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# Assessment of Megech River Bank Erosion and Sedimentation Upper Blue Nile Basin, Ethiopia

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**Assessment of Megech River Bank Erosion and Sedimentation Upper Blue Nile Basin, Ethiopia**


**Bahir Dar University Institute of Technology**

**Faculty of Civil and Water Resource Engineering**

**School of Research and Post graduate Studies**

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# Assessment of Megech River Bank Erosion and Sedimentation Upper Blue Nile Basin

**Thesis**

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Hydraulic Engineering Submitted to the Faculty of Civil and Water Resources Engineering

Bahir Dar Institute of Technology

Supervised by Mengiste Abate (PhD)

Bahir Dar, Ethiopia

July, 2020

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**Abstract**

The change in river morphology in river systems is described by river bank erosion, river bed level change and lateral channel change. The alluvial river channels in Lake Tana sub basin in the upper Blue Nile basin have been disturbed by natural and human-induced factors. This paper examines stream bank erosion and sedimentation of the Megech River which drains towards Lake Tana and then to the Blue Nile. Soil samples at the banks and bed of the river were collected and analyzed. River cross sections have been surveyed for about 10 km starting from the newly constructed Megech Embankment Dam. Stream flow and climatological data have been collected from Ministry of Water, Irrigation and Energy and National Metrology Agency. Using HEC-RAS and BSTEM models, the collected data have been analyzed and simulated. The simulated result has been analyzed by dividing total study reaches into three sub –reaches as upper, middle and lower reaches. The result shows that sediment was accumulated in some location and degraded in another location for the past ten years. The upper reach average bed change was found to be aggradation while the middle and lower reaches show that there is small amount of degradation. For the studied River reach, when looked in general, the average mass bed change was found to be 2.031 ton/day (aggradation). The average River bed invert level change was found to be 0.289 m which indicates again deposition or aggradation. There was on average 41.696 ton/day sediment discharge found for the whole study reach and from which 14.415ton/day was contributed from the banks of the river. The general trend of river bank stability shows that 76% of right bank is stable and 24% is unstable while the left bank is 35% stable and 65% is unstable. In general, even though higher record is observed at some location and at high flow season, the Megech River bed change and bank erosion as compared to sediment discharge found to be on average small from year to year and from location to location. But the sediment discharge is higher according to the simulation result and this needs action to minimize Lake Tana and Megech reservoir sedimentation. Hence, an integrated river catchment management and river bank stabilization work has to be in place to minimize sediment discharge and bank erosion.

**Keywords**: Aggradation, degradation, erosion, Megech-River, Sedimentation Simulation

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**Nomenclature**

BSTEM –bank stability and toe erosion model

USACE – Unite states of America corps of Engineers

HEC-RAS – Hydrologic Engineering Center-River Analysis system

RS – River station

SRC – sediment rating curve

ECDSWC- Ethiopian construction design and supervision works corporation

Ds –downstream

Us –upstream

$\phi'$ –friction angle

$\phi^b$–phi –b

MoWIE- Ministry of Water, Irrigation and Energy

Dn- $d_{50}$, $d_{75}$, d90

# 1 INTRODUCTION

## *1.1 Background*

Rain water flowing down slopes comes together to form a stream flow. The space where a stream flow runs is a channel. A river is the general term for a channel and the water in it. The area supplying water into a channel is a drainage basin. The boundary between drainage basins is a water divide (Matsuda, 2004). Rivers and streams are products of their catchments. They are often referred to as dynamic systems which mean they are in a constant state of change. The factors controlling river and stream formation are complex and interrelated. These factors include the amount and rate of supply of water and sediment into stream systems, catchment geology, and the type and extent of vegetation in the catchment. As these factors change over time, river systems respond by altering their shape, form and/or location. In stable streams the rate of these changes is generally slow and imperceptible (Matsuda, 2004).

Stream bank erosion is a natural process that over time has resulted in the formation of the productive floodplains and alluvial terraces common to river systems (Matsuda, 2004).

Streams change in response to variations in discharge and sediment supply are dynamic by nature. These changes vary spatially according to the position within the basin and influenced by local variations in geology, soils, bank characteristics, vegetation, hydraulics and other factors that influence stability such as various types of land use (Garcìa et al., 2008).

The possible link between climate change and river instability is one of the most difficult and certainly the most contentious issues facing the river engineer at the present time. The land degradation resulted in impoverishment of upland soil resource (by leaching and by accelerated erosion) and adverse hydrological effects such as channel siltation and flooding in the low lands (Macklin & Lewin, 2003).

The above human induced consequences affect discharge and sediment indirectly typically by increasing peak flows and increasing the quantities of sediment considerably.

*Figure 1: Megech River bank being widened by erosion:* Taken from 200m downstream of Megech Dam, June 07/2019

## *1.2 Statement of the Problem*

Since the beginning of mankind, sedimentation processes have affected water supplies, Irrigation, agricultural practices, flood control, river migration, hydroelectric projects, navigation, fisheries, and aquatic habitat. In the last few years, sediment also has been found to play an important role in the transport and fate of pollutants; thus, sedimentation control has become an important issue in water quality management. By studying the quantity, quality, and characteristics of sediment in rivers and streams, scientists and engineers can determine the sources of the sediment and evaluate the impact of pollutants on the aquatic environment.

Similarly reasons, the instability of Megech River banks and its tributaries are being threatened during flooding of adjoining areas and so far, there has been a report on the loss of properties taken away by the Megech River. Again, the instability of Megech River banks and beds has direct effects on Lake Tana sedimentation. If sedimentation transport of this river is known and treated as recommended, it is believed that Lake Tana sedimentation decreases and some lives can be saved as much as possible. The reach of this river follows a meandering path and the channel is incised and gets widened from time to time posing a great threat of flooding danger for the adjoining dwellers. The Megech River is also getting aggraded continuously as a result the flood way of this river is also becoming wider and shallower there by over stepping the banks and flooding the adjoining areas. Thus assessment of stability problems of those river reaches is helpful for implementation of proper stabilization measures. Erosion and sedimentation can also have these affects *(Elliott et al., 2016).*

Loss of fertile soil, flooding from clogged ditches, culverts and storm sewers, muddy or turbid streams, damages plant and animal life ,clogs ponds, lake, and reservoirs, damages aquatic and other habitats, decreased recreational value and use structural damage to buildings and roads.

Accordingly, Megech River is affecting the surrounding farm lands, main and dam construction access bridges, Lake Tana due to bank erosion and sedimentation from time to time.

Moreover, Bahir Dar - Gondar Bridge Pire foundation which is found on Megech River is being scoured due to erosion of the banks along the River.

Along the river and in its catchment the infrastructural and socio economic developments have been increasing more than ever. These anthropogenic and natural impacts resulting bank erosion and aggradation and consequent flooding which will have significant influence in damaging the properties and infrastructures along the adjoining areas. So this study focuses on the assessment and understanding of the morphological responses of Megech River due to natural factors (flow and sediment inputs) so that appropriate measures can be suggested.

## *1.3 Objective of the Research*

### 1.3.1 General objectives

The general objective of this thesis is to analyze the bank stability and sediment transport rate of the Megech River by evaluating its capacity and stability in response to discharge and sediments that are supplied from the catchments. In addition to these, the amount of sediment added to sediment transport routine from bank erosion and failures will be determined by using the model so called BSTEM.

### 1.3.2 Specific objective

The specific objectives are:

- ❖ To characterize the bed and bank materials of the lower reach of Megech River
- ❖ To estimate average bed change rate of Megech River
- ❖ To determine Megech River's sediment discharge
- ❖ To determine bank erosion rate
- ❖ To analyses bank stability of Megech River

## *1.4 Research question*

The research question included in this research are:

- ❖ How much Megech River bed change is observed in past ten years by aggradation or degradation;
- ❖ How much is Megech River sediment discharge;

- ❖ How much sediment is added from bank erosion to sediment transport processes in Megech River on selected river reach ;
- ❖ How can bank erosion and sedimentation affect hydraulic structures on Megech River;
- ❖ How can sedimentation affects water supply quality and quantity;
- ❖ How can bank erosion displace the surrounding people, etc.?

## *1.5 Scope of the study*

The scope of this research includes the 10 km river reach stretch starting from at the toe of Megech Dam (geographic location=332391.06, Y=1382491.44, Z=1873.52) to downstream up to geographic location of X=329926.46, Y=1375834.84, Z=1826.87. This river reach includes two main river joined at upstream of the dam, namely upper Megech River, Dimaza and Angereb Rivers. After joining both rivers got the name "Megech River" and the study is focused on estimating average bed change rate, to determine stream bank erosion rate and sediment discharge rate in past ten years.

The study does not include upper and lower river reach of the above listed of my study reach because of economic capacity of data collection for all river's stretch. The study required time duration from November, 2019 to March, 2020 to complete the whole processes starting from data collection to model simulation and interpretation.

## *1.6 Limitation of the study*

To execute the study on more than 10km, data collection can be beyond my economical capacity as surveying instruments and professional labors perdium is high to pay. Not only that but also Soil laboratory is very expensive to analyze river bed and bank material for HEC-RAS model as in put parameters. The other limitation on this study is the use of duration of flow data. I used past ten years daily flow records because the HEC-RAS model takes very long time to simulate if more than ten years' daily flow record is used. It usually breakout or interrupted when too much daily flow records are feed. Therefore, for this research, Ten kilometers of river reach and ten year daily flow records are applied in general.

## *1.7 Significance of the study*

The adverse consequence of increased stream bank erosion results not only in accelerated sediment yields, but also to changes in stream channel instability and associated stream type changes. Stream types can evolve in over a wide range of scenarios from meandering to braided, to incised channels due to various processes (Rosgen, 2001). These instabilities and consequential shifts in stream type not only produce higher sediment yields, but can degrade the physical and biological function of rivers. At downstream of this research area, there is a weir to be constructed to head up irrigation water released from Megech Dam and irrigation canals as well. Therefore, it is necessary to know sediment movement in this channel to design effective hydraulic structures, irrigation canals, for managing river level and uplands.

# 2 LITERATURE REVIEW

## *2.1 General*

The need for graduate engineering education in sedimentation and river mechanics is becoming an essential part of hydraulics, hydrology and environmental programs. The role played by sediments is not only important to solve problems of reservoir sedimentation and dredging, but also plays a significant role in river mechanics, fluvial morphology, bridge crossings, bank protection, water supply, water quality, fish habitat, contaminant transport (Bogárdi & Bogárdi, 1974).Since the rivers are the main basic and accessible resource of water for miscellaneous uses, the erosion and Sedimentation condition of rivers are of a great deal of importance (Azarang & Bajestan, 2015).

## *2.2 Morphological due to bank erosion and sedimentation*

Azarang & Bajestan (2015) conducted research on Karun River, the greatest river of Iran, which has a considerable interest because of strategic and environmental conditions regarding its water projects planning, agriculture, water supply of cities, and industrial units. The morphological changes due to erosion processes, sedimentation, and Sediment transport affects the hydraulic structures like Intake port, irrigation systems, and pump stations

### 2.2.1 Human-related or natural impacts

Bank erosion is the wearing away of the banks of a stream or river. This is distinguished from erosion of the bed of the watercourse, which is referred to as scour (Rosgen, 1996). The nature and stability of different alluvial channels are different. Each behaves in a slightly different way when subject to human-related or natural impacts. Knowledge of this behavior is important in anticipating and understanding stability problems.(Rechardson, Simon, & Legasse, 2001). An alluvial river generally is continually changing its position and shape because of hydraulic forces acting on its bed and banks. These changes may be slow or rapid and may result from natural environmental changes from man's activities or a combination of both. It must be stressed that a river through time is dynamic that man induced changes frequently set in motion a response that can be propagated for long distances.

Evidence from several sources demonstrates that river channels are continually undergoing changes of position, shape, dimensions and pattern and in time, these changes can accumulate to dramatic proportions (Rechardson et al., 2001).

Accelerated stream bank erosion is a major cause of non-point source pollution associated with increased sediment supply. A quantitative prediction of stream bank erosion rate provides a tool to apportion sediment contribution of stream bank sediment source to the total load transported by a river (Rosgen, 2001).

### 2.2.2 Practical method of computing streambank erosion rate

Rosgen (2001) conducted researches on Pagosa Springs, Colorado, and identified that the key stream bank characteristics would be sensitive to the various processes of erosion in order to develop the Bank erosion height index (BEHI) rating. These stream bank variables included: bank height ratio (stream bank height/maximum bank full depth), ratio of rooting depth/bank height, rooting density, per cent surface area of bank protected, bank angle, number and location of various soil composition layers or lenses in the bank, and bank material composition.

## *2.3 Influence of Aggradation and Degradation on River Channels*

The sediment load has a direct impact on the channel morphology based on the concentration and caliber of the load, defined as the grain size of sediment carried by the flow. If the concentration of load increases without a corresponding increase to the discharge, the rivers energy may be insufficient to transport the load resulting in deposition on the bed. Continued deposition will decrease the channels cross-sectional area thereby increasing the velocity of the river to pass the discharge and sediment load.

Aggradation and Degradation are the fluvial processes mostly associated with a river and its differentiating parameters. Aggradation and degradation are generally influenced by river discharge, sediment load, morphological characteristics of river channel and human interventions. If the river water is unable to transfer the bed load or the channel material then the sediment is deposited within the channel and channel depth will be decreased and the flow velocity will be increased and then, aggradation occurs. This also leads to change the river morphology and hydraulic geometry. Degradation is another process which is responsible for the lowering of river bed and also shifting the channel banks (Mugade & Sapkale, 2015).

## *2.4 Bank Erosion and Sediment Transport in Stream Restoration*

Excessive stream bank erosion and channel aggradation and degradation cause poor ecological function and biodiversity, which are among the motivating factors for the implementation of many stream restoration projects (Kassa, 2019).

Specifically, Kassa (2019) evaluated approaches such as Bank Erosion Hazard Index (BEHI), the Bank Assessment for Nonpoint Source Consequences of Sediment (BANCS), the Bank Stability and Toe Erosion Model (BSTEM), and the one-dimensional (1-D) and two-dimensional (2-D) versions of the Hydrologic Engineering Center - River Analysis System (HEC-RAS).finally he arrived at the results which indicate that the suitability of the evaluated approaches highly depends on the mobility of the channel bed and the processes that govern stream bank deformation.

## 2.5 Assesment of Riverbed Change Due to the Operation of a Series of Gates in a Natural Rive

Sediment plays an important role in maintaining the ecosystem in a river, but its effect through the project has not been fully quantified. Thus, when the project is finished, it is important to evaluate its role. In other words, analyzing the effect of the project on riverbed change and determining proper management is vital for maintaining a sound ecosystem (Kim, 2013).

Kim (2013) conducted research on Geum River bed changes (L=130 km from Daechung regulation dam to Geum River estuarial bank) in South Korea and predicted using the 1-D HEC-RAS model. According to Kim's Thesis, three movable weirs have been installed and dredging has been carried out in Geum River under the Four Major Rivers Restoration Project (2009-2012).

## *2.6 River plan form change*

### 2.6.1 River plan form change

In south Gondar, Ethiopia, the conducted research on Rib River to understand the plan form changes of Ribb River using past and recent satellite images of the last 30 years. This researcher used different topographic induces by ArcGIS 10.1 software from 90x90m Digital Elevation Model (DEM) and hydrological, soil and land use data. Finally the researcher arrived at the result which suggested *huge sediment deposition* in the lower reach of Ribb River. According to his findings, the Ribb River is a meandering River, whose sinuosity index values varying in between 1.82 and1.94 and directly drains to Lake Tana. His findings shows that Rib River was shifted by 6.22 km from the old course. All the above results indicate that the lower reach of Ribb River plan form change is linked with huge sediment deposition (Ammar, 2017).

### 2.6.2 Morphological Changes in the Lower Reach of Megech River, Lake Tana Basin, Ethiopia

Asmare & Abate ( 2018) conducted research on morphological change in lower reach of Megech River and their overall result showed that the Megech River and its catchment boundary shifted to the east ward and now the left side of the old catchment boundary line has become the divide line for the current drainage flow. They have found that the increased watershed area contributes much flow and sediment to the Dembia floodplain and to the Lake Tana. This may be one of the reason why the lower course of Megech River is shifted to east.

As their findings, the total area of bank erosion from 1984 to 2014 were about 437 ha, of which 293 ha were on the left bank and 144 ha on the right bank. The total area of bank accretion (deposition) from 1984 to 2014 equaled 221 ha, of which 120 ha were on the left bank and 101 ha on the right bank. They have found that the total area lost as a result of erosion were 437 ha and the total area gained as a result of sediment deposition along its bank were about 221 ha.

These totals translate into annual bank erosion rates of 2.9 ha/year from 1984 to 2006, 31 ha/year from 2006 to 2009, 56 ha/year from 2009 to 2014 and total of 89.87 ha/year from 1984 to 2014 and became part of channel and the trend shows increasing (Asmare & Abate, 2018).

The above studies quoted as literature review used the available tools or models for River morphology studies HEC-RAS, ArcGIS, and CCHE2D-model.

# 3 MATERIAL AND METHODS

## *3.1 Description of the study area*

The Megech River, found in North Gonder administrative zone, Ethiopia, which is about 75 km long, has a drainage area of about 850 $km^2$ and an average annual discharge of 11.1 $m^3/s$. The catchment area at the dam site is 424 $km^2$ with a mean annual flow of 5.6 $m^3/s$ or 176 MCM. The river, which flows generally in a southern direction and empties into Lake Tana, is one of the main streams flowing into Lake Tana from the North. The highest elevation of the watershed is 2,991 m above mean sea level, in its north eastern part. Four major tributaries join the Megech River: two from the right bank and two from the left one. The watershed is highly vulnerable to sheet, rill and gully erosions. During a field visit in June 2006, it was observed that new gullies which directly ran into the Megech River were being formed as a result of the increased agricultural activities performed in the watershed such as steep area farming, and aggressive grazing (ECDSWC, 2008).

It drains from the mountainous chains and escarpments found in the north Gondar plateau and gates tributaries such as Keha River, Shinta River and Angereb River at different reaches. All these tributaries join Megech River by crossing Gondar Town. The dam constructed on Angereb River for Gondar town water supply minimized the sediment transport to Megech River as it is trapped by the dam. This is one advantage of Angereb dam for Megech River and also for Lake Tana.

**Climate**

The climate of the Megech catchment is marked by a rainy season from May to October, with monthly rainfall varying from 67 mm in October to 306 mm in July. Mean annual precipitation is about 1,100 mm in the upper part and about 1,000 mm in the lower part. Rainfall over the Megech watershed is mono-modal with nearly 79 % of the annual rainfall occurring in the period June – September. The dry season, from November to April, has a total rainfall of about 8% of the mean annual rainfall. Dependable rainfall (85%) varies from less than 1.2 mm during the dry season to 88–225 mm/month during the period of June to July/August, equivalent to 55–75% of the average values. Temperature variations throughout the year are minor. Maximum temperatures vary from 23 ºC in July to 30 ºC in March, whereas minimum temperatures range from 11.5 ºC in January to 15.6 ºC in April and May. Humidity varies between 39% in March and 79% in August. Wind speed is low, thus minimizing potential evapotranspiration values between 101 mm/month in July and 149 mm/month in March. Sunshine duration is reduced to 4.2 – 4.9 hours during July and June, respectively(ECDSWC, 2008).

***Catchment Characteristics***

The Megech watershed is characterized as a mountainous, wedge-shaped and steep-sloped (3.2%) watershed. The lowest topography land is at the Lake Tana joint. The upstream catchments are characterized by mountainous and while downstream parts are flat and very suitable for irrigational agricultures.

On Megech River, there is a dam being constructed which is named as Megech Dam at the location of about 30km from Gondar Town. So the study of Megech River banks and beds stability plays major role for the safety and life time of this huge dam on the Megech River. The dam axis is located in between the geographic grid ref. UTM E 332995, N1382164 and E332492, N1382864. Both the left and right abutments rise to an elevation higher than 1965 m. The location of the river bed at the center of the dam axis (in UTM) is E = 332646 m and N= 1382648 m with an elevation of 1877 m.

The study reach started from Megech Dam toe 10km to downstream and this reach has low bed slope and erodible river banks. Currently it has wide bed width and almost no plantation along the river. The soil characteristics along study reach is totally covered by very fine soil type classified as clay being used for farming. This can be wash load when over flooding of river channel and when there is high run off. Cobles and alluvial materials are observed on river bank slopes which can be eroded and slides in to bed channel leading be bed loads when high flow discharge.

**Land use and land cover**

Because of the rapid growth of population, the demand for increase of the cultivation area is growing and even steeply sloped areas are being ploughed to be cultivated. More over the use of woods for fuel consumption and as a construction material is influencing the land use land cover pattern of the area. Mainly for these reasons the catchments is getting degraded from time to time. The vegetation cover of the area includes Eucalyptus, Acacia and Juniper trees over a small area and bushes and shrubs cover the larger area proportion (ECDSWC, 2008).

Asmare & Abate ( 2018) conducted research on land use, land cove change and dynamics of the Megech catchment and have been analyzed for the years 1984, 2000, 2006, 2009 and 2014. Field observations that they made in the catchment, information obtained from satellite images and Google maps showed that the major portions of the forest land and bush and shrubs including grass land have decreased continuously in these years. The results showed that there was a significant agricultural development from 1984 (57.4%) to 2009 (90.6%).Based on the land use map, about 63.2% of the vegetation (forest) covers and 34.0% of bush and shrubs were lost or converted to other land use.

Generally they tabulated the land use –land cover approximately in to six types and was shown as follows.

*Table 1: Megech River catchment land use land cover from 1984 to 2014*

| Land use type code (ha) | Change assessment year and area coverage in ha from the total watershed area | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1984 | % | 2000 | % | 2006 | % | 2009 | % | 2014 | % |
| Bush and shrub land | 27712.60 | 35.10 | 26398.90 | 33.50 | 19156.70 | 24.30 | 4142.40 | 5.30 | 4058.10 | 5.15 |
| Wetland | 541.50 | 0.70 | 620.70 | 0.80 | 20.50 | 0.00 | 104.50 | 0.10 | 282.10 | 0.36 |
| Built-up area | 541.50 | 0.70 | 334.90 | 0.40 | 552.30 | 0.70 | 646.60 | 0.80 | 722.34 | 0.92 |
| Water body | 358.40 | 0.50 | 446.20 | 0.60 | 488.70 | 0.60 | 470.90 | 0.60 | 534.98 | 0.68 |
| Cultivated land | 45277.00 | 57.40 | 48108.00 | 61.00 | 55783.80 | 70.80 | 71400.10 | 90.60 | 71621.18 | 90.84 |
| Forest land | 4413.10 | 5.60 | 2935.70 | 3.70 | 2842.40 | 3.60 | 2079.90 | 2.60 | 1625.66 | 2.06 |
| Total | 78844.40 | 100.00 | 78844.40 | 100.00 | 78844.40 | 100.00 | 78844.40 | 100.00 | 78844.40 | 100.00 |

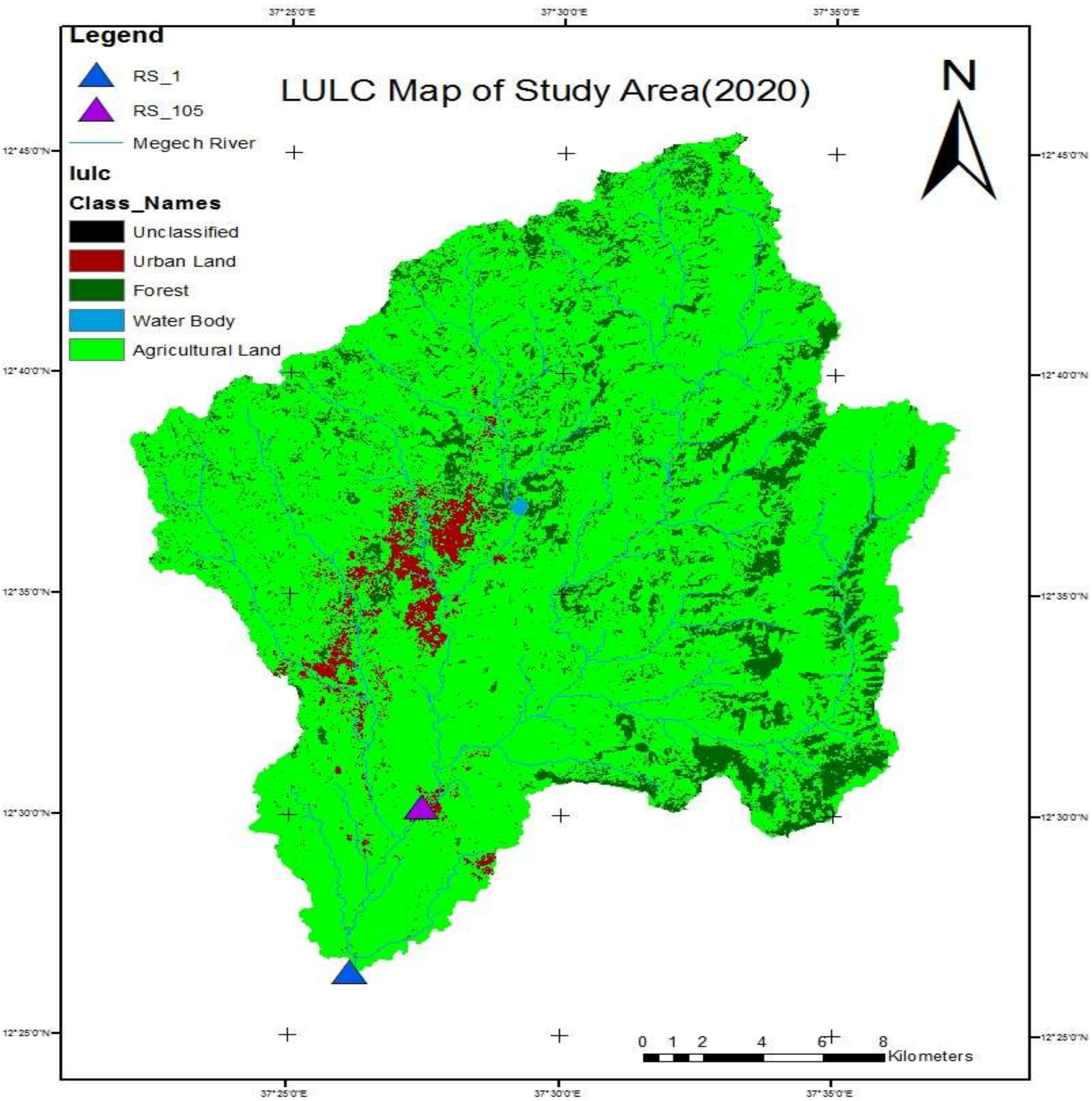


*Figure 2: Land use land cover (LULC) of Megech River catchment and the study reach*

Most of land use land cover (LULC) of Megech River catchment is covered by agricultural areas while the others are forest and urban areas.

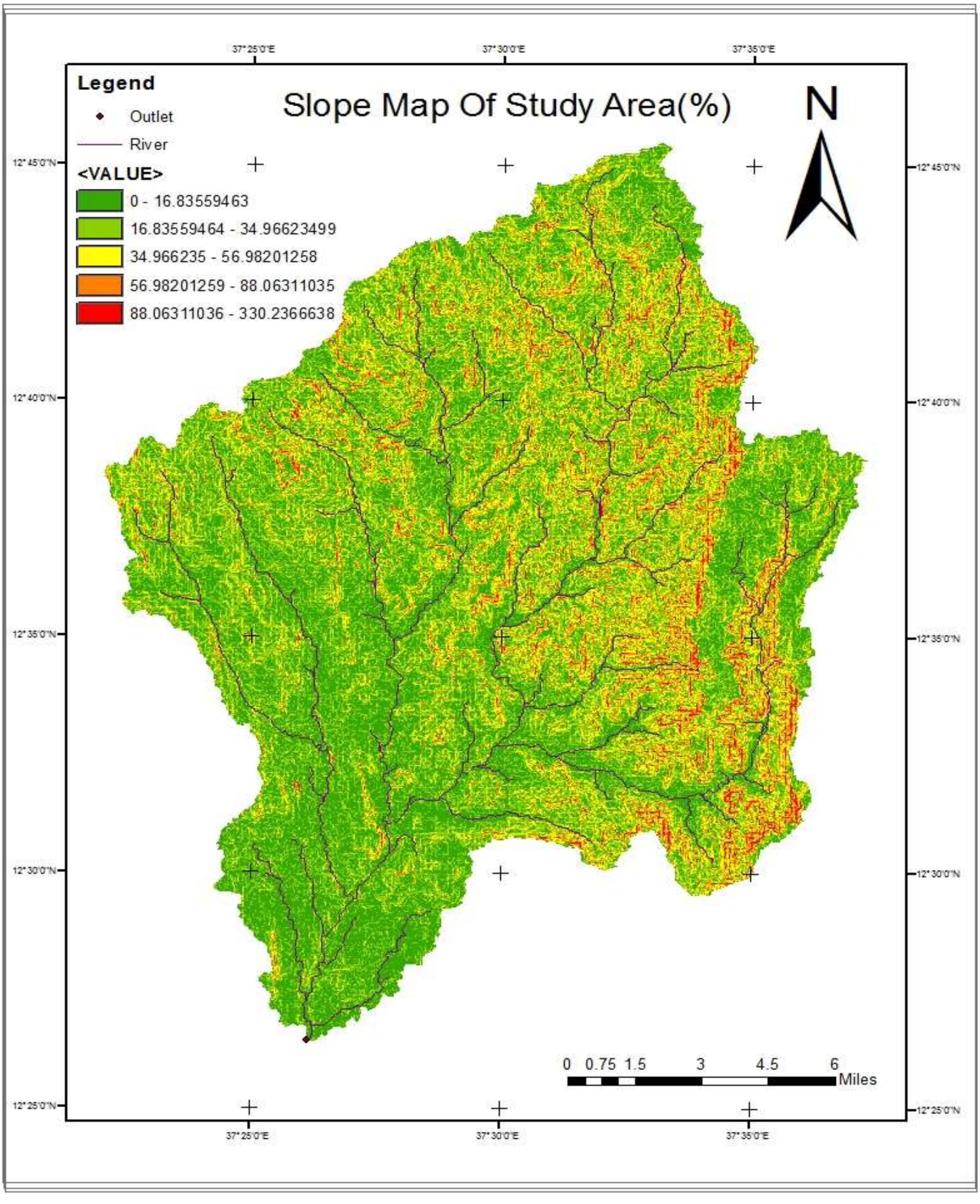


*Figure 3: Slope of Megech River catchment*

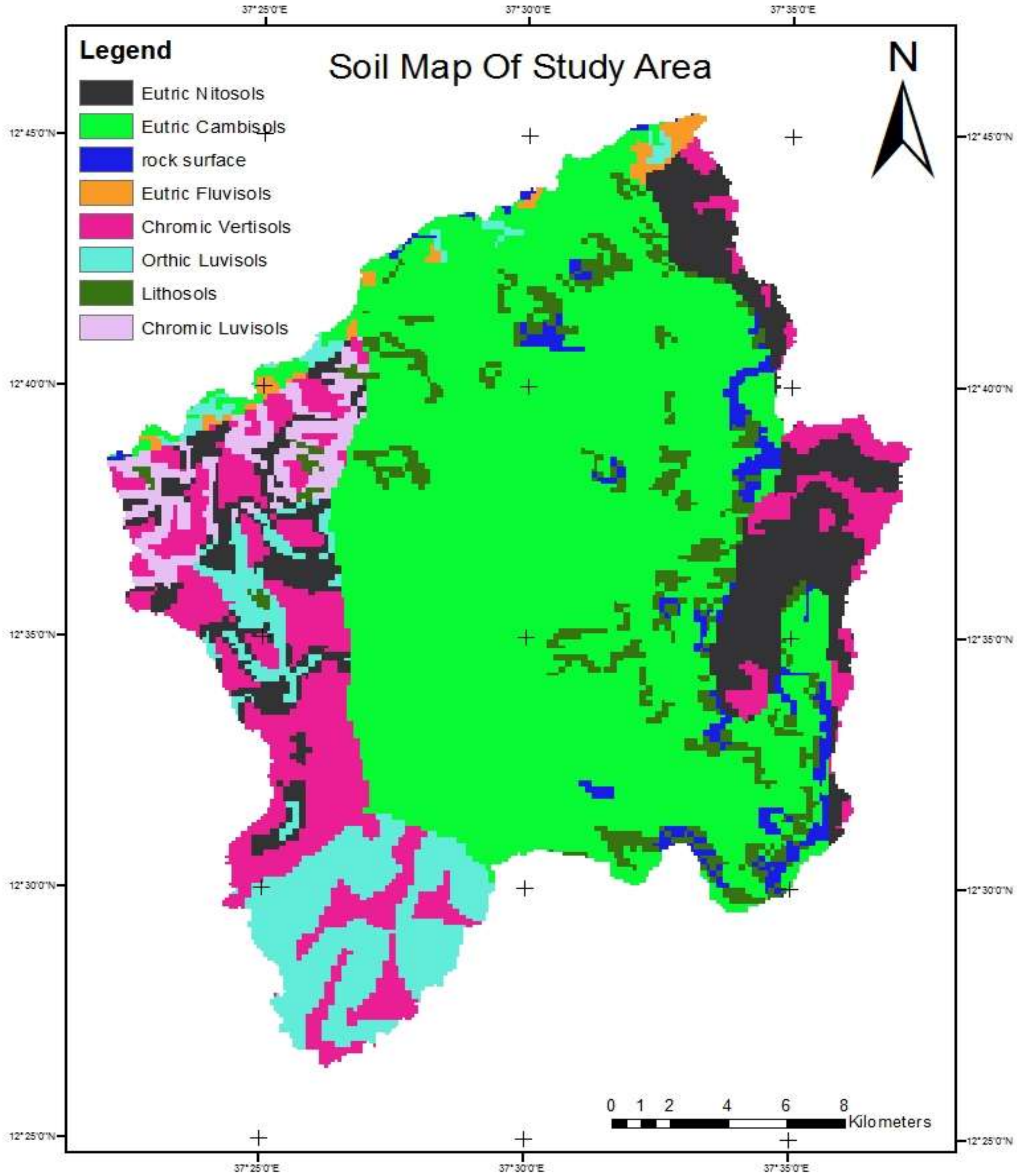


*Figure 4: Soil map of Megech River catchment*

This Megech catchment soil type is mostly covered by eutric cambisoil and chromic verti soil as shown on the above soil type map of figure 4.

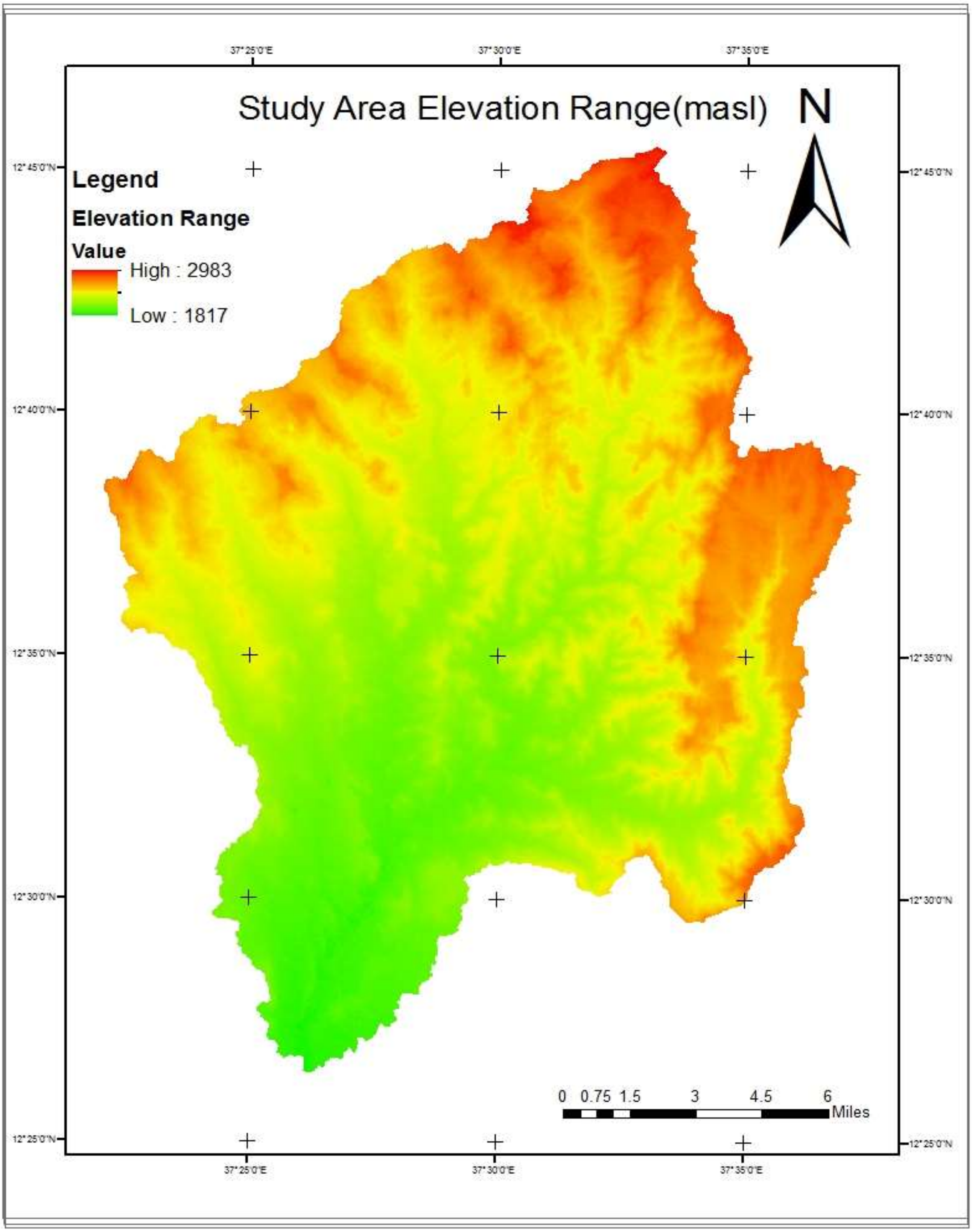


*Figure 5: Megech River catchment elevation range*

## *3.2 Methodology*

## 3.3 Data collection and analysis

The basic data requirement for HEC-RAS and Bank Stability and Toe Erosion Model (BSTEM) model are the followings:

### 3.3.1 Geometric data

From the toe of Megech Dam to downstream, river reach is selected and this reach is divided into different sub reaches depending on river characteristics. Cross sections are required at representative locations throughout a stream reach and at locations where changes occur in discharge, slope, shape, or roughness, at location where levees begin or end and at bridges or inline control structure such as weirs. Cross section spacing is also function of stream size, slope, and the uniformity of cross section shape (Brunner, 20016).

*Figure 6: Surveying work for Megech River cross section:(June 07/2019, 1km US of Megech main bridge)*

### 3.3.2 Flow data

Megech daily flow data has been collected from Ethiopian Ministry of Water, Irrigation and Energy for the model. The flow gaging station is at Megech main bridge which is near to my starting point of study reach. The ten year flow data from 1996 to 2005 was applied for Megech bank erosion and sedimentation research.

**Sediment Rating Curves**

Depending upon HEC-RAS model requirement, sediment rating curve is calculated to use as basic input data from sediment concentration sampled by Ministry of water and energy according to the following. Most of the sediment transport problems are most obviously defined in terms of the supply of sediment (which includes at least its volume or rate and its grain size) and the water supply, or discharge. Eventually, we need to estimate sediment concentration as a function of water discharge Q.

A relation giving Qs as a function of Q is called a sediment rating curve. A sediment rating curve typically takes the form of a power function (Wilcock, 2004).

$SSL = aQ^b$ ---------------------------------------------------- (1)

Where: SSL is in g/l and Q is in $m^3/s$.

Concerning sediment data, a regional approach can be applied in order to construct a composite sediment rating curve by using the Megech, Q-SSL data based on 1990-2017 period. The developed sediment rating curve is given in Figure 3.

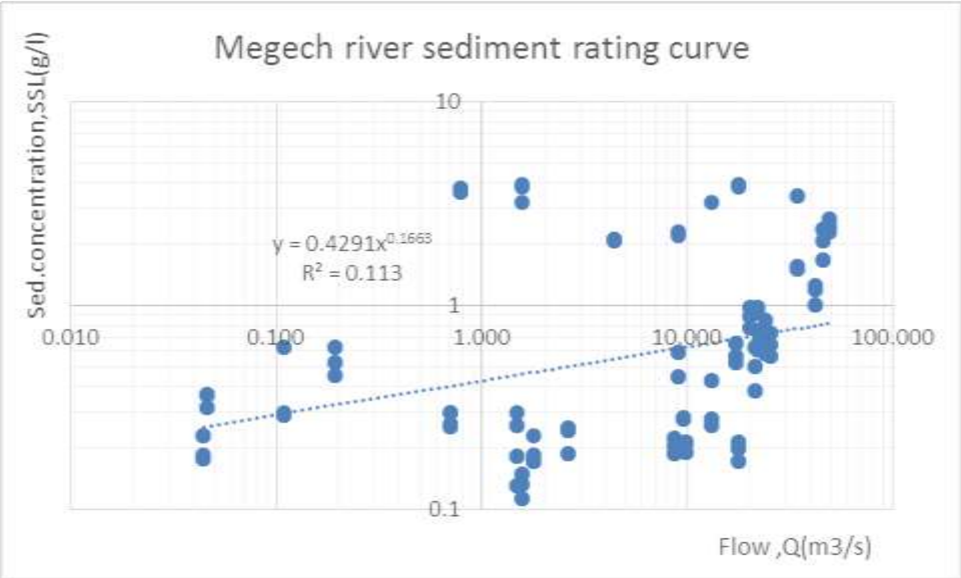


Figure 7: Megech River Sediment Rating Curve: *Data Source, Ministry of water, Energy and Irrigation, Ethiopia*

### 3.3.3 Bed and bank materials characteristics

The first five parameters: unit weight, friction angle, cohesion, phi –b and erodibility, which were identified by soil laboratory for this paper work, are intrinsic soil strength parameters and are associated with the Computation of a critical failure plan and the factor of safety associated with the failure plan. These five Parameters emerge from classical geotechnical measurements that most soil labs would be able to handle. HEC-RAS uses four user defined parameters with hydrodynamic and geometric data to compute a factor of safety for a range of possible failure planes by computing the ratio of the resisting forces to the driving forces; cohesion (c’), saturated unit weight (W), the angle of internal friction (ϕ'), and the angle representing the relationship between shear matrix suction and apparent cohesion ($\phi^b$). These four defined parameters are entered in the bank stability and toe erosion model material parameters editor.

*Figure 8: Sampling Megech River bed and bank material*

**(a) Unit weight:**

This is the saturated unit weight (combined weight of the solids and water of the soil when saturated).Note that is different than the unit weight used elsewhere in HEC-RAS sediment transport computations. The unit weight used elsewhere in HEC-RAS sediment transport computations is the mass of the solids per unit volume.

**(b) Friction angle (ϕ');**

The friction angle is a classic geometrical parameter that is a measurement of the soil strength that quantifies the friction shear resistance of soil. The ‘angle ‘of friction angle is derived from the Mohr-coulomb failure criterion. Labuz and Zang (2012) and is the angle of inclination in the classical Mohr diagram. The angle of inclination is the theoretical angle (the rate of increasing strength with increasing normal force) used to compute soil strength and should not be confused with physically intuitive angles like the angle of response. Also, the angle of inclination is not the minimum angle of the failure plane. In case where ground water elevation is higher than the water surface elevation the bank can lose frictional strength and be left only with cohesion, allowing for a shallower failure plane angle. The friction angle can be determined by collecting 'undisturbed' cores for tri-axial testing in a soils laboratory or it can be measured in situ with a borehole shear test. The Iowa borehole shear device .Thorne (1981) is a hand held instrument that is commonly used to collect this parameter from hand augured eight centimeter boreholes for BSTEM studies.

**(c) Cohesion:**

Cohesion is the attractive force of particles in a soil mixture, usually as a result of electrochemical or biological bonding forces. These forces increase the strength of a soil matrix. Cohesion is generally a minor consideration in granular soils but can account for a substantial amount of soil strength in cohesive materials. Cohesive is computed from the same data as the friction angle and, therefore, must be measured either by tri-axial laboratory tests or in situ bore holes shear measurements.

**(d)Phi b ($\phi^b$):**

As soil drains, capillary tension induce negative pore water pressure or matrix suction. Suction resists bank failure and increase the shear strength of the soil matrix. In the bank failure algorithms, suction is quantified as an" apparent cohesion' or the equivalent increase in cohesion required to generate the same increase in shear strength. $\phi'$ is a function soil moisture and maximizes at the friction angle $\phi'$ at saturation. For most materials $\phi^b$ is generally between ten to thirty degrees depending on soil type. $\phi^b$ is very difficult to go out and fundamentally measure $\phi^b$. $\phi^b$ has been measured a handful of times in research settings. Most applications start between ten and fifteen degrees but $\phi^b$ goes to A maximum of the friction angle when the material is saturated (Fredlund, Xing, Fredlund, & Barbour, 1996). Because of the estimated nature of this parameters, it can be used as a calibration factor.

**(e)Gradation sample:** HEC-RAS requires a fifth bank material parameter that is required but not used until after the failure calculation. In order to partition any failed material in to grain classes for transport by the sediment transport model, the bank material has to have a bed gradation associated with it.

Any gradation defines here become automatically available in the **Gradation Sample** list on the bank stability and toe erosion model (BSTEM) material Parameter Editor (CEIWR-HEC, 2015).

**(f)Erodibility parameters**

The second set of parameters on the BSTEM Material parameters Editor are the erodibility parameters. These parameters are specialized for bank failure analysis. Erodibility parameters are measurements of the erodibility of the soils in response to hydrodynamic forcing.

**Critical shear stress**: Critical shear stress is occurred when the bank begins to scour.

**Erodibility (k):** the rate of sediment removal in response to a unit shear stress.

In the absence of these parameters,Rinaldi and Casagli (1999) described a relationship between critical shear and erosion of the cohesive and non-cohesive banks based on the shear stress relations of Komar (1987) and Millar (1993). Additionally, Simon (2000) summarized their database of cohesion less measurement to find a relationship between critical shear stress and erodibility as:

E or k = $1.42\tau_c^{-0.824:}$ k ($cm^3/Ns^{-1}$) …………………………………………………… (2)

This relationship is based on the regression depicted in which includes a great deal of scatter in log space. This underscores the variable and site specific nature of these parameters, therefore, if possible, local measurement of these parameters is highly recommended.

So, from laboratory result, the critical shear stress and erodibility relationship is shown in Table 2.

It is necessary to know the important variables that represent the characteristics of a river in order to analyze the behavior and the stability nature of an alluvial river. The most important ones are water discharge, bed material transport rate, representative size of the bed material, stream slope, width to depth ratio that characterizes the shape of cross section; and the ratio of the stream mileage to valley mileage, which characterizes the shape of the stream in plan i.e. meander pattern.

Water discharge and size of the bed material are certainly independent variables. Whereas the variable that represents the shape of the cross section and shape in plan is dependent. But the dependency of the bed material transport rate and stream slope rely on the course of the stream (CEIWR-HEC, 2015).

In the upper course of the stream the slope of the land and hence the slope of stream is determined by the geologic factors and stream slope can be treated as an independent variable thus the bed material transport rate would become a dependent variable and its magnitude is determine by water discharge, representative size of the bed material and stream slope. In the lower course of the stream water discharge , bed material transport rate, and representative size of the bed material become the independent variables and hence slope becomes a dependent variable along with the variables that represent the shape in cross section and the shape in plan (USACE, 1994)

**Energy loss coefficients**

Several types of loss coefficients are utilized by program to evaluate energy losses: (1).Manning's n value for friction loss, (2).contraction and expansion coefficients to evaluate transition (shock) losses, (3).bridge and culvert loss coefficients to evaluate losses related to weir shape, piers, pressure flow, and entrance and exit conditions.

**Manning's n:**

Sellection of an apropriate value of Manning's n is very significant to the accuracy of the computed water surface profiles.The value of Manning's n is highly variable and depends on a number of factors including surface roughness, vegetation, channel irrigularity, channel alignment, scour and deposition,obsructions, size and shape of the channel, stage and discharge, seasonal changes, tempreture, suspended material and bedload. There are different referances a user can access that show

Manning's n values for typical channels. An extensive compilation of n values for streams and floodplains can be found in chow's book of open channel hydraulics .Accordingly, usually the following equations are used to calculate manning's n value for natural streams (Chow, 1959) .

$n = 0.038(d_{75})^{1/6}$ or

$n = 0.0342(d_{50})^{1/6}$ source : (Chanson, 2004). ……………………………………………… (3)

where $d_{50}$ is samples median grain size (m)

For sample one, $d_{50}$ is interpolated from bed material laboratory result between 8mm and 16mm,which gives us 12 mm.

So, $d_{50}$ = 12 mm = 0.012 m and $n = 0.0342(0.012)^{1/6} = 0.01636$

For sample two, $d_{50}$ is interpolated between 8mm and 16mm in the same way and the result will be =10 mm = 0.010 m and $n = 0.0342(0.01)^{1/6} = 0.0158$

For left over bank, $d_{50}$ ~0.0125 mm =0.0000125 m and $n = 0.0342(0.0000125)^{1/6} = 0.005$. In the same mannner, n= 0.005 aproximately for right over bank material.

For sample two, the Right Over Bank (ROB) n value is calculated as above for $d_{50}$ interpolated between 4mm and 8mm , $d_{50}$ = 6 mm =0.006 m and n ROB = $0.0342(0.006)^{1/6} = 0.0146$.

Again for the Left Over Bank (LOB), n is found from $d_{50}$ =4 mm= 0.004 m .So, $n = 0.0342(0.004)^{1/6} = 0.0136$

The left over bank and right over bank materials are fine clay material which can be wash load while main channel matrials are courser and its manning's n is larger reratively.

*Table 2:* Summery table for manning's n calculation:

| | Sample one | | Sample two | |
|---|---|---|---|---|
| | d50(mm) | n-value | d50(mm) | n-value |
| Left over bank | 0.0125 | 0.0050 | 0.0040 | 0.0136 |
| Main channel | 0.0120 | 0.0164 | 0.0100 | 0.0158 |
| Right over bank | 0.0125 | 0.0050 | 0.0060 | 0.0146 |

**Contraction and expansion coefficients**

Contraction or expansion of flow due to changes in cross section is acommon couse of energy losses within a reaches (between two cross sections). When ever this occur,the loss is computed from the contraction and expansion coefficients specified on the cross section data editor. The coefficients which are applied between cross section, are specified as part of the data for the upstream cross section.the coefficients are multiplied by the absolute difference in velocity heads between the current cross section and the next cross section downstream, which gives the energy loss caused by the transition (G. W. Brunner, 2016).

Where the change in river cross section is small, and the flow is subcritical, coefficient of contraction and expansion are typically on the order of 0.1 and 0.3, respectively. When the change in effective cross section area is abrupt, such as at bridge, contraction and expansion coefficients of 0.3 and 0.5

are often used (G. W. Brunner, 2016). According to observed when site surveying,the change in cross section is small and the flow is subcritical, so I can use 0.3 and 0.1 for expansion and contraction coefficients respevtively

**Hydraulic conductivity of bank materials**

Hydraulic conductivity of bank materials can be determined by first determining the soil's volumetric water content. After determining volumetric water content of the soil (can be sand, clay, silt), hydraulic conductivity of the soil can be read from Figure 9:

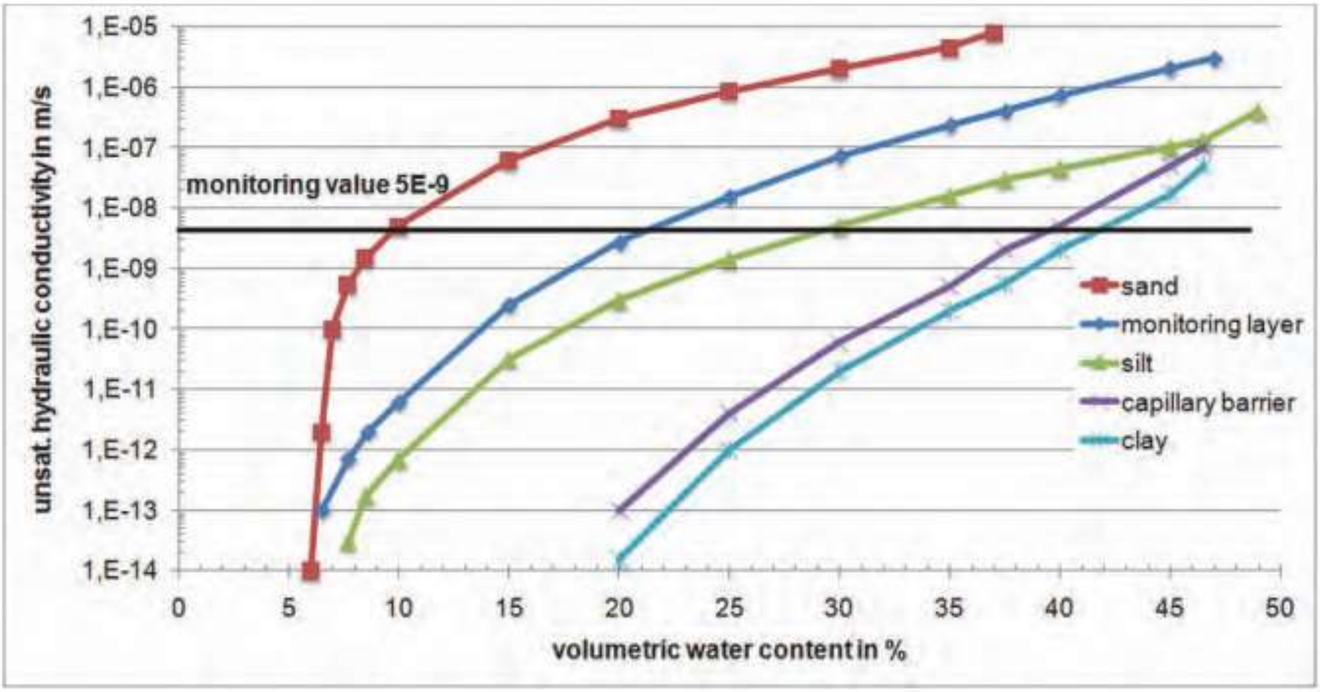


*Figure 9: Hydraulic conductivity determination chart*

Sediment in streams can be divided in to the bed material load and wash load. Bed material load consists of grain sizes found in significant quantities on the bed. The channel characteristic most sensitive to bed material size is bed slope. The coarser and steeper channel would also have smaller depths and higher velocities. The influence of bed material size on width is relatively small and difficult to separate from other factors. But generally increased bed material load tends to reduce channel stability, because it forms local deposits that divert flow against banks and so on (USACE, EM 1110-2-1480).

The size of bed material in a natural stream is found to decrease continually along the length of the stream. This reduction in size is partly due to sorting action and partly due to abrasion. As the stream comes down from mountainous regions to the plains the slope decreases and stream width gradually increases. Such a decrease in slope reduce the capacity of the channel to transport the coarser particles brought from upstream and the coarser particles are thus deposited on the stream bottom (Vittal, Ranga Raju, & Garde, 1977).

The general methodology followed to execute this research is HEC-RAS model simulation for bank erosion and sediment analysis. After compiling all input data described above, they were put into the model according to the model requirement.

The study river reach was selected considering about the location where two large rivers are joined together namely Angereb River and Megech River. Both of these rivers contribute their own sediment for the study reach especially during the summer. Not only that, but also the Megech River reach upstream of the joint is hilly and river bed and banks are very hard rock which can notify us very low bank erosion and sedimentation. Sedimentation is expected at gentle or flat river bed slope and bank erosion is also expected at loose river bank formation. Therefore, the study reach includes the contribution the large two rivers named above.

Cross section data were collected by spacing according to model requirement and bed slope, bank material formation and cross section changes. The flow duration is twenty four hours and computational increment varies according to the season in the year. During summer, as the discharge is large and vary from time to time, high sedimentation is expected and so small computational time interval was used. During the winter, discharge magnitude is very small and variation is not feasible and so larger computational time increment can be used.

### 3.3.4 Sediment modeling (HEC- RAS application)

Sediment transport models require hydraulic parameters. Therefore, HEC-RAS computes hydraulics each time steps before it routs sediment or updates cross sections. HEC RAS v.5.0.0 couples sediment transport computations with either quasi-unsteady hydraulics or unsteady hydraulics. Unsteady flow is not unique to sediment studies. HEC-RAS can simulate unsteady flow without sediment data but quasi unsteady hydraulics, on the other hand are only used for sediment studies. Therefore, the quasi-unsteady flow will be used in this sediment study (G. W. Brunner, 2016).

The quasi-unsteady flow model simplifies hydrodynamics, representing a continuous hydrograph with a series of discrete steady flow profiles. HEC-RAS keeps flow constant for each flow record, computing transport over flow record duration. The steady flow profiles are more stable than the matrix solution of the unsteady saint equations, but approximating a hydrograph with series of steady flow which does not conserve flow or explicitly account for volume. The quasi-unsteady flow model divides time into three time steps. HEC-RAS divides each discrete steady flow profile(flow duration),over which HEC-RAS holds flow constant, into computational increments, which are the hydraulic and sediment transport time steps. HEC-RAS updates the hydraulics and cross sections every computational increment, but further subdivides this time step into bed mixing time steps, updated bed gradation accounting for each bed layer several times each computational increment (G. W. Brunner, 2016).

**Duration**

Duration is the constant time step. HEC-RAS assumes that flow, stage, temperature, or sediment is constant over the duration. In this research, the flow duration is 24 hour duration is applied.

Computational increment, on the other hand, is the primary quasi-unsteady hydraulic and sediment time step. The computational increment usually subdivides the duration, though it can be equal but not larger, to the duration. While flow remains constant over the entire flow duration, HEC-RAS updates the bed geometry and hydro dynamics after each computational increment. Model stability can be sensitive to the computational increment because HEC-RAS assumes that hydraulics and bed geometry are constant. We can see the following figure for flow duration and computational increment (G. W. Brunner, 2016).

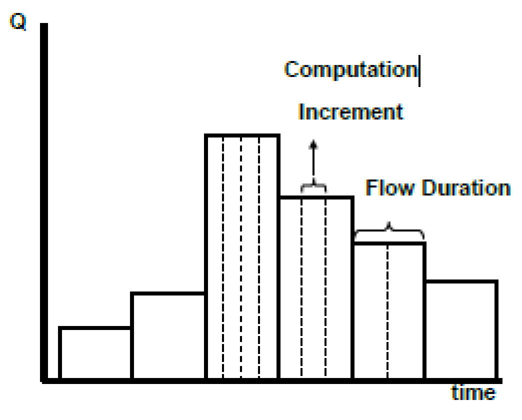


Figure 10**:** Flow duration and computational increment

## Bed mixing time step

Finally HEC-RAS also subdivides computational increments into the bed mixing time steps. Bed gradation can evolve very quickly, so HEC-RAS updates the bed gradation, accounting (running the bed sorting and armoring routines) several times during each computation increment. HEC-RAS holds hydraulic parameters and cross section elevation constant over all mixing time step in a computation increment throughout the computation increment. However, the model updates the composition of the bed mixing layers( e.g. active, cover and/or inactive layers) at the mixing time step, revising the grain class accounting in these layers several times between hydraulic and sediment capacity computations (G. W. Brunner, 2016).

**Sediment continuity**

The HEC-RAS sediment routing solves the sediment continuity equation known as the Exner equation:

$$(1-\lambda_p)B\frac{\partial \eta}{\partial t} = -\frac{\partial QS}{\partial X} \quad \ldots\ldots \quad (4)$$

where: B= channel width

η = channel elevation (m)

$\lambda_p$ = active layer porosity

t = time (sec)

X = distance (m)

$Q_S$ = transported sediment load (ton/day

Like most continuity equations the Exner equation (Paola & Voller, 2005) simply states that the difference between sediment entering and leaving control volume must be stored or removed from storage. The unique feature of the Exner equation is that sediment storage is stored in the bed in a multiphase mixture with water, requiring porosity to translate mass change into volume change. The Exner equation translates the difference between inflowing and out flowing loads into bed change, eroding or depositing sediment. HEC-RAS solves the sediment continuity equation by computing a sediment transport capacity for control volume ($Q_{s\ out}$) associated with each cross section, comparing it to the sediment supply ($Q_{s\ in}$) entering the control volume from the upstream control volume or local sources. If capacity is greater than supply, HEC-RAS satisfies the deficit by eroding bed sediments. If supply exceeds capacity, HEC-RAS deposits the sediment surplus (G. W. Brunner, 2016).

### 3.3.5 Sediment Transport functions

HEC-RAS includes eight sediment transport potential functions. Since sediment transport is sensitive to many variables, transport potentials computed by different equations can vary by orders of magnitude, depending on how the material and hydrodynamics compare to the parameters over which the transport function was developed.

Accordingly, the Acker and white (1973) which is total load equation has been selected for this research because both bed load and suspended load is required to be quantified by a single equation.

## *3.4 Simulated Result validation*

The evaluation of hydrologic model behavior and performance is commonly made and reported through comparisons of simulated and observed variables. Frequently, comparisons are made between simulated and measured values. In distributed hydrological modelling approaches, additional comparisons of simulated and observed measurements for multi-response validation can be integrated into the evaluation procedure to assess overall modelling performance (Krause, Boyle, & Bäse, 2005). Accordingly for this sediment simulation model, observed values are sediment concentration sampled by ministry of water, irrigation and energy in the past years at gaging stations. This sampled sediment concentration was converted to sediment discharge by multiplying by measured flow discharge during sampling. The corresponding sediment discharge predicted or simulated values were arranged from simulated values to test model’s efficiency.

I selected two types of model efficiency validation techniques, namely: Index of agreement (d) and Nash-Sutcliffe efficiency (E). Both of this methods validates simulated result independently according to the following equations:

### 3.4.1 Index of agreement (d) method

The index of agreement, d, was proposed by Panjer & Willmot (1981) to calculate the fitness of simulated or predicted and observed results formulating to the differences in the observed and predicted means and variances .The index of agreement represents the ratio of the mean square error and the potential error (Panjer & Willmot, 1981).

$$d = 1 - \frac{\sum_{i=1}^{n}(Oi-Pi)2}{\sum_{i=1}^{n}(|Pi-\acute{O}|+|Oi-\acute{O}|)2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where: $O_i$ = observed or measured values

$P_i$ = predicted or simulated value

$\acute{O}$ = mean of observed values

In this case, the observed value and simulated value has to be at similar time and location. The range of d and lies between 0 (no correlation) and 1 (perfect fit) (Willmot, 1981).

### 3.4.2 Nash-Sutcliffe efficiency (NSE) method (1970)

The efficiency (E) proposed by Nash and Sutcliffe (1970) is defined as one minus the sum of the absolute squared differences between the predicted and observed values normalized by the variance of the observed values during the period under investigation (sutcliffe, 1970). It is calculated as:

$$d = 1 - \frac{\sum_{i=1}^{n}(Oi-Pi)2}{\sum_{i=1}^{n}(Oi-\acute{O})2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

where: $O_i$ = observed or measured values

$P_i$ = predicted or simulated value

$\acute{O}$ = mean of observed values

The range of E lies between 1.0 (perfect fit) and $-\infty$. An efficiency of lower than zero indicates that the mean value of the observed time series would have been a better predictor than the model (sutcliffe, 1970)

# 4 RESULTS AND DISCUSSION

## 4.1 Results

The bed and bank material characterization result obtained from laboratory was presented by the following table

*Table 3: bed and bank material characterization result*

| Sample | Requested test | sample one | sample two | Remark |
|---|---|---|---|---|
| Bed material | specific gravity | 2.585 | 2.699 | laboratory result |
| | shape factor(%) | 4% | 2% | laboratory result |
| | sediment density (kg/m3) | 2585 | 2699 | laboratory result |
| | cohesiveness( kg/m2) | 12 | 14 | laboratory result |
| | Angle of friction | 20 | 23 | laboratory result |
| Right bank material | saturated bulk density(kg/m3) | 2589 | 2618 | laboratory result |
| | friction angle( degree) | 19 | 23 | laboratory result |
| | cohesiveness (kpa) | 11 | 14 | laboratory result |
| | phi (degree) | 19 | 23 | equal to f.angle |
| | critical shear stress(pa) | 1.695 | 1.695 | calculated |
| | Eridiblity | 0.0001084 | 0.00011 | laboratory result |
| Left bank material | saturated bulk density(kg/m3) | 2565 | 2673 | laboratory result |
| | friction angle( degree) | 21 | 21 | laboratory result |
| | cohesiveness (kpa) | 14 | 11 | laboratory result |
| | phi (degree) | 21 | 21 | equal to f.angle |
| | critical shear stress(pa) | 4.08 | 4.08 | calculated |
| | Erodiblity | 0.000082 | 0.000113 | calculated |

*Table 4*: Determination of bank soil erodibility factor (k)

| | Sample one | | Sample two | |
|---|---|---|---|---|
| | critical shear stress(τc) | Erodiblity(k)(m3/N/s) | critical shear stress(τc) | Erodiblity(k)(m3/N/s) |
| Left bank material | 2.188 | 0.745 | 4.970 | 0.379 |
| Right bank material | 1.695 | 0.919 | 4.280 | 0.429 |

Using the above material characterization result, the result obtained from Megech bank erosion and Sedimentation simulation carried out by HEC-RAS, the following average values for ten years and for the whole reach study are described for reports for all cross sections in Summery Table 6 below. The result is presented by converting the computational time step to daily result in order to make it suitable to discuss about the rate of sedimentation.

Because the results seem to be different for all river station in the studied river reach of 10 km and for ten years daily flow starting from Megech Dam toe to downstream. However, the study reach was divided into three sub-reaches for discussion depending on river bed slope, bed roughness and cross section change simulated result. These three reaches are upper reach, middle reach and lower reach.

Upper reach is from river station 105 to 71, middle reach is from river station 70 to 36, while lower reach is from 35 to 1. All River stations have their own geographic coordinate collected by total station. Some divide locations are the following.

*Table 5: Geographical location of selected studied river station*

| River station(RS) | Geographic location | | Relative location along Megech river |
|---|---|---|---|
| | Easting | Northing | |
| 105 | 332396.470 | 1382478.570 | At Megech dam toe |
| 71 | 331235.080 | 1380547.030 | 3.5km far from Megech dam to dwon stream |
| 36 | 330495.800 | 1378575.920 | 7.3km far from Megech dam to dwon stream |
| 1 | 329905.380 | 1375835.380 | 10.3km far from Megech dam to dwon stream |

For each reach, simulated result average values were presented in Appendix 1. In the upper reach, average river bed change result is -2.199 ton/day and for middle reach 1.802 ton/day which means that it is degradation. For lower reach average bed change is 1.623 ton/day which is aggradation. When estimating average value for the whole reach together, it is -0.793 ton/day which is degradation in general.

The followings are simulated result shown in table at appendix A

- Mass bed change in table and graphs
- Sediment discharge in table form and in a sample graphs
- BSTEM all in table and a sample graphs

*Table 6: Summary of Simulation results*

| Reach | Average mass bed change(ton/day) | Average river bed Invert level change(m) | Average Sidiment discharge(ton/day) | Average bank Erosion(ton/day) |
|---|---|---|---|---|
| Upper reach | -2.199 | -2.644 | 55.556 | 30.826 |
| Middle reach | -1.802 | -1.081 | 64.451 | 29.803 |
| Lower reach | 1.623 | -0.390 | 59.722 | 27.810 |
| Total reach | -0.793 | -1.554 | 59.910 | 29.480 |

The simulated results was presented by the following graphs as a sample because it requires too much space for all simulation time results.

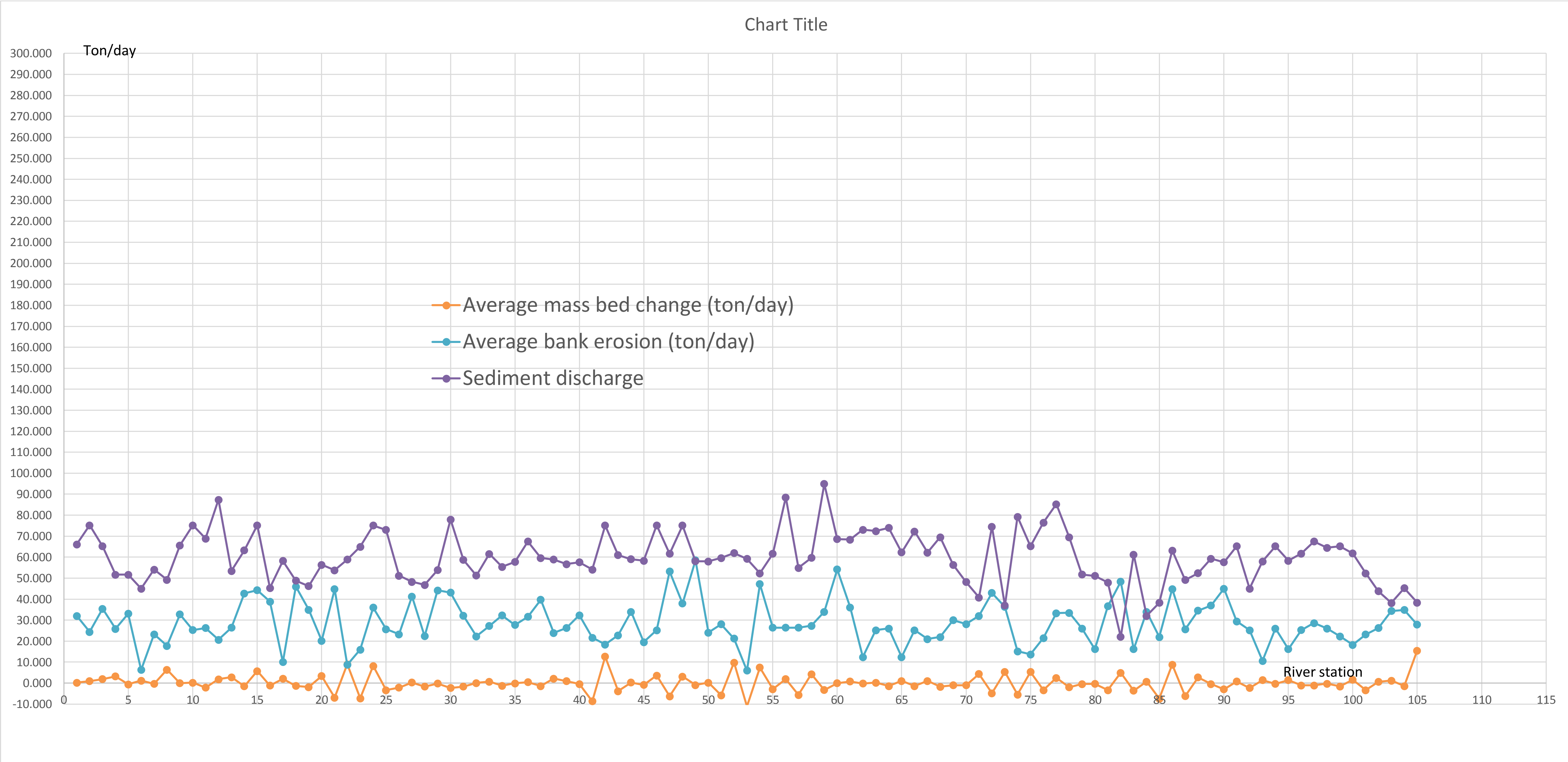


*Figure 11: Average simulated results for mass bed change, sediment discharge and bank erosion*

The sediment discharge is larger than bank erosion because sediment discharge is general potential of sediment that can be moved by flow while bank erosion is amount of sediment that is added to sediment routine from bank erosion.

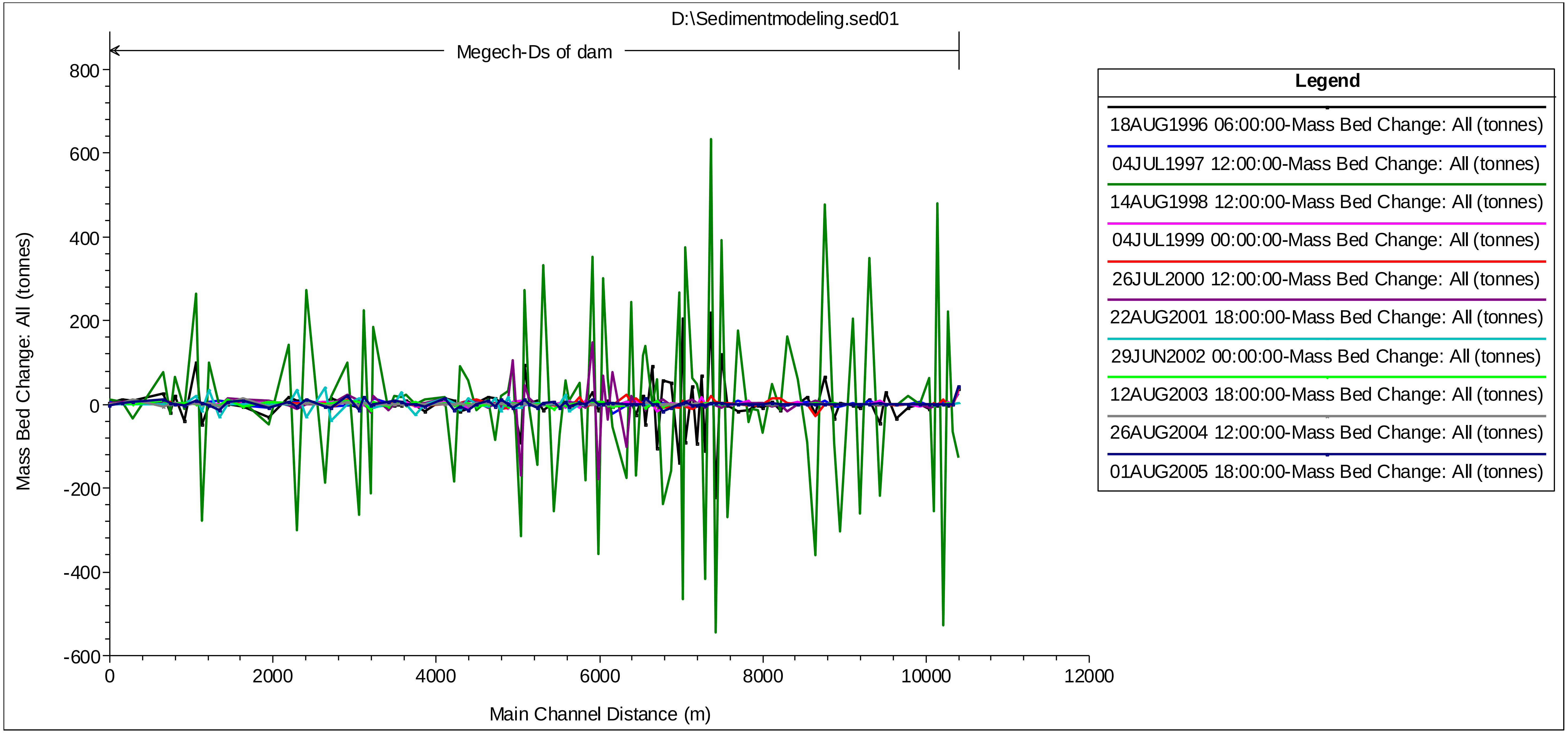


*Figure 12 Mass bed change at August (high flow season) for all reaches at*

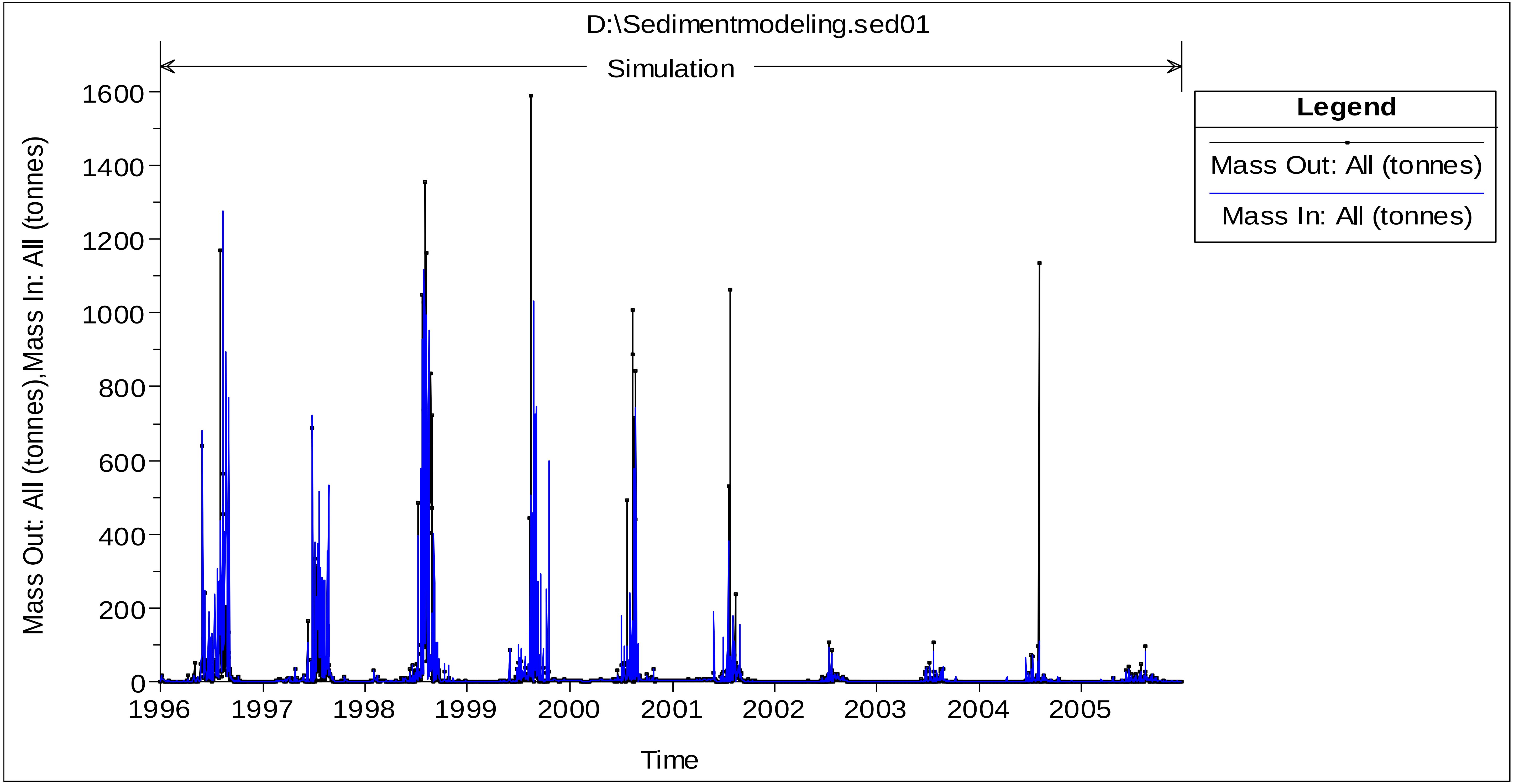


*Figure 13 Mass out mass in for ten years at RS 97*

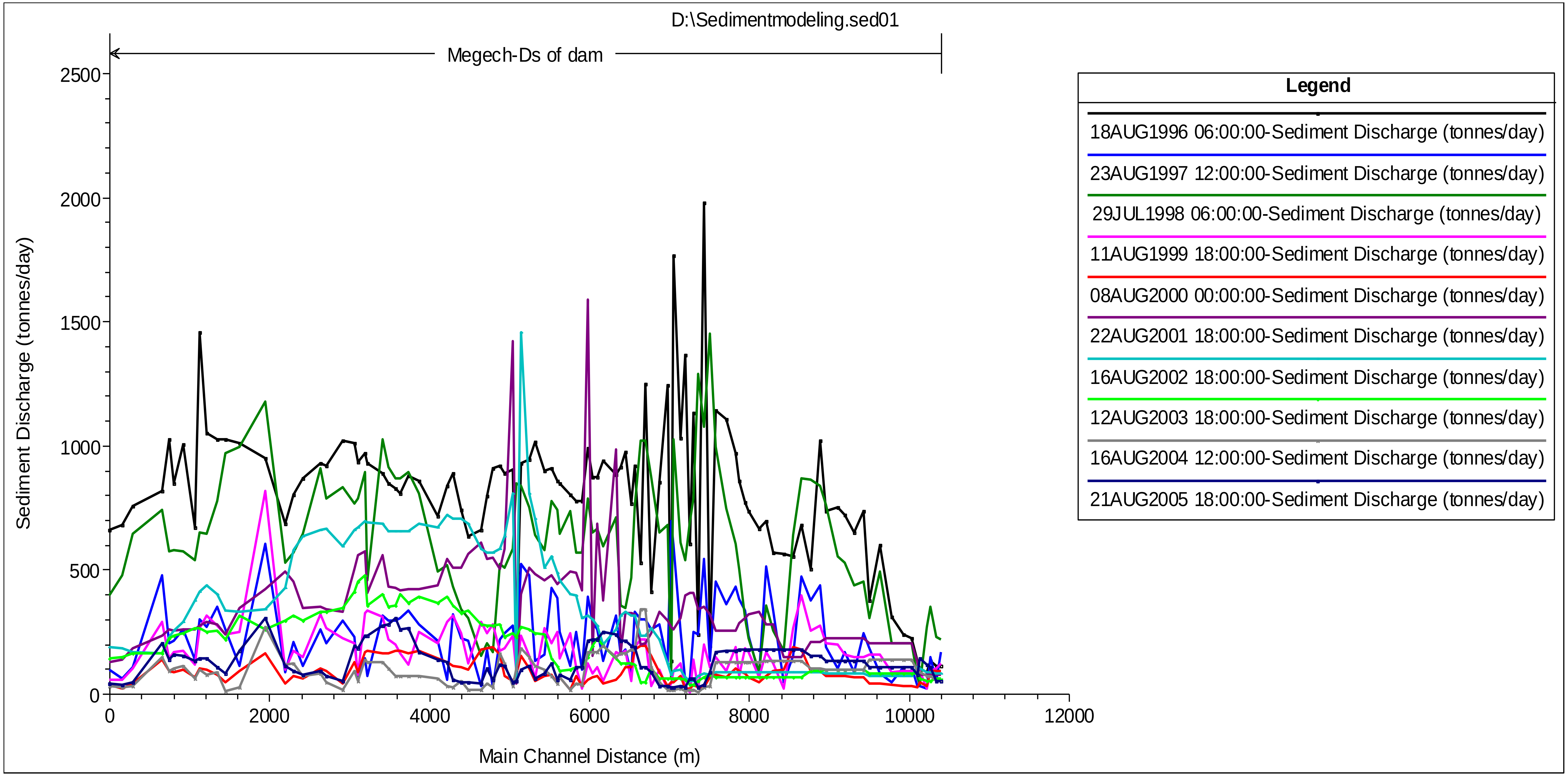


*Figure 14 Sediment discharge in August –high flow season*

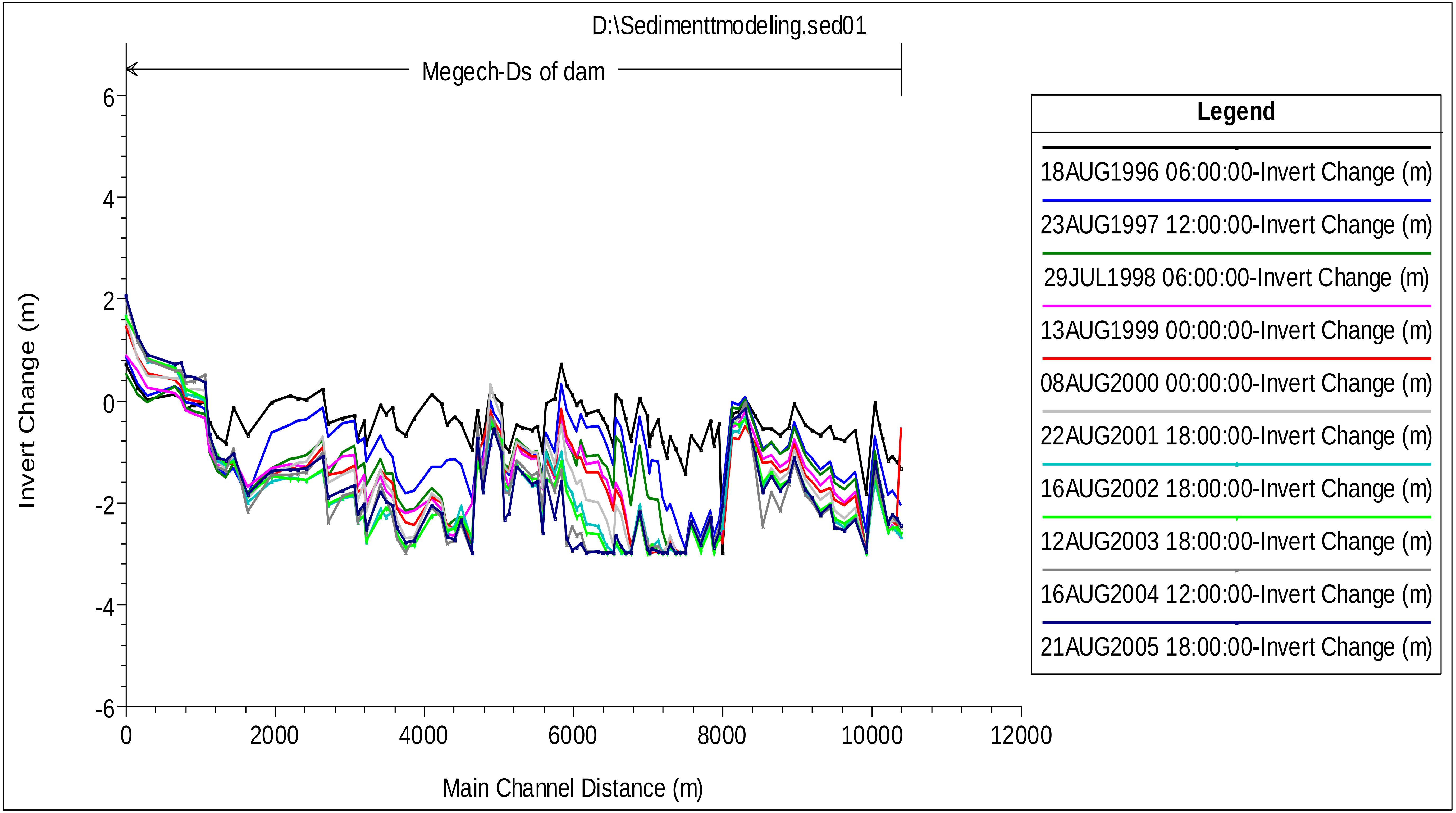


*Figure 15 River bed invert change in August –high flow season*

Upper and middle reach   of the study reach are almost in scouring while sediment deposition is observed at lower reac

## *4.2 River bank stability result*

Using bank stability and toe erosion model (BSTEM) integrated with HEC-RAS, Megech River bank stability condition was simulated for my study reach for factor of safety (FS).

By site surveying, the bank materials are almost divided in to two layers as soft clay on upper layer and cobbles at bottom layers according to the following typical site picture.

Figure 16(a) June 07/2019, 2km downstream of Megech main bridge, east direction

Figure 16(b) June 07/2019, 2km far from Megech main bridge to downstream right bank in west direction

Figure 16(c) (June 07/2019, near Megech main bridge to east direction (left side)
*Figure 16: Megech River bank being eroded*

As model's manual, bank stability was run by considering worst conditions such as highest flow condition in a 24 flow time duration. The highest flow record was observed during summer flow series records received from ministry of water, irrigation and energy. Water table level at the station was considered as the same level to water level in the channel during peak flow. The water level in the channel was collected from HEC-RAS water level simulation during sediment discharge simulation. The typical right and left section of river bank cross section simulated is as shown below in Figure 17. The right banks and left banks were simulated separately by putting their cross section profiles and their material type in to the model

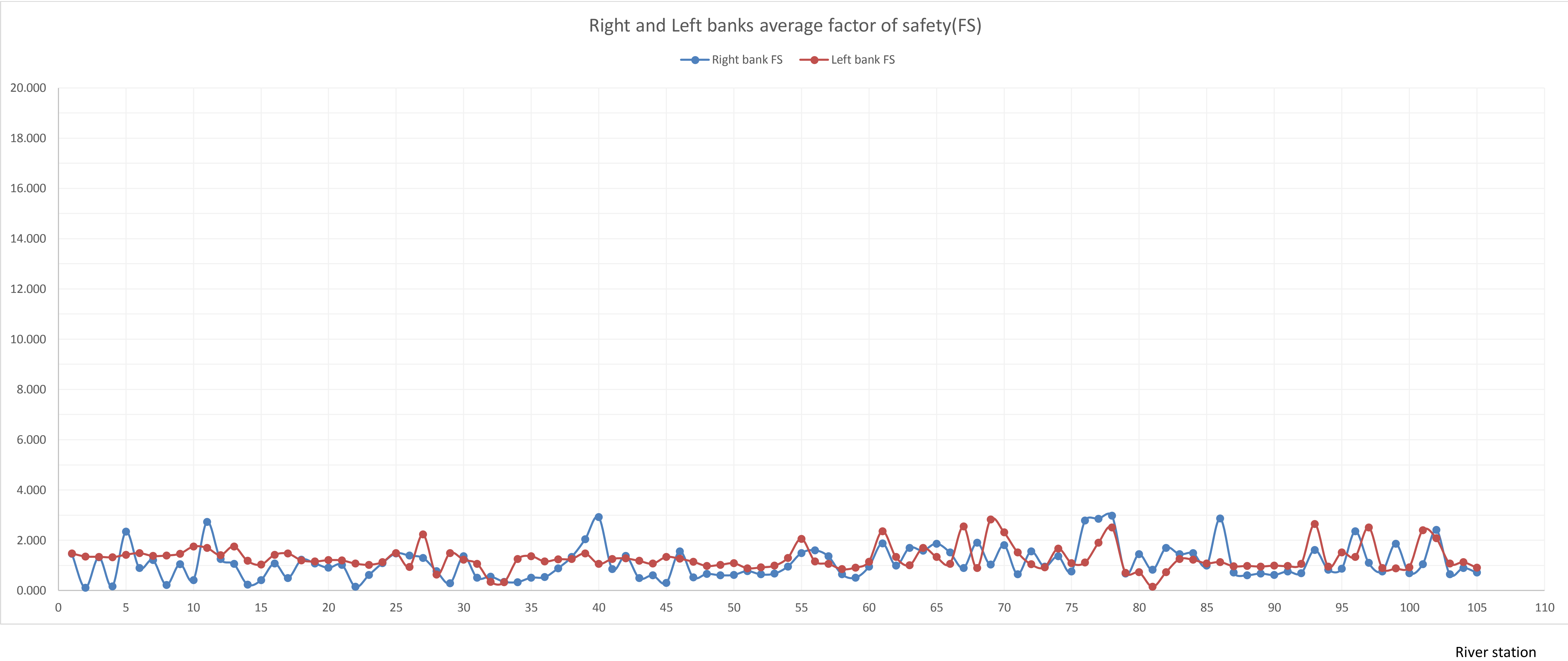


*Figure 17: Simulated average factor of safety*

The whole sections result are presented in appendix A by table. The model's manual notifies that the factor of safety value greater than one shows "stable" and the value less than one indicates "unstable" river bank. In this simulation, plant protection was not considered because the bank has no as such plants that can contribute bank protection.

**Definition of the above output variables**:

Concerning result validation, two types of validation techniques were used for comparison. The observed or measured sediment values and simulated values has almost fitted according to both of validation techniques.

***Mass bed change:***

This output variable is incremental total mass change in the bed for the current computational time step. It is the difference of mass in and mass out per time step.

**Sediment discharge:** is total sediment discharge in ton/day going out of sediment control volume for a specific cross section per individual computational time step.

**BSTEM all**: total sediment mass removed from both banks by toe scour and bank failure for each cross section for each computational increment. It is presented by bank erosion rate in the above table.

**Invert change**: This variable is bed scouring or deposition for each cross section for each computational increment and it is given by meter.

## 4.3 Discussion

Megech River at studied reach has different slope range which is cause for high and low flow velocity, in turn high scouring and sedimentation at different location and so high morphological change.

My study showed that there is Considerable River bed scouring or degradation at upper and middle study reaches while sediment deposition in the lower studied reach for the last ten years. This river bed scouring can be the cause for channel deepening and bank instability. Bank instability in turn accelerates bank collapse and finally channel widening and high river course change. According to this study, morphological change is not only carried out by sediment deposition but also supported by a considerable bank erosion and bank failures. Specially, this study notifies that right bank (to ward west is 54% unstable and this can accelerate morphological change to right or to west while 25%unstable for left bank or to east direction.

At lower reach, sediment deposition is observed because river slope is flatter and so, lower flow velocity.

Therefore, the expected consequence of sediment deposition or aggradation causes less conveyance capacity and overflow or flooding of the area. When flooding happens, it can damage roads, bridges, farming and life a long river reach. High bank and bed erosion also can lose fertile farm land, bridge and road collapse and can displace dwellers along the river and be accelerator for high Lake Tana sedimentation and river course sedimentation. Lake and river course high sedimentation in turn affects water quality, quantity and also damages hydraulic structures which will be constructed for irrigation at lower reach. It can also affect aquatic life found in river course and in Lake Tana.

For high sediment discharge supplied from catchment, human induced factors and natural factors play great role in accelerating bank erosion and high sedimentation. Human induced factors can be listed as catchment deforestation, traditional farming methods and less catchment management. Natural induced factors can be climate change which can cause high rain intensity and earth quick which can vibrate river banks and collapse.

The above shown results was prepared from simulated result by converting to daily rate for sedimentation results in order to make it suitable for result presentation in uniform ways. Because during simulation, different computational time step were used depending on flow discharge quantity and variation. During summer, discharge is high and variation is also high from time to time. Hence, it has high capacity of transporting large quantity of sediment. Therefore, lower computational time step was used according to model manual. During low discharge season, obviously no large amount of sedimentation and larger computational time step was applied. All were converted to daily result (24 hours) for uniformity of result presentation.

Here, the negative value on the Figure 12 indicates degradation or river bed scouring and positive values are aggradation or bed sediment deposition.

The Megech River bank stability result shown in Figure 15 above was calculated by bank stability and toe erosion model integrated with HEC-RAS for both right and left banks at each river cross section. The simulation was carried out by not considering plants' root protection for the banks as there is no much plantation a long Megech River banks. The result shows that river banks are stable for right bank (west direction) at most of cross section while instability was detected at left bank (east direction).

The sediment aggradation and degradation vary from one section to another and from year to year in a small amount. At some river section, the value is near to zero which implies that there is no much aggradation or deposition and degradation or scouring. The average degradation for each cross section vary from minimum 0.14 ton/day to 15.477ton/day. If we look general average value for all cross section and in ten years, it is about -0.793 ton/day which implies degradation or scouring. Hence we can see that the general trend of sediment discharge is degradation and there is considerable river bed change on those sections. The average value for sediment discharge for each cross section varies from 22.35 ton/day to 94.87 ton/day. The highest value is recorded during the summer and the lowest value is during low discharge seasons. The total average value of sediment discharge for the whole study reach is about 59.910 ton/day shown in the above table.

Concerning bank erosion, Figure 11 shows that Megech River banks are being eroded considerably and bank scour values are worry. Even during high flow season, much amount of materials are removed from the banks and added to sediment routine. When we see longitudinal mass bed change of the studied river reach in the last ten years, the result at most cross sections showing bed scouring in graphs and they are cumulative result for all years and it is increasing amount in tones.

I believe that the major factor for considerable bed change is higher river bed gradient, hence, high flow velocity which can allow river bed scouring at upper and middle study reaches. Much bank erosion is observed because the river the bank materials has low shear strength and easily detached from their original position, especially in saturated condition. In addition to these, most of Megech River banks are not covered by plants. High sediment discharge was observed due to that there is improper use of lands on Megech River catchment by farmers and no plantation cover observed. The steep slope observed at upper reach can also be the cause for soil erosion in catchment, in turn for high sediment discharge at lower reach.

# 5 CONCLUSION AND RECOMMENDATION

## *5.1 Conclusion*

From this research, we can see that Megech River's sediment transport is almost in degradation or scouring at most of cross section in last ten years (1996 – 2005). This degradation or scouring is supported by high higher river bed gradient .Hence, higher flow velocity at upper and middle study reach of Megech River. In addition to sediment supplied from River catchment, sediments are being added from bank erosion and bank mass failure. It is believed that this bed degradation deepens channel's bed by scouring river bed and bottom banks and are finally results in bank collapse and channel widening. The eroded sediment is deposited when getting lower bed gradient at downstream of this study reach and Lake Tana. At downstream around Lake Tana, it decreases conveyance capacity and causes overflow which finally leads to flooding the area. Flooding will also affects human life and can change land demography by accelerating morphological change of the river. It is obvious that morphological change is accelerated by river bank erosion and high bed aggradation as such lower Megech River reach. The passed over sediment also can affect Lake Tana by sediment deposition and this can damage water quality and quantity in the Lake and leads to environmental change. It can also affect aquatic life and causes distortion of ecological chain of the surrounding. Not only these but also the irrigation hydraulic structure that will be constructed at lower reach can be affected by sedimentation.

Even though it is being constructed at upstream of this study reach, Megech Dam reservoir which is at moment on construction phase, can be affected by this estimated potential high sediment discharge. It is possible to estimate after how much years sediment deposition rise to any level from sediment discharge simulated result of 59.910ton/day. The sediment discharge is minimum at the river reach with low bed slope and low flow velocity as shown in Figure 14 above. Mass in decreases with increasing water surface level because of low bed slope and low flow velocity. When low flow velocity, sediment's fall rate or deposition increase before reaching high water surface river station.

In general, for the study reach, this research highlighted that there is considerable Megech River bed change by vertical change of degradation from year to year and there is high river bank erosion that can be cause for farm land loss and high sedimentation and finally can lead to people displacement

The simulated results validation techniques verify that the result has fitness of 86.4% by index of agreement and 82% by Nash-Sutcliffe efficiency methods of validation techniques.

Generally, river engineering is governed by factors such as discharge, catchment characteristics, bed and bank material characteristics, river bed slope and human activities on catchments. Finally all these conditions are summed up for sedimentation condition that determines river morphology.

## *5.2 Recommendation*

I would like to recommend that to reduce sediment discharge of Megech River, it is better to work integrated catchment management such as afforestation and reforestation as catchment treatment. Even the farmers found on Megech River catchment should be aware of reducing sedimentation by not using traditional ploughing method which can contribute sediments to the river. It is possible to minimize the bank erosion by working on river bank stabilization. This can be done by river bank plantation and preparation of stone riprap along river banks at a place where high erosion is observed. By doing all the above listed methods of catchment management and bank stabilization, it is possible to reduce Megech River sediment discharge, in another word, we can reduce lake and reservoir sedimentation.

I recommend that people living on the lower reach of Megech River has to be aware of flooding that can be happen at any time, especially during extreme rainy season.

In addition to these, anyone needing to use this research for further Megech River development and feasibility study, it is recommended to review all result simulated and attached below in graphs varying from one section to another. As the model output generation is too much in hydraulic and sediment variables, it is difficult to present all in this document. Therefore, I recommend him/her to find all generated outputs in soft copy by contacting me in physical or on line. In this paper, I tried to present representative results for explanation and giving direction where the full report is available in graphs.

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# 6 Appendixes

## 6.1 Appendix A: Simulated result and validation calculation tables

Table 7: Maximum and Average mass bed change and bank erosion,

| River station (RS) | Maximum bed chanche/aggradaion (tone/day) | Maximum degration (tone/day) | Average mass bed change (ton/day) | Max. bank erosion (ton/day) | Average bank erosion (ton/day) |
|---|---|---|---|---|---|
| 105 | 80.417 | -278.011 | -15.477 | 785.302 | 27.850 |
| 104 | 186.050 | -483.357 | -1.396 | 975.302 | 34.870 |
| 103 | 287.081 | -540.759 | 1.217 | 403.300 | 34.381 |
| 102 | 154.965 | -148.045 | 0.624 | 1000.000 | 26.298 |
| 101 | 479.495 | -678.791 | -3.334 | 1050.000 | 23.200 |
| 100 | 191.965 | -708.252 | 1.564 | 978.210 | 18.230 |
| 99 | 462.446 | -712.246 | -1.525 | 1934.000 | 22.300 |
| 98 | 207.428 | -479.970 | -0.268 | 978.000 | 46.534 |
| 97 | 348.893 | -162.843 | -1.088 | 1748.080 | 28.640 |
| 96 | 119.942 | -768.019 | -1.047 | 1268.000 | 25.280 |
| 95 | 768.029 | -385.734 | 1.399 | 445.000 | 16.242 |
| 94 | 163.504 | -101.762 | -0.336 | 210.811 | 26.000 |
| 93 | 189.885 | -817.961 | 1.450 | 1217.300 | 10.580 |
| 92 | 153.311 | -158.941 | -2.328 | 210.811 | 25.200 |
| 91 | 374.206 | -824.736 | 0.824 | 1575.700 | 29.437 |
| 90 | 422.189 | -208.479 | 2.941 | 975.302 | 45.000 |
| 89 | 132.100 | -757.981 | -0.411 | 210.811 | 37.000 |
| 88 | 287.424 | -175.358 | 2.709 | 1982.120 | 46.534 |
| 87 | 343.575 | -796.888 | -6.157 | 4615.000 | 25.650 |
| 86 | 177.661 | -390.671 | -8.787 | 1340.000 | 44.810 |
| 85 | 554.521 | -145.210 | -7.392 | 3009.656 | 21.991 |
| 84 | 371.264 | -239.240 | 0.668 | 975.302 | 46.534 |
| 83 | 125.867 | -511.221 | -3.598 | 2689.180 | 16.242 |
| 82 | 124.272 | -414.059 | -4.914 | 2959.350 | 48.320 |
| 81 | 236.708 | -584.589 | -3.318 | 2326.870 | 36.650 |
| 80 | 662.575 | -667.908 | -0.356 | 1441.310 | 16.242 |
| 79 | 977.899 | -122.764 | -0.438 | 2942.860 | 26.000 |
| 78 | 170.726 | -134.396 | -2.011 | 1668.880 | 46.534 |
| 77 | 230.435 | -128.745 | 2.480 | 3620.360 | 33.300 |
| 76 | 229.085 | -957.627 | -3.353 | 2309.270 | 21.504 |
| 75 | 179.371 | -189.375 | -5.320 | 1088.350 | 13.690 |
| 74 | 252.477 | -177.994 | -5.480 | 1558.540 | 46.534 |
| 73 | 258.209 | -145.223 | -5.364 | 1493.983 | 36.330 |
| 72 | 148.914 | -112.800 | -4.789 | 211.692 | 43.000 |
| 71 | 236.662 | -112.168 | -4.363 | 139.191 | 32.020 |
| **Av.ge value for upper reach reach in 10yrs** | | | **-2.199** | | **30.826** |

Cont…………

| River station (RS) | maximum bed chanche/aggradaion (tone/day) | Maximum degration (tone/day) | Average mass bed change (ton/day) | Max. bank erosion (ton/day) | Average bank erosion (ton/day) |
|---|---|---|---|---|---|
| 70 | 149.080 | -121.141 | -1.036 | 2225.400 | 28.112 |
| 69 | 127.652 | -195.558 | -1.038 | 224.770 | 30.000 |
| 68 | 743.504 | -135.085 | -1.759 | 789.000 | 22.000 |
| 67 | 199.038 | -751.633 | 0.992 | 2453.903 | 21.000 |
| 66 | 290.465 | -154.180 | -1.363 | 809.574 | 25.250 |
| 65 | 288.516 | -116.663 | 1.017 | 7806.600 | 46.534 |
| 64 | 157.879 | -214.999 | -1.405 | 134.215 | 26.000 |
| 63 | 191.246 | -181.852 | 0.224 | 389.526 | 25.230 |
| 62 | 123.247 | -163.867 | -0.158 | 233.320 | 46.534 |
| 61 | 118.184 | -176.694 | 0.827 | 210.811 | 36.100 |
| 60 | 328.383 | -193.543 | -0.026 | 187.645 | 34.144 |
| 59 | 335.530 | -148.277 | -3.302 | 568.000 | 34.000 |
| 58 | 102.956 | -540.807 | -4.301 | 985.302 | 17.360 |
| 57 | 756.632 | -165.567 | -5.642 | 210.811 | 26.420 |
| 56 | 310.677 | -143.019 | 1.958 | 464.939 | 26.420 |
| 55 | 245.467 | -197.568 | -2.847 | 1256.000 | 26.420 |
| 54 | 154.837 | -135.113 | -7.474 | 260.381 | 47.209 |
| 53 | 114.911 | -131.984 | -11.129 | 286.974 | 5.941 |
| 52 | 252.874 | -290.644 | -9.756 | 344.331 | 21.233 |
| 51 | 692.122 | -277.694 | -5.824 | 210.811 | 28.012 |
| 50 | 136.495 | -151.909 | 0.210 | 235.231 | 24.059 |
| 49 | 268.369 | -213.625 | -0.880 | 186.395 | 58.544 |
| 48 | 114.227 | -176.268 | 3.152 | 1415.210 | 37.936 |
| 47 | 153.978 | -146.369 | 6.265 | 377.016 | 53.210 |
| 46 | 188.940 | -901.336 | -3.642 | 882.535 | 25.210 |
| 45 | 120.328 | -142.853 | -0.797 | 9837.130 | 19.557 |
| 44 | 137.027 | -134.042 | 0.267 | 623.070 | 33.992 |
| 43 | 174.019 | -815.799 | 3.862 | 214.359 | 22.763 |
| 42 | 292.370 | -294.255 | -12.627 | 610.375 | 18.381 |
| 41 | 226.048 | -173.960 | -8.594 | 509.492 | 21.633 |
| 40 | 377.054 | -276.273 | -0.418 | 721.092 | 32.384 |
| 39 | 877.787 | -566.404 | 0.913 | 2610.790 | 26.254 |
| 38 | 562.433 | -175.980 | 2.144 | 444.739 | 23.904 |
| 37 | 104.499 | -793.513 | -1.388 | 808.5217 | 39.744 |
| 36 | 204.865 | -101.410 | 0.493 | 671.7278 | 31.607 |
| **Average value for middle reach in 10yrs** | | | **-1.802** | | **29.803** |

Cont…………

| River station (RS) | maximum bed chanche/aggradaion (tone/day) | Maximum degration (tone/day) | Average mass bed change (ton/day) | Max. bank erosion (ton/day) | Average bank erosion (ton/day) |
|---|---|---|---|---|---|
| 35 | 157.800 | -179.614 | -0.140 | 837.905 | 27.686 |
| 34 | 452.044 | -374.314 | -1.236 | 1144.778 | 32.240 |
| 33 | 239.713 | -283.535 | 0.668 | 210.811 | 27.230 |
| 32 | 651.869 | -209.058 | 0.079 | 773.831 | 22.250 |
| 31 | 843.088 | -403.501 | -1.670 | 1416.040 | 32.140 |
| 30 | 854.094 | -602.788 | -2.272 | 1542.512 | 43.150 |
| 29 | 282.578 | -573.073 | -0.149 | 210.811 | 44.180 |
| 28 | 181.803 | -113.533 | -1.685 | 1790.631 | 22.337 |
| 27 | 239.828 | -124.188 | 0.287 | 210.811 | 41.250 |
| 26 | 290.844 | -261.608 | -2.114 | 279.768 | 23.230 |
| 25 | 279.540 | -113.976 | 3.374 | 317.943 | 25.680 |
| 24 | 144.385 | -277.113 | 8.163 | 640.372 | 36.000 |
| 23 | 149.886 | -910.466 | 7.232 | 1126.172 | 16.000 |
| 22 | 110.013 | -212.242 | 8.948 | 1463.000 | 8.736 |
| 21 | 169.035 | -160.542 | 6.953 | 644.988 | 44.792 |
| 20 | 125.205 | -882.437 | 3.400 | 3518.110 | 20.170 |
| 19 | 137.038 | -180.485 | -1.900 | 2959.249 | 34.976 |
| 18 | 213.052 | -881.427 | -1.289 | 452.000 | 25.976 |
| 17 | 234.667 | -244.613 | 2.061 | 2971.573 | 10.060 |
| 16 | 280.160 | -177.710 | 1.192 | 1015.408 | 38.827 |
| 15 | 121.577 | -131.390 | 5.731 | 5316.646 | 44.286 |
| 14 | 131.385 | -358.473 | 1.498 | 2068.374 | 42.718 |
| 13 | 358.357 | -283.223 | 2.776 | 2666.109 | 26.420 |
| 12 | 162.786 | -758.023 | 1.804 | 1470.520 | 20.651 |
| 11 | 922.808 | -169.805 | 2.115 | 709.208 | 26.230 |
| 10 | 134.758 | -196.310 | 0.218 | 9243.020 | 25.320 |
| 9 | 196.310 | -110.991 | -0.060 | 1071.500 | 32.793 |
| 8 | 190.383 | -960.750 | 6.390 | 298.673 | 17.739 |
| 7 | 320.750 | -623.683 | -0.312 | 609.661 | 23.233 |
| 6 | 357.384 | -705.140 | 1.166 | 1562.300 | 6.329 |
| 5 | 566.708 | -194.116 | -0.623 | 1805.660 | 23.050 |
| 4 | 13394.116 | -522.610 | 3.196 | 1541.094 | 25.870 |
| 3 | 522.610 | -303.213 | 1.897 | 3607.650 | 25.419 |
| 2 | 170.123 | -195.408 | 0.931 | 1044.399 | 24.368 |
| 1 | 96.643 | -176.315 | 0.189 | 377.016 | 32.000 |
| **Average value for lower reach in 10yrs** | | | **1.623** | | **27.810** |

*Table 8: Average sediment discharge and river bed invert change*

| River station | Maximum diposition(m) | Maximum scour(m) | Average bed invert change(m) | Maximum sediment discharge(ton/day) | Average sediment discharge(ton/day) |
|---|---|---|---|---|---|
| 105 | 143.135 | -3.997 | -3.580 | 2686.816 | 38.374 |
| 104 | 0.104 | -3.839 | -3.007 | 3192.296 | 45.230 |
| 103 | 0.960 | -3.041 | -2.229 | 3230.270 | 38.229 |
| 102 | 0.000 | -3.999 | -3.181 | 3371.268 | 43.791 |
| 101 | 0.063 | -3.424 | -2.651 | 3504.670 | 52.320 |
| 100 | 0.089 | -3.533 | -2.506 | 3480.794 | 61.840 |
| 99 | 0.080 | -3.085 | -2.176 | 3720.065 | 65.230 |
| 98 | 0.045 | -3.999 | -3.499 | 2084.202 | 64.469 |
| 97 | 0.055 | -3.584 | -3.287 | 1598.714 | 67.523 |
| 96 | 0.126 | -3.770 | -3.296 | 1598.714 | 61.734 |
| 95 | 0.214 | -3.999 | -3.580 | 1138.291 | 58.282 |
| 94 | 9.504 | -0.006 | 7.418 | 1755.100 | 65.230 |
| 93 | 0.000 | -3.999 | -3.531 | 1756.800 | 57.955 |
| 92 | 0.041 | -3.986 | -3.422 | 1719.436 | 45.000 |
| 91 | 0.105 | -3.999 | -3.452 | 2349.624 | 65.230 |
| 90 | 0.050 | -3.999 | -3.453 | 1651.540 | 57.600 |
| 89 | 0.060 | -3.999 | -3.413 | 1285.010 | 59.281 |
| 88 | 0.001 | -3.999 | -3.381 | 1250.275 | 52.360 |
| 87 | 0.001 | -3.999 | -3.227 | 1605.281 | 49.187 |
| 86 | 0.059 | -3.999 | -3.197 | 1116.608 | 63.210 |
| 85 | 0.082 | -3.999 | -2.990 | 2759.849 | 38.277 |
| 84 | 0.395 | -3.485 | -2.570 | 3177.980 | 32.007 |
| 83 | 0.156 | -3.999 | -3.414 | 2934.675 | 61.251 |
| 82 | 0.038 | -3.999 | -3.300 | 1460.286 | 22.073 |
| 81 | 0.028 | -3.604 | -3.034 | 1068.078 | 47.890 |
| 80 | 0.081 | -3.868 | -3.187 | 1014.538 | 51.133 |
| 79 | 0.050 | -3.999 | -3.273 | 851.445 | 51.761 |
| 78 | 0.118 | -3.999 | -3.127 | 703.604 | 69.451 |
| 77 | 0.127 | -3.999 | -3.097 | 801.086 | 85.260 |
| 76 | 0.024 | -3.999 | -3.025 | 774.622 | 76.507 |
| 75 | 1.879 | -3.377 | -1.206 | 586.338 | 65.230 |
| 74 | 0.076 | -3.999 | -2.605 | 828.770 | 79.283 |
| 73 | 0.065 | -3.999 | -2.232 | 1350.466 | 36.964 |
| 72 | 0.700 | -2.900 | -1.417 | 748.929 | 74.545 |
| 71 | 1.159 | -3.999 | -1.423 | 982.331 | 40.765 |
| **Average value for upper reach** | | | **-2.644** | **400.000** | **55.556** |

Cont……….

| River station | Maximum diposition(m) | Maximum scour(m) | Average bed invert change(m) | Maximum sediment discharge(ton/day) | Average sediment discharge(ton/day) |
|---|---|---|---|---|---|
| 70 | 0.178 | -3.868 | -1.869 | 1237.672 | 48.161 |
| 69 | 0.240 | -2.856 | -1.317 | 1024.589 | 56.353 |
| 68 | 0.081 | -2.675 | -1.257 | 656.240 | 69.503 |
| 67 | 0.382 | -2.138 | -0.739 | 580.979 | 62.230 |
| 66 | 0.906 | -1.207 | -0.058 | 590.645 | 72.257 |
| 65 | 1.630 | -0.654 | 0.355 | 798.467 | 62.303 |
| 64 | 0.747 | -0.981 | -0.467 | 658.234 | 74.001 |
| 63 | 1.830 | -0.981 | -0.147 | 849.266 | 72.464 |
| 62 | 0.396 | -3.999 | -3.794 | 980.553 | 73.060 |
| 61 | 1.272 | -3.999 | -2.647 | 595.846 | 68.401 |
| 60 | 0.092 | -3.999 | -3.143 | 860.162 | 68.586 |
| 59 | 0.041 | -3.290 | -2.652 | 617.421 | 94.871 |
| 58 | 0.101 | -3.999 | -2.784 | 808.033 | 59.655 |
| 57 | 0.144 | -3.648 | -2.356 | 658.730 | 54.944 |
| 56 | 0.014 | -3.999 | -2.394 | 1116.254 | 88.534 |
| 55 | 0.664 | -3.997 | -1.917 | 741.389 | 61.665 |
| 54 | 0.006 | -3.999 | -1.990 | 594.047 | 52.321 |
| 53 | 0.077 | -3.999 | -1.451 | 594.909 | 59.228 |
| 52 | 0.567 | -3.999 | -0.960 | 628.047 | 61.926 |
| 51 | 1.372 | -2.811 | -0.195 | 599.174 | 59.621 |
| 50 | 0.437 | -3.997 | -1.188 | 983.360 | 57.988 |
| 49 | 0.341 | -2.635 | -0.683 | 1250.915 | 58.037 |
| 48 | 0.197 | -3.015 | -1.627 | 1360.897 | 75.088 |
| 47 | 0.000 | -2.064 | -1.246 | 1829.081 | 61.628 |
| 46 | 0.000 | -1.683 | -1.144 | 1709.687 | 75.188 |
| 45 | 0.126 | -1.458 | -0.678 | 2090.920 | 58.278 |
| 44 | 0.849 | -0.757 | -0.068 | 3915.080 | 59.037 |
| 43 | 1.078 | -1.393 | -0.327 | 4786.492 | 61.000 |
| 42 | 1.733 | -3.999 | -0.301 | 5122.269 | 75.088 |
| 41 | 1.147 | -1.032 | 0.462 | 6870.076 | 54.104 |
| 40 | 2.130 | -0.306 | 1.095 | 4171.342 | 57.570 |
| 39 | 2.208 | -0.344 | 1.243 | 4887.097 | 56.689 |
| 38 | 2.498 | -3.743 | 0.304 | 4148.707 | 58.917 |
| 37 | 1.323 | -0.714 | 0.313 | 3519.562 | 59.619 |
| 36 | 0.671 | -3.999 | -2.194 | 3612.530 | 67.467 |
| **Average value for midle reach** | | | **-1.081** | **400.000** | **64.451** |

Cont…….

| River station | Maximum diposition(m) | Maximum scour(m) | Average bed invert change(m) | Maximum sediment discharge(ton/day) | Average sediment discharge(ton/day) |
|---|---|---|---|---|---|
| 35 | 0.087 | -2.697 | -1.884 | 4142.842 | 57.768 |
| 34 | 0.028 | -2.694 | -1.439 | 3516.454 | 55.355 |
| 33 | 0.122 | -3.999 | -2.906 | 3474.903 | 61.528 |
| 32 | 0.051 | -3.589 | -2.574 | 3662.329 | 51.262 |
| 31 | 0.083 | -2.988 | -2.213 | 3962.804 | 58.703 |
| 30 | 0.000 | -3.999 | -3.124 | 4140.473 | 77.961 |
| 29 | 0.013 | -3.999 | -3.114 | 4028.475 | 53.834 |
| 28 | 0.258 | -3.510 | -2.800 | 4071.776 | 46.786 |
| 27 | 0.125 | -3.999 | -3.219 | 4796.352 | 48.264 |
| 26 | 0.001 | -3.999 | -3.005 | 4965.563 | 51.153 |
| 25 | 0.022 | -3.736 | -2.815 | 5263.352 | 72.981 |
| 24 | 0.014 | -3.999 | -2.983 | 5435.379 | 75.088 |
| 23 | 0.245 | -3.229 | -2.176 | 6944.410 | 64.972 |
| 22 | 0.397 | -3.999 | -1.990 | 6267.423 | 58.863 |
| 21 | 0.123 | -2.270 | -1.156 | 7704.063 | 53.752 |
| 20 | 0.386 | -2.460 | -0.947 | 5178.886 | 56.359 |
| 19 | 0.431 | -1.225 | -0.467 | 2917.053 | 46.229 |
| 18 | 0.360 | -1.451 | -0.648 | 1499.171 | 48.809 |
| 17 | 0.286 | -1.297 | -0.522 | 2542.979 | 58.237 |
| 16 | 0.337 | -1.063 | -0.340 | 2209.328 | 45.324 |
| 15 | 0.534 | -0.801 | -0.159 | 2415.197 | 75.188 |
| 14 | 0.403 | -0.813 | -0.312 | 2937.803 | 63.291 |
| 13 | 0.348 | -2.625 | -0.777 | 7130.379 | 53.467 |
| 12 | 0.116 | -1.181 | -0.427 | 7665.350 | 87.328 |
| 11 | 1.031 | -1.377 | -0.001 | 5841.986 | 68.849 |
| 10 | 0.770 | -1.591 | -0.217 | 5303.836 | 75.188 |
| 9 | 0.755 | -1.378 | -0.044 | 3458.966 | 65.637 |
| 8 | 1.005 | -1.017 | 0.195 | 3371.417 | 49.209 |
| 7 | 1.417 | -0.804 | 0.517 | 3358.643 | 54.094 |
| 6 | 1.534 | -0.609 | 0.687 | 3022.309 | 45.029 |
| 5 | 1.950 | -0.408 | 1.063 | 3025.435 | 51.636 |
| 4 | 2.365 | -0.043 | 1.412 | 2437.425 | 51.636 |
| 3 | 2.334 | -0.433 | 1.398 | 3372.164 | 65.230 |
| 2 | 2.616 | -0.374 | 1.730 | 3842.201 | 75.188 |
| 1 | 3.504 | -0.062 | 2.405 | 3525.316 | 66.067 |
| **Average value for lower reach** | | | **-0.939** | | **59.722** |

*Table 9: Right and left banks stability factor of safety*

| River station | Right bank factor of safety | Remark | Left bank Factor of safety | Remark |
|---|---|---|---|---|
| 105 | 0.715 | unstable | 0.910 | unstable |
| 104 | 0.899 | unstable | 1.128 | stable |
| 103 | 0.648 | unstable | 1.074 | stable |
| 102 | 2.416 | stable | 2.083 | stable |
| 101 | 1.052 | stable | 2.406 | stable |
| 100 | 0.698 | unstable | 0.931 | unstable |
| 99 | 1.862 | stable | 0.881 | unstable |
| 98 | 0.764 | unstable | 0.893 | unstable |
| 97 | 1.100 | stable | 2.514 | stable |
| 96 | 2.357 | stable | 1.345 | stable |
| 95 | 0.865 | unstable | 1.515 | stable |
| 94 | 0.829 | unstable | 0.949 | unstable |
| 93 | 1.622 | stable | 2.650 | stable |
| 92 | 0.690 | unstable | 1.063 | stable |
| 91 | 0.764 | unstable | 0.977 | unstable |
| 90 | 0.620 | unstable | 0.993 | unstable |
| 89 | 0.678 | unstable | 0.956 | unstable |
| 88 | 0.614 | unstable | 0.980 | unstable |
| 87 | 0.724 | unstable | 0.966 | unstable |
| 86 | 2.866 | stable | 1.135 | stable |
| 85 | 0.996 | unstable | 1.084 | stable |
| 84 | 1.488 | stable | 1.223 | stable |
| 83 | 1.444 | stable | 1.253 | stable |
| 82 | 1.703 | stable | 0.732 | unstable |
| 81 | 0.824 | unstable | 0.150 | unstable |
| 80 | 1.444 | stable | 0.732 | unstable |
| 79 | 0.684 | unstable | 0.709 | unstable |
| 78 | 2.980 | stable | 2.506 | stable |
| 77 | 2.852 | stable | 1.904 | stable |
| 76 | 2.790 | stable | 1.114 | stable |
| 75 | 0.762 | unstable | 1.092 | stable |
| 74 | 1.364 | stable | 1.668 | stable |
| 73 | 0.952 | unstable | 0.925 | unstable |
| 72 | 1.554 | stable | 1.046 | stable |
| 71 | 0.651 | unstable | 1.526 | stable |

Cont…………..

| River station | Right bank factor of safety | Remark | Left bank Factor of safety | Remark |
|---|---|---|---|---|
| 70 | 1.808 | stable | 2.323 | stable |
| 69 | 1.035 | stable | 2.823 | stable |
| 68 | 1.902 | stable | 0.897 | unstable |
| 67 | 0.898 | unstable | 2.550 | stable |
| 66 | 1.514 | stable | 1.067 | stable |
| 65 | 1.870 | stable | 1.336 | stable |
| 64 | 1.595 | stable | 1.693 | stable |
| 63 | 1.705 | stable | 1.005 | stable |
| 62 | 0.998 | unstable | 1.334 | stable |
| 61 | 1.880 | stable | 2.365 | stable |
| 60 | 0.949 | unstable | 1.153 | stable |
| 59 | 0.513 | unstable | 0.915 | unstable |
| 58 | 0.647 | unstable | 0.850 | unstable |
| 57 | 1.363 | stable | 1.065 | stable |
| 56 | 1.605 | stable | 1.165 | stable |
| 55 | 1.495 | stable | 2.060 | stable |
| 54 | 0.957 | unstable | 1.301 | stable |
| 53 | 0.672 | unstable | 0.989 | unstable |
| 52 | 0.644 | unstable | 0.920 | unstable |
| 51 | 0.777 | unstable | 0.891 | unstable |
| 50 | 0.622 | unstable | 1.087 | stable |
| 49 | 0.609 | unstable | 1.025 | stable |
| 48 | 0.662 | unstable | 0.980 | unstable |
| 47 | 0.529 | unstable | 1.147 | stable |
| 46 | 1.564 | stable | 1.267 | stable |
| 45 | 0.302 | unstable | 1.337 | stable |
| 44 | 0.605 | unstable | 1.073 | stable |
| 43 | 0.494 | unstable | 1.182 | stable |
| 42 | 1.384 | stable | 1.278 | stable |
| 41 | 0.861 | unstable | 1.260 | stable |
| 40 | 2.919 | stable | 1.062 | stable |
| 39 | 2.044 | stable | 1.474 | stable |
| 38 | 1.340 | stable | 1.257 | stable |
| 37 | 0.889 | unstable | 1.247 | stable |
| 36 | 0.534 | unstable | 1.159 | stable |

Cont….

| River station | Right bank factor of safety | Remark | Left bank Factor of safety | Remark |
|---|---|---|---|---|
| 35 | 0.512 | unstable | 1.369 | stable |
| 34 | 0.338 | unstable | 1.250 | stable |
| 33 | 0.350 | unstable | 0.330 | unstable |
| 32 | 0.554 | unstable | 0.350 | unstable |
| 31 | 0.506 | unstable | 1.070 | stable |
| 30 | 1.362 | stable | 1.228 | stable |
| 29 | 0.290 | unstable | 1.494 | stable |
| 28 | 0.772 | unstable | 0.630 | unstable |
| 27 | 1.300 | stable | 2.232 | stable |
| 26 | 1.390 | stable | 0.947 | unstable |
| 25 | 1.482 | stable | 1.486 | stable |
| 24 | 1.098 | stable | 1.134 | stable |
| 23 | 0.623 | unstable | 1.028 | stable |
| 22 | 0.148 | unstable | 1.073 | stable |
| 21 | 1.020 | stable | 1.200 | stable |
| 20 | 0.906 | unstable | 1.213 | stable |
| 19 | 1.078 | stable | 1.159 | stable |
| 18 | 1.223 | stable | 1.205 | stable |
| 17 | 0.504 | unstable | 1.473 | stable |
| 16 | 1.077 | stable | 1.420 | stable |
| 15 | 0.411 | unstable | 1.032 | stable |
| 14 | 0.243 | unstable | 1.185 | stable |
| 13 | 1.057 | stable | 1.757 | stable |
| 12 | 1.254 | stable | 1.415 | stable |
| 11 | 2.731 | stable | 1.701 | stable |
| 10 | 0.419 | unstable | 1.752 | stable |
| 9 | 1.056 | stable | 1.466 | stable |
| 8 | 0.223 | unstable | 1.394 | stable |
| 7 | 1.210 | stable | 1.379 | stable |
| 6 | 0.900 | unstable | 1.490 | stable |
| 5 | 2.341 | stable | 1.427 | stable |
| 4 | 0.167 | unstable | 1.327 | stable |
| 3 | 1.324 | stable | 1.345 | stable |
| 2 | 0.106 | unstable | 1.358 | stable |
| 1 | 1.468 | stable | 1.477 | stable |

*Table 10: Validation calculation table by Index of agreement (d) Method*

| Observed sediment discharge(O) (ton/day) | predicted sediment discharge(P) (ton/day) | (Oi -Pi)2 | \|Pi-Ó\| | \|Oi-Ó\| | \|Pi-Ó\|+\|Oi-Ó\| | col(6)^2 |
|---|---|---|---|---|---|---|
| 0.74 | 8.38 | 58.38 | 156.85 | 111.58 | 268.43 | 72053.69 |
| 0.96 | 9.07 | 65.77 | 156.16 | 111.36 | 267.52 | 71565.26 |
| 53.54 | 8.25 | 2051.29 | 156.98 | 58.78 | 215.76 | 46550.68 |
| 68.52 | 8.78 | 3568.71 | 156.45 | 43.80 | 200.25 | 40099.48 |
| 86.02 | 15.25 | 5008.59 | 149.98 | 26.30 | 176.28 | 31073.16 |
| 250.41 | 80.38 | 28910.05 | 84.85 | 138.09 | 222.94 | 49702.05 |
| 250.41 | 83.17 | 27969.41 | 82.06 | 138.09 | 220.15 | 48466.27 |
| 250.41 | 84.83 | 27416.68 | 80.40 | 138.09 | 218.49 | 47737.80 |
| 0.73 | 8.67 | 62.99 | 156.56 | 111.59 | 268.14 | 71901.30 |
| 0.77 | 9.67 | 79.27 | 155.56 | 111.55 | 267.11 | 71348.18 |
| 0.77 | 8.67 | 62.47 | 156.56 | 111.55 | 268.11 | 71883.40 |
| 4.86 | 13.22 | 70.00 | 152.01 | 107.46 | 259.47 | 67325.88 |
| 4.86 | 14.22 | 87.74 | 151.01 | 107.46 | 258.47 | 66807.94 |
| 4.86 | 11.22 | 40.54 | 154.01 | 107.46 | 261.47 | 68367.77 |
| 39.74 | 15.80 | 573.20 | 149.43 | 72.58 | 222.01 | 49289.41 |
| 48.93 | 16.80 | 1032.31 | 148.43 | 63.39 | 211.82 | 44869.47 |
| 37.70 | 14.80 | 524.44 | 150.43 | 74.62 | 225.05 | 50648.91 |
| 46.08 | 30.01 | 258.06 | 135.22 | 66.24 | 201.46 | 40585.72 |
| 46.87 | 26.01 | 435.16 | 139.22 | 65.45 | 204.66 | 41886.88 |
| 46.87 | 28.01 | 355.72 | 137.22 | 65.45 | 202.66 | 41072.23 |
| 2.06 | 16.93 | 221.28 | 148.30 | 110.26 | 258.56 | 66854.71 |
| 2.03 | 17.93 | 252.77 | 147.30 | 110.29 | 257.59 | 66350.47 |
| 2.03 | 21.93 | 395.96 | 143.30 | 110.29 | 253.59 | 64305.78 |
| 63.80 | 19.36 | 1975.51 | 145.87 | 48.52 | 194.39 | 37788.08 |
| 63.80 | 18.66 | 2038.23 | 146.57 | 48.52 | 195.09 | 38060.72 |
| 63.80 | 20.06 | 1913.78 | 145.17 | 48.52 | 193.69 | 37516.43 |
| 91.03 | 15.46 | 5710.91 | 149.77 | 21.29 | 171.07 | 29263.60 |
| 91.03 | 14.46 | 5863.05 | 150.77 | 21.29 | 172.07 | 29606.74 |
| 101.40 | 16.46 | 7216.09 | 148.77 | 10.92 | 159.69 | 25500.59 |
| 50.16 | 9.81 | 1628.15 | 155.42 | 62.16 | 217.58 | 47341.21 |
| 32.59 | 10.61 | 482.94 | 154.62 | 79.73 | 234.35 | 54922.15 |
| 32.59 | 10.91 | 469.85 | 154.32 | 79.73 | 234.05 | 54781.63 |
| 52.75 | 84.83 | 1029.20 | 80.40 | 59.57 | 139.97 | 19591.27 |
| 48.23 | 8.67 | 1564.83 | 156.56 | 64.09 | 220.65 | 48686.12 |
| 41.54 | 9.67 | 1015.50 | 155.56 | 70.78 | 226.34 | 51229.94 |
| 66.40 | 8.67 | 3332.72 | 156.56 | 45.92 | 202.48 | 40997.17 |
| 60.83 | 13.22 | 2266.63 | 152.01 | 51.49 | 203.50 | 41410.75 |
| 78.61 | 14.22 | 4145.27 | 151.01 | 33.71 | 184.72 | 34122.10 |
| 82.77 | 11.22 | 5118.63 | 154.01 | 29.55 | 183.56 | 33694.59 |
| 75.88 | 15.80 | 3609.51 | 149.43 | 36.44 | 185.87 | 34549.33 |
| 73.85 | 16.80 | 3254.68 | 148.43 | 38.47 | 186.90 | 34933.08 |
| 89.44 | 14.80 | 5571.42 | 150.43 | 22.88 | 173.31 | 30036.98 |

Cont……..

| Observed sediment discharge(O) (ton/day) | predicted sediment discharge(P) (ton/day) | (Oi -Pi)2 | \|Pi-Ó\| | \|Oi-Ó\| | \|Pi-Ó\|+\|Oi-Ó\| | col(6)^2 |
|---|---|---|---|---|---|---|
| 115.57 | 16.43 | 9830.28 | 148.80 | 3.25 | 152.06 | 23121.56 |
| 109.42 | 14.43 | 9023.85 | 150.80 | 2.90 | 153.70 | 23624.79 |
| 90.75 | 22.14 | 4706.86 | 143.09 | 21.57 | 164.66 | 27113.31 |
| 139.39 | 20.14 | 14221.27 | 145.09 | 27.07 | 172.16 | 29640.08 |
| 139.39 | 19.14 | 14460.77 | 146.09 | 27.07 | 173.16 | 29985.41 |
| 106.74 | 15.79 | 8271.08 | 149.44 | 5.58 | 155.02 | 24030.94 |
| 97.79 | 14.79 | 6887.74 | 150.44 | 14.53 | 164.97 | 27215.83 |
| 126.36 | 18.79 | 11570.17 | 146.44 | 14.04 | 160.47 | 25752.13 |
| 17.41 | 52.58 | 1236.87 | 112.65 | 94.91 | 207.56 | 43079.16 |
| 15.96 | 53.58 | 1415.16 | 111.65 | 96.36 | 208.00 | 43265.93 |
| 17.76 | 50.58 | 1077.21 | 114.65 | 94.56 | 209.21 | 43767.54 |
| 122.83 | 60.36 | 3902.16 | 104.87 | 10.51 | 115.38 | 13311.91 |
| 130.86 | 62.36 | 4691.88 | 102.87 | 18.54 | 121.41 | 14739.74 |
| 149.89 | 58.36 | 8378.02 | 106.87 | 37.57 | 144.44 | 20863.35 |
| 86.70 | 44.47 | 1783.22 | 120.76 | 25.62 | 146.38 | 21427.47 |
| 85.09 | 44.47 | 1649.95 | 120.76 | 27.23 | 147.99 | 21900.99 |
| 87.39 | 44.47 | 1841.78 | 120.76 | 24.93 | 145.69 | 21226.59 |
| 20.60 | 40.11 | 380.41 | 125.12 | 91.72 | 216.84 | 47019.08 |
| 23.03 | 43.51 | 419.30 | 121.72 | 89.29 | 211.01 | 44525.86 |
| 17.52 | 43.11 | 654.91 | 122.12 | 94.80 | 216.93 | 47056.90 |
| 37.98 | 73.28 | 1246.24 | 91.95 | 74.34 | 166.28 | 27650.17 |
| 19.17 | 71.28 | 2715.77 | 93.95 | 93.15 | 187.09 | 35004.31 |
| 26.98 | 73.28 | 2143.84 | 91.95 | 85.34 | 177.28 | 31429.24 |
| 39.23 | 65.00 | 664.32 | 100.23 | 73.09 | 173.32 | 30039.01 |
| 35.94 | 60.00 | 579.12 | 105.23 | 76.38 | 181.61 | 32981.51 |
| 46.44 | 65.00 | 344.62 | 100.23 | 65.88 | 166.11 | 27591.57 |
| 109.40 | 77.28 | 1031.62 | 87.95 | 2.92 | 90.88 | 8258.85 |
| 100.29 | 78.28 | 484.57 | 86.95 | 12.03 | 98.98 | 9797.88 |
| 126.65 | 77.28 | 2437.67 | 87.95 | 14.33 | 102.28 | 10461.76 |
| 21.81 | 196.40 | 30479.38 | 31.17 | 90.51 | 121.67 | 14804.43 |
| 21.58 | 186.40 | 27166.29 | 21.17 | 90.74 | 111.91 | 12524.30 |
| 21.81 | 181.40 | 25466.88 | 16.17 | 90.51 | 106.67 | 11379.23 |
| 77.29 | 107.11 | 889.13 | 58.12 | 35.03 | 93.15 | 8676.78 |
| 72.28 | 108.11 | 1283.94 | 57.12 | 40.04 | 97.16 | 9440.67 |
| 79.60 | 119.11 | 1560.99 | 46.12 | 32.72 | 78.84 | 6215.80 |
| 114.55 | 177.14 | 3917.47 | 11.91 | 2.23 | 14.14 | 199.87 |
| 106.64 | 177.45 | 5015.05 | 12.22 | 5.68 | 17.91 | 320.66 |
| 95.27 | 177.25 | 6720.52 | 12.02 | 17.05 | 29.07 | 844.99 |
| 73.68 | 68.54 | 26.43 | 96.69 | 38.64 | 135.34 | 18316.23 |
| 46.39 | 70.54 | 582.96 | 94.69 | 65.93 | 160.62 | 25799.78 |
| 45.07 | 70.19 | 631.12 | 95.04 | 67.25 | 162.29 | 26337.55 |
| 77.54 | 156.17 | 6182.47 | 9.06 | 34.78 | 43.85 | 1922.47 |
| 55.37 | 148.28 | 8631.60 | 16.95 | 56.95 | 73.89 | 5460.41 |
| 55.37 | 149.28 | 8818.41 | 15.95 | 56.95 | 72.89 | 5313.62 |
| 118.96 | 49.85 | 4776.47 | 115.38 | 6.64 | 122.02 | 14889.37 |
| 93.91 | 50.85 | 1854.32 | 114.38 | 18.41 | 132.80 | 17634.59 |
| 83.59 | 55.85 | 769.61 | 109.38 | 28.73 | 138.12 | 19075.81 |
| | SUM | **410,531.40** | | | | **3,019,818.31** |
| | | **f =** | **0.136** | | | |
| | | **d =** | **0.864** | | | |

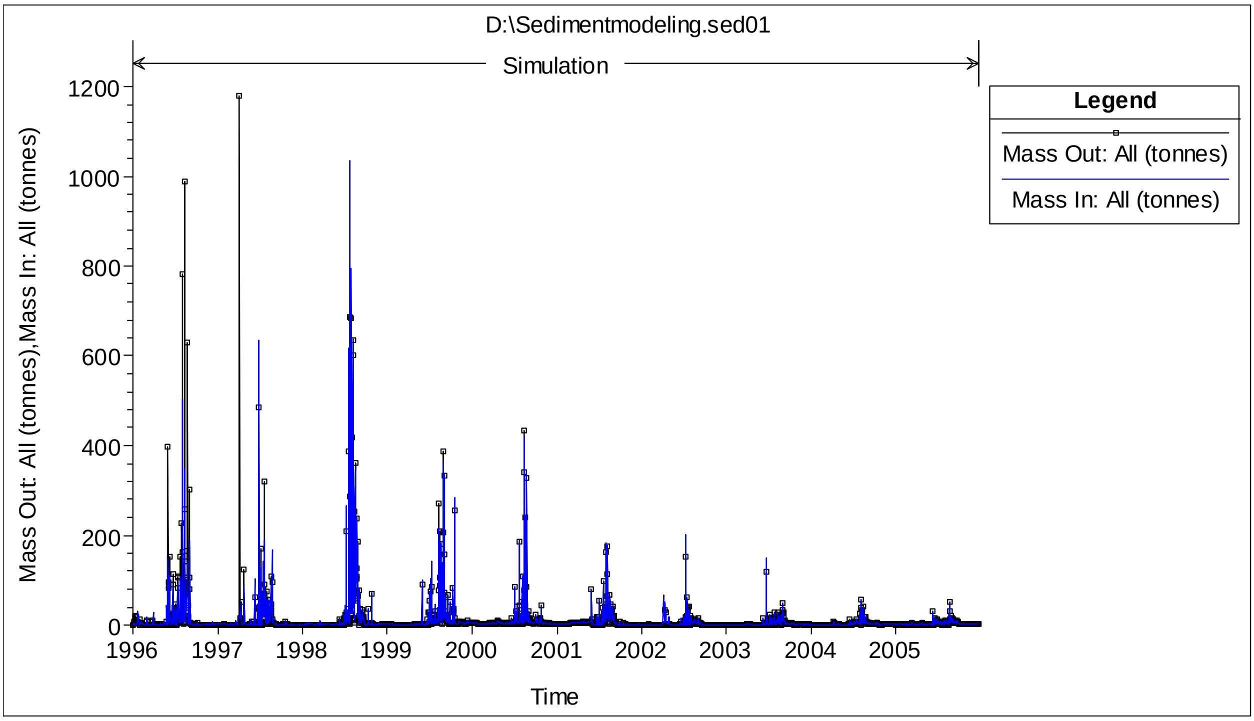
*Table 11: Validation by Nash Sutcliffe efficiency (E) method*

| Observed sediment discharge(O) (ton/day) | predicted sediment discharge(P) (ton/day) | (Oi -Pi)2 | (Oi-Ó)^2 |
|---|---|---|---|
| 0.74 | 8.38 | 58.38 | 48175.67 |
| 0.96 | 9.07 | 65.77 | 48078.56 |
| 53.54 | 8.25 | 2051.29 | 27784.71 |
| 68.52 | 8.78 | 3568.71 | 23015.90 |
| 86.02 | 15.25 | 5008.59 | 18011.58 |
| 250.41 | 80.38 | 28910.05 | 910.89 |
| 250.41 | 83.17 | 27969.41 | 910.89 |
| 250.41 | 84.83 | 27416.68 | 910.89 |
| 0.73 | 8.67 | 62.99 | 48178.29 |
| 0.77 | 9.67 | 79.27 | 48163.63 |
| 0.77 | 8.67 | 62.47 | 48163.63 |
| 4.86 | 13.22 | 70.00 | 46386.20 |
| 4.86 | 14.22 | 87.74 | 46386.20 |
| 4.86 | 11.22 | 40.54 | 46386.20 |
| 39.74 | 15.80 | 573.20 | 32576.76 |
| 48.93 | 16.80 | 1032.31 | 29344.47 |
| 37.70 | 14.80 | 524.44 | 33317.66 |
| 46.08 | 30.01 | 258.06 | 30329.03 |
| 46.87 | 26.01 | 435.16 | 30052.36 |
| 46.87 | 28.01 | 355.72 | 30052.36 |
| 2.06 | 16.93 | 221.28 | 47599.97 |
| 2.03 | 17.93 | 252.77 | 47610.04 |
| 2.03 | 21.93 | 395.96 | 47610.04 |
| 63.80 | 19.36 | 1975.51 | 24469.54 |
| 63.80 | 18.66 | 2038.23 | 24469.54 |
| 63.80 | 20.06 | 1913.78 | 24469.54 |
| 91.03 | 15.46 | 5710.91 | 16693.36 |
| 91.03 | 14.46 | 5863.05 | 16693.36 |
| 101.40 | 16.46 | 7216.09 | 14119.55 |
| 50.16 | 9.81 | 1628.15 | 28923.80 |
| 32.59 | 10.61 | 482.94 | 35210.42 |
| 32.59 | 10.91 | 469.85 | 35210.42 |
| 52.75 | 84.83 | 1029.20 | 28049.54 |
| 48.23 | 8.67 | 1564.83 | 29584.23 |
| 41.54 | 9.67 | 1015.50 | 31930.71 |
| 66.40 | 8.67 | 3332.72 | 23663.34 |
| 60.83 | 13.22 | 2266.63 | 25407.90 |
| 78.61 | 14.22 | 4145.27 | 20057.34 |
| 82.77 | 11.22 | 5118.63 | 18896.11 |
| 75.88 | 15.80 | 3609.51 | 20837.68 |
| 73.85 | 16.80 | 3254.68 | 21427.71 |
| 89.44 | 14.80 | 5571.42 | 17106.01 |

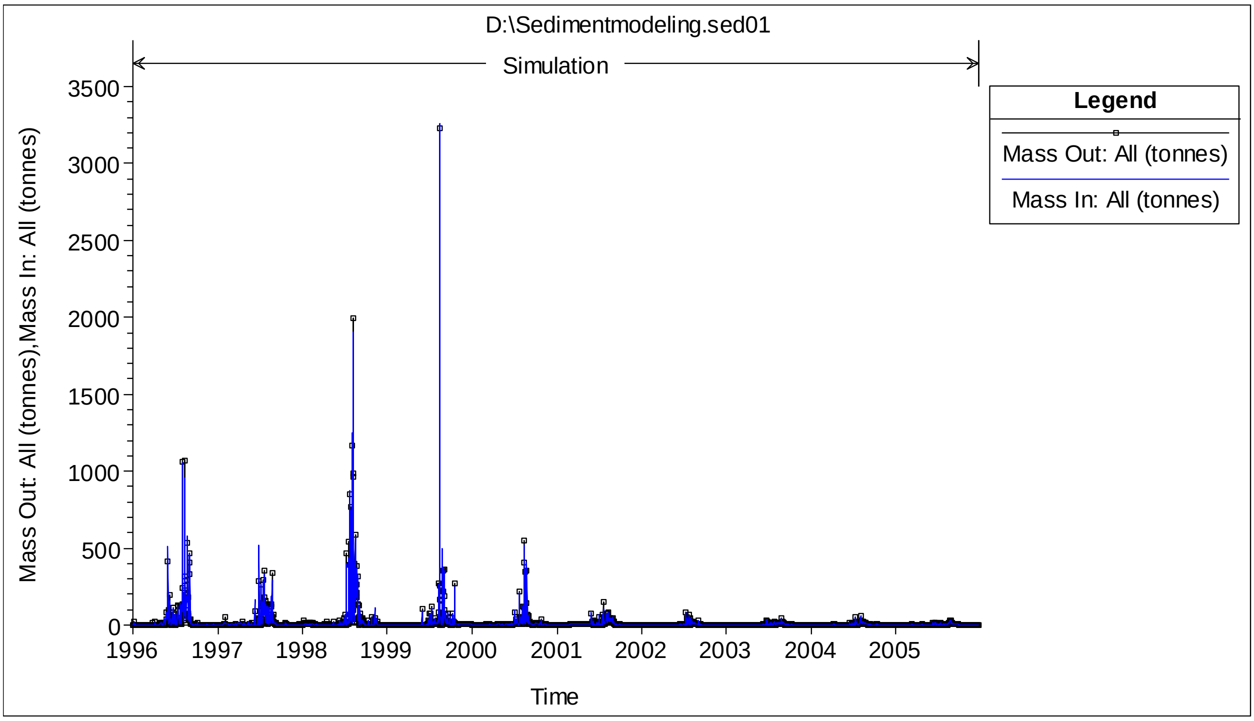
Cont…..

| **Observed sediment discharge(O) (ton/day)** | **predicted sediment discharge(P) (ton/day)** | **(Oi -Pi)2** | **(Oi-Ó)^2** |
|---|---|---|---|
| 115.57 | 16.43 | 9830.28 | 10952.88 |
| 109.42 | 14.43 | 9023.85 | 12278.81 |
| 90.75 | 22.14 | 4706.86 | 16765.67 |
| 139.39 | 20.14 | 14221.27 | 6534.45 |
| 139.39 | 19.14 | 14460.77 | 6534.45 |
| 106.74 | 15.79 | 8271.08 | 12880.40 |
| 97.79 | 14.79 | 6887.74 | 14992.75 |
| 126.36 | 18.79 | 11570.17 | 8812.07 |
| 17.41 | 52.58 | 1236.87 | 41134.80 |
| 15.96 | 53.58 | 1415.16 | 41724.85 |
| 17.76 | 50.58 | 1077.21 | 40993.66 |
| 122.83 | 60.36 | 3902.16 | 9486.75 |
| 130.86 | 62.36 | 4691.88 | 7986.98 |
| 149.89 | 58.36 | 8378.02 | 4947.11 |
| 86.70 | 44.47 | 1783.22 | 17830.67 |
| 85.09 | 44.47 | 1649.95 | 18262.85 |
| 87.39 | 44.47 | 1841.78 | 17647.46 |
| 20.60 | 40.11 | 380.41 | 39850.72 |
| 23.03 | 43.51 | 419.30 | 38887.50 |
| 17.52 | 43.11 | 654.91 | 41092.83 |
| 37.98 | 73.28 | 1246.24 | 33214.24 |
| 19.17 | 71.28 | 2715.77 | 40424.61 |
| 26.98 | 73.28 | 2143.84 | 37344.51 |
| 39.23 | 65.00 | 664.32 | 32761.38 |
| 35.94 | 60.00 | 579.12 | 33963.37 |
| 46.44 | 65.00 | 344.62 | 30203.14 |
| 109.40 | 77.28 | 1031.62 | 12284.32 |
| 100.29 | 78.28 | 484.57 | 14385.77 |
| 126.65 | 77.28 | 2437.67 | 8757.37 |
| 21.81 | 196.40 | 30479.38 | 39368.85 |
| 21.58 | 186.40 | 27166.29 | 39463.57 |
| 21.81 | 181.40 | 25466.88 | 39368.85 |
| 77.29 | 107.11 | 889.13 | 20431.48 |
| 72.28 | 108.11 | 1283.94 | 21889.98 |
| 79.60 | 119.11 | 1560.99 | 19776.75 |
| 114.55 | 177.14 | 3917.47 | 11168.49 |
| 106.64 | 177.45 | 5015.05 | 12903.80 |
| 95.27 | 177.25 | 6720.52 | 15614.17 |
| 73.68 | 68.54 | 26.43 | 21477.83 |
| 46.39 | 70.54 | 582.96 | 30219.93 |
| 45.07 | 70.19 | 631.12 | 30681.13 |
| 77.54 | 156.17 | 6182.47 | 20361.11 |
| 55.37 | 148.28 | 8631.60 | 27177.33 |
| 55.37 | 149.28 | 8818.41 | 27177.33 |
| 118.96 | 49.85 | 4776.47 | 10255.93 |
| 93.91 | 50.85 | 1854.32 | 15957.18 |
| 83.59 | 55.85 | 769.61 | 18670.94 |
| | SUM | **410,531.40** | **2,312,077.06** |
| | | **f** | **0.18** |
| | | **E** | **0.82** |

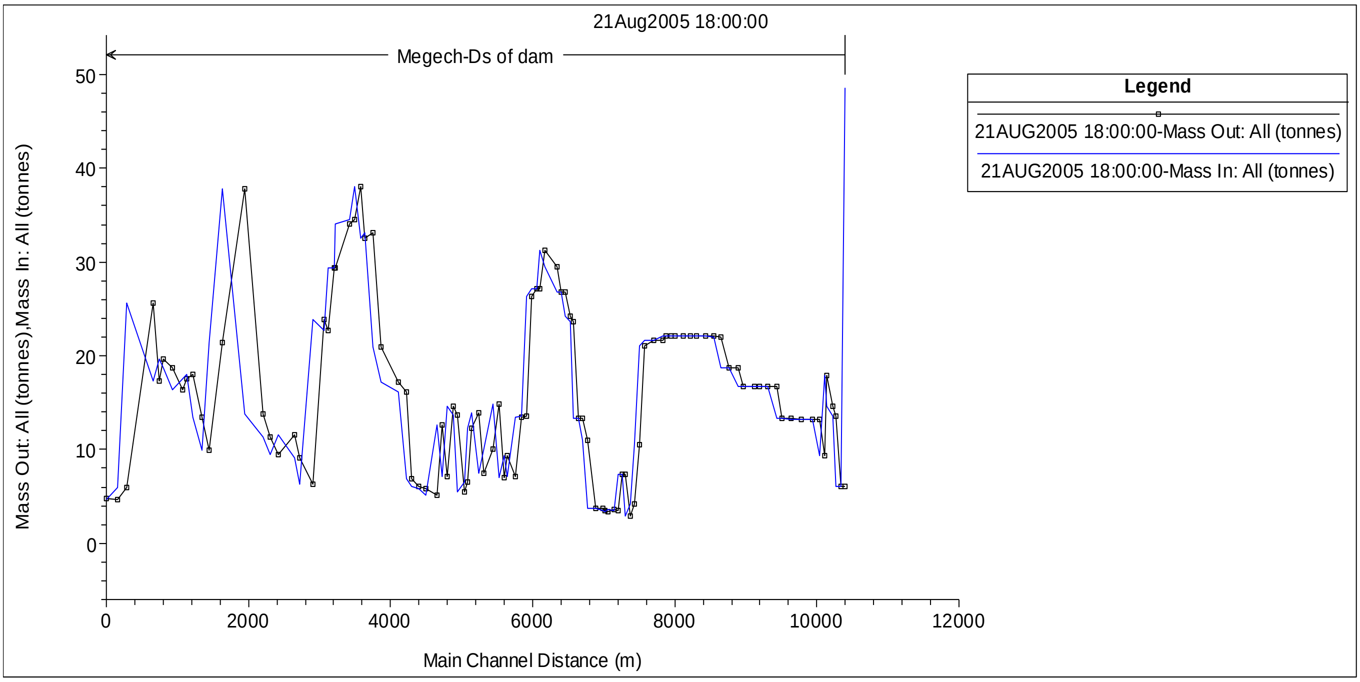
## 6.2 *Appendix B: Selected Model simulation result in graphs as a sample*



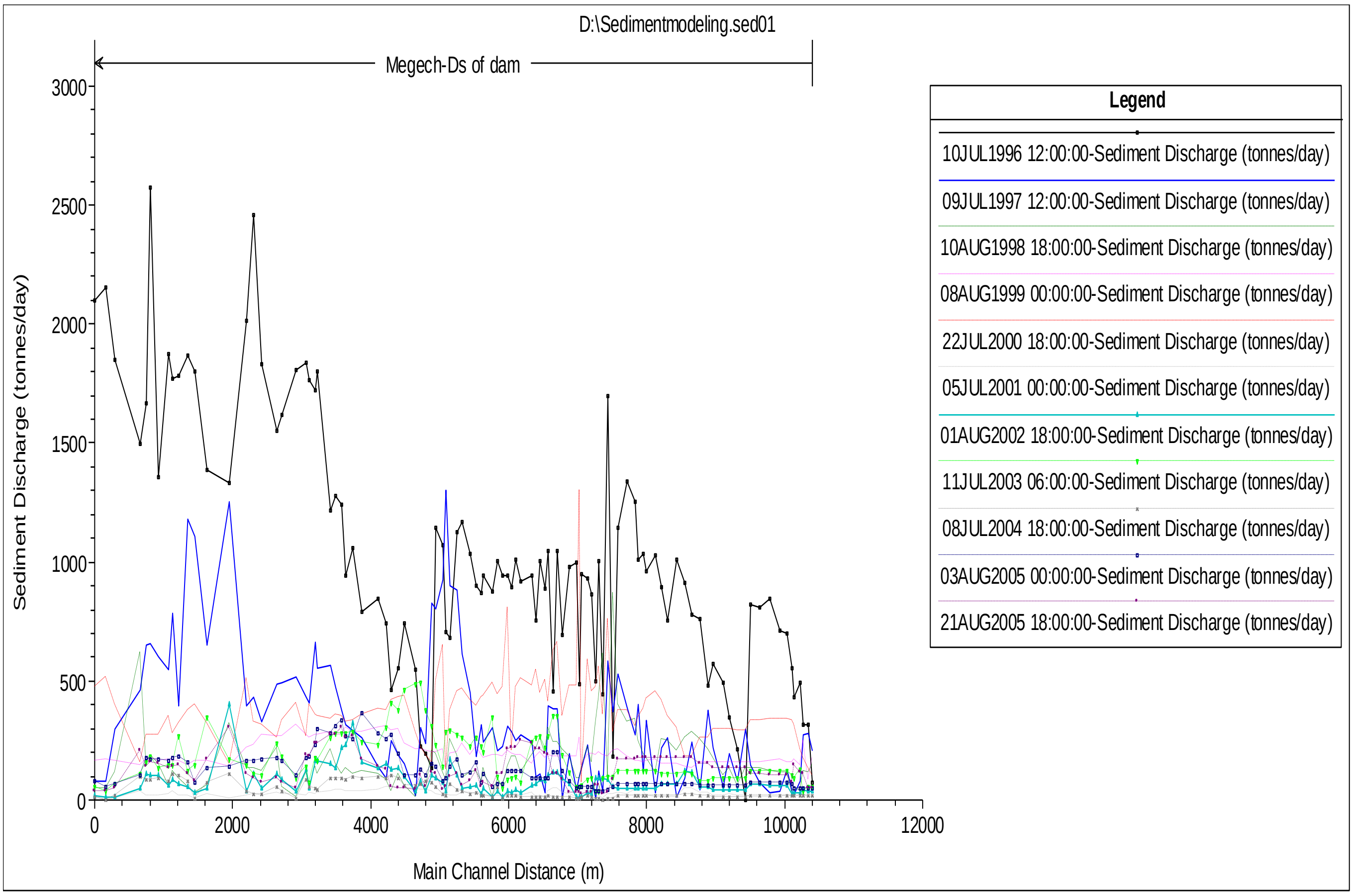

Mass in and mass out Taken from RS 97 with respect to time increase



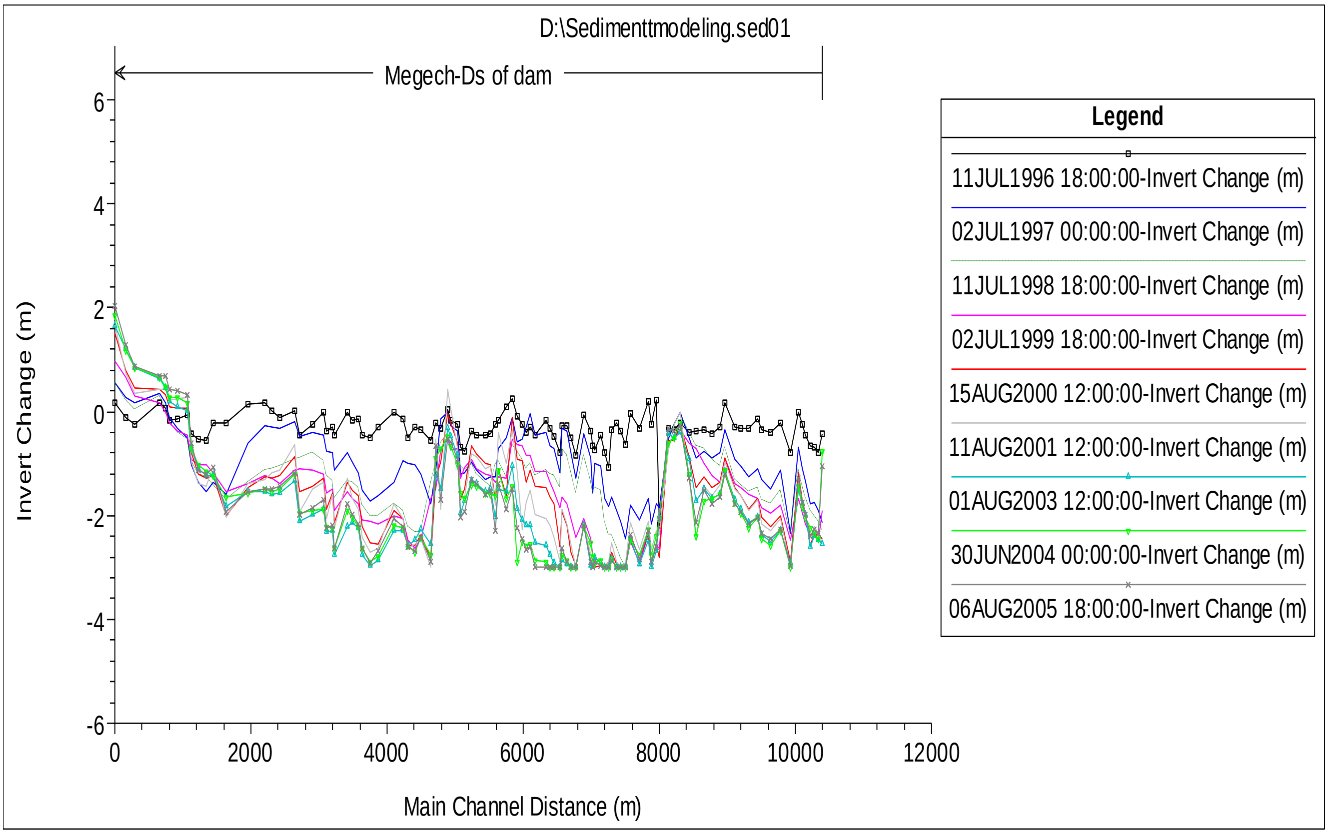

Mass in and mass out Taken from RS 80 with respect to time increase



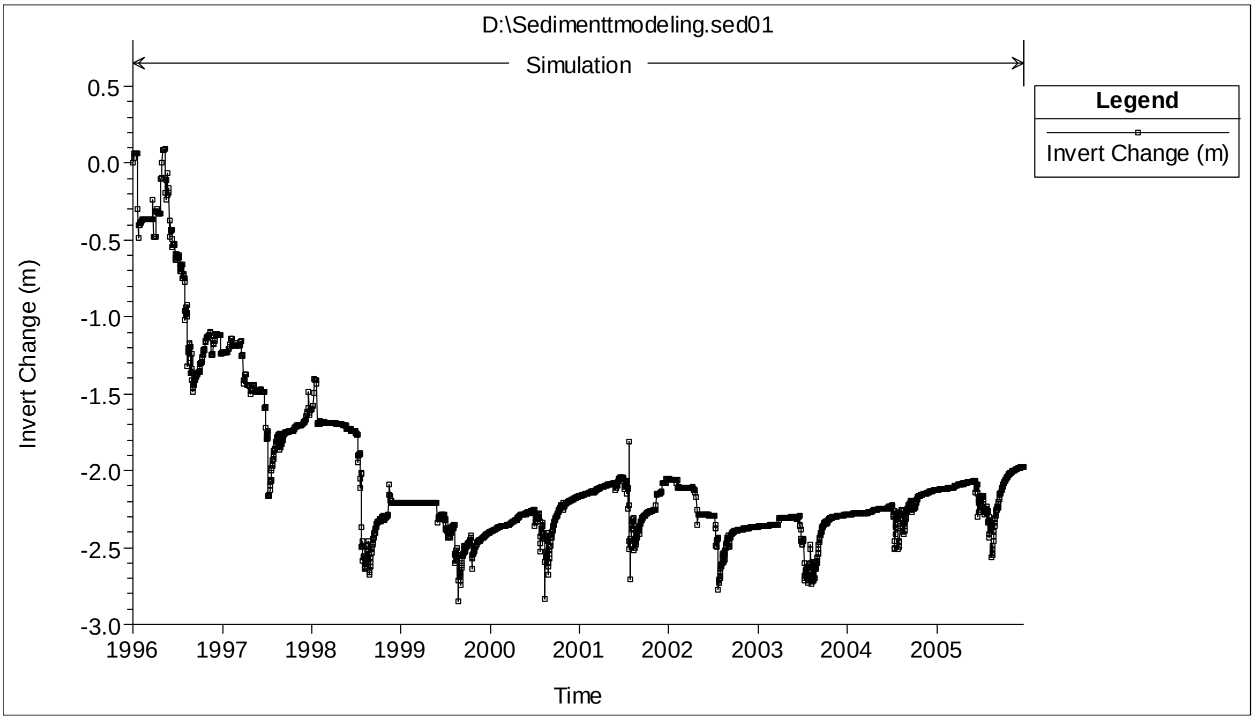

Mass in and mass out for all river station on August 21,2005



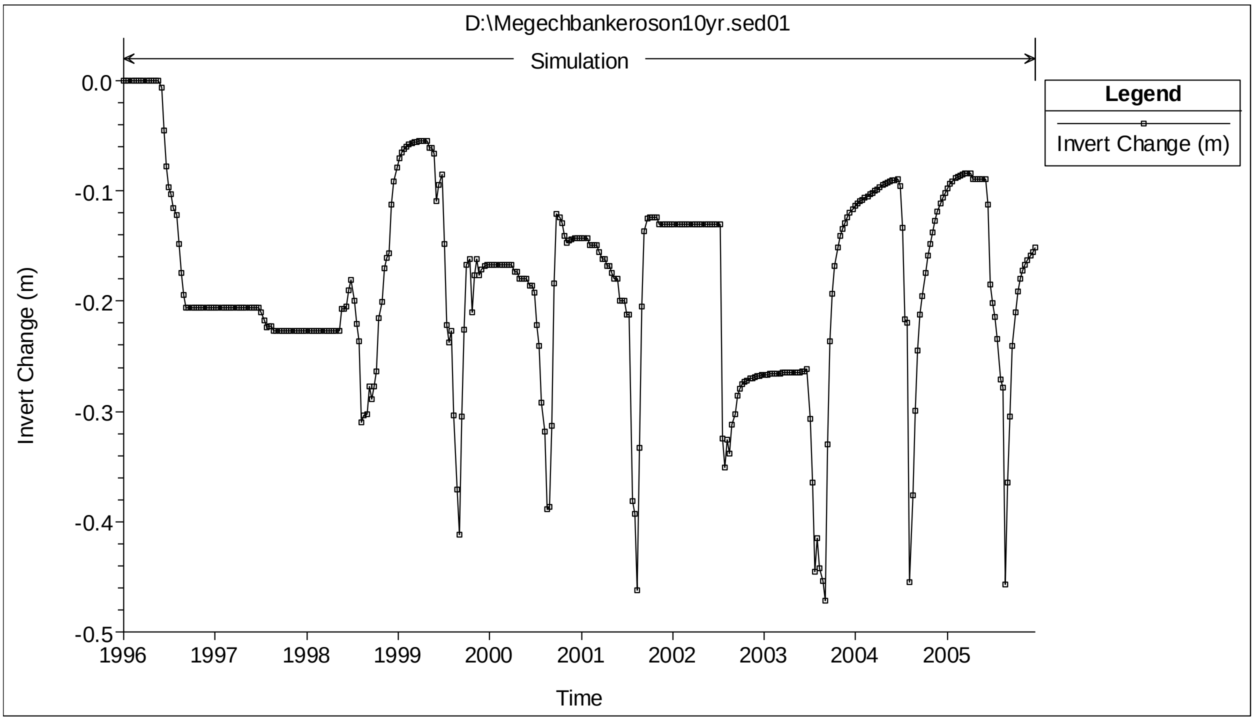

Sediment discharge for all river station during high flow



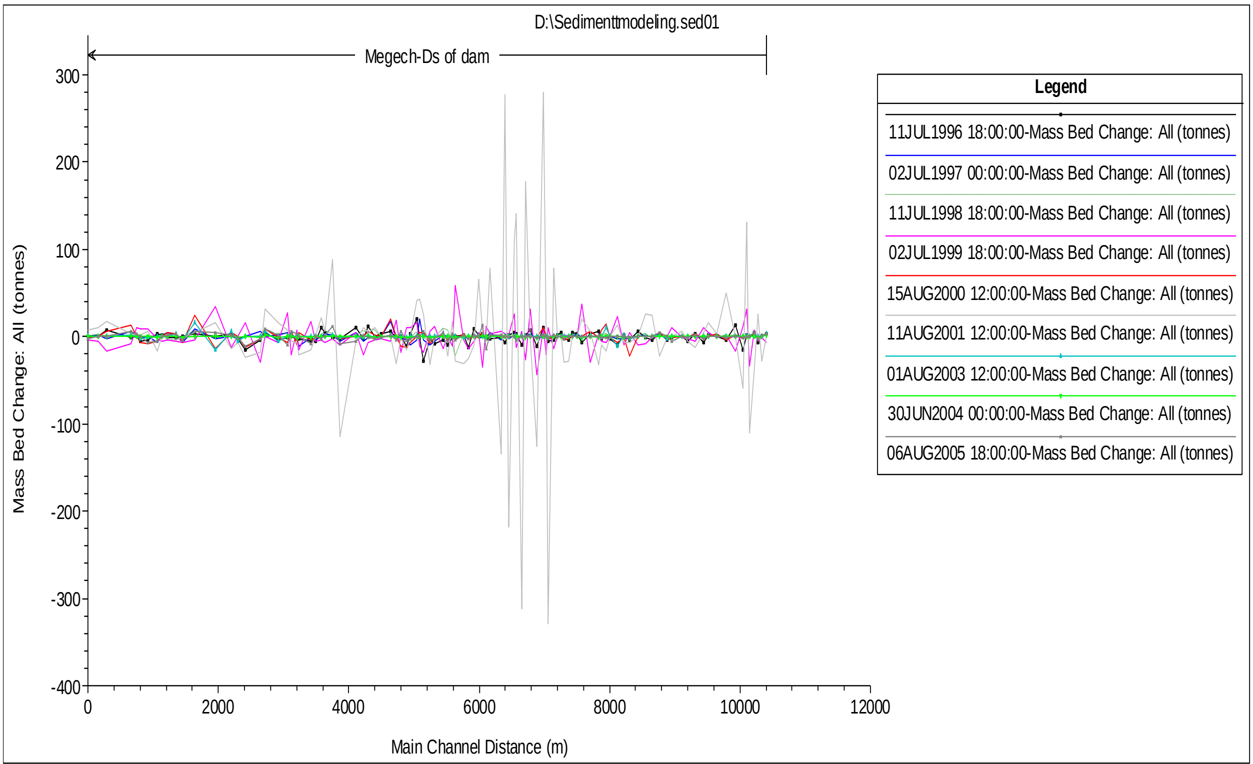

Invert change during high flow season



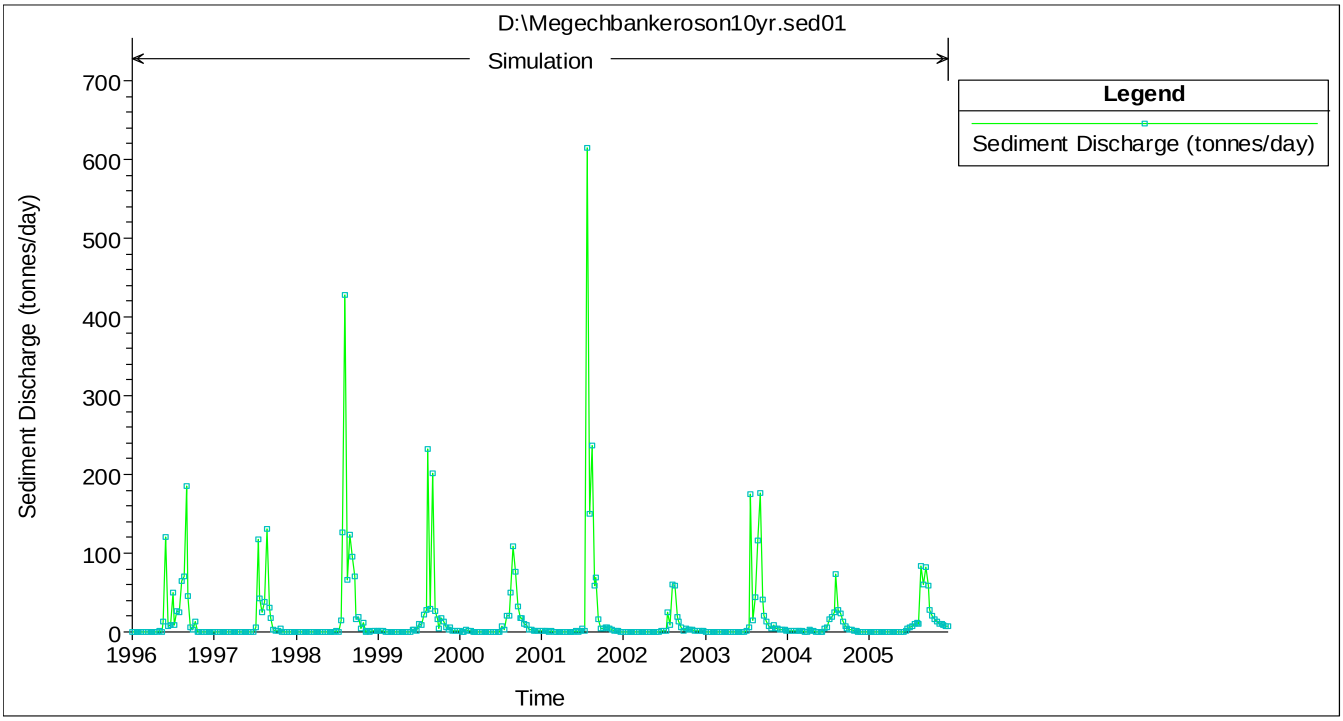

Invert change for 10years At RS 87



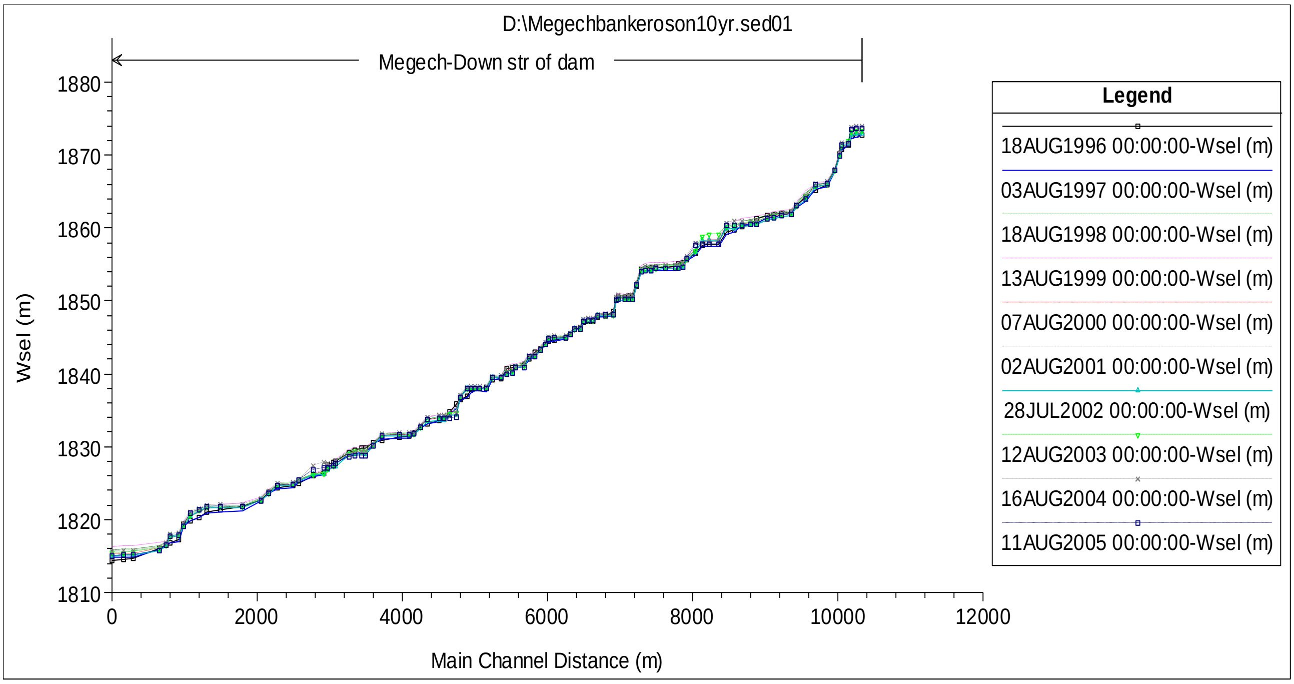

Invert change for 10years at RS 74- degradation or scouring



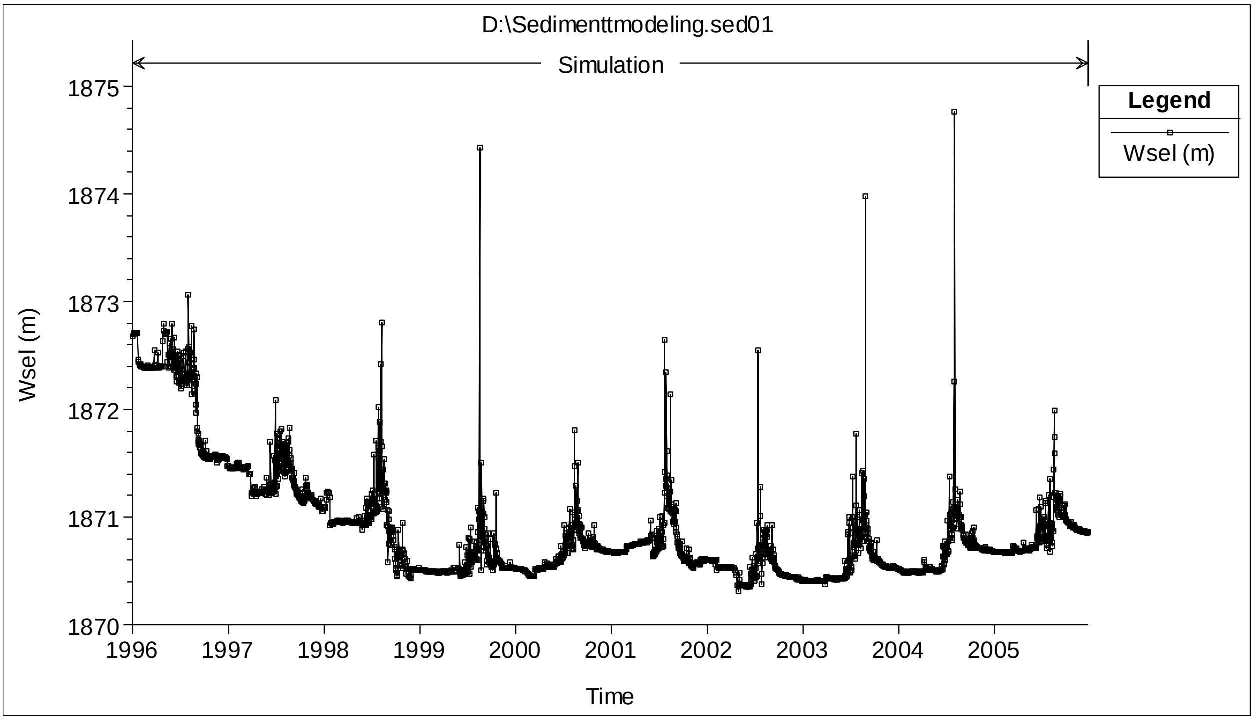

Mass bed change at RS 78




Sediment discharge at RS 80 for 10years




Uniform water surface elevation during august for all river station



water surface elevation at RS 98 for 10years

When water surface increase, the flow velocity decreases and mass in usually decreases because of deposition at upstream of the location.

## *6.3 Appendix C: Sample one Bed and Bank material characterization Laboratory Result*

**Sample One:-Bed Material**

**River Name:-Megch**

**Purpose:- Reaserch on Bank Erosion and Sedimentation**

**Sample Location:-1 KM Far From Dam toe**

**Requested By:-Efa Baisa (Hydraulic Engineering(Mcs)) Bahir Dar University**

**Sample Date:-02/07/2019**

**Teste Date:-17/07/2019**

**SPECIFIC GRAVITY AND ABSORPTION**

**(AASHTO DESIGNATION: T84-00)**

| Item | Description | | 1 | 2 | Avg. |
|---|---|---|---|---|---|
| A | Mass of oven -dry test sample in air ,g | | 2370 | 2367 | |
| B | Mass of Saturated-surface-dry test sample in air ,g | | 2404.7 | 2408 | |
| C | Mass of saturated test sample in water ,g | | 1472.3 | 1478.9 | |
| 1 | Bulk Specific Gravity (DRY) = | A / (B-C) | 2.542 | 2.548 | 2.545 |
| 2 | Bulk Specific Gravity (SSD) = | B / (B-C) | 2.579 | 2.592 | 2.585 |
| 3 | Apparent Specific Gravity = | A / (A-C) | 2.640 | 2.665 | 2.653 |
| 4 | Absorption ,percent(%) = | ((B-A)/A)*100 | 1.464 | 1.732 | 1.598 |

Remark :

Teste By: Gashaw Asaye

Checked By:Nasir Shifa

Sample One:-Bed Material
River Name:-Megch
Purpose:- Reaserch on Bank Erosion and Sedimentation
Sample Location:-1 KM Far From Dam toe
Requested By:-Efa Baisa (Hydraulic Engineering(Mcs)) Bahir Dar University
Sample Date:-02/07/2019
Teste Date:-17/07/2019

## FLAKINESS INDEX

## TEST METHOD : BS 812 PART -105

| Sl.NO | PASSING THROUGH Sieve in size (mm) | Retained on sieve size (mm) | Flakiness Index: weight of the agggregate taken in each fraction (gm) | | Flakiness Index: weight of the agggregate in each fraction passing thickness gauge (gm) | |
|---|---|---|---|---|---|---|
| 1 | 63 | 50 | | | | |
| 2 | 50 | 37.5 | | | | |
| 3 | 37.5 | 28 | | | | |
| 4 | 28 | 20 | 1862 | | 6.3 | |
| 5 | 20 | 14 | 1435 | | 49.7 | |
| 6 | 14 | 10 | 1008 | | 15.9 | |
| 7 | 10 | 6.3 | 581 | | 131 | |
| | | | W: | 4886 | w: | 202.9 |

Flakiness index (w/W)*100 4%

Teste By: Gashaw Asaye

Checked By:Nasir Shifa

**Sample One:-Bed Material**
**River Name:-Megch**
**Purpose:- Reaserch on Bank Erosion and Sedimentation**
**Sample Location:-1 KM Far From Dam toe**
**Requested By:-Efa Baisa (Hydraulic Engineering(Mcs)) Bahir Dar University**
**Sample Date:-02/07/2019**
**Teste Date:-17/07/2019**

## FLAKINESS INDEX

## TEST METHOD : BS 812 PART -105

| SI.NO | PASSING THROUGH Sieve in size (mm) | Retained on sieve size (mm) | Flakiness Index: weight of the agggregate taken in each fraction (gm) | | Flakiness Index: weight of the agggregate in each fraction passing thickness gauge (gm) | |
|---|---|---|---|---|---|---|
| 1 | 63 | 50 | | | | |
| 2 | 50 | 37.5 | | | | |
| 3 | 37.5 | 28 | | | | |
| 4 | 28 | 20 | 1862 | | 6.3 | |
| 5 | 20 | 14 | 1435 | | 49.7 | |
| 6 | 14 | 10 | 1008 | | 15.9 | |
| 7 | 10 | 6.3 | 581 | | 131 | |
| | | | W: | 4886 | w: | 202.9 |
| | | Flakiness index (w/W)*100 | | 4% | | |

Teste By: Gashaw Asaye

Checked By:Nasir Shifa

**Sample One:-Left Bank Material**

**River Name:-Megch**

**Purpose:- Reaserch on Bank Erosion and Sedimentation**

**Sample Location:-1 KM Far From Dam toe**

**Requested By:-Efa Baisa (Hydraulic Engineering(Mcs)) Bahir Dar University**

**Sample Date:-02/07/2019**

**Teste Date:-17/07/2019**

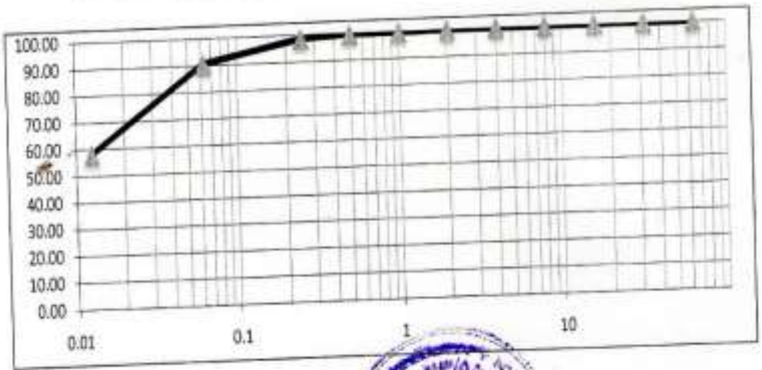
## SIEVE ANALYSIS(AASHTO T88)

### Wet Sieve Analysis

**Sample Befor washing (A)=** **1000.0**

**Sample After washing (B)=** **420**

| Sieve Size(mm) | Wt. Rt. | %. Rt. | %. Pass |
|---|---|---|---|
| 64 | 0 | 0.00 | 100.00 |
| 32 | 0 | 0.00 | 100.00 |
| 16 | 0 | 0.00 | 100.00 |
| 8 | 0 | 0.00 | 100.00 |
| 4 | 0 | 0.00 | 100.00 |
| 2 | 1.7 | 0.17 | 99.83 |
| 1 | 2.5 | 0.25 | 99.58 |
| 0.5 | 1.5 | 0.15 | 99.43 |
| 0.25 | 9.2 | 0.92 | 98.51 |
| 0.0625 | 80 | 8.00 | 90.51 |
| 0.0125 | 325.1 | 32.51 | 58.00 |
| pan | 580 | 58.00 | 0.00 |
| total | 1000 | 100.00 | |




Teste By: Geshaw Asaye

Checked By:Nasir Shifa

Sample One:-Left Bank Material

River Name:-Megch

Purpose:- Reaserch on Bank Erosion and Sedimentation

Sample Location:-1 KM Far From Dam toe

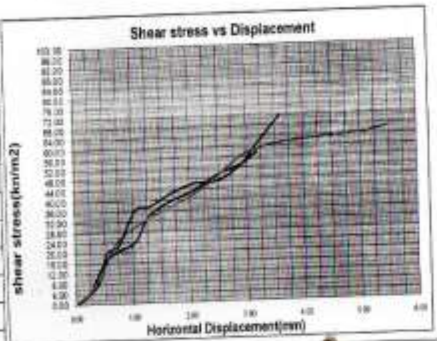
Requested By:-Efa Baisa (Hydraulic Engineering(Mcs)) Bahir Dar University

Sample Date:-02/07/2019

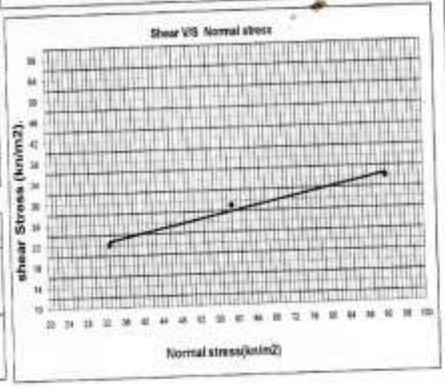
Teste Date:-17/07/2019

## DIRECT SHEAR TEST RESULTS (BS1377 part B)

| H.D(mm) | A | B | C |
|---|---|---|---|
| | shear str(kn/m2) | shear str(kn/m2) | shear str(kn/m2) |
| 0.00 | 0.00 | 0.00 | 0.00 |
| 0.20 | 3.60 | 2.90 | 3.70 |
| 0.40 | 7.80 | 11.40 | 9.40 |
| 0.55 | 19.60 | 17.20 | 16.20 |
| 0.75 | 22.40 | 20.40 | 24.70 |
| 1.05 | 36.10 | 23.80 | 29.50 |
| 1.30 | 37.40 | 34.00 | 33.10 |
| 1.70 | 42.50 | 39.50 | 37.40 |
| 2.10 | 46.10 | 43.60 | 42.10 |
| 2.50 | 46.90 | 49.20 | 48.70 |
| 2.90 | 52.70 | 52.90 | 56.30 |
| 3.20 | 61.10 | 58.10 | 59.00 |
| 3.60 | 72.00 | | 61.40 |
| 4.90 | | | 64.30 |
| 5.20 | | | 65.20 |
| 5.50 | | | 66.70 |




| Speciemen | A | B | C |
|---|---|---|---|
| Normal stress(kn/m2) | 33 | 59 | 92 |
| shear stress(kn/m2) | 22 | 29 | 34 |




Cohesion,c (kn/m2)= 14

Angle of internal friction in degree= 21

Teste By: Gashaw Asaye

Checked By:Nasir Shifa

Sample One:-Left Bank Material
River Name:-Megch
Purpose:- Reaserch on Bank Erosion and Sedimentation
Sample Location:-1 KM Far From Damtoe
Requested By:-Efa Baisa (Hydraulic Engineering(Mcs)) Bahir Dar University
Sample Date:-02/07/2019
Teste Date:-17/07/2019

## FLAKINESS INDEX
## TEST METHOD : BS 812 PART -105

| SI.NO | PASSING THROUGH Sieve in size (mm) | Retained on sieve size (mm) | Flakiness Index | | | |
|---|---|---|---|---|---|---|
| | | | weight of the agggregate taken in each fraction (gm) | | weight of the agggregate in each fraction passing thickness gauge (gm) | |
| 1 | 63 | 50 | | | | |
| 2 | 50 | 37.5 | | | | |
| 3 | 37.5 | 28 | | | | |
| 4 | 28 | 20 | 1230 | | 12 | |
| 5 | 20 | 14 | 945 | | 24 | |
| 6 | 14 | 10 | 540 | | 45 | |
| 7 | 10 | 6.3 | 215 | | 17 | |
| | | | W: | 2930 | w: | 98 |
| | | Flakiness index (w/W)*100 | | 3% | | |

Teste By: Gashaw Asaye

Checked By:Nasir Shifa

**Sample One:-Left Bank Material**

**River Name:-Megch**

**Purpose:- Reaserch on Bank Erosion and Sedimentation**

**Sample Location:-1 KM Far From Dam toe**

**Requested By:-Efa Baisa (Hydraulic Engineering(Mcs)) Bahir Dar University**

**Sample Date:-02/07/2019**

**Teste Date:-17/07/2019**

**SPECIFIC GRAVITY AND ABSORPTION OF COURSE AGGREGATE**

**(AASHTO DESIGNATION: T84-00)**

| Item | Description | | 1 | 2 | Avg. |
|---|---|---|---|---|---|
| A | Mass of oven -dry test sample in air ,g | | 1992 | 2074 | |
| B | Mass of Saturated-surface-dry test sample in air ,g | | 2025 | 2110 | |
| C | Mass of saturated test sample in water ,g | | 1235 | 1288 | |
| 1 | Bulk Specific Gravity (DRY) = | $\frac{A}{(B-C)}$ | 2.522 | 2.523 | 2.522 |
| 2 | Bulk Specific Gravity (SSD) = | $\frac{B}{(B-C)}$ | 2.563 | 2.567 | 2.565 |
| 3 | Apparent Specific Gravity = | $\frac{A}{(A-C)}$ | 2.631 | 2.639 | 2.635 |
| 4 | Absorption ,percent(%) = | ((B-A)/A)*100 | 1.657 | 1.736 | 1.696 |

Remark :

Teste By: Gashaw Asaye

Checked By:Nasir Shifa

**Sample One:-Right Bank Material**

**River Name:-Megch**

**Purpose:- Reaserch on Bank Erosion and Sedimentation**

**Sample Location:-1 KM Far From Dam toe**

**Requested By:-Efa Baisa (Hydraulic Engineering(Mcs)) Bahir Dar University**

**Sample Date:-02/07/2019**

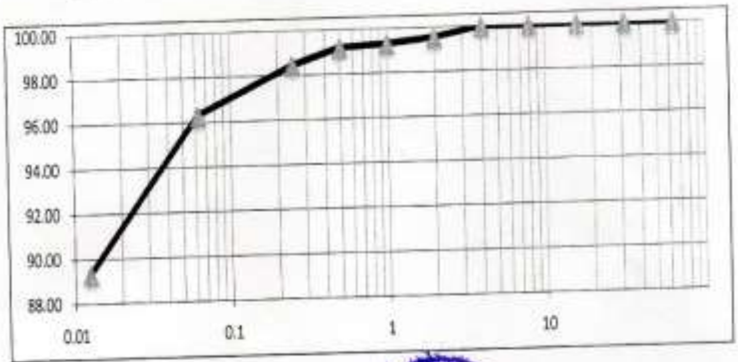
**Teste Date:-17/07/2019**

## SIEVE ANALYSIS(AASHTO T88)
## Wet Sieve Analysis

**Sample Befor washing (A)=** **1000.0**

**Sample After washing (B)=** **107**

| Sieve Size(mm) | Wt. Rt. | %. Rt. | %. Pass |
|---|---|---|---|
| 64 | 0 | 0.00 | 100.00 |
| 32 | 0 | 0.00 | 100.00 |
| 16 | 0 | 0.00 | 100.00 |
| 8 | 0 | 0.00 | 100.00 |
| 4 | 0 | 0.00 | 100.00 |
| 2 | 4.5 | 0.45 | 99.55 |
| 1 | 2.4 | 0.24 | 99.31 |
| 0.5 | 1.2 | 0.12 | 99.19 |
| 0.25 | 7.4 | 0.74 | 98.45 |
| 0.0625 | 21.5 | 2.15 | 96.30 |
| 0.0125 | 70 | 7.00 | 89.30 |
| pan | 893 | 89.30 | 0.00 |
| total | 1000 | 100.00 | |




Teste By: Gashaw Asaye

Checked By:Nasir Shifa

## 6.4 *APPENDIX D: Sample two bed and bank material characterization laboratory result*

**Sample Two:-Bed Material**

**River Name:-Megch**

**Purpose:- Reaserch on Bank Erosion and Sedimentation**

**Sample Location:-4 KM Far From Dam toe**

**Requested By:-Efa Baisa (Hydraulic Engineering(Mcs)) Bahir Dar University**

**Sample Date:-02/07/2019**

**Teste Date:-17/07/2019**

**SPECIFIC GRAVITY AND ABSORPTION OF COURSE AGGREGATE**

**(AASHTO DESIGNATION: T84-00)**

| Item | Description | | 1 | 2 | Avg. |
|---|---|---|---|---|---|
| A | Mass of oven -dry test sample in air ,g | | 2442 | 2443 | |
| B | Mass of Saturated-surface-dry test sample in air ,g | | 2512 | 2510 | |
| C | Mass of saturated test sample in water ,g | | 1580 | 1581 | |
| 1 | Bulk Specific Gravity (DRY) = | A / (B-C) | 2.620 | 2.630 | 2.625 |
| 2 | Bulk Specific Gravity (SSD) = | B / (B-C) | 2.695 | 2.702 | 2.699 |
| 3 | Apparent Specific Gravity = | A / (A-C) | 2.833 | 2.834 | 2.834 |
| 4 | Absorption ,percent(%) = | ((B-A)/A)*100 | 2.867 | 2.743 | 2.805 |

Remark :

Teste By: Gashaw Asaye

Checked By: Nasir Shifa

Sample Two:-Right Bank Material
River Name:-Megch
Purpose:- Reaserch on Bank Erosion and Sedimentation
Sample Location:-4 KM Far From Dam toe
Requested By:-Efa Baisa (Hydraulic Engineering(Mcs)) Bahir Dar University
Sample Date:-02/07/2019
Teste Date:-17/07/2019

## FLAKINESS INDEX

### TEST METHOD : BS 812 PART -105

| Sl.NO | PASSING THROUGH Sieve in size (mm) | Retained on sieve size (mm) | Flakiness Index: weight of the agggregate taken in each fraction (gm) | | weight of the agggregate in each fraction passing thickness gauge (gm) | |
|---|---|---|---|---|---|---|
| 1 | 63 | 50 | | | | |
| 2 | 50 | 37.5 | | | | |
| 3 | 37.5 | 28 | | | 12 | |
| 4 | 28 | 20 | 710 | | 2 | |
| 5 | 20 | 14 | 1002 | | 0 | |
| 6 | 14 | 10 | 600 | | 15 | |
| 7 | 10 | 6.3 | 500 | | | |
| | | | W: | 2812 | w: | 29 |
| | | Flakiness index (w/W)*100 | | 1% | | |

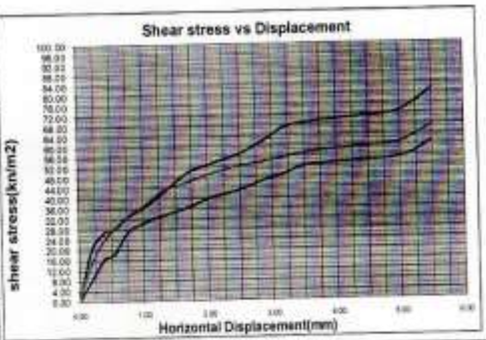
Teste By: Gashaw Asaye

Checked By: Nasir Shifa

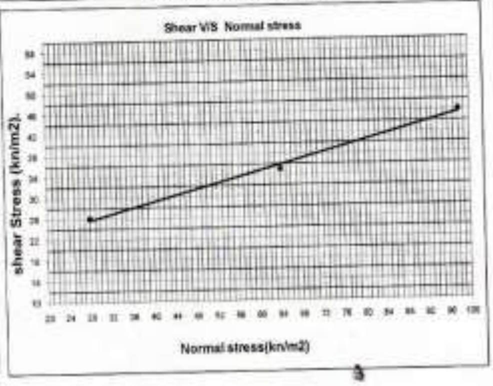
**Sample Two:-Right Bank Material**
**River Name:-Megch**
**Purpose:- Reaserch on Bank Erosion and Sedimentation**
**Sample Location:-4 KM Far From Dam toe**
**Requested By:-Efa Baisa (Hydraulic Engineering(Mcs)) Bahir Dar University**
**Sample Date:-02/07/2019**
**Teste Date:-17/07/2019**

## DIRECT SHEAR TEST RESULTS (BS1377 part B)

| H.D(mm) | A | B | C |
|---|---|---|---|
| | shear str(kn/m2) | shear str(kn/m2) | shear str(kn/m2) |
| 0.00 | 0.00 | 0.00 | 0.00 |
| 0.20 | 20.10 | 8.20 | 14.90 |
| 0.40 | 26.80 | 16.40 | 24.00 |
| 0.55 | 27.90 | 18.20 | 28.00 |
| 0.75 | 32.70 | 26.40 | 32.60 |
| 1.05 | 36.90 | 30.70 | 37.80 |
| 1.30 | 41.70 | 33.00 | 42.50 |
| 1.70 | 49.80 | 36.10 | 46.20 |
| 2.10 | 53.60 | 40.30 | 49.70 |
| 2.50 | 57.10 | 42.80 | 52.30 |
| 2.90 | 62.40 | 46.80 | 54.10 |
| 3.20 | 67.20 | 49.10 | 55.60 |
| 3.60 | 69.30 | 52.50 | 57.60 |
| 4.90 | 72.50 | 54.70 | 60.40 |
| 5.20 | 76.00 | 56.80 | 63.20 |
| 5.50 | 81.60 | 61.20 | 67.30 |




| Speciemen | A | B | C |
|---|---|---|---|
| Normal stress(kn/m2) | 28 | 64 | 98 |
| shear stress(kn/m2) | 26 | 35 | 46 |




Cohesion,c (kn/m2)= 14

Angle of internal friction in degree= 23

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