	**188.5**	**28.3**	**216.8**	**3384.5**

Table C.4 Sediment data and its rating curve development for Tato station

no	Date of Sampling	Gage Height, H m	Flow m^3/s	Measured		Computed	
				Sediment Conc. mg/ l	Sediment Discharge (Qsm) kg/day	Sediment Conc. mg/ l	Sediment Discharge (Qsc) kg/day
1	26-Jan-88	0.17	0.28	87.78	2153.9	112.8	2768.2
2	3-Apr-88	0.08	0.06	111.78	598.8	49.4	264.7
3	20-Jun-88	0.28	1.77	434.45	66477.7	304.5	46594.9
4	22-Jul-88	0.29	1.41	268.90	32665.2	268.7	32638.3
5	3-Aug-88	0.36	2.55	1908.38	419794.5	370.8	81563.8
6	22-Aug-88	0.45	3.65	2195.28	691354.8	450.5	141866.3
7	23-Aug-88	0.33	1.99	405.33	69830.4	324.7	55948.3
8	24-Aug-88	0.32	2.09	236.70	42742.7	333.1	60157.0
9	25-Aug-88	0.30	1.88	627.00	101682.3	314.3	50965.9
10	26-Aug-88	0.31	1.79	448.08	69181.7	306.0	47245.8
11	27-Aug-88	0.30	1.78	488.45	74993.4	305.1	46838.6
12	28-Aug-88	0.29	1.55	266.37	35557.3	282.8	37747.0
13	29-Aug-88	0.30	1.62	763.72	106699.0	289.8	40494.5
14	30-Aug-88	0.29	1.67	275.68	39658.3	294.5	42363.5
15	30-Oct-88	0.28	1.12	108.86	10524.8	237.4	22949.9
16	27-Nov-88	0.28	0.49	87.54	3721.3	152.0	6461.3
17	20-Dec-88	0.40	0.11	45.66	449.7	68.8	677.2
18	24-Jan-89	0.40	0.14	63.61	742.0	75.4	879.0
19	27-Jan-89	0.12	0.13	54.30	628.7	75.1	869.0
20	25-Feb-89	0.11	0.90	42.66	3316.9	210.9	16401.4
21	30-Mar-89	0.14	0.07	21.42	131.4	53.2	326.2
22	24-Apr-89	0.13	0.23	52.72	1061.2	101.3	2039.9
23	21-May-89	0.13	0.22	83.91	1609.5	98.7	1893.3
24	14-Jun-89	0.19	0.66	137.50	7852.9	178.4	10188.8
25	27-Sep-89	0.25	2.44	464.61	97786.0	362.0	76192.2
26	19-Dec-89	0.17	0.49	97.67	4151.8	152.0	6461.3
27	22-Jan-90	0.13	0.17	223.35	3203.4	84.3	1209.1
28	23-Feb-90	0.10	0.07	175.55	1061.7	52.8	319.2
29	26-Mar-90	0.10	0.15	37.21	469.4	78.6	991.9
30	26-Apr-90	0.11	0.17	125.18	1795.4	84.3	1209.1
31	22-Jun-90	0.19	0.52	174.37	7804.1	156.3	6995.4
32	31-Jul-90	0.39	2.21	253.24	48420.6	343.6	65704.4
33	17-Oct-90	0.24	1.11	134.60	12885.3	236.1	22602.9
34	5-Sep-91	0.45	5.36	224.56	104071.0	555.5	257452.6
35	18-Aug-92	0.42	8.46	466.13	340672.5	711.2	519816.9
36	3-Sep-92	0.28	2.05	203.93	36049.1	329.3	58214.7
37	25-Sep-92	0.23	1.82	158.73	24945.6	309.0	48557.1
38	31-Jan-95	0.14	0.10	86.18	737.1	63.7	544.8
39	8-Aug-95	0.45	3.04	247.38	65061.3	408.5	107442.0
40	1-Jun-96	0.18	0.29	144.55	3659.2	114.7	2904.7
41	4-Aug-96	0.49	1.15	272.52	27077.9	240.9	23938.0
42	9-Sep-96	0.34	0.64	412.27	22796.8	175.3	9693.8
Sum					2,586,076		1,960,393
Average			1.39	312	61,573	231	46,676
% difference			= ((Sum of Qsm) – (Sum of Qsc))/(Sum of Qsm)				24%

Table C.5 Sediment data and its rating curve development for Guder station

				Measured		Computed	
No	Date of Sampling	G.H. h (m)	Flow Q (m^3/s)	Sediment conc. mg/ l	Sed. Discharge kg/day	Sediment concentration mg/ l	Sediment Discharge kg/day
1	20-Jun-68	0.61	1.31	76.98	8712.735	66.25	7498.33
2	19-Jul-68	1.43	17.01	95.96	141003.3	103.46	152031.44
3	8-Aug-68	2.13	67.20	41.48	240818.8	131.39	762866.11
4	19-Aug-68	1.88	52.65	244.02	1110024	125.93	572860.77
5	19-Sep-68	2.10	67.21	196.59	1141605	131.39	762999.38
6	21-Oct-68	1.27	13.74	71.26	84600.87	99.70	118363.90
7	23-Nov-68	0.60	1.01	24.34	2121.816	63.31	5519.09
8	21-Dec-88	0.51	0.62	32.36	1741.687	58.22	3133.64
9	24-Jan-89	0.51	0.57	29.90	1474.926	57.34	2828.88
10	20-Feb-89	0.47	0.50	36.78	1573.178	55.93	2392.19
11	26-Mar-89	0.48	0.46	22.16	884.696	55.27	2206.09
12	19-Apr-89	0.66	1.93	498.28	83046.89	70.86	11810.03
13	16-May-89	0.61	1.43	63.05	7779.244	67.25	8297.27
14	30-Oct-89	0.74	0.82	41.17	2909.91	61.04	4314.00
15	14-Dec-89	0.57	1.15	38.23	3808.243	64.79	6454.77
16	18-Jan-90	0.51	0.70	223.65	13584.26	59.45	3611.11
17	17-Feb-90	0.64	1.87	144.48	23392.63	70.51	11415.73
18	23-Mar-90	0.59	1.29	46.91	5216.353	66.05	7344.02
19	11-Apr-90	0.52	1.06	109.94	10088.06	63.87	5860.94
20	8-Sep-90	1.83	39.53	85.60	292365.5	119.81	409184.36
21	10-Oct-90	1.17	10.99	73.85	70113.32	95.90	91040.35
22	25-Aug-91	1.90	37.82	90.94	297194.9	118.89	388532.43
23	28-Oct-91	0.62	1.63	98.46	13840.52	68.79	9670.47
24	31-Aug-92	1.93	39.09	107.03	361470.4	119.58	403854.96
25	23-Sep-92	1.90	28.14	130.43	317080.5	112.93	274552.15
26	30-Sep-92	2.32	67.59	150.73	880264	131.52	768119.35
27	23-Jan-95	0.49	8.50	148.89	109347.4	91.71	67351.06
28	28-Dec-96	0.56	0.61	97.85	5148.632	57.99	3051.14
Sum					5,231,211		4,867,164
Average			16.7	108	186,830	85	173,827
% difference			= ((Sum of Qsm) – (Sum of Qsc))/(Sum of Qsm)				7%

Appendix D. Elevation-Area-Storage Capacity relationship

The Elevation-Area-Storage relationship for pre-impoundment condition was generated from Digital Elevation Model (DEM) of the basin for 5 m elevation interval.

H, m	Elevation masl	Area km^2	Volume Billion m^3	Volume Million m^3	Remark
0	**500**	**0.12**	**0.0003**	**0.31**	Bed level at a dam
5	505	0.68	0.0023	2.31	
10	510	1.83	0.0086	8.56	
15	515	3.92	0.0229	22.9	
20	520	6.71	0.0495	49.5	
25	525	13.92	0.1011	101	
30	530	20.64	0.1875	187	
35	535	33.47	0.3227	323	
40	540	49.29	0.5296	530	
45	545	66.63	0.8194	819	
50	550	93.29	1.2192	1,219	
55	555	119.95	1.7523	1,752	
60	560	155.87	2.4419	2,442	
65	565	194.11	3.3168	3,317	
70	570	241.10	4.405	4,405	
75	575	296.15	5.748	5,748	
80	580	360.08	7.388	7,389	
85	585	427.70	9.358	9,358	
90	590	501.88	11.682	11,682	
95	595	583.17	14.394	14,395	
96	**596**	**601.67**	**15**	**15,000**	Minimum Water Level
100	600	675.67	17.542	17,542	
105	605	774.29	21.166	21,166	
110	610	878.31	25.30	25,298	
115	615	994.13	29.979	29,979	
120	620	1121.03	35.267	35,267	
125	625	1260.37	41.220	41,220	
130	630	1399.71	47.871	47,871	
135	635	1548.10	55.240	55,240	
140	640	1698.98	63.358	63,358	
145	645	1849.85	72.230	72,230	
146	**646**	**1884.55**	**74**	**74,000**	Full Supply Level
150	650	2000.57	81.856	81,856	

Appendix E. Deposition pattern

Table E.1 Deposition pattern for annual sediment yield = 172 million t/year (965 t/km^2/year)

Elevation masl	20		40		60		80		100		120		160	
	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3
646	1884	70938	1884	67875	1884	64813	1884	61443	1884	58688	1884	55561	1734	38945
645	1850	69168	1850	66105	1850	63043	1850	59673	1850	56918	1850	53791	1542	30755
640	1733	60383	1733	57321	1733	54260	1732	50892	1731	48138	1730	45014	1442	26369
635	1547	52181	1546	49124	1544	46068	1542	42708	1539	39963	1535	36851	1371	23468
630	1398	44820	1395	41773	1390	38731	1385	35392	1378	32668	1370	29588	1190	17061
625	1256	38184	1251	35159	1244	32145	1233	28846	1222	26165	1206	23146	989	11608
620	1115	32256	1106	29265	1095	26297	1079	23065	1061	20455	1036	17538	784	7171
615	985	27005	973	24066	957	21166	933	18034	909	15528	873	12765	573	3775
610	866	22376	850	19507	828	16702	797	13708	763	11347	715	8794	360	1438
605	759	18312	738	15537	710	12856	670	10041	627	7870	565	5593	142	179
600	657	14772	631	12114	597	9588	547	7000	494	5068	417	3137	0	0
595	561	11728	530	9212	488	6875	429	4562	365	2920	274	1410	0	0
590	476	9137	439	6789	391	4676	321	2688	248	1387	140	374	0	0
585	398	6953	356	4799	301	2944	222	1331	137	425	15	5	0	0
580	327	5142	280	3207	219	1643	129	453	35	31	0	0	0	0
575	259	3678	208	1986	141	745	42	24	0	0	0	0	0	0
570	201	2527	146	1100	73	211	0	0	0	0	0	0	0	0
565	152	1645	93	502	15	12	0	0	0	0	0	0	0	0
560	111	987	50	145	0	0	0	0	0	0	0	0	0	0
555	74	524	11	10	0	0	0	0	0	0	0	0	0	0
550	47	222	0	0	0	0	0	0	0	0	0	0	0	0
545	20	55	0	0	0	0	0	0	0	0	0	0	0	0
540	4	0	0	0	0	0	0	0	0	0	0	0	0	0

Table E.2 Deposition pattern for annual sediment yield = 196 million t/year (1103 t/km^2/year)

Elevation masl	20		40		60		80		100		120		160	
	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3
646	1884	70500	1884	67000	1884	63500	1884	60000	1884	56500	1884	53000	1734	35445
645	1850	68730	1850	65230	1850	61730	1850	58230	1850	54730	1850	51230	1539	27263
640	1733	59945	1733	56447	1732	52948	1732	49450	1731	45952	1729	42456	1433	22893
635	1547	51745	1545	48251	1543	44759	1540	41270	1536	37785	1531	34306	1357	20014
630	1397	44384	1393	40903	1388	37429	1382	33965	1373	30512	1360	27075	1156	13722
625	1256	37752	1249	34296	1240	30857	1228	27440	1212	24049	1190	20697	927	8506
620	1114	31827	1103	28414	1089	25033	1070	21695	1045	18407	1010	15194	684	4470
615	984	26583	969	23233	949	19938	921	16717	885	13583	836	10577	429	1681
610	864	21963	844	18699	817	15523	780	12464	731	9542	665	6823	165	191
605	756	17910	731	14760	696	11740	648	8893	586	6249	501	3905	0	0
600	654	14385	622	11377	579	8553	520	5972	443	3677	339	1805	0	0
595	557	11359	519	8524	467	5938	397	3680	304	1809	179	510	0	0
590	471	8789	427	6159	366	3854	284	1978	176	607	30	16	0	0
585	393	6629	342	4236	273	2255	179	820	56	27	0	0	0	0
580	321	4846	264	2720	187	1105	82	166	0	0	0	0	0	0
575	253	3412	191	1582	106	374	0	0	0	0	0	0	0	0
570	194	2294	127	787	35	22	0	0	0	0	0	0	0	0
565	144	1448	73	287	0	0	0	0	0	0	0	0	0	0
560	104	828	29	33	0	0	0	0	0	0	0	0	0	0
555	66	403	0	0	0	0	0	0	0	0	0	0	0	0
550	39	142	0	0	0	0	0	0	0	0	0	0	0	0
545	12	15	0	0	0	0	0	0	0	0	0	0	0	0
540	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table E.3 Deposition pattern for annual sediment yield = 220 million t/year (1241 t/km^2/year)

Elevation masl	20		40		60		80		100		120	
	Area km^2	volume mill. m^3	Area km^2	volume mill. m^3	Area km^2	volume mill. m^3	Area km^2	volume mill. m^3	Area km^2	volume mill. m^3	Area Km^2	volume mill. m^3
646	1884	70062	1884	66125	1884	62187	1884	57929	1884	53911	1884	49893
645	1850	68293	1850	64355	1850	60418	1850	56159	1850	52141	1850	48123
640	1733	59508	1733	55572	1732	51636	1731	47380	1730	43366	1728	39353
635	1547	51308	1545	47378	1542	43450	1538	39207	1532	35210	1525	31222
630	1397	43949	1392	40034	1386	36129	1376	31920	1364	27967	1346	24041
625	1255	37319	1247	33435	1236	29573	1219	25431	1196	21564	1164	17762
620	1113	31399	1100	27566	1083	23776	1056	19744	1020	16021	970	12423
615	982	26162	964	22404	939	18721	900	14852	850	11343	778	8050
610	862	21551	838	17897	804	14362	752	10719	685	7505	588	4632
605	754	17511	723	13993	679	10652	613	7305	526	4477	402	2155
600	650	14001	612	10654	559	7557	476	4581	369	2239	216	608
595	553	10993	507	7854	443	5053	345	2528	216	776	33	16
590	466	8445	413	5552	338	3100	223	1109	73	53	0	0
585	387	6311	327	3702	241	1653	110	277	0	0	0	0
580	315	4557	247	2268	151	675	4	0	0	0	0	0
575	246	3155	172	1221	66	133	0	0	0	0	0	0
570	187	2071	107	526	0	0	0	0	0	0	0	0
565	137	1262	51	132	0	0	0	0	0	0	0	0
560	96	682	6	2	0	0	0	0	0	0	0	0
555	58	299	0	0	0	0	0	0	0	0	0	0
550	30	79	0	0	0	0	0	0	0	0	0	0
545	4	2	0	0	0	0	0	0	0	0	0	0
540	0	0	0	0	0	0	0	0	0	0	0	0

Table E.4 Deposition pattern for annual sediment yield = 233 million t/year (1311 t/km^2/year)

Elevation masl	20		40		60		80		100		120	
	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3
646	1884	69844	1884	65687	1884	61531	1884	57036	1884	52795	1884	48554
645	1850	68074	1850	63918	1850	59761	1850	55266	1850	51025	1850	46784
640	1733	59289	1733	55135	1732	50980	1731	46488	1729	42251	1727	38016
635	1547	51089	1545	46941	1542	42796	1537	38319	1531	34102	1521	29895
630	1397	43731	1392	39600	1385	35479	1374	31039	1360	26874	1339	22741
625	1255	37103	1246	33005	1234	28932	1214	24566	1188	20502	1151	16513
620	1112	31186	1099	27142	1079	23149	1049	18907	1008	15009	949	11259
615	981	25952	962	21991	934	18115	891	14056	832	10407	748	7011
610	861	21346	835	17497	798	13785	740	9979	661	6673	548	3768
605	752	17312	719	13612	671	10113	596	6638	495	3782	351	1519
600	648	13810	607	10296	548	7065	456	4006	331	1715	153	259
595	551	10813	501	7524	430	4619	320	2066	170	461	0	0
590	464	8276	406	5255	323	2734	195	778	20	7	0	0
585	384	6156	319	3443	224	1366	77	99	0	0	0	0
580	311	4417	238	2052	132	476	0	0	0	0	0	0
575	243	3032	162	1053	45	34	0	0	0	0	0	0
570	183	1968	96	410	0	0	0	0	0	0	0	0
565	133	1178	39	73	0	0	0	0	0	0	0	0
560	91	619	0	0	0	0	0	0	0	0	0	0
555	53	258	0	0	0	0	0	0	0	0	0	0
550	26	61	0	0	0	0	0	0	0	0	0	0
545	0	0	0	0	0	0	0	0	0	0	0	0
540	0	0	0	0	0	0	0	0	0	0	0	0

Table E.5 Deposition pattern for annual sediment yield = 245 million t/year (1378 t/km^2/year)

Elevation masl	20		40		60		80		100		120	
	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3
646	1884	69625	1884	65250	1884	60875	1884	56143	1884	51679	1884	47214
645	1850	67855	1850	63480	1850	59105	1850	54373	1850	49909	1850	45444
640	1733	59071	1733	54697	1732	50324	1731	45596	1729	41136	1726	36679
635	1547	50871	1544	46504	1541	42142	1536	37430	1528	32993	1518	28570
630	1396	43513	1391	39165	1383	34830	1371	30160	1355	25782	1330	21444
625	1254	36886	1245	32574	1231	28292	1210	23705	1180	19443	1136	15273
620	1112	30972	1097	26719	1075	22525	1042	18076	995	14004	926	10114
615	981	25741	960	21577	929	17513	880	13270	813	9482	715	6007
610	860	21140	832	17098	790	13215	725	9255	635	5860	503	2959
605	751	17112	715	13232	662	9584	578	5995	462	3115	293	965
600	647	13618	602	9939	537	6589	433	3465	291	1231	82	25
595	549	10630	495	7196	417	4206	293	1649	122	199	0	0
590	461	8106	399	4960	307	2396	163	508	0	0	0	0
585	381	5998	310	3187	206	1114	41	37	0	0	0	0
580	308	4274	229	1839	111	322	0	0	0	0	0	0
575	239	2905	152	889	23	16	0	0	0	0	0	0
570	180	1858	85	298	0	0	0	0	0	0	0	0
565	129	1088	28	18	0	0	0	0	0	0	0	0
560	87	549	0	0	0	0	0	0	0	0	0	0
555	49	209	0	0	0	0	0	0	0	0	0	0
550	21	33	0	0	0	0	0	0	0	0	0	0
545	0	0	0	0	0	0	0	0	0	0	0	0
540	0	0	0	0	0	0	0	0	0	0	0	0

Table E.6 Deposition pattern for annual sediment yield = 257 million t/year (1448 t/km^2/year)

Elevation masl	20		40		60		80		100		120	
	Area km^2	volume mill. m^3	Area km^2	volume mill. m^3	Area km^2	volume mill. m^3	Area km^2	volume mill. m^3	Area km^2	volume mill. m^3	Area km^2	volume mill. m^3
646	1884	69406	1884	64813	1884	60219	1884	55625	1884	50562	1884	45875
645	1850	67636	1850	63043	1850	58449	1850	53855	1850	48793	1850	44105
640	1733	58852	1733	54260	1732	49669	1730	45078	1728	40022	1725	35342
635	1547	50652	1544	46068	1540	41488	1535	36915	1526	31886	1513	27246
630	1396	43296	1390	38731	1382	34181	1370	29651	1350	24693	1321	20156
625	1254	36670	1244	32145	1229	27654	1207	23208	1170	18390	1118	14053
620	1111	30758	1095	26297	1071	21903	1037	17598	980	13011	899	9006
615	980	25531	957	21166	923	16917	874	12820	792	8577	676	5066
610	859	20934	828	16702	782	12653	716	8845	607	5077	450	2248
605	749	16914	710	12856	651	9067	566	5637	426	2492	225	556
600	645	13428	597	9588	524	6129	419	3172	246	809	0	0
595	546	10449	488	6875	401	3815	276	1435	69	21	0	0
590	459	7936	391	4676	290	2087	143	387	0	0	0	0
585	379	5842	301	2944	185	899	18	7	0	0	0	0
580	305	4133	219	1643	89	213	0	0	0	0	0	0
575	236	2781	141	745	0	0	0	0	0	0	0	0
570	176	1753	73	211	0	0	0	0	0	0	0	0
565	125	1002	15	12	0	0	0	0	0	0	0	0
560	83	484	0	0	0	0	0	0	0	0	0	0
555	45	165	0	0	0	0	0	0	0	0	0	0
550	17	12	0	0	0	0	0	0	0	0	0	0
545	0	0	0	0	0	0	0	0	0	0	0	0
540	0	0	0	0	0	0	0	0	0	0	0	0

Table E.7 Deposition pattern for annual sediment yield = 270 million t/year (1520 t/km^2/year)

Elevation masl	20		40		60		80		100		120	
	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3
646	1884	69187	1884	64375	1884	59563	1884	54750	1884	49446	1884	44536
645	1850	67418	1850	62605	1850	57793	1850	52980	1850	47677	1850	42766
640	1733	58633	1733	53823	1732	49013	1730	44204	1727	38907	1724	34006
635	1546	50434	1544	45632	1540	40835	1534	36045	1524	30780	1509	25924
630	1396	43078	1390	38297	1381	33532	1367	28791	1344	23608	1310	18869
625	1254	36454	1243	31716	1226	27014	1201	22368	1160	17346	1100	12837
620	1110	30544	1093	25876	1067	21280	1029	16791	963	12036	870	7907
615	979	25321	954	20757	917	16318	862	12063	768	7705	634	4142
610	858	20730	825	16310	775	12088	700	8156	574	4347	395	1565
605	748	16715	705	12484	642	8546	546	5038	385	1947	154	189
600	643	13238	591	9244	512	5663	394	2686	195	498	0	0
595	544	10270	481	6564	387	3416	246	1085	7	1	0	0
590	456	7769	383	4403	273	1767	108	199	0	0	0	0
585	376	5689	292	2716	166	670	0	0	0	0	0	0
580	302	3995	208	1466	67	88	0	0	0	0	0	0
575	232	2661	129	624	0	0	0	0	0	0	0	0
570	172	1651	60	151	0	0	0	0	0	0	0	0
565	120	922	2	0	0	0	0	0	0	0	0	0
560	79	425	0	0	0	0	0	0	0	0	0	0
555	40	128	0	0	0	0	0	0	0	0	0	0
550	12	14	0	0	0	0	0	0	0	0	0	0
545	0	0	0	0	0	0	0	0	0	0	0	0
540	0	0	0	0	0	0	0	0	0	0	0	0

Table E.8 Deposition pattern for annual sediment yield = 294 million t/year (1654 t/km^2/year)

Elevation masl	20		40		60		80		100		120	
	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3
646	1884	68750	1884	63500	1884	58250	1884	53000	1884	47750	1884	42500
645	1850	66980	1850	61730	1850	56480	1850	51230	1850	45980	1850	40730
640	1733	58196	1732	52948	1731	47701	1729	42456	1726	37213	1722	31976
635	1546	49997	1543	44759	1538	39527	1531	34306	1519	29099	1501	23920
630	1395	42643	1388	37429	1377	32237	1360	27075	1334	21962	1291	16934
625	1253	36022	1240	30857	1220	25741	1190	20697	1142	15767	1065	11035
620	1109	30117	1089	25033	1058	20044	1010	15194	936	10568	816	6326
615	977	24902	949	19938	904	15137	836	10577	729	6402	557	2890
610	855	20322	817	15523	757	10983	665	6823	522	3272	290	767
605	745	16322	696	11740	619	7542	501	3905	318	1171	21	4
600	639	12862	579	8553	484	4784	339	1805	112	96	0	0
595	539	9916	467	5938	354	2689	179	510	0	0	0	0
590	451	7440	366	3854	234	1220	30	16	0	0	0	0
585	369	5390	273	2255	122	332	0	0	0	0	0	0
580	295	3730	187	1105	17	8	0	0	0	0	0	0
575	224	2432	106	374	0	0	0	0	0	0	0	0
570	163	1463	35	22	0	0	0	0	0	0	0	0
565	111	777	0	0	0	0	0	0	0	0	0	0
560	69	326	0	0	0	0	0	0	0	0	0	0
555	30	77	0	0	0	0	0	0	0	0	0	0
550	3	0	0	0	0	0	0	0	0	0	0	0
545	0	0	0	0	0	0	0	0	0	0	0	0
540	0	0	0	0	0	0	0	0	0	0	0	0

Table E.9 Deposition pattern for annual sediment yield = 319 million t/year (1792 t/km^2/year)

Elevation masl	20		40		60		80		100		120	
	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3	Area Km^2	volume mill. m^3
646	1884	68312	1884	62625	1884	56937	1884	51250	1884	45562	1884	39875
645	1850	66543	1850	60855	1850	55168	1850	49480	1850	43793	1850	38105
640	1733	57759	1732	52073	1731	46390	1728	40708	1725	35030	1718	29359
635	1546	49561	1542	43887	1537	38221	1528	32568	1513	26938	1487	21345
630	1395	42208	1387	36562	1374	30942	1353	25363	1318	19855	1261	14464
625	1252	35590	1237	30001	1214	24472	1176	19037	1114	13767	1011	8773
620	1108	29691	1085	24195	1048	18815	989	13621	892	8746	731	4408
615	975	24483	942	19126	890	13969	805	9131	667	4844	436	1483
610	853	19914	809	14748	738	9898	625	5554	438	2079	128	68
605	742	15928	685	11013	594	6566	449	2867	210	457	0	0
600	635	12486	565	7887	454	3945	274	1057	0	0	0	0
595	535	9561	451	5345	317	2017	102	115	0	0	0	0
590	445	7112	348	3347	191	745	0	0	0	0	0	0
585	363	5091	252	1848	73	84	0	0	0	0	0	0
580	288	3464	163	812	0	0	0	0	0	0	0	0
575	217	2204	80	206	0	0	0	0	0	0	0	0
570	155	1275	7	-9	0	0	0	0	0	0	0	0
565	102	632	0	0	0	0	0	0	0	0	0	0
560	60	227	0	0	0	0	0	0	0	0	0	0
555	21	25	0	0	0	0	0	0	0	0	0	0
550	0	0	0	0	0	0	0	0	0	0	0	0
545	0	0	0	0	0	0	0	0	0	0	0	0
540	0	0	0	0	0	0	0	0	0	0	0	0