CHANNEL STABILTY ANALYSIS -THE CASE OF

BORKENA RIVER (ETHIOPIA)

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Abstract

Rivers dynamically respond to changes in the discharge and sediment supply of catchments. A change of land use and other natural factors in catchments result in changes on sediment supply and discharge. And this process of change of river geomorphology seeking for its equilibrium may affect people and property especially in urban areas located adjacent to rivers. The Kombolcha town, situated on flat land plains in the middle course of the Borkena River is facing a danger of flooding and destruction of properties due to the instability of the Borkena and Berberie River reaches crossing the town.

To prevent the loss of lands and properties resulting from the changes in the characteristics of those river reaches, stabilization measures must be employed. For proper design and implementation of any stabilization measures, analysis on stability of these channel reaches must be carried out. So this thesis deals with analysis of the stability of the channel reaches by evaluating their capacity and stability in response to discharge and sediments that are supplied from the catchments.

Field investigation and surveying to collect data for channel cross sections, bed & bank material, and the vegetation covers is carried out. Gradations of bed and bank materials are determined in laboratory using sieve analysis. Design discharges of different return periods and quasi unsteady flow data are analyzed from measured maximum daily instantaneous discharge data. Using such flow and existing field data as input, HEC-RAS 4.0 beta version is used for simulation of flow and mobile bed sediment transport

Based on the model results which are analyzed using the Meyer Peter Muller and Yang's sediment transport formula, deposition is observed in almost all of the stations of the Borkena River. And there is deposition at some of the down stream stations in the tributary reach and degradation in the rest. It is also analyzed that the material on the banks is less resistance to the minimum shear induced by the flow, besides much of the stations in the tributary reach are geotechnically unstable. Over flooding still is the problem on upper and lower reaches of Borkena which is resulted from the complex processes of aggradational problems. And stabilization measures are proposed and should be implemented with further engineering, economical and hydraulic analysis for effective and sustainable stabilization of the rivers.

1. INTRODUCTION

1.1. General

Streams change in response to variations in discharge and sediment supply and are dynamic by nature. These changes vary spatially according to the position with in 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 .Besides channel changes are variable in time depending on some what on the timings of floods and draughts and also land use changes. Especially now a days the variation of climate due to the global warming which is becoming the cause for the change in the frequency of sever floods and draughts; and land degradation due to extensive deforestation for fuel wood production and in advance of cultivation in the catchments as a result of rapid population growth, are leading to higher peak discharges, stream sediment loads and unstable rivers.

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 debate fuelled by concern over the importance of anthropogenic enhancement of ‘the green house ‘effect on global climate has become one of the central issues in water resources management and catchments planning. And 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. (*MARCK G.MACKLIN and JHON LEWIN*, 1997)

The above human induced consequences affect discharge and sediment indirectly typically by increasing peak flows and increasing the quantities of sediment considerably. In addition dams and flood plain mining are some activities that have indirect effects on channel form and hydrology. More over activities like channelization and in stream mining have a direct impact on river systems. Then the resulting physical impacts may include deposition of the channel bars, transportation of coarser sediments, erosion of channel banks, shifting channel bottoms and change in channel position and pattern. So this in turn causes damage on the adjoining social and developmental activities, especially such activities are intense on river reaches which cross towns on flat areas.

For similar reasons the instability of Borkena River and its tributary the Berberie River at the reaches they cross the town are being a threat in flooding the adjoining areas and so far there has been a report on the loss of properties eaten away by the Borkena River and houses swept away by the Berberie River. The Berberie River drains from the mountainous catchments on the north eastern direction of the town of Kombolcha and joins the Borkena River immediately upstream of the bridge on the high way from Addis to Dessie. The reach of this river where it crosses the town 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 Borkena 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 help full for implementation of proper stabilization measures.

1.2. Description of the Study Area

1.2.1. Location

The Borkena River is one of the main tributaries of the Awash River. It drains from the mountainous chains and escarpments found in the northern plateau which is adjacent to the Afar rift down to south eastern direction and after joining the Jara River in around the Cheffa swamp, it finally enters the Awash River. And the Berberie River also drains from the mountainous area situated mainly on the north eastern direction of the town of Kombolcha and after passing the meandering path through the town joins the Borkena River a few meters upstream of the bridge on the main high way connecting Addis to Dessie. The town of Komblocha is found in the south Wello Zone at 377 kms away from Addis, and geographically it is located at 11^{o}06'N, 39^{o}45'E. The catchments upstream of the town extend from the town of Kutaber, and the average elevation varies between 1680m to 3360m a.b.s.l.The following figure shows the location map.

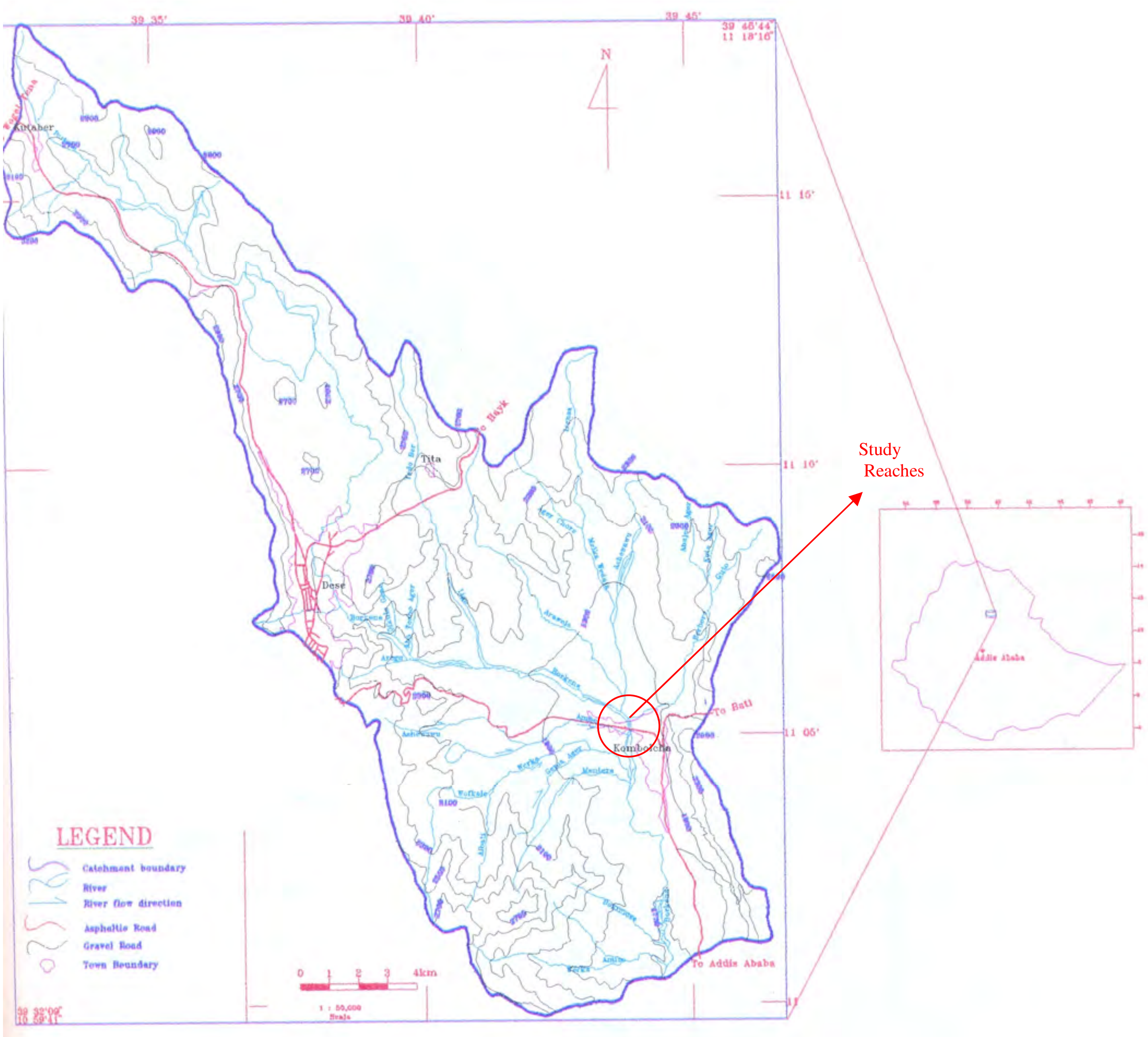

Figure 1-1: Location map for Borkina River Catchament

1.2.2. Climate

The climate of the area upstream of the town of Kombolcha varies between sub humid and sub tropical, and according to the traditional classification of climate which is mainly based on altitude variation, the climate is classified as “Dega and Weyna Dega”.Location map is shown in fig 1.1 .(Adopted from Mesfin,2001)

The main annul rain fall over the catchments is 1028mm and most of which is concentrated in the big rainy months that lasts from July to September and contribute about 84% of the annul rain fall. The mean monthly temperature considering the Kombolcha station varies between 16.1^{o}c to 22.1^{o}c which corresponds to December and June respectively. Monthly mean sunshine hour and relative humidity varies between 5.0 to 8.5 and 40.1% to 64.3% respectively with rainy seasons being humid and have lower sunshine hour. The sub humid area covers about 50.3% and the subtropical aerial coverage is about 49.7 % of the total catchments area. *(Mesfin S., 2001).*

1.2.3. Catchments Characteristics

I) Topography and Drainage

The topographic variation of the area ranges from about 3360m a.s.l on the top of the ridge in around the north west of the water divide at Kutaber, to 1680m a.s.l in the floor of the graben at around the town of Kombolcha, fig1:2, Mesfin, 2001). Both the towns of Dessie and Kombolcha are located at an elevation of about 1800m a.s.l and 2660m a.s.l. The fault bounded graben form large plain areas such as the Boru plain, Alaska plain, Marim Weha plain, and large flat lands in Kombolcha and its surroundings. These plains are seasonally flooded by the Borkena River.

The catchments are bounded by very steep fault bounded grabens. To the west it is bounded by the Tossa, Wefkele and Walet ridges, and to the east it is bounded by Dosheny, KundiAmeraro, and Irfo ridge. As one goes from Dessie to Kombolcha the topography gets lowered from the ridge towards the floor of the graben. On topographically high areas the drainage pattern is denser and most of the streams entering in to the Borkena River originate from the surrounding ridge, hills and fault escarp regions.

Figure 1-2: Topographic map for Borkina River Catchament

II) *LAND USE-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.

Generally the land use –land cover is categorized approximately in to six types and is tabulated as follows. *Adopted from (Mesfin, 2001)*

III) *SOIL TYPE*

The major soil types in the catchment are clay, loam soil, residual clay soil rich in organic material, gravelly sand soil and fractured rock with big boulders and cobbles. These different soils occupy the flat, gentle-moderate, and moderate steep slopes respectively.

On the basis of the Ministry of Agriculture, land use and regulatory department, the slope ranges were identified and mapped as accordingly. The following tables show soil types and slope ranges in the catchment. *Adopted from (Mesfin, 2001)*

Table 1-1: Land use-land cover

Number	Land use-land cover type	Aerial Coverage (km^2)	Aerial Coverage (%)
1	Bushes, shrubs with scattered trees	96	29.5
2	Large settlement area	11.8	3.6
3	Wood land	19.4	6.0
4	Large cultivation and small irrigated land	140.7	43.2
5	Inundated/marshy and large grazing land	10.6	3.3
6	Bare ground with occasional trees and shrubs	47.4	14.5

Table 1-2: Soil type coverage in the catchments:

Number	Soil type	Aerial coverage (km^2)	Aerial coverage (%)
1	Clay loam soil	108.0	33.2
2	Residual clay soil rich in organic matter	5.0	1.5
3	Gravelly sand soil	42.5	13.1
4	Fractured rock with big boulder and cobble	169.8	52.2

Table 1-3: slope classification in the catchment

Number	Slope Range	Aerial coverage (km^2)	Aerial coverage (%)
1	<5%	108.0	33.2
2	5-12%	5.0	1.5
3	12-35%	42.5	13.1
4	35-60%	169.8	52.2
5	>60%	3.9	12

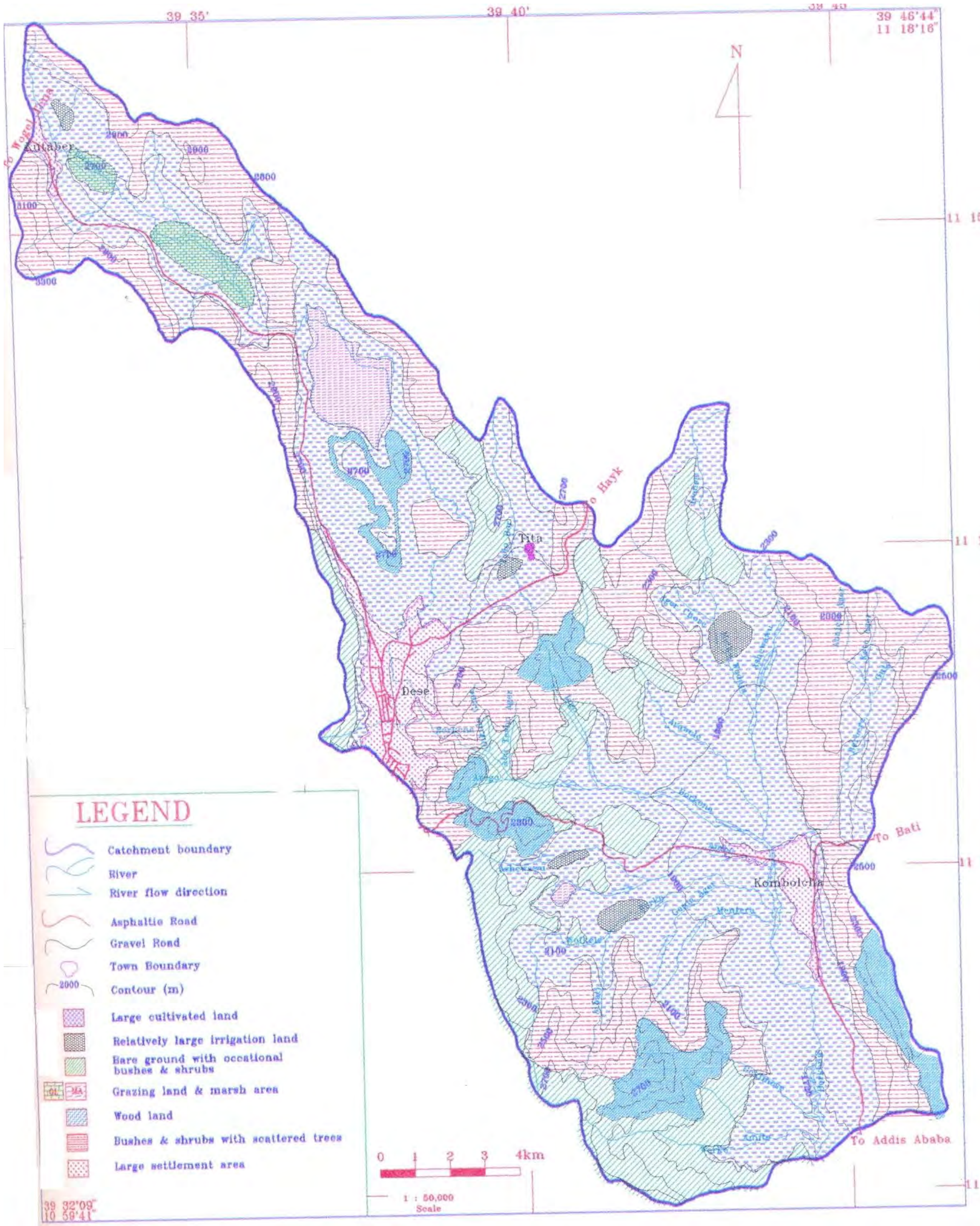

Figure 1-3: Soil map for Borkina River Catchament

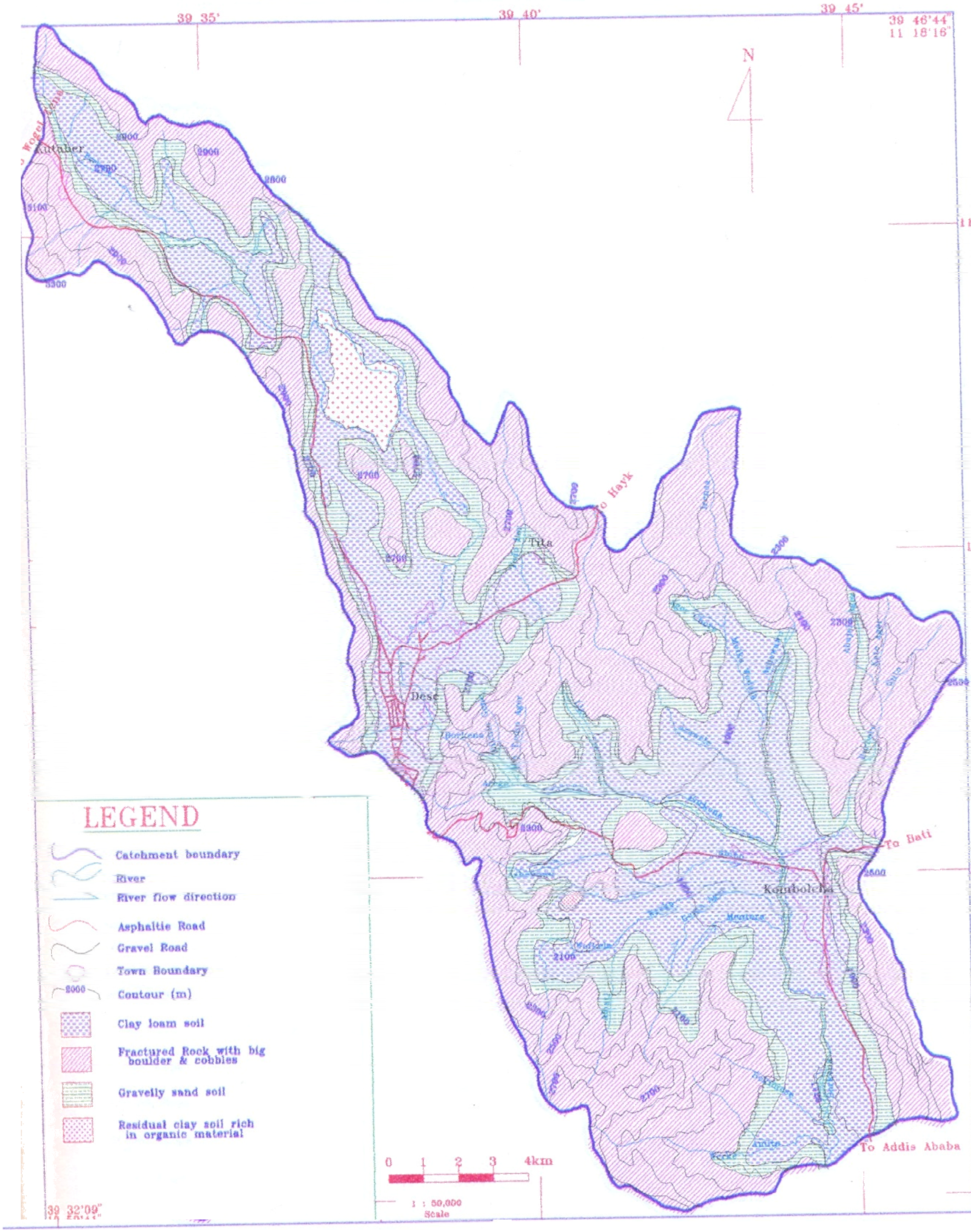

Figure 1-4: Land use land cover map for Borkina River Catchament

IV) Geology:

Regionally the catchment is located on the western escarpment of the main Ethiopian rift. The rocks out cropping along Dessie-Kombolcha-Bati traverse can be attributed mainly to three great pre- rift volcanic series.

- The oldest Eocene Ashange volcanic cycle dated 48,55,66m.y.
- The Oligocin to Miocene Alaji rhyoltic series with local intercalation of basalts and basaltic dykes.
- The overlying Tarmaber basalts.

The rocks in the Kombolcha area belong to the Alaji rhyoltic to the Tarmaber basaltic series. Minor out crops belong to the Ashangi series on the floor of Borkena graben.The Borkena river cuts deeply in to volcanic sequence where a series of Alaji rhyoltic flows was overlain by Tarmaber basalts.

The Borkena, Berberi, Arawle, Worka and Livole river banks constitute alluvial or lacustrine soils. Because such soils are composed of clays (that comprise organic matter and silt), sands and gravels (very rounded), the banks are highly susceptible for bank erosion. *Cited in (Kombolcha city service bank protection design document).*

The geological map of the catchment is shown on fig:

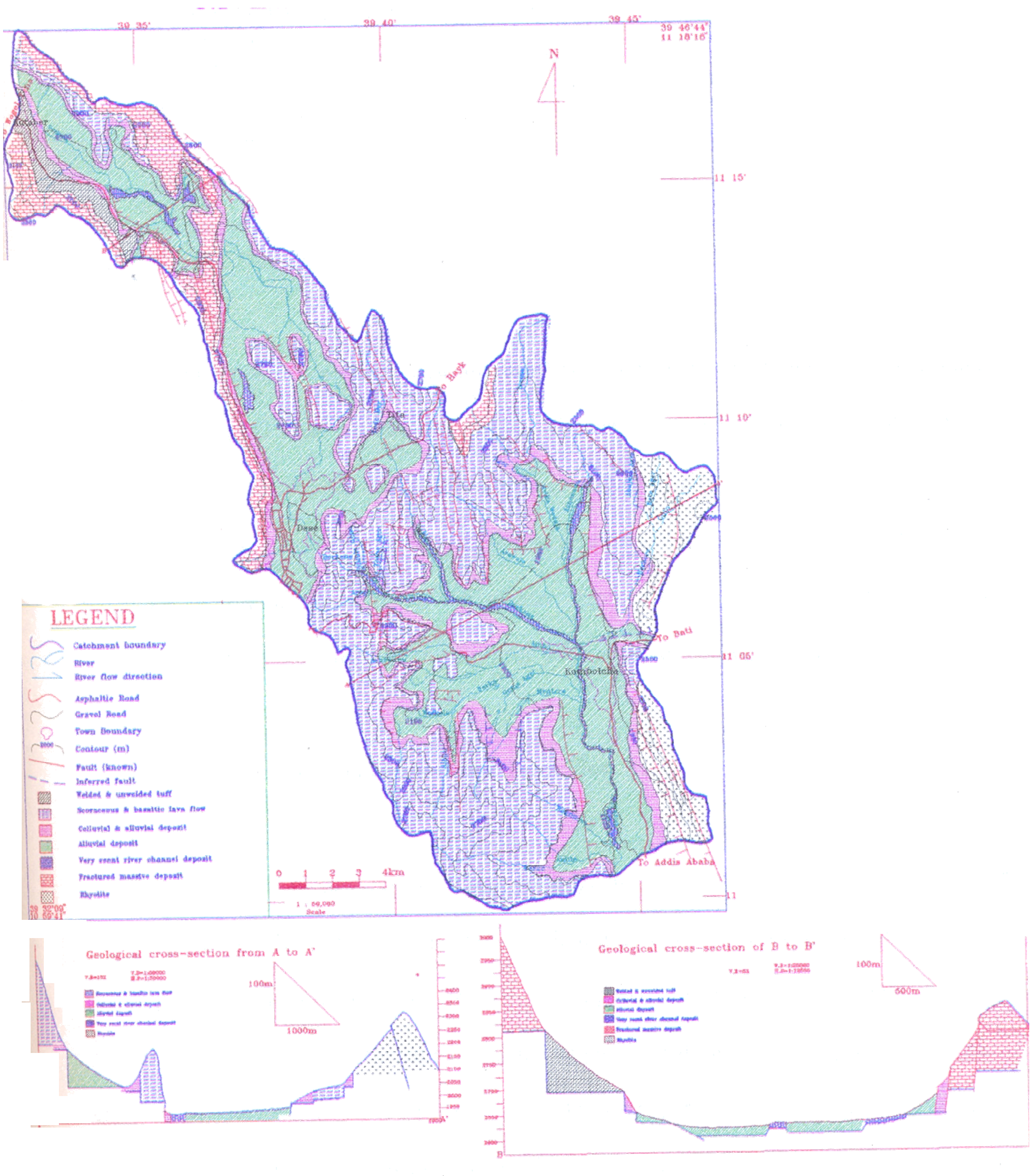

Figure 1-5: Geological map for Borkina River Catchament

1.3. Problem Definition

The town of Kombolcha is located at the flat lands and the materials over the river banks on the reach which cross the town is highly erodible. As a result excessive surface run off from the high slope mountains following intense rain fall in the catchment accelerates erosion of the banks and consequently the adjoining areas get frequently flooded.

As per to the report by the Kombolcha city service about 100m of farm lands were lost in a single year in northern part of the town due to Borkena River . More over houses and other properties have been swept away due to erosion of the banks along the Berberie River.

The slope for the Borkena River is seen to decrease as it crosses the town. Hence the transporting capacity of the river channel is likely to decrease as a result aggradations is observed .Because of such reasons the channel is increasing its flood way by eroding the banks and over flooding the adjoining area. And as it leaves the flat area around the town it enters in the deep gorges near Mitikovo in the east of the town.

The Beriberi River follows a meandering route with a high speed. The bed and bank materials are loose and can easily be eroded. The rate of widening and deepening of the channel is therefore fast. According to information I get from the elderly people from the neighboring area, the width of the channel before 20 years near to the bridge which is located at around 700m up stream of the confluence was not more than 4m approximately, but by now the width at this bridge is about 20m.

The length of the reaches where a problem due to those streams is concentrated is about 2kms down stream of the bridge on the Borkena River, about 1km upstream of the bridge along the Borkena River, and 1km up stream of the confluence along the Berberi River.

The town of Kombolcha serves as the main junction to connect the regions of Afar and Amhara. It is also a home for big industries like the Textile and BGI brewery factories, and is generally found in a good pace of infrastructural and socio economical developments. And a problem resulting from such series bank erosion and consequent flooding can have its own significant influence for the development of the town by damaging the properties and infrastructures along the adjoining areas so it should be controlled and managed properly.

1.4. Objective of The Research

The general objective of this thesis is to analyze the stability of the channel by evaluating its capacity and stability in response to discharge and sediments that are supplied from the catchments.

The following are the specific objectives:

- To evaluate the extent of flood zone corresponding to the less frequent floods of different return periods
- To identify possible causes for stability problems
- To study the extent of instability problem
- To select alternative solutions for channel stability problems

1.5. Methods

- Literature review
- Field investigation and surveying to collect data for channel cross sections and bed &bank material, and the vegetation covers.
- Laboratory works for determination of the gradation of bed and bank materials
- Data analysis and simulation of flow and sediment transport using the HEC-RAS
- Analysis, interpretation and discussion of simulation results
- Conclusion and recommendation

2. LITERATURE REVIEW

2.1. Fluvial Geomorphology Principles and Channel stability Concepts

Geomorphology is the relation ship of stream channels and flood plains, the geology and physiography of the region. (USACE, Em 1110-2-1418).And the stream morphology is the expressed form complex interrelation ships between the independent and dependant variables. Independent variables are governed by changes in the water shed that are external to the stream. The driving independent variables are discharge and sediment supply. Geology, soils, land form and climate are independent variables. Channel slope, width, depth and pattern are considered as dependant variables. Changes in any independent or dependant variables initiate adjustment process in one or more of the dependant variables.

When discharge and sediment load are not significantly changing, stream adjustment process tend toward stability. Stream channel stability is the ability of a stream, over time in the present climate, to transport the sediment and flows produced by its water shed in such a manner that the stream maintains its dimension, pattern and profile with out either aggrading or degrading. (Rosgen, 1996)

Streams that transport sediment loads and convey flows with out significant erosion or deposition are in balance and have acquired dynamic equilibrium. And channels governed by dynamic equilibrium typically have movable or sand beds and erodible banks. Streams with non mobile beds and banks are not free to adjust and are highly stable. The classic example is a stream found in bed rock. Dynamically stable channels are often referred to as "in regime" or" graded" and express an average channel morphology that remains relatively constant over time. *(The Virginia Stream Restoration & Stabilization Best Management Practices Guide, 2004)*

Mackin(1948)describes an equilibrium" graded" channel as one in which over a period of years , slope is delicately adjusted to provide with available discharge and with prevailing channel characteristics, just the velocity required for the transportation of the load supplied from the drainage basin. The graded stream is a system in equilibrium. A graded stream does not have to be fixed in space or time, but is allowed to vary around some mean value in response to the events. However as long as the recovery time (time required for the system to return to equilibrium conditions) is shorter than the recurrence interval (the return period for the extreme event) then the stream is considered to be dynamically stable. This is called "dynamic equilibrium" or "dynamic stability" (Watson et al, 2005).As cited in (Susan J. Novak, 2006). Figure in the following is a plot of the concept of dynamic equilibrium

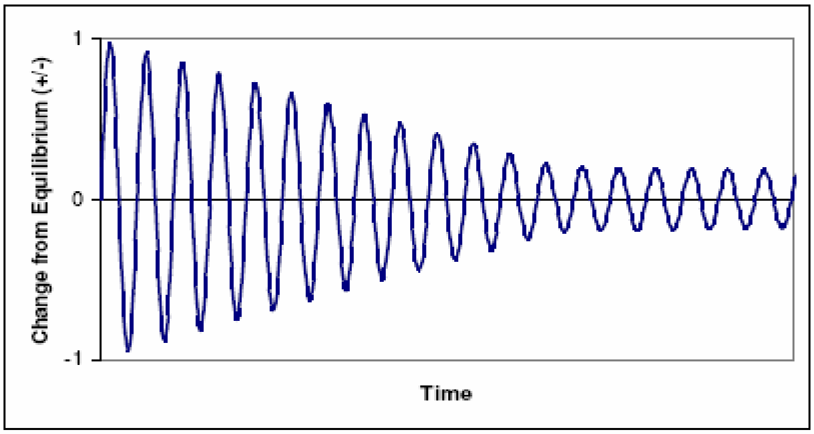

Figure 2-1: Graphical interpretation of concept of dynamic equilibrium.

Lanes 1955 balance model applies to the concept of dynamic equilibrium Lance's balance (*Fig 2.2*). QS~*QsD50 (where Q is discharge, Q_s is rate of sediment volume, S is longitudinal slope, and D_{50} represents 50% finer of the sample from the bed of a river)* show how the change in any the four deriving variables in a stream (discharge, slope, median grain size, sediment discharge) influence the remaining variables towards a new equilibrium state.

Lanes' relations can be used as channel stability assessment tools. But mostly are applied in quick preliminary assessment tools when disturbance is dominated by a shift in one variable. It is limited to fully alluvial systems, does not allow for complex system, and predicts direction of response but not magnitude.

If either of the two important controls; sediment supply and flow discharges which determine whether or a channel is stable over a period of years or decades under goes progressive or sudden change, the channel may cross an extrinsic threshold and under go changes.(Allan Werrity,1997)

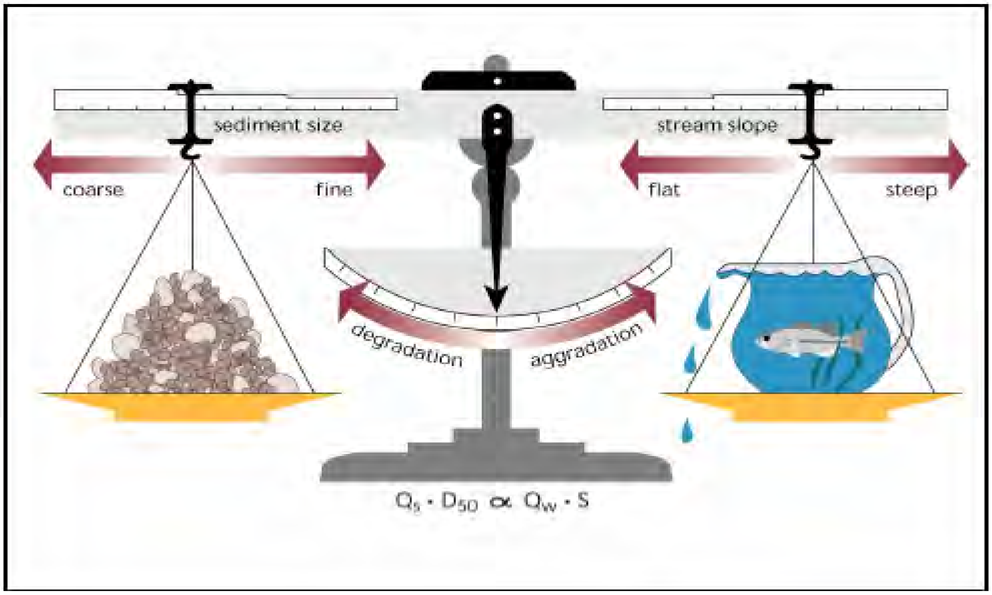

Figure 2-2: Lane's balance (1955)

The supply of sediment to a channel can vary in response to changes in resource areas, hill slopes small tributary channels, or margins of a channel itself. Except for the impact of major floods, most changes in sediment supply relate to changes in land use with in the catchments of which the three most important are afforestation, urbanization and mineral extraction.

In general process of stream channel scour and or deposition have to occur in a natural stable channel, but over time if this leads to degradation or aggradations, respectively then the stream would not be stable. This definition summarizes many of the above mentioned ideas.

2.2. Channel Characteristics

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. Where as the variables that represents the shape of the cross section and shape in plan is dependant. But the dependency of the bed material transport rate and stream slope rely on the course of the stream. 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 dependant 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 dependant variable along with the variables that represent the shape in cross section and the shape in plan.

2.2.1. Channel Geometry and Processes

Channel geometry has four main components: plan form, cross section, slope (gradient) and bed topography. The term process refers to natural change in plan form, cross sectional boundaries, longitudinal profile and bed topography**.** (USACE, Em.1110-2-1410)

I) Plan Form: stream plan forms can generally be classified as braided, meandering and straight, but a wide variety of natural forms are now recognized.

A braided stream can be defined as one which flows in to two or more channels around alluvial islands. Their study shows that braided pattern develops after local deposition of coarser material which can be transported under local conditions existing in the reach. The formation of the bar deflects the stream to wards the banks and causes erosion. Where as meandering streams follow sinus path. Leopold and Wolman have arbitrarily classified streams with sinuosity, which is thalweg length to valley length, greater than 1.5 as meandering streams.

Criterion for prediction of the plan form , braided or meandering have been evolved by Leopled and Wolman after studying of many rivers from different parts of the world. They proposed the relation ship:

$S=0.06Q^{-0.044}$ in fps units, to demarcate between braided and meandering streams .Hendrson modified the foregoing equation to:

$S=0.64d^{1.14}Q^{-0.44}$ in which d is the media size in ft (Garde, Ranga Raju 1977)

As cited in Susan Novak, 2004, the channel type classifications are stated as below according to different authors.

Ackers and Charlteno (1979, Ackres 1982) developed a relation ship that would distinguish a meandering channel from a straight channel or a straight channel with alternating bars

$S_w<0.001Q^{-0.12}$ straight channel

$0.001Q^{-0.12}<S_w<0.0014Q^{-0.12}$ straight channel with alternating bars.

$S_y>0.0014Q^{-0.12}$ meandering channel

S_w represents water surface slope along a straight channel's axial line in m/m. and S_y represents the straight line slope for meandering channels in m/m.

Schumm and Khan (1972): Suggested the following valley slope thresholds to determine channel type.

$S<0.0026$	straight channel
$0.0026<S<0.016$	meandering channel (meandering thalweg)
$S>0.016$	braided channel

These relation ships were empirically derived from flume experiments.

Rosgen (1994): Use slope, entrenchments, sinuosity, and bed material characteristics to classify channels in to seven stream types. Graph shown below is widely used to classify rivers and streams.

Parker (1976) does not factor in sediment transport when classifying rivers. His method delineated meandering from braided streams independently of sediment transport by examining width-depth ratios and slopes. If slope and width-depth ratios are high, braided systems are favored.

If slope and width-depth ratios are low, the following patterns of meandering plan form are likely to happen.

· Meandering channel: $So/Fr << d/b$

· Transitional channel: $So/Fr \sim d/b$

· Braided channel: $So/Fr >> d/b$

In these criteria, So/Fr represents the ratio of the bed slope to the Froude number, and d/b represents the width-depth ratio.

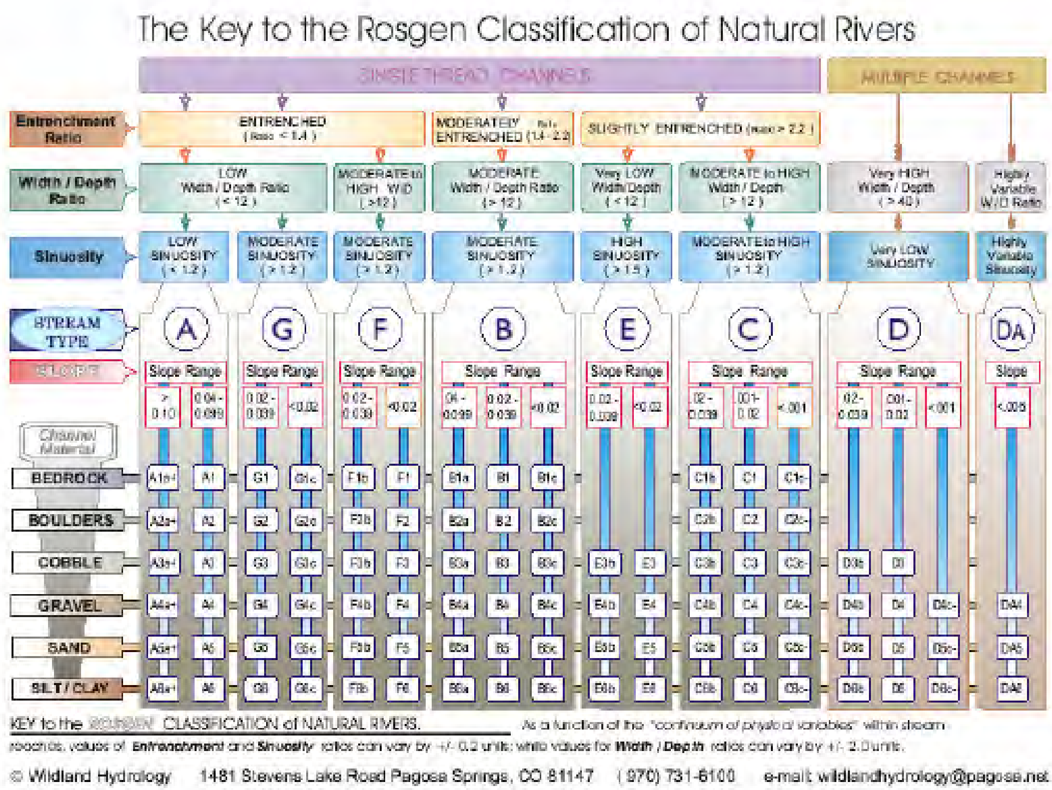

Figure 2-3: Rosgen classification system key (Rosgen 1996).

II) Cross-Section:

The cross section of a natural channel depends on basin run off, sediment input, and boundary soil and vegetation. Usually the average cross section a channel does not change under natural conditions over a period of years. Systematic trends of enlargement or shrinkage usually result from changes in discharge or sediment inputs as a result of basin changes, or on stream works. The variability of cross section from point to point along the channel depends on many factors; it may be quiet small in stable nearly stable channels, and large in highly active channels of complex plan form. (USACE, Em1110-2-14180)

Most of the alluvial stream channels are found to be relatively wide and shallow. If the channel is deep and narrow, the banks become unstable due to higher velocities and the consequent higher shear stresses along the sides. The material that is eroded from the sides drops on the bed and thus a narrow and deep channel tends to widen until the velocities near the side are too low to cause further erosion.

III) Slopes and Profiles:

The longitudinal profile is only partly determined by the landscape. The channel is flatter than the valley slope unless the channel is straight. In many case the channel slope represents along term equilibrium conditions. When a meandering stream is straightened, a steeper non equilibrium slope is temporarily imposed. Responses in the form of erosion and deposition are then set in motion, in the direction of restoring equilibrium. (Em1110-2-1418), 31 Oct 94.

IV) Bed topography and roughness.

The bed topography and hydraulic roughness of natural channels may vary greatly along the channel and also with stage of flow. The total hydraulic resistance results from a combination of grain roughness and form roughness. Form roughness can arise from bed and bank irregularities and from changes in plan form. In active sand channels, bed forms may range from small ripples a few inches in height, to dunes a few feet in height, to larger waves and bars. These forms depend on flow conditions and mainly control the hydraulic roughness of the bed. Also, the bed topography at any time depends on the preceding flow history as well as on present conditions. Roughness therefore varies with stage and is not always the same at similar stages - one reason for the looped or erratic stage-discharge curves found in many alluvial streams. Other important sources of form roughness are trees and bushes, river bank protection and structures, floodplain obstructions, bedrock outcrops, bends and scour holes and abrupt changes in cross section.

In gravel-bed streams, the dominant form of bed topography tends to be an alternation of pools and riffles: the pools are characterized by flatter local slopes and finer bed materials, and the riffles by steeper slopes and coarser materials.

2.2.2. Material Composition

a) **Bed Material**

Bed material describes the composition of the channel boundary and sediment characteristics describe how flow events interact with the channel boundary including cohesive scour, armored reaches, and the threshold between wash load and bed material load. Local sources describe sediment supply from features outside of the modeled reaches such as gullies, net bank failure, surface erosion, and augmentation.

The entrainment and transport of sedimentation is governed in large part, by the composition and arrangement of the particles that make up the channel bed. Bed composition and arrangement (i.e. fabric) have been shown to vary systematically in a down steam direction, the coarse sediment of head waters giving way to progressively finer alluvium as base level is approached (James Bathurst)

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. (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.(Garde,Range Raju,)

b) **Bank material**:

Bank erodibility primarily reflects bank material composition (% fine or coarse alluvium, colluviums, and bedrock).According to (Robert G.Miller, and MichleC.) “The bank stability criterion accounts for the increased stability of the channel banks due to consolidation of the bank sediment; cementing by fines and binding of the sediment by root masses.” And they also stated that a sensitivity analysis of the two parameters i.e. the median grain diameter of the bank sediment D_{50bank} , and the modified friction angle of the bank sediment ϕ' can exert a large influence on the channel geometry.(Journal of ASCE, 1992)

2.2.3. Vegetation Cover

For fully alluvial streams flowing within an envelope of self-deposited sediments, it is debatable whether bank materials should be considered as independent factors affecting channel characteristics Vegetation, however, is more clearly an independent factor. Instability is often triggered by the clearing of vegetation from stream banks, and sometimes by eroded and deadfall vegetation within the channel. The role of bank vegetation varies greatly with the region and type of vegetation. Vegetation established on bars during low flow periods can have a significant effect on channel capacity and processes. Vegetation has been treated as a variable in some hydraulic geometry relationships (Hey and Thorne 1986). (Em1110-1280)

There is a common sense that bank vegetation does have a significant influence in reducing the channel capacity of natural rivers and flood control channels. The lack of understanding of the acknowledged beneficial effects of vegetation cover can have in increasing the stability of a bank and reducing erosion, leads to expensive and environmentally unfriendly maintenance work that is carried out to remove the vegetation along the boundary of the channel. According to Richard Masterman and Colin R.Throne The approaches based on the argument that bank vegetation significantly reduces channel capacity is based mostly on the assignment of high Manning’s n values to streams with in channel vegetation, as indicated in flow resistance guides such as those of Chow (1959) and Barnes (1967), do not properly account for the effects of composite roughness found when a channel has vegetation lined banks but a bed formed in sediment.(Journal of ASCE, 1992)

2.2.4. Flow Characteristics

According to Leopold et al.(1960), channel formation and reformation occur during a range of flows lying between the lower limits of competence and the upper limit at which flow is no longer confined with in the channel (bank full stage). Significantly, the effectiveness of discharge greater than bank full does not increase proportionally to its level above bank full, since over flow in the flood plain dissipates the energy of the stream over a greater area. Therefore it is useful to consider the effectiveness of bank full flows in mobilizing the largest sized particles present in the stream bed as a basis for evaluating changes in sediment transport and channel stability.

This bank full discharge also referred to as effective or dominant discharge is defined as the increment of discharge that transports the largest portion of annual sediment, including bed load over a period of years (Wolman and Miller, 1990, Andrew, 1980, Carling, 1988, Andrews and Mankervis, 1985), cited in *Journal of American Water Resource Association by A.CWhitker, and D.FPatts.*

Hey(1975 observed that the return period for bank full discharge for gravel bed rivers was around one year, it was much less than this for sand bed channels. But as Williams and others have noted ,the unambiguous morphological definition of bank full discharge is fraught with difficulties , and the frequency with which it occurs can vary between one and thirty two(32) years. Alan Werrity (1997) referring to the works of other workers have noted that incision the frequency of bank full discharge. Thus the widely reported assertion that bank full discharge occurs on average once every one to two years is now seen to be an over simplification.(*Cited in Applied Fluvial Geomorphology for River Engineering and management)*

2.2.5. Sediment Transport Analysis

In general, channel changes like BED aggregation / degradation, bank erosion, etc are mostly expressed as a function of water and sediment supply. The basic sediment problem that should be considered in analyzing channel change should therefore be; how much sediment can the channel transport with the available water; is the transport rate greater or smaller than the rate at which sediment is being supplied to a reach.

Based on the mechanism by which grains move sediment transport is often separated in to two classes as bed load and suspended load. The bed load consists of sediment particles moving by either rolling, sliding or bouncing along the bed. The suspended load consists of sediment particles moving in suspension, where in grains are picked up off the bed and move through the water column in generally wavy paths defined by turbulent eddies in the flow. According to (Peter Wilcock, 2004), in many streams grains smaller than 1/8mm tend to always travel in suspension, grains coarser than about 8mm tend to always travel as bed load depending on the strength of the flow.

Sediment transport in streams can also be divided in other classes based on the source of grains. These are bed material load, which is the total rate of sediment transport for those sediment particle size that are readily apparent on the surface of stream bed (or $d>d_5$ of sediment bed material size), and wash load which is composed of grains found in only (less than a percent two) amounts in the bed. The sources of wash load grains are either the channel banks or the hill slope area contributing runoff to the streams. (Hsieh Wenshun, PierreY.Jullien).

Movements of the bed material load particles are related to the flow and sediment characteristics of the bed. Thus bed material load can in principle be calculated from sediment transport equations. According to (Hsieh Wenshun, PierreY.Jullien), bed material load can be divided in to two parts. Suspended bed material load is the total rate transport of sediment that is transported as suspended load with sediment sizes appearing readily on the streambed surface. The second parts of bed material load that moves along the stream bed is bed load.

Einstein concludes that there is a close relation ship between bed material load and bed load because there is a continuous exchange of particles between the bed material and bed load. In addition particles are transported along the channel bed in the sequence of steps with the average distance of each step proportional to the particle size. It was also noted that a particular particle is not always moving. Einstein found that the deposition rate of particle per unit area depends on both the transport rate of the particle at a particular point and the probability that the forces on the particle are such that the particle will deposit.

Therefore in river engineering under takings consideration of bed load is very important as it determines the morphological aspect of rivers. The major features such as bed forms and bars result from bed load transport. Any action which changes the bed load transport rate affects the morphology of the river channel (Davies 1987)

Thus proper measurement and prediction of bed load transport rate and channel morphology helps in the formulation of rational river instability problems' management strategies. But it is difficult to determine a reliable bed load transport to be used in the field because of the lack of reliable data from streams. How ever, it is helpful to use empirical formulas than totally aborting the effort.

Generally the transport of sediments through the stream system depends on the sediment supply (size and quantity) and the ability of the stream to transport the sediment supply.

i)*Sediment Inflow*:

The large variety of sediment yield methods can be placed into two broad categories: methods based on direct measurement and mathematical methods. Only those based on direct field measurements are considered a rigorous approach; mathematical methods are trend indicators at best. One of the direct methods to determine sediment inflow concentration is the flow duration sediment discharge rating curve which is based on measured inflow sediment concentration. Occasionally, measured suspended sediment concentrations, expressed as milligrams per liter, are available. These are usually plotted against water discharge and often exhibit very little correlation with discharge; however, use of such graphs is encouraged when developing or extrapolating the inflowing sediment data. As the analysis proceeds, it is desirable in most situations to convert the concentrations to sediment discharge in tons/day and to express that as a function of water discharge. As cited in (*EM 1110-2-4000, Change 1, 31 Oct 95)*, a scatter of about 1 log cycle is common in such graphs. The scatter is smaller than on a concentration plot because water discharge is being plotted on both axes. The scatter may be the result of seasonal effects, random measurement errors, changes in watershed or hydrology during the measurement period, or other sources. One should carefully examine these data and attempt to understand the shape and variance of the relationship. The following graph shows a type of sediment discharge curve.

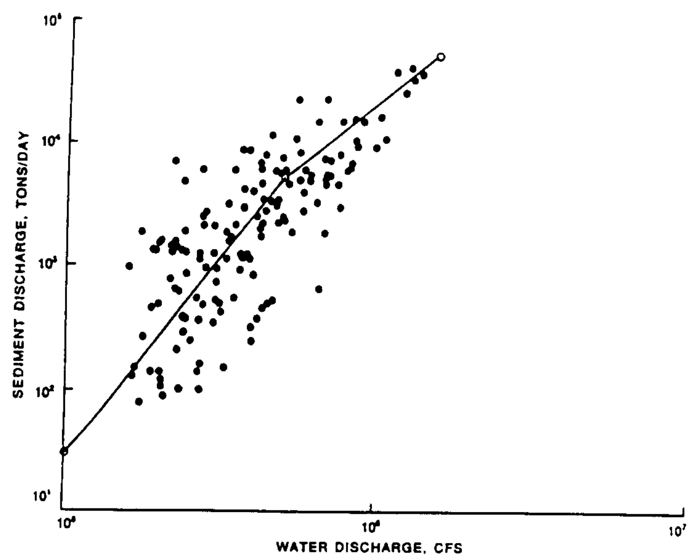

Figure 2-4: Sediment-discharge rating curve

When no suspended sediment measurements are available, the inflowing sediment boundary condition must be calculated. That is possible for sand and gravel using mobile bed hydraulics and sediment transport theory. There is no comparable theory for the wash load inflow. When making a calculation for the boundary condition, select the reach of channel very carefully. It should be one approaching the project which has a slope, velocity, width, and depth typical of the hydraulics which is transporting the sediment into the project reach. It should also have a bed surface that is in equilibrium with the sand and gravel discharge being transported by the flow. Having located such a reach, by selecting a representative cross section for that reach, calculations by particle size for the full range of water discharges should be made in the study plan.

The other method for estimation of sediment inflow is using water shed models. In concept, the computer is used to simulate water movement and the associated processes of sediment erosion, transportation and deposition, throughout the watershed. Most are hydrologic models with sediment runoff capability added through soil loss equations, one of the example based on such methods is using SWAT water shed model to calculate sediment yield from the catchments.

ii) ***Sediment transport capacity***:

The stability of the existing channel should be evaluated by first performing an incipient-motion analysis to identify the range of flows over which the bed material will be mobile, and then estimating the quantity of material that can be transported in response to those flows. Comparison of the bed material-transport capacity of the various sub reaches with an estimate of the upstream sediment supply provides quantification of the degradation or aggradations of a channel's reach.

The initiation of motion of particles in the bed depends on the hydraulic characteristics in the near-bed region. Therefore, flow characteristics in that region are of primary importance. Since determining the actual velocity at the bed level is difficult, shear stress has become the more prevalent, though not exclusive, way of determining the point of incipient motion. Shear stress at the bed is represented by the following:

$$\tau_b = \gamma RS \qquad (2.1)$$

Where: τ_b = Bed shear stress

γ = Unit weight of water

R = Hydraulic radius

S = Energy slope

Another factor that plays an important role in the initiation and continued suspension of particles is the turbulent fluctuations at the bed level. A measure of the turbulent fluctuations near the bed can be represented by the current-related bed shear velocity:

$$u_* = \sqrt{\frac{\tau_b}{\rho}} \qquad (2.2)$$

Or

$$u_* = \sqrt{grS} \qquad (2.3)$$

Where: u_* = Current-related bed shear velocity

Additionally, the size, shape, roughness characteristics, and fall velocity of the representative particles in the stream have a significant influence on their ability to be set into motion, to remain suspended, and to be transported. The particle size is frequently represented by the median particle diameter (d_m). For convenience, the shape is typically represented as a perfect sphere, but sometimes can be accounted for by a shape factor, and the roughness is a function of the particle size. In general, a typical sediment transport equation for multiple grain size classes can be represented as follows:

$$g_{si} = f(D, V, S, B, d, \rho, \rho_s, sf, d_i, p_{i,} T) \qquad (2.4)$$

Where: g_{si} = Sediment transport rate of size class i

D = Depth of flow

V = Average channel velocity

S = Energy slope

B = Effective channel width

d = Representative particle diameter

ρ = Density of water

ρ_s = Density of sediment particles

sf = Particle shape factor

d_i = Geometric mean diameter of particles in size class i

p_i = Fraction of particle size class i in the bed.

T = Temperature of water

Not all of the transport equations will use all of the above parameters. Typically one or more correction factors are used to adapt the basic formulae to transport measurements. (*HEC-RAS 3.1 reference manual).*

Aggradations or degradation of a streambed can be analyzed using the non-equilibrium sediment transport. The non-equilibrium is typically addressed in using numerical sedimentation modeling. This can help in calculating change in the bed surface elevation in response to non-equilibrium sediment conditions and to feed those changes back in to the calculation of the flow intensity sediment load. It should account for sediment transport by size class and maintain a continuous account of the gradation in the streambed and on its surface.

The numerical model should also account for: bed roughness, which can vary with discharge; bed armoring and sorting; bed surface thickness and porosity; and bed compaction. (*Em1110-2-400, change1, 31oct1995)*.More over hydraulics analysis provides the foundation of river restoration design, particularly analytical approaches to design, as channel hydraulics are the basis for further analysis like sediment transport and conveyance (Morris1996). At the most basic level of analysis is Manning's equation which simply relates channel velocity to reach characteristics such as channel slope hydraulic radius, and an estimate of roughness(Chow1959).there are a number of computer programmes available that can be used to conduct such analysis on across section by cross section basis. Among which, HEC-RAS is the widely used and widely accepted numerical model, and by the latest version of it, HEC-RAS 4.0 beta, it is possible to conduct mobile bed sediment transport analysis. So for its capability in modeling the mobile bed sediment transport analysis and in performing the sediment impact assessments, in consideration of the various hydraulic structures in the steady or unsteady river flow analysis, HEC-RAS 4.0 is appropriate to be used in analyzing the stability of the river channel.

2.3. Application of HEC-RAS 4.0 Model for Analyzing River Cannel Stability

HEC-RAS is an integrated system of software, designed for interactive use in a multi-tasking environment. The HEC-RAS system contains four one-dimensional river analysis components for: (1) steady flow water surface profile computations; (2) unsteady flow simulation; (3) movable boundary sediment transport computations; and (4) water quality analysis. A key element is that all four components use a common geometric data representation and common geometric and hydraulic computation routines. In addition to the four river analysis components, the system contains several hydraulic design features that can be invoked once the basic water surface profiles are computed.

HEC-RAS can perform mobile bed sediment routing computations with quasi steady (histogram) flow series data. For each flow in the time series a water surface profile is calculated. Hydraulic parameters required for sediment processes are also calculated. The model calculates sediment transport capacity by a number of available methodologies. The sediment continuity equation is then solved in conjunction with sorting and armoring algorithms to solve for the actual volume of deposition or erosion. Additionally, temporal entrainment and deposition functions have been adapted.

I) *STEADY FLOW WATER SURFACE PROFILES:* This component of the modeling system is intended for calculating water surface profiles for steady gradually varied flow. The steady flow component is capable of modeling sub critical, supercritical, and mixed flow regime water surface profiles. The basic computational procedure is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head). The momentum equation is utilized in situations where the water surface profile is rapidly varied. These situations include mixed flow regime calculations (i.e., hydraulic jumps), hydraulics of bridges, and evaluating profiles at river confluences (stream junctions). The effects of various obstructions such as bridges, culverts, dams, weirs, and other structures in the flood plain may be considered in the computations.

Equations for Basic Profile Calculations:

Water surface profiles are computed from one cross section to the next by solving the Energy equation with an iterative procedure called the standard step method. The Energy equation is written as follows:

$$Y_2 + Z_2 + \frac{\alpha_2 V_2^2}{2g} = Y_1 + Z_1 + \frac{\alpha_1 V_1^2}{2g} + h_e \tag{2.5}$$

where: Y_1, Y_2 = depth of water at cross sections

Z_1, Z_2 = elevation of the main channel inverts

V_1, V_2 = average velocities (total discharge / total flow area)

a_1, a_2 = velocity weighting coefficients g = gravitational acceleration

h_e = energy head loss

A diagram showing the terms of the energy equation is shown in Figure 2-1.

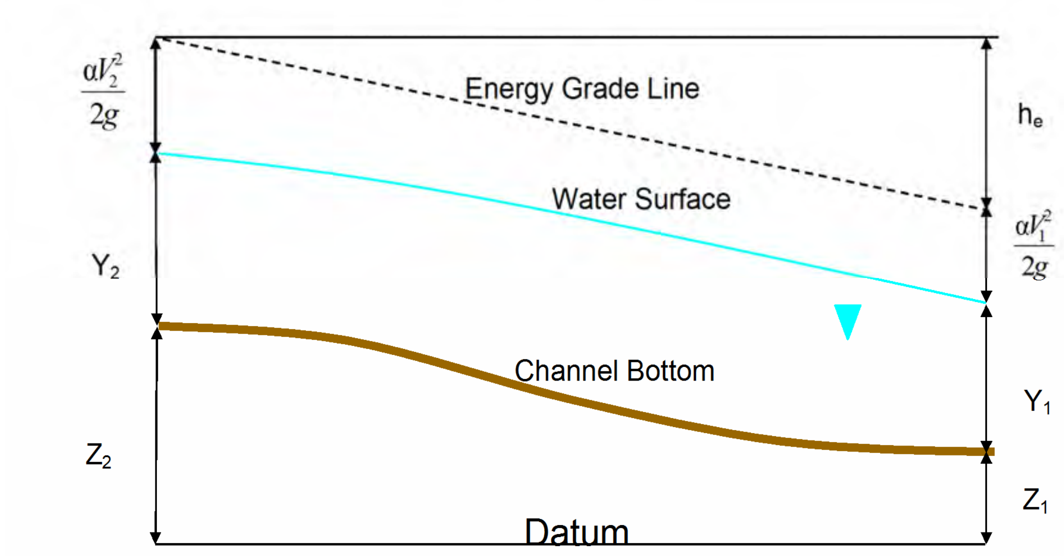

Figure 2-5: Representation of Terms in the Energy Equation

The energy head loss h_e between two cross sections is comprised of friction losses and contraction or expansion losses. The equation for the energy head loss is as follows:

$$h_e = L\overline{S}_f + C\left|\frac{a_2 V_2^2}{2g} - \frac{a_1 V_1^2}{2g}\right| \tag{2.6}$$

Where: L = distance weighted reach length

$\overline{S_f}$ = representative friction slope between two sections

C = expansion or contraction loss coefficient

The distance weighted reach length, L, is calculated as:

$$L = \frac{L_{lob}\overline{Q}_{lob} + L_{ch}\overline{Q}_{ch} + L_{rob}\overline{Q}_{rob}}{\overline{Q}_{lob} + \overline{Q}_{ch} + \overline{Q}_{rob}} \tag{2.7}$$

Where: L_{lob}, L_{ch}, L_{rob} = cross section reach lengths specified for flow in the left over bank, main channel, and right over bank, respectively.

$\overline{Q}_{lob}, \overline{Q}_{ch}, \overline{Q}_{rob}$ = arithmetic average of the flows between sections for the left over bank, main channel, and right over bank, respectively

Cross Section Subdivision for Conveyance Calculations:

The determination of total conveyance and the velocity coefficient for a cross section requires that flow be subdivided into units for which the velocity is uniformly distributed. The approach used in HEC-RAS is to subdivide flow in the over bank areas using the input cross section n-value break points (locations where n-values change) as the basis for subdivision (Figure 2-2). Conveyance is calculated within each sub division from the following form of Manning's equation (based on English units):

$$Q = KS_f^{1/2} \qquad (2.8)$$

$$K = \frac{1.486}{n} AR^{2/3} \qquad (2.9)$$

Where: K = conveyance for subdivision

n = Manning's roughness coefficient for subdivision

A = flow area for subdivision

R = hydraulic radius for subdivision (area / wetted perimeter)

The program sums up all the incremental conveyances in the over banks to obtain a conveyance for the left over bank and the right over bank. The main channel conveyance is normally computed as a single conveyance element. The total conveyance for the cross section is obtained by summing the three subdivision conveyances (left, channel, and right).

Friction Loss Evaluation:

Friction loss is evaluated in HEC-RAS as the product of $\overline{S}_f$ and L (Equation 2-2), where $\overline{S}_f$ is the representative friction slope for a reach, and L is defined by Equation 2-3. The friction slope (slope of the energy grade line) at each cross section is equation as follows:

$$S_f = \left(\frac{Q}{K}\right)^2 \qquad (2.10)$$

Alternative expressions for the representative reach friction slope $\overline{S}_f$ in HEC-RAS are as follows:

Average Conveyance Equation:

$$\overline{S}_f = \left(\frac{Q_1 + Q_2}{K_1 + K_2}\right)^2 \qquad (2.11)$$

Average Friction Slope Equation:

$$\overline{S}_f = \frac{S_{f1} + S_{f2}}{2} \qquad (2.12)$$

Geometric Mean Friction Slope Equation:

$$\overline{S}_{f1} = \sqrt{S_{f1} + S_{f2}} \qquad (2.13)$$

Harmonic Mean Friction Slope Equation:

$$\overline{S}_f = \frac{2(S_{f1} + S_{f2})}{S_{f1} + Sf2} \qquad (2.14)$$

Table 2-1: Criteria for selecting friction loss calculation

Profile Type	Is friction slope at current cross section greater than friction slope at the preceding one	Equation Used
Sub critical (M_1, S_1)	Yes	2-7
Sub critical (M_2)	No	2-9
Supercritical	Yes	2-7
Supercritical	Yes	2-8

The criteria given in Table 2.1 for selecting the appropriate energy loss equation are derived based on investigations conducted in order to select the appropriate equation which can approximate the loss for a given type of flow.

The first equation is the default equation

Contraction and Expansion Loss Evaluation

Contraction and expansion losses in HEC-RAS are evaluated by the following equation:

$$h_{ce} = C\left|\frac{\alpha_1 V_1^2}{2g} - \frac{\alpha_2 V_2^2}{2g}\right| \qquad (2.15)$$

Where: C = the contraction or expansion coefficient

The program assumes that a contraction is occurring whenever the velocity head downstream is greater than the velocity head upstream. Likewise, when the velocity head upstream is greater than the velocity head downstream, the program assumes that a flow expansion is occurring.

Computation Procedure:

The unknown water surface elevation at a cross section is determined by an iterative solution of Equations 2-5 and 2-6. The computational procedure is as follows:

1. Assume a water surface elevation at the upstream cross section (or downstream cross section if a supercritical profile is being calculated).

2. Based on the assumed water surface elevation, determine the corresponding total conveyance and velocity head.

3. With values from step 2, compute $\overline{S}_f$ and solve Equation 2-6 for h_e.

4. With values from steps 2 and 3, solve Equation 2-1 for WS2.

5. Compare the computed value of WS2 with the value assumed in step 1; repeat steps 1 through 5 until the values agree to within .01 feet (.003 m), or the user-defined tolerance.

The criterion used to assume water surface elevations in the iterative procedure varies from trial to trial. The first trial water surface is based on projecting the previous cross section's water depth onto the current cross section. The second trial water surface elevation is set to the assumed water surface elevation plus 70% of the error from the first trial (computed W.S. - assumed W.S.). In other words, W.S. new = W.S. assumed + 0.70 * (W.S. computed - W.S. assumed). The third and subsequent trials are generally based on a "Secant" method of projecting the rate of change of the difference between computed and assumed elevations for the previous two trials.

Applications of the Momentum Equation:

Whenever the water surface passes through critical depth, the energy equation is not considered to be applicable. The energy equation is only applicable to gradually varied flow situations, and the transition from sub critical to supercritical or supercritical to sub critical is a rapidly varying flow situation. There are several instances when the transition from sub critical to supercritical and supercritical to sub critical flow can occur. These include significant changes in channel slope, bridge constrictions, drop structures and weirs, and stream junctions. In some of these instances empirical equations can be used (such as at drop structures and weirs), while at others it is necessary to apply the momentum equation in order to obtain an answer.

Within HEC-RAS, the momentum equation can be applied for the following specific problems: the occurrence of a hydraulic jump; low flow hydraulics at bridges; and stream junctions.

Steady Flow Program Limitations:

The following assumptions are implicit in the analytical expressions used in the current version of the program:

(1) Flow is steady.

(2) Flow is gradually varied. (Except at hydraulic structures such as: bridges; culverts; and weirs. At these locations, where the flow can be rapidly varied, the momentum equation or other empirical equations are used.)

(3) Flow is one dimensional (i.e., velocity components in directions other than the direction of flow are not accounted for).

(4) River channels have 'small' slopes; say less than 1:10

Flow is assumed to be steady because time-dependent terms are not included in the energy equation (Equation 2-5). Flow is assumed to be gradually varied because Equation 2-5 is based on the premise that a hydrostatic pressure distribution exists at each cross section. At locations where the flow is rapidly varied, the program switches to the momentum equation or other empirical equations. Flow is assumed to be one-dimensional because Equation 2-19 is based on the premise that the total energy head is the same for all points in a cross section. Small channel slopes are assumed because the pressure head, which is a component of Y in Equation 2-5, is represented by the water depth measured vertically.

II) *SEDIMENT TRANSPORT FOR RIVER ANALYSIS:*

It is possible to analyze the mobile bed sediment transport using HEC-RAS 4.0. And this can be done by specifying transport function, sorting method, fall velocity method, sediment control volume and the bed gradation associated with each cross section.

Transport Potential Functions:

In HEC- RAS 4.0 there are seven transport potential functions to select from.

- Ackers-White
- Englund-Hansen
- Laursen (Copeland)
- Myer-Peter-Meuler
- Toffaleti
- Yang (Sand and Gravel)

These functions were selected based on their validity and collective range of applicability. The ranges of input parameters used in the development of each function are shown in Table 2.2.

Table 2-2: Range of input values for sediment transport functions (SAM users manual, 1998)

Function	d	d_m	s	V	D	S	W	T
Ackers-White (*flume*)	0.04 - 7.0	NA	1.0 - 2.7	0.07 - 7.1	0.01 - 1.4	0.00006 - 0.037	0.23 - 4.0	46 - 89
Englund-Hansen (*flume*)	NA	0.19 - 0.93	NA	0.65 – 6.34	0.19 – 1.33	0.000055 – 0.019	NA	45 - 93
Laursen (*field*)	NA	0.08 – 0.7	NA	0.068 – 7.8	0.67 – 54	0.0000021 – 0.0018	63 – 3640	32 - 93
Laursen (*flume*)	NA	0.011 - 29	NA	0.7 - 9.4	0.03 – 3.6	0.00025 – 0.025	0.25 – 6.6	46 - 83
Meyer-Peter Muller (*flume*)	0.4 – 29	NA	1.25 – 4.0	1.2 – 9.4	0.03 – 3.9	0.0004 – 0.02	0.5 – 6.6	NA
Tofaletti (*field*)	0.062 – 4.0	0.095 – 0.76	NA	0.7 - 7.8	0.07 – 56.7 (R)	0.000002 – 0.0011	63 - 3640	32 – 93
Tofaletti (*flume*)	0.062 – 4.0	0.45 – 0.91	NA	0.7 - 6.3	0.07 – 1.1 (R)	0.00014 – 0.019	0.8 – 8	40 - 93
Yang (*field-sand*)	0.15 – 1.7	NA	NA	0.8 - 6.4	0.04 – 50	0.000043 – 0.028	0.44 – 1750	32 - 94
Yang (*field-gravel*)	2.5 – 7.0	NA	NA	1.4 - 5.1	0.08 – 0.72	0.0012 – 0.029	0.44 – 1750	32 - 94

Where: d = Overall particle diameter, mm

d_m = Median particle diameter, mm

s = Sediment specific gravity

V = Average channel velocity, fps

D = Channel depth, ft

S = Energy gradient

W = Channel width, ft

T = Water temperature, ^{o} F

(R) = Hydraulic Radius, ft

NA = Data not available

Transport Capacity:

As mentioned above, for river analysis mostly the bed material is the essential one, and based on this it is divided in to separate grain classes (up to 20).Then the sediment potential is calculated for each grain size. The sediment transport capacity is therefore transport potential for each size multiplied by fraction of material in active layer of bed.

Sorting and Armoring

To compute active layer thickness and vertical bed layer tracking assumptions. Two methods are currently available:

Exner5:- A three layer active bed model that includes the capability of forming a coarse surface layer that will limit erosion of deeper material thereby simulating bed armors (default method).

Active layer: - This is a simplified two layer active bed approach. The active layer thickness is set equal to the d_{90} of the layer. This assumption is only appropriate for gravel beds and is intended for use with the Wilcock transport method in particular.

Fall Velocity:

Several methods are available for computing fall velocity. The options include: Ruby, Toffaleti, Van Rijn, Report 12 (Default method in HEC 6).

Erosion and Deposition: Erosion, and removal of particles from the active layer, occurs when transport capacity exceeds the inflowing sediment concentration in a size class. And it is based on the characteristic length.

Erosion = (GS-Qs)*Ce Entrainment coefficient

$$Ce = 1.368 - e^{\frac{L}{30.D}}$$

And deposition is calculated from particle settling velocity

$$\text{Deposition efficiency coefficient} = \frac{V_s(i).\Delta t}{D_e(i)}$$

Among the above sediment transport formulas the commonly used formulas for gravel bed rivers are the Yang's and the Meyer Peter Muller sediment transport formulas as they are tested against a wider range of variables and have been found appropriate for many natural gravel bed rivers (HEC-RAS reference manual). And according to the existing reach characteristics of the channel the Meyer Peter Muller and the Yang sediment transport formula are so closer to be applied.

3. COLLECTION AND ANALYSIS OF DATA

3.1. Geometry of the Channel

a) Cross-Section

The rivers to be modeled are segmented in to three reaches. The upper reach is the reach on the Borkena River upstream of the confluence where Berberie and Borkena rivers meet. And eight cross sections are taken along the 500m length of this reach. The lower reach is about 1km downstream of the confluence and ten cross section are taken along this reach .Most of the sections along those reaches are wider, shallower and relatively straight. The bank heights along the left side of the upper reach of Borkena River vary from 0.35m at river station17 to 3.86m at river station 12.And the bank height along the right side of this reach vary from 0.42m at station 18 to 2.06m at station 14. Between stations 13 and 12, on the left side of the channel, a guide wall of length about 10m and average height 3.0 m is constructed in trying to protect banks from getting eroded. The bank heights in the left side of lower reach also vary from 6.13m at station 10 (near to the bridge station) to 0.37m at river station 1, and from 0.3m at station 1 to 6.37m at river station 10.

The other reach is the reach named as tributary which is about 1.2km length along the Berberie River up stream of the junction. For this reach thirty four cross section stations are taken. This reach follows a meandering route and it is an incised channel. The banks along this reach are getting eroded continuously and guide walls are being constructed along the toe of the banks in trying to solve this problem.

Cross sections and reach lengths are arranged in such away that every point in the cross section is defined by two values; the distance of the point from a reference point on the left side of the river and with increasing order towards right looking down stream and an elevation of that point in meters. The reach lengths for the main and over bank channels are also taken as the distance between the station of interest and the respective cross section segments on the down stream cross section. The data is shown in appendex-1.

b) Longitudinal Slopes:

The longitudinal water line profile for the tributary reach is about 2.24%. And the average longitudinal slope along the thalweg on the Broken River is about 1.24%.

C) Shape in Plan:

The upper and lower reaches of Borkena River although taken for short distances are nearly straight and most of the channel reaches comprise wide and shallow cross sections.

According to the proposed classification by Lane:

S*Q^0.25 = 0.0124*93^0.25 = 0.043>0.04, thus channel can be classified as braided channel.

The channel reaches in the tributary are incised and sinuosity is greater than 1.3. The width to depth ratios for most of the stations along this reach are less than 12m ; the dominant material on the bed is gravel; the average bed slope is about 0.024 thus the channel falls under the A_4 stream type according to the Rosgen's classification.

3.2. Bank and Bed Materials

Soil samples are taken from the bed, and left and right banks of the river reaches. The bed materials comprise a wider range of particle sizes ranging from gravel to fine sands and the bank materials are in the category of silt and clay sizes, thus sieve analysis is used to determine the particle size analysis and it is shown in appendex-5

The typical grain sizes for each of the samples are also shown in table 3-1 as below

Table 3-1: typical grain sizes for each of the samples

Sample Size	**d_{25} (mm)**	**d_{50}, (mm)**	**d_{65} (mm)**	**d_{90}, (mm)**
Upper reach bed material	4.72	18	22.3	46
Upper reach left bank material	0.0063	0.016	0.046	0.5
Upper reach right bank material	0.0038	0.02	0.031	0.16
Lower reach bed material	2.8	9.2	16.5	31.4
Lower reach left bank material	0.023	0.064	0.075	0.5
Lower reach right bank material	1.68	6.1	8.57	22.4
Tributary bed material	2.3	7.6	14.8	37
Tributary left bank material	0.0123	0.0316	0.075	0.51
Tributary right bank material	0.0086	0.016	0.03	0.38

3.3. Discharge

3.3.1. Discharge for Steady Flow Profiles

There is a record of more than 10 years maximum daily instantaneous discharge data at the bridge of Borkena River, (data shown in appendex-3). To analyze the conveyance capacity of the flood way of each of the reaches, which includes the channel and adjacent flood plains, a 100 year discharge must be used .This helps to know how flood restriction projects affect flood water elevation and most of the adjacent city infrastructures also must be safe at a lower risk of probability by taking this discharge. This can also help to design bank protection structures. And at a bank full discharge which is taken as a 2 year discharge can generally help as a primary design discharge to assess the channel characteristics such as channel width, depth and slope. Generally the strength of the flow due to 2, 50, & 100 year discharges must be analyzed against the stability of the banks of the river reaches. Therefore these discharges are calculated based on the log normal distribution for which the hydrological data fits and values are shown in table3.2. More over the discharges at the upper stream of the tributary, and the discharge at the upper reach for the Borkena River is calculated based on the catchment area ratio method in a similar way followed in calculation of the quasi- unsteady flow data in the following paragraphs.

Table 3-2: Design Discharges

Return Period (Years)	Discharge(m^3/s)		
	At upper boundary of Lower reach (Gage site)	At upper boundary of Tributary reach	At upper boundary of upper reach
2	92	6.2	60.3
50	325.4	14	213
100	385	26	252

3.3.2. Quasi Unsteady Flow Data

Due to the non linear nature of the alluvial sediment movement, transport is usually concentrated during large peak flow events. These flow events are usually of relatively short duration and are characterized by rapidly changing flow. Because of the non linearity, an irregular time step is desirable, and by approximating low flows by larger durations and peak flows by relatively shorter durations a quasi-unsteady flow series is developed for modeling the mobile bed sediment transport.

Measured daily instantaneous stream flow data for about thirteen years (1989-2001G.C) of Borkena River from the gauged station at the bridge in the town of Kombolcha is available from Ministry of Water Resources. This station is close to the external boundary of the reach considered as lower reach. The daily maximum flows are peaked for each month and the average of these maximum flows are taken for each water year. This stream flow data is extended up to 2007G.C based on correlation with the precipitation data. The flow series at the external boundary of the lower reach is calculated by manipulation of the measured instantaneous daily flow data of the thirteen years. The data is manipulated based on the compression technique and a single representative water year is obtained. Using those measured data quasi – unsteady flow is determined at this boundary.

From the formula for average flow calculation based on area ratio of the catchments and assuming uniform distribution of aerial rain fall through out the catchment, the average steady flows with varying durations for the boundary conditions of the external boundary for tributary reach can be calculated based on the catcment area of Berberie River and lateral boundary flow series due to inflow from Arawlle River at upper reach also can be calculated based on catchment area of Arawlle River. And the quasi unsteady flow series at the external boundary of the upper reach is calculated by deducting the sum of the flow series at the lateral flow and at the external boundary of the tributary reach from the flow series at the external boundary of the lower reach.

$$Q_{average} = k*N*A$$

k = runoff coefficient

A = catchment area

N = basin normal annual precipitation (taken as uniform for all Sub catchments)

Then based on the area ratio method:

$$Q_L = \frac{k_L Q_B * A_R}{k_B A_B}$$

$$Q_T = \frac{k_T Q_B * A_T}{k_B A_B}$$

Where:

A_L = 70km^2 Q_L = flow at lateral boundary on the upper reach

A_T = 18km2 Q_T = flow at external boundary on tributary

k_T = 0.45, k_B = 0.5, k_L = 0.44

k = run off coefficient for the catchment of the tributary Berberie River, the Borkena River and that from the unmodelled tributary called Arawlle River, and calculation is shown in appendex-4

A_B = 281km^2 (catchment area upstream of the gauged station)

Based on this calculation the quasi unsteady flow data is developed for each boundary and the values are shown in the following table 3.3.

Table 3-3: Quasi unsteady flow data

external boundary of lower reach			tributary external boundary		lateral boundary		external boundary of upper reach	
Month	Duration	Average flows	Duration	Average flows	Duration	Average flows	Duration	Average flows
January	720.00	2.71	720.00	0.18	720.00	0.75	720.00	1.77
Feb-mar	1440.00	4.11	1440.00	0.28	1440.00	1.14	1440.00	2.69
May	720.00	2.75	720.00	0.18	720.00	0.76	720.00	1.80
June	720.00	1.67	720.00	0.11	720.00	0.46	720.00	1.09
July	360.00	7.72	360.00	0.52	360.00	2.15	360.00	5.06
July	360.00	18.24	360.00	1.22	360.00	5.07	360.00	11.94
August	144.00	44.24	144.00	2.97	144.00	12.30	144.00	28.97
August	198.72	62.50	198.72	4.19	198.72	17.38	198.72	40.93
August	123.12	96.60	123.12	6.48	123.12	26.86	123.12	63.26
August	43.92	107.50	43.92	7.21	43.92	29.89	43.92	70.40
August	170.64	112.50	170.64	7.54	170.64	31.28	170.64	73.67
August	51.12	117.90	51.12	7.90	51.12	32.79	51.12	77.21
September	147.60	113.50	147.60	7.61	147.60	31.56	147.60	74.33
September	136.80	106.80	136.80	7.16	136.80	29.70	136.80	69.94
September	71.28	98.80	71.28	6.62	71.28	27.47	71.28	64.70
September	66.24	79.50	66.24	5.33	66.24	22.11	66.24	52.06
September	141.84	59.60	141.84	4.00	141.84	16.57	141.84	39.03
September	141.12	33.39	141.12	2.24	141.12	9.28	141.12	21.86
October	720.00	14.63	720.00	0.98	720.00	4.07	720.00	9.58
November	720.00	4.10	720.00	0.27	720.00	1.14	720.00	2.68
December	720.00	10.90	720.00	0.73	720.00	3.03	720.00	7.14

3.4. Other Hydraulic Input data

3.4.1. Loss Coefficients

a) Roughness coefficients

Manning's equation is used to calculate water surface profiles. But it is usually difficult to determine the actual value. But according to Chow (1958) it is possible to estimate this value by the method of analytical procedures considering the existing channel physical characteristics such as surface roughness, vegetation, channel plan forms and bank and bed materials. Therefore the n value for each of the segments; the main channel and left & right flood plains are estimated as per to the following equation (Chow, 1958).

$n = (n_o+n_1+n_2+n_3+n_4)\ m_5$……………………………(3-1)

Where:

n_0 = a basic value for a straight, uniform, smooth channel in a natural material involved

n_1 = a value added to n_o to account for the effect of surface irregularities

n_2 = a value for variations in shape and size of the channel x-section

n_3 = a value for obstruction

n_4 = a value for vegetation and flow condition

m_5 = correction factor for meandering of a channel.

Because of slight variation in channel characteristics within the study reach, a uniform n value is taken as an average for all the cross sections in a reach. That is an average Manning's n for the main channel and an average n for the right and left over banks is taken for all the cross sections in a reach.

The basic value, n_o, is estimated by the following empirical relations (French, 1986):

$n_o = 0.039 * d_{50}^{1/6}$ (d, ft) (3-2)

$n_o = 0.047 * d_{50}^{1/6}$ (d, m) (3-3)

$n_o = 0.038 * d_{90}^{1/6}$ (d, m (3-4)

Where d_i is a grain size in which i percentage of the particles finer than d.

Equations 3-2, 3-3 and 3-4 are due to Garde and Raju, Subramanju and Meyer Peter and Muller, respectively. (Cited in Micheal, 2003)

For example the Manning's, n, for the main channel bed of the upper reach of Borkena river is calculated as follows based on the formula given above referring to the bed material size and in consideration of the conditions given in table 3.4 below.

For the sample in the bed of the upper reach of Borkena River, d_{50} = 0.06 ft, d_{90} = 0.046 m and d_{75} = 34 mm (Appendix II), Then n_o values computed from Equations (3-2, 3-3, 3-4) are 0.0244, 0.026 and 0.022, respectively. The average of these values (=0.024) is taken to be the basic n_o value of Manning's roughness of the channel.

The other values are selected from table 3.4.

n_1 = 0.01, moderate degree of irregularity

n_2 = 0.007, channel cross-section vary occasionally

n_3 = 0.00, obstruction is negligible except at the bridges which will be considered separately

n_4 = 0.005, vegetation effect is low as discussed in Section 3.2.3

m = 1.00, degree of meandering is minor.

Therefore, n = (0.024 + 0.01 + 0.007 + 0 + 0.005) x 1.00 = 0.046

The roughness values for rest of the channel reaches and the flood plains are estimated based on this way and are shown in appendex-1 together with the cross sectional data.

Table 3-4: values for computation of roughness coefficient

Channel condition		Values	
Degree of irregularity	Smooth	n1	0.000
	Minor		0.005
	Moderate		0.01
	Severe		0.02
Variations of channel cross-section	Gradual	n1	0.000
	Alternating occasionally		0.005
	Alternating frequently		0.010-0.015
Relative of effective obstructions	Negligible	n1	0.000
	Minor		0.010-0.015
	Appreciable		0.020-0.030
	severe		0.040-0.06
Vegetation	Low	n1	0.005-0.010
	Medium		0.010-0.025
	High		0.025-0.050
	Very high		0.05-0.100
Degree of meandering	Minor	n1	1.000
	Appreciable		0.15
	Severe		1.3

b. Coefficients of contraction and expansion

Contraction and expansion coefficients for different channel conditions are given in Table 3.6

Table 3-5: contraction and expansion for various channel conditions (Chow, 1958).

Channel condition	Coefficient	
	Expansion	Contraction
Gradual change	0.2	0 -1.0
Abrupt change	0.5	0.5

Based on Table 3.5 and by evaluating the change in channel cross section variations, and the plan forms, values for expansion and contraction coefficients are estimated for each cross section. The values for each cross section are shown in appendex-1.

c. Bridge losses:

There is one bridge between stations 22&21 in the tributary reach which spans about 21m with a clear water way of about 5m.And another bridge at Borkena River is located between stations 10&9 of the lower reach and spans about 71m with a clear water way depth of not more than 6m .There are two piers in this bridge..

Depending on the flow situation HEC-RAS automatically selects the suitable flow equations As a result a weir coefficient of 1.44 and maximum submergence of 0.95 are used from the default values.

According to table 3.5 the contraction and expansion losses at bridge locations are taken as 0.3 and 0.5 respectively.

4. MODEL APPLICATION AND DISSICUSION OF ESULTS

4.1. Sediment Transport Computations

The sediment transport component used to analyze for the stability of the channels is focused on providing for sediment continuity. From the context of stability that for the channel reaches neither to aggrade nor to degrade, the volume of material moving in must equal the volume of material moving out of the reaches. Hence an upstream sediment supply concentration must be used and against it the transport capacity of each of the reaches based on the given material size will be assessed. But there is not any measured sediment concentration data of the flow at the upstream boundaries. Therefore an assumed sediment supply must be developed .Upstream channel dimensions are used to calculate an equivalent sediment supply. Calculation of the upstream sediment concentration based on the calculation of the transport capacity of the upstream boundary can consider the worst condition scenario that the maximum sediment that can come form the catchment can never exceed the maximum transporting capacity of the cross section, based on many observations of natural rivers. (Bogardi, 1960)

Thus from the sediment transport analysis component in HEC-RAS 4.0 (beta),the equilibrium boundary condition is used, and then HEC-RAS will compute sediment transport capacity for each time step at a specified cross section and this is used as a sediment inflow.

The transport analysis is computed using the sediment transport formula by Yang (1984) which is applicable for gravel bed rivers at a wider range of particle size and channel geometry. The other thing that the Yang’s is preferable is that it uses the concept of the minimum stream power, the commonly used theory for analyzing the potential of degrading or aggrading of channel reaches. Further the model is also applied using the Meyer Peter Muller sediment transport formula as it is also applicable for gravel Bed Rivers, and its transport theory is based on the concept that the transport rate is proportional to the difference between the mean shear stress acting on the grain and the critical shear stress. Then based on this analysis model results are plotted and tabulated in the following sections.

4.2. CHANNEL STABILITY ANALYSIS

4.2.1. Bed Stability

Based on the model results which are analyzed using the Meyer Peter Muller and Yang's sediment transport formula, deposition is observed in almost all of the stations of the Borkena River. And there is deposition at some of the down stream stations in the tributary reach and degradation in the rest. Results are plotted and tabulated as follows.

According to the Meyer Peter Müller sediment transport formula, a maximum degradation to a depth of 1.5 m at station 26 and a deposition of 1.38m at station 2 of the tributary reaches is observed. But as shown in the plot of bed profile (fig 4.1), this river reach yet indicates a trend of degradation in most of the stations.

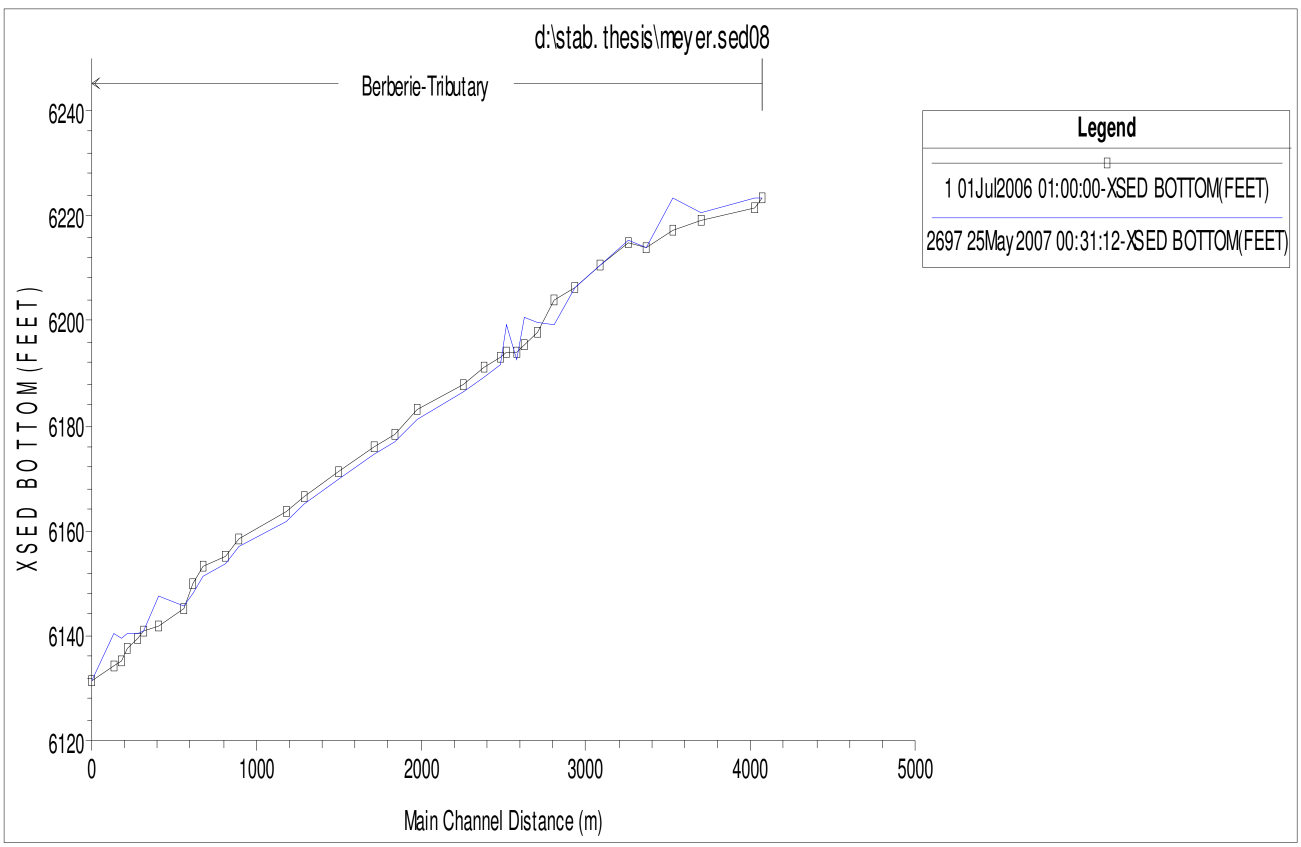

Figure 4-1: Bed profile plot of tributary reach for start and end of simulation times

Tabular results and time series plots for selected cross sections of the tributary reach according to this transport formula are shown below.

Table 4-1: Bed elevation differences along the bed profile of tributary reach. For one year time interval

Station	Elevation		Difference (m)
	Start of Simulation	End Of Simulation	
34.00	1896.89	1896.89	0.00
33.00	1896.35	1896.86	0.51
32.00	1895.56	1895.97	0.41
31.00	1895.06	1896.87	1.281
30.00	1894.00	1894.01	0.01
29.00	1894.24	1894.49	0.25
28.00	1893.00	1893.01	0.01
27.00	1891.69	1891.69	0.00
26.00	1891.00	1889.50	-1.50
25.00	1889.07	1889.68	0.61
24.00	1888.43	1890.02	1.59
23.00	1888.00	1887.51	-0.49
22.00	1887.98	1889.47	1.49
21.00	1887.68	1887.19	-0.49
20.00	1887.00	1886.49	-0.51
19.00	1886.04	1885.55	-0.49
18.00	1884.54	1884.05	-0.49
17.00	1883.19	1882.70	-0.49
16.00	1882.48	1882.00	-0.48
15.00	1881.00	1880.51	-0.49
14.00	1879.60	1879.05	-0.55
13.00	1878.63	1878.14	-0.49
12.00	1877.02	1876.59	-0.43
11.00	1876.14	1875.65	-0.49
10.00	1875.43	1874.91	-0.52
9.00	1874.43	1873.84	-0.59
8.00	1873.09	1873.18	0.09
7.00	1872.03	1873.72	1.69
6.00	1871.76	1871.77	0.01
5.00	1871.28	1871.54	0.26
4.00	1870.76	1871.53	0.77
3.00	1870.00	1871.26	1.26
2.00	1869.69	1871.53	1.34
1.00	1868.85	1868.86	0.01

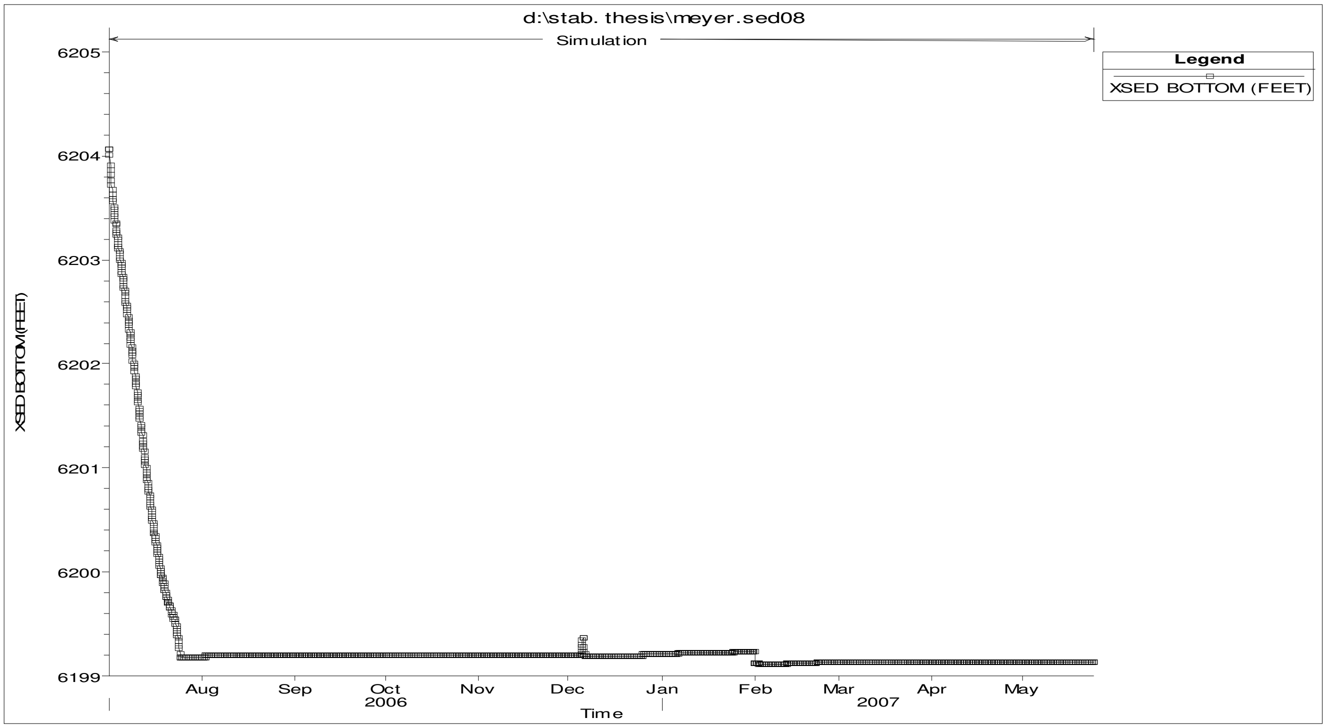

Figure 4-2: Time Series plots for cross section stations of 26 of tributary reach.

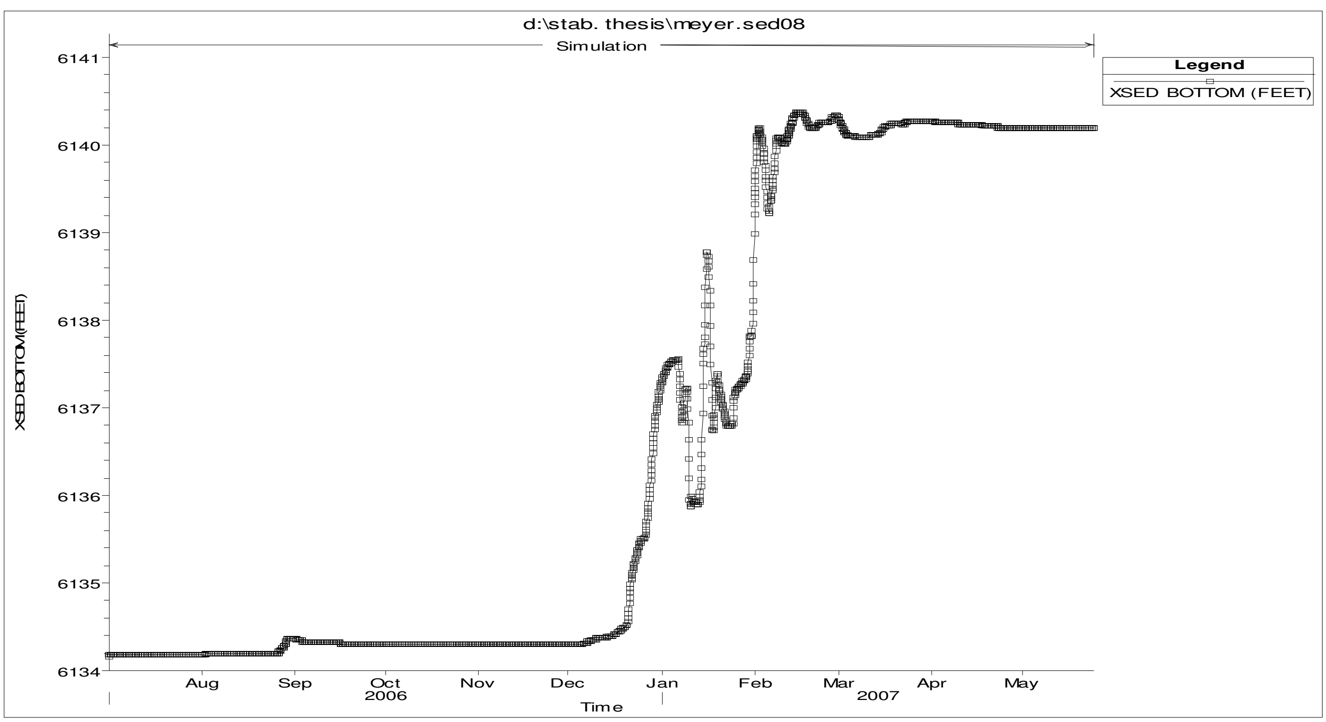

Figure 4-3: Time Series plots for cross section stations of 2 of tributary reach.

For the upper and lower reaches of the Borkena River the result shows only aggradations, and maximum aggradation seen is at river station 10 which is about 0.0235m, table below shows the deposition depths on each stations.

Table 4-2: Bed elevation changes along the bed profile of Borkena River for one year time interval

River station	Elevation		Difference
	Start of Simulation	End Of Simulation	
19.00	1875.10	1875.10	0.00
18.00	1874.60	1874.61	0.01
17.00	1873.78	1873.79	0.01
16.00	1872.88	1872.89	0.01
15.00	1871.76	1871.77	0.01
14.00	1871.41	1871.42	0.01
13.00	1870.68	1870.69	0.01
12.00	1869.72	1869.73	0.01
11.00	1869.13	1869.14	0.01
10.00	1868.48	1868.50	0.02
9.00	1868.39	1868.41	0.02
8.00	1866.96	1866.97	0.01
7.00	1865.11	1865.12	0.01
6.00	1863.75	1863.77	0.02
5.00	1862.62	1862.64	0.02
4.00	1861.34	1861.35	0.01
3.00	1860.70	1860.72	0.02
2.00	1860.03	1860.04	0.01
1.00	1859.68	1859.69	0.01

The graphs of the longitudinal profile and the time series plot are shown below. As compared to the practical expected bed elevation changes simply judged by field observation, as there are not measured data, the Meyer Peter Muller looks to work better with the tributary reach than that of the reaches on Borkena River. Although it shows aggradational trends, it under estimates the depth of deposition. Where as it better works the depth of deposition and erosion for the tributary reach so can effectively be used for analysis and design.

The other sediment formula used is the Yangs sediment transport formula .Most of the results are closer to those obtained by the Myer peter, but it over estimates aggradation at river station 2 of the tributary reach as above 2m depth of deposition which looks unrealistic.

The results by the Yangs are presented in the following tables and graphs. According to this formula aggradation results for the Borkena River stations look to have similar trends as that of the Meyer Peter, but the Yang gives more sound results on depth of deposition.

Table 4-3; Bed elevation changes along the bed profile of Borkena River according to Ynags

station	Elevation		Difference
	Start of Simulation	End Of Simulation	
19.00	1875.10	1875.10	0.00
18.00	1874.60	1874.62	0.02
17.00	1873.78	1873.79	0.01
16.00	1872.88	1872.89	0.01
15.00	1871.76	1871.78	0.02
14.00	1871.41	1871.43	0.01
13.00	1870.68	1870.69	0.01
12.00	1869.72	1869.74	0.02
11.00	1869.13	1869.14	0.01
10.00	1868.48	1869.70	1.22
9.00	1868.39	1868.42	0.03
8.00	1866.96	1866.97	0.01
7.00	1865.11	1865.13	0.02
6.00	1863.75	1863.76	0.01
5.00	1862.62	1862.64	0.02
4.00	1861.34	1861.36	0.02
3.00	1860.70	1860.72	0.02
2.00	1860.03	1860.05	0.02
1.00	1859.68	1859.70	0.02

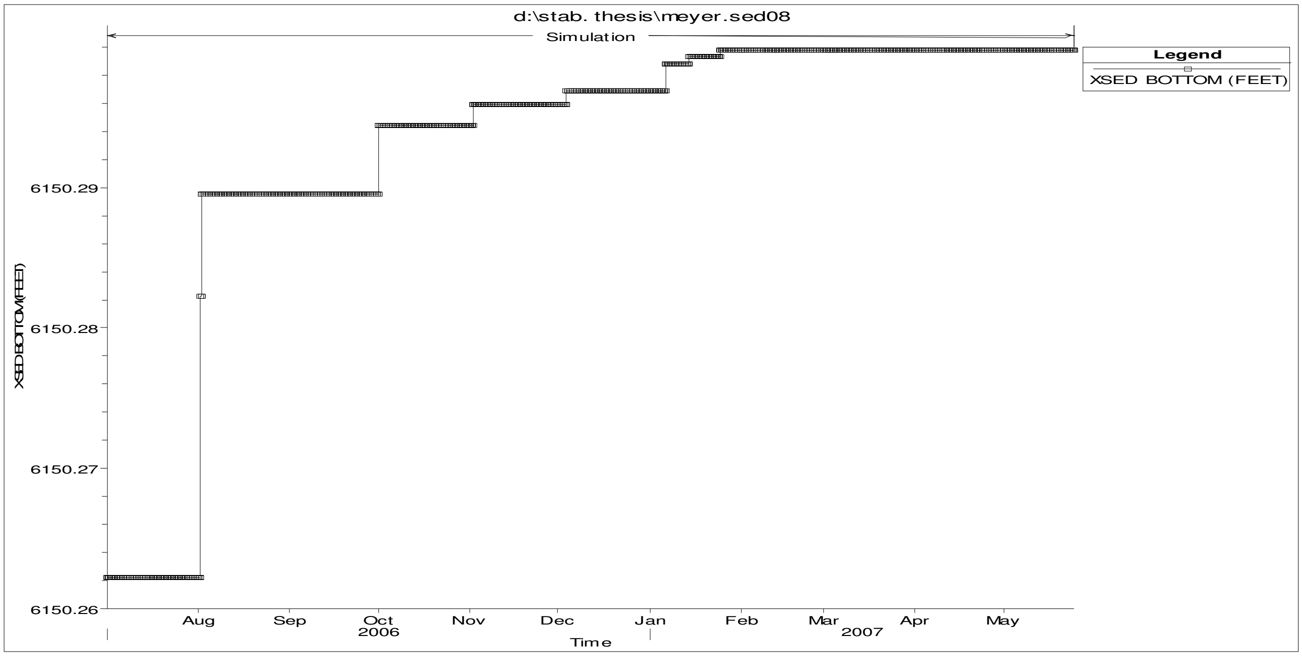

Figure 4-4: Time series cross section plot at stations 18 and 10 of Borkena River Station 18

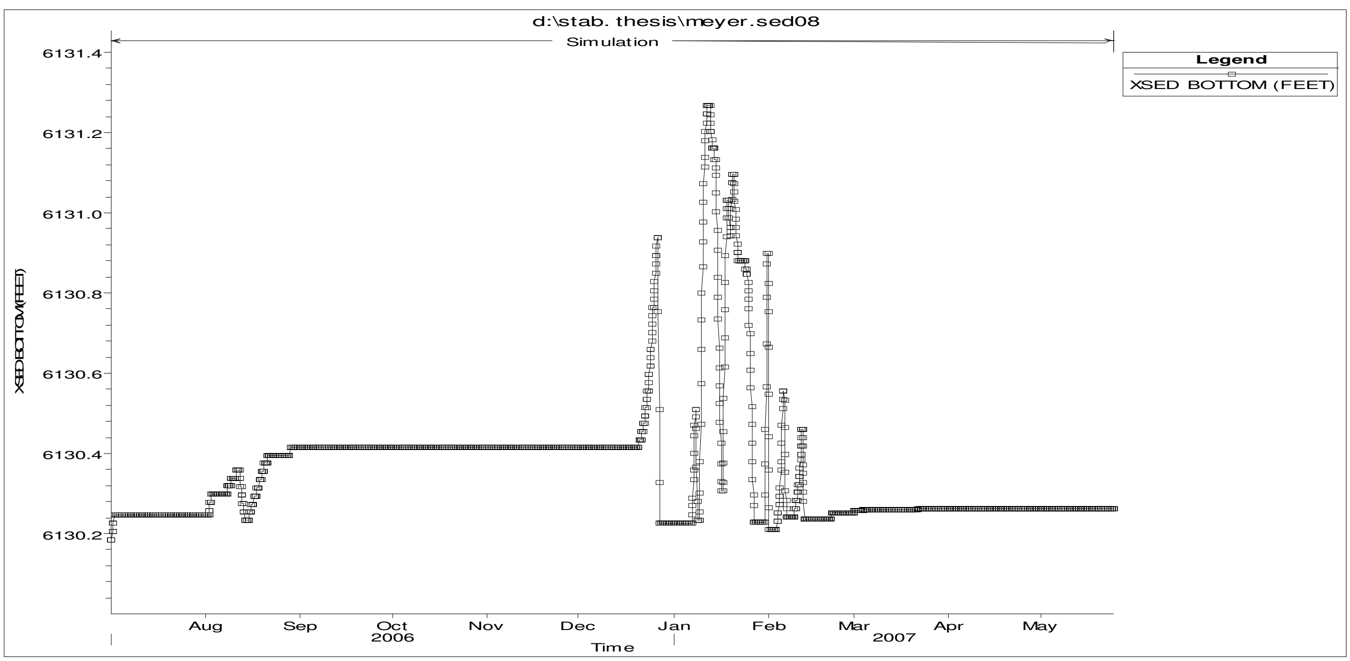

Figure 4-5: Time series plot at station 10

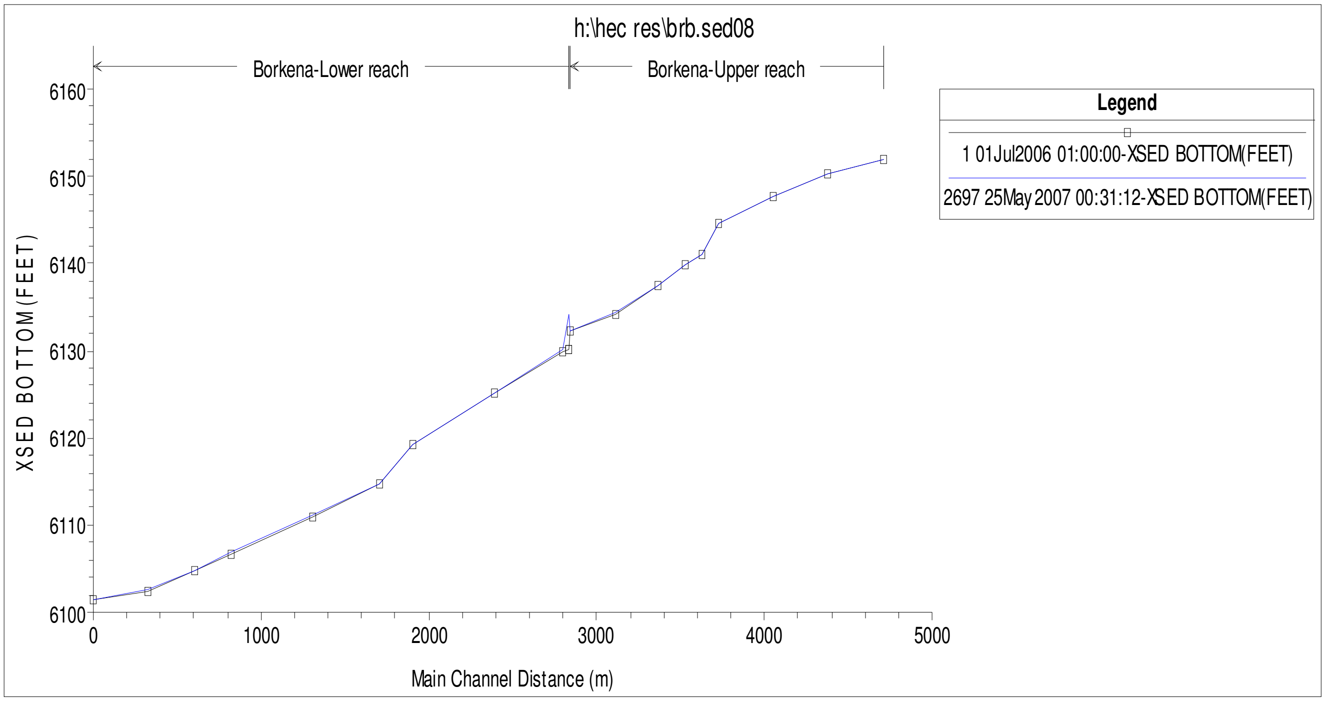

Figure 4-6: Bed profile plot of Borkena River reach at start & end of simulation time according to Yang

The time series plot for cross section stations at 26 and 2 of the tributary reach are also shown in the following graph. Though the results show similar trends as that by the Meyer peter Muller, the magnitudes are overestimated.

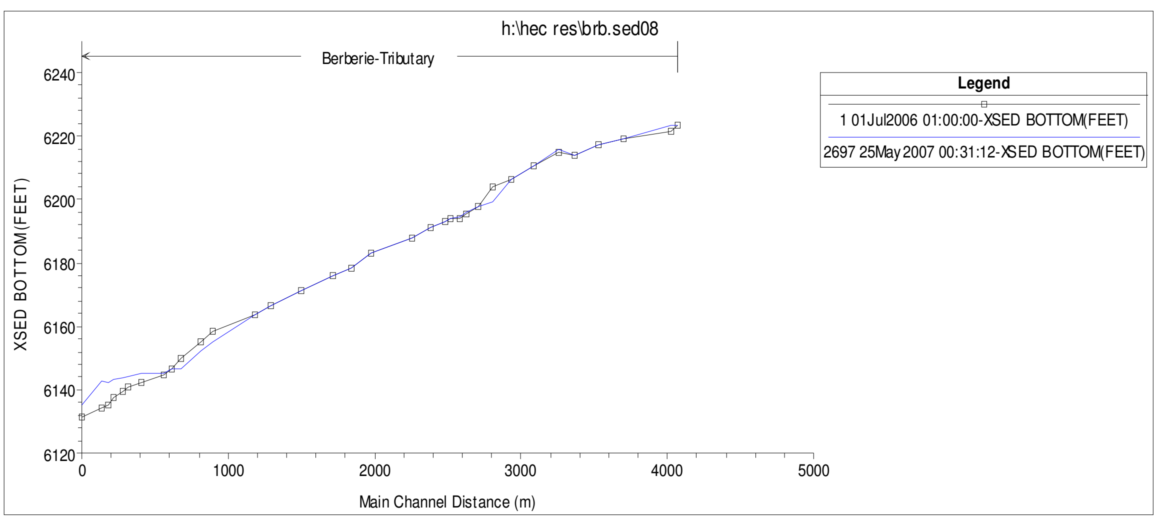

Figure 4-7: Bed profile plot of tributary reach for start and end of simulation times according to Yangs Transport formula

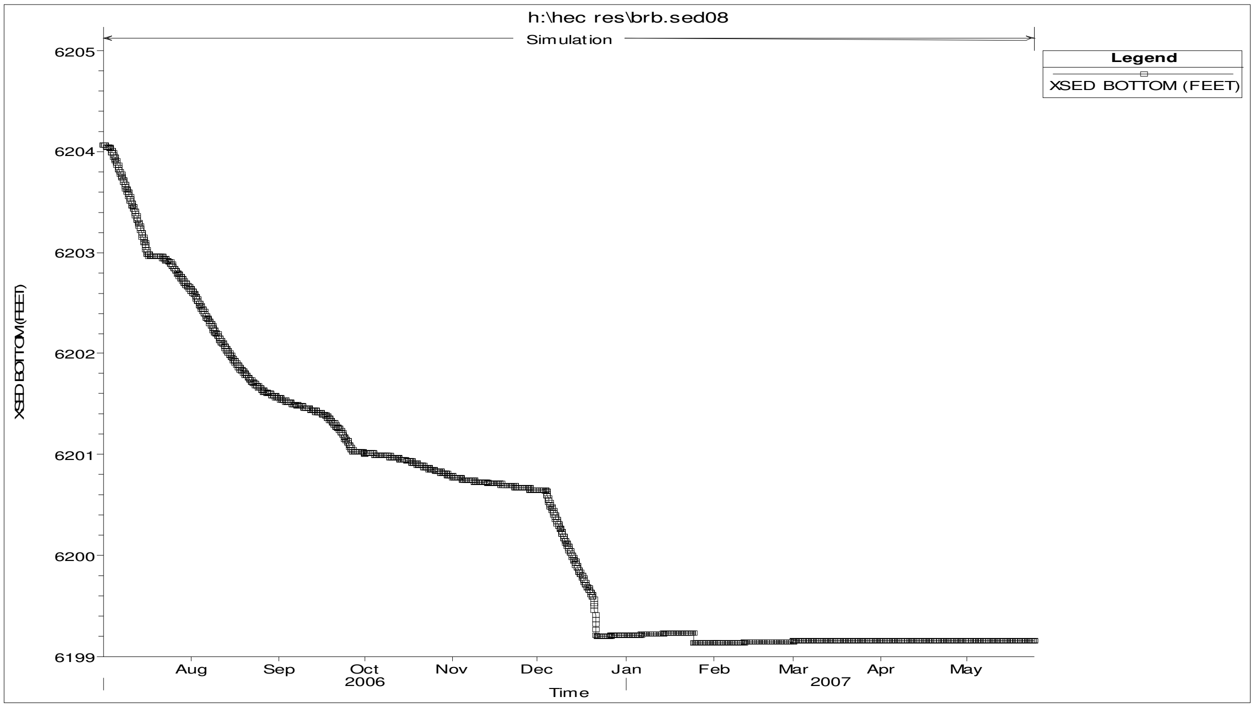

Figure 4-8: Time series plot at station 26 of tributary according to the Yang sediment transport

Table 4-4: Bed elevation differences along the bed profile of tributary reach

station	Elevation		Difference
	Start of Simulation	End Of Simulation	
34.00			0.00
33.00	1896.35	1896.86	0.51
32.00	1895.56	1895.58	0.02
31.00	1895.06	1895.02	-0.04
30.00	1894.00	1894.01	0.01
29.00	1894.24	1894.60	0.36
28.00	1893.00	1893.02	0.02
27.00	1891.69	1891.69	0.00
26.00	1891.00	1889.50	-1.50
25.00	1889.07	1889.08	0.01
24.00	1888.43	1888.44	0.01
23.00	1888.00	1888.01	0.01
22.00	1887.98	1887.99	0.01
21.00	1887.68	1887.70	0.02
20.00	1887.00	1887.02	0.02
19.00	1886.04	1886.06	0.02
18.00	1884.54	1884.55	0.01
17.00	1883.19	1883.20	0.01
16.00	1882.48	1882.50	0.02
15.00	1881.00	1881.01	0.01
14.00	1879.60	1879.61	0.01
13.00	1878.63	1878.63	0.00
12.00	1877.02	1876.04	-0.98
11.00	1876.14	1875.16	-0.98
10.00	1874.43	1873.44	-0.99
9.00	1873.43	1873.44	0.01
8.00	1872.85	1872.97	0.12
7.00	1872.20	1872.98	0.78
6.00	1871.76	1872.69	0.93
5.00	1871.28	1872.60	1.32
4.00	1870.76	1872.41	1.65
3.00	1870.00	1872.13	2.13
2.00	1869.69	1872.33	2.44
1.00	1868.85	1870.07	1.22

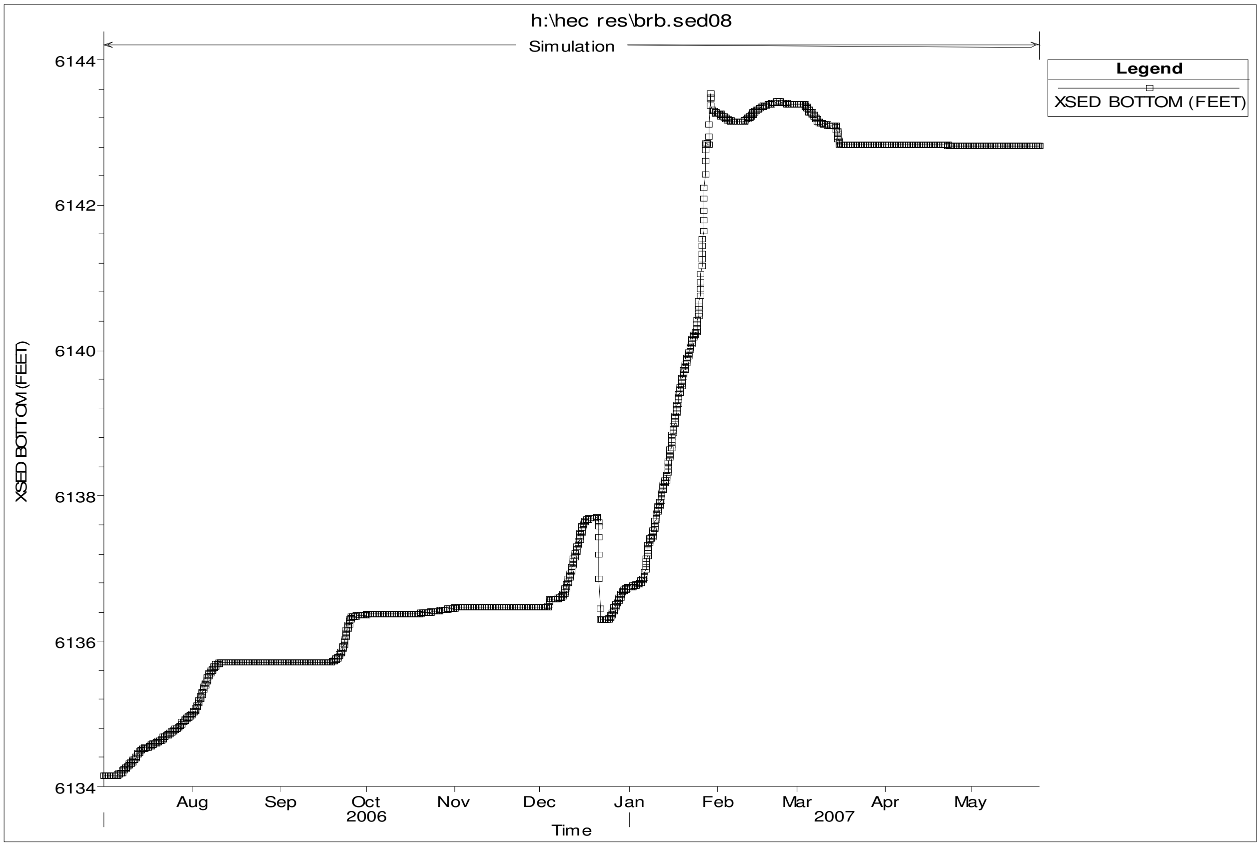

Figure 4-9: Time series plot at station 2 of tributary according to the Yang sediment transport

4.2.2. Bank Stability

The stability of the banks is evaluated by the resistance for erosion of the banks against the maximum and minimum shear stresses induced by the flow on the boundary, by the vegetation cover and from the geometry of the banks.

From the steady flow analysis, a shear induced due to the flow for the design discharges of 50Yr and 100 Yr together with the channel forming discharge which is taken as a 2 Yr return period is analyzed .

The maximum shear stress (N/m^2) on channel bed of the upper reach of Borkena is observed on station 13 and values are 134 for the 2 Yr, 200 for the 50 Yr and 205.57 for the100 Yr return periods. The minimum shear is observed at station 19 and values are, 14.72 for the two year return period, 28.37 for the 50 Yr return period, and 30.88 for the 100 Yr discharges. Similarly maximum shear induced at station 9 on lower reach of Borkena are 137, 240, 257.83 for 2, 50, and 100 Yr discharges respectively. And minimum shear stress is observed at station 1 in this reach and values are 8.49, 17.87, and 19.54 for the 2, 50, and 100 Yr discharges respectively. Taking 75% of the above values as the shear on the banks and this is compared with critical shear stress τ_c , for non cohesive bed material which is described by Shields.

$$\tau_c = \varphi_s \gamma (G_s - 1) d_s$$

Where:

G_s = specific gravity of particles (taken as 2.65)

d_s = particle size (the median size is taken)

φ_s = varies from 0.3 to 0.03 for sands and has an approximately constant value of 0.04 for coarse particles such as gravel and stone

γ = unit weight of water (9.81 KN/m^2)

Then for the lower reach d_{50} on the right bank is about 6mm thus τ_c = 4 N/m^2, which is even much lower than the minimum shear stress induced by any of the above designed flows.

The rest of the bank materials comprise finer material than the lower reach bank material but they also constitute a lesser amount of clay less than 50% which lack adequate adherence for resistance of shear. And the vegetation on the banks is dominated by grasses with rarely placed eucalyptus trees, shrubs and short height bushes whose roots are so shallow that there is not reinforcement of the banks due to vegetation cover. Thus the banks of Borkena River can generally get easily eroded and are less resistance to shear.

The slope of the banks on the tributary reach is nearly vertical that the angle of repose of the material is much lesser on almost all of the stations (Appendex1&2). It is due to the continuous degradation of the channel bed that the banks get steeper and steeper. From the principle that banks inclined at angles greater than the angle of repose of the material should not remain stable, the banks of the Berberie River are not stable. However there are factors that increase stability of even vertical slopes, such as better inter locking angularity of particles, density of the soil and reinforcing effects of other embedded materials such as roots of plants, composition of large materials of silts in the soil of the banks. But as the channel passes through the town there is not vegetation cover, and the soil on the bank of the river doesn't comprise significant amount of clay that can increase the binding effect of particles on the bank. Thus generally the banks on the tributary reach of the Berberie River are unstable.

4.3. Flood Way Delineation

Water surface profile for the design discharges of 2, 50, and 100 Yr return period discharge is calculated using Mannings method.

According to the results, the 2 Yr design discharge is almost accommodated with in the flood plain limits in all of the stations of the Borkena River reaches. But there is a condition that significant areas adjoining the flood could be flooded by the 50 and 100Yr design discharges. For example, on river stations from 19 to 15 a height of about 0.5m excess flood over flows the extent of the right and left flood plains, and this can inundate an extent of about 10 meters to the right and left sides of the flood plain for a terrain that slopes at not more than 3%.

A plot of water surface profile for selected cross sections is shown in figures below.

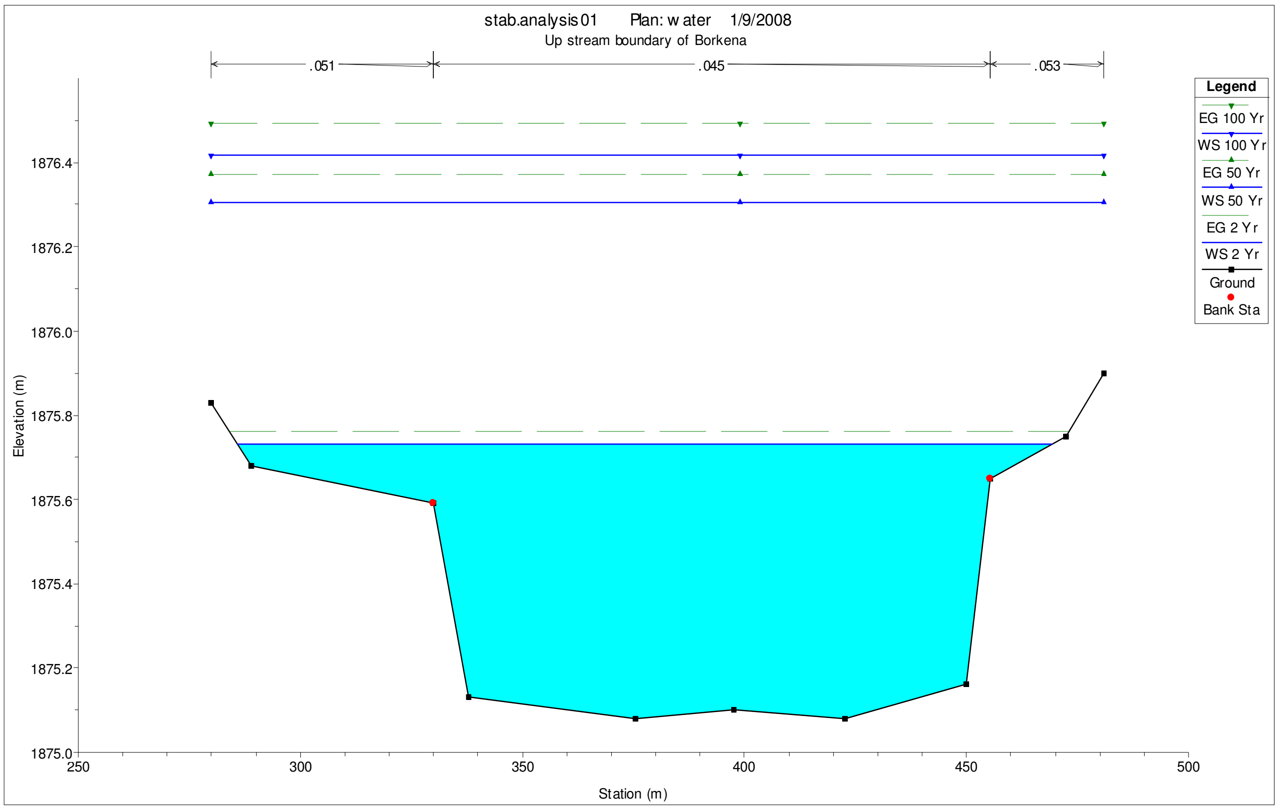

Figure 4-10: Cross section plots at station 19 of upper reach

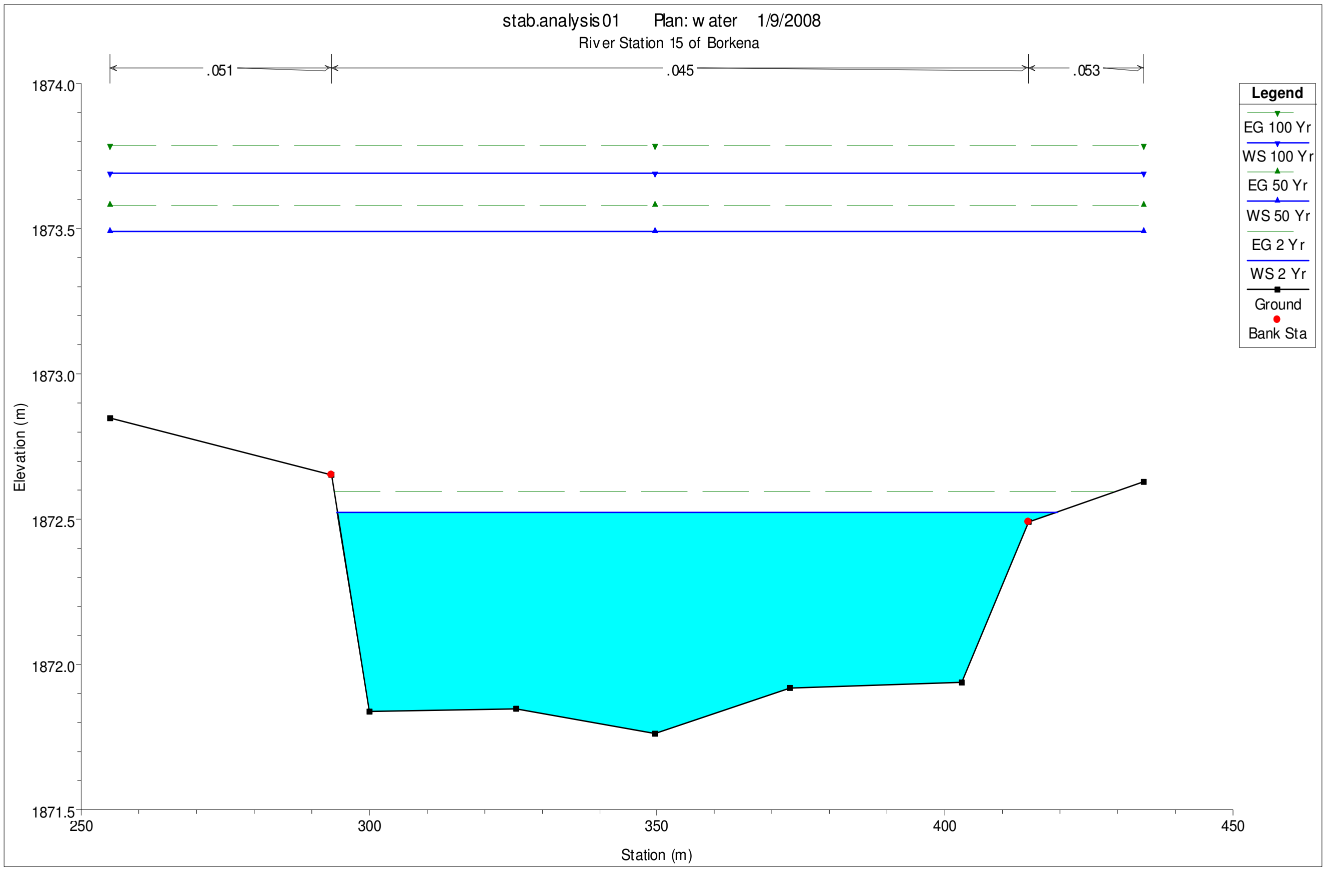

Figure 4-11: Cross section plot at station 15 of upper reach

In the lower reach of the Borkena River about 1.6m excess flood height at river station 2 and about 0.7m at station 8 is observed from the 100Yr design discharge. Over flooding of this much will affect an area to the extent of more than 30m to the right of the channel as the adjoining area is gently sloped at about 5%. The area on the right side along the lower reach can not be affected by the flood because the terrain is situated at a relatively higher elevation.

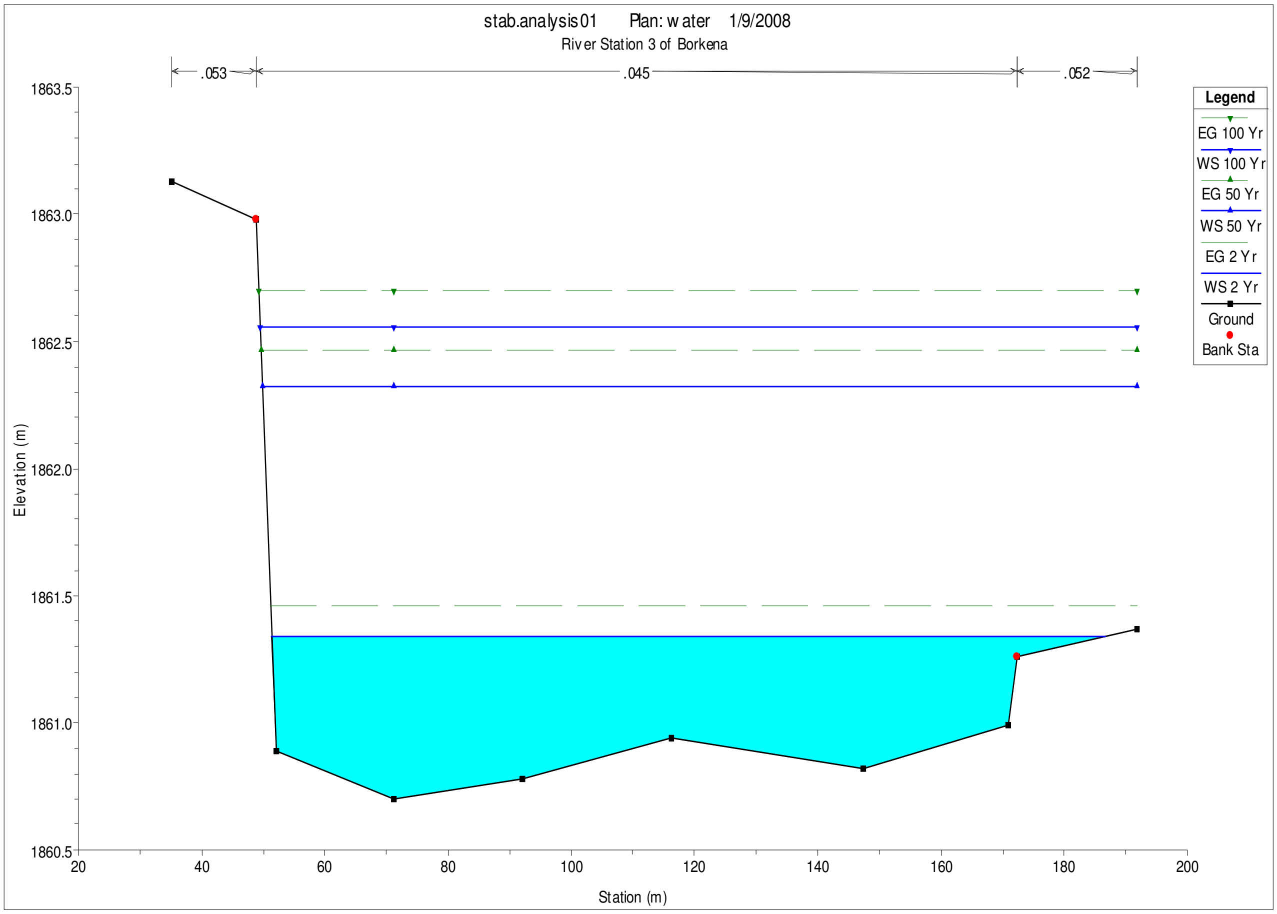

Figure 4-12 Cross section plot on River station 3 of Borkena River.

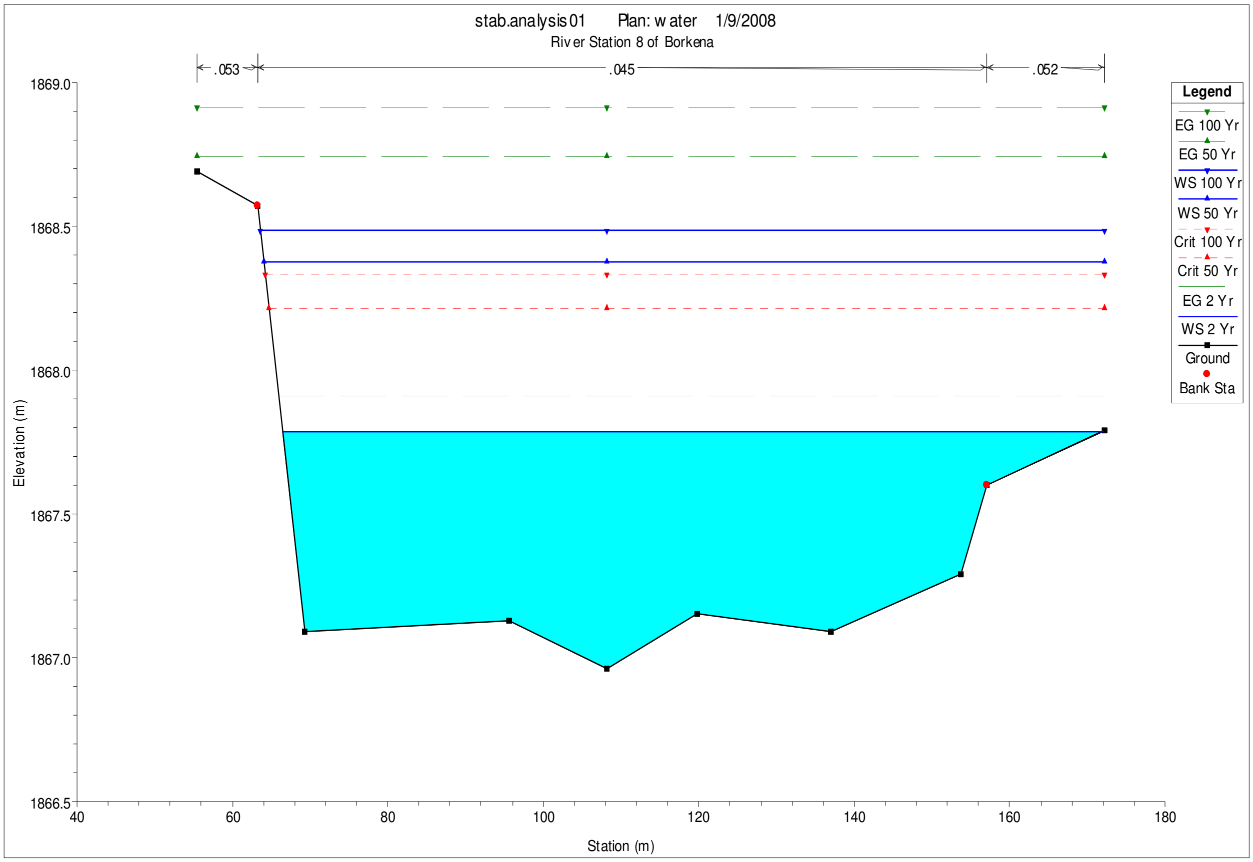

Figure 4-13: Cross section plot at station 8 of Borkena River

The longitudinal water surface profile plot and the x-y-z perspective plots of the Borkena River are shown below

As the sections on the tributary reach are deep there is not over flooding due the discharge from the 100 Yr return period, but there is a trend of aggradation and lateral widening. Results indicate that at stations 3 to 1 the water surface is approaching the bank levels so at these stations since there is problem of aggradation through time, the sections may get shallower and over flooding may occur.

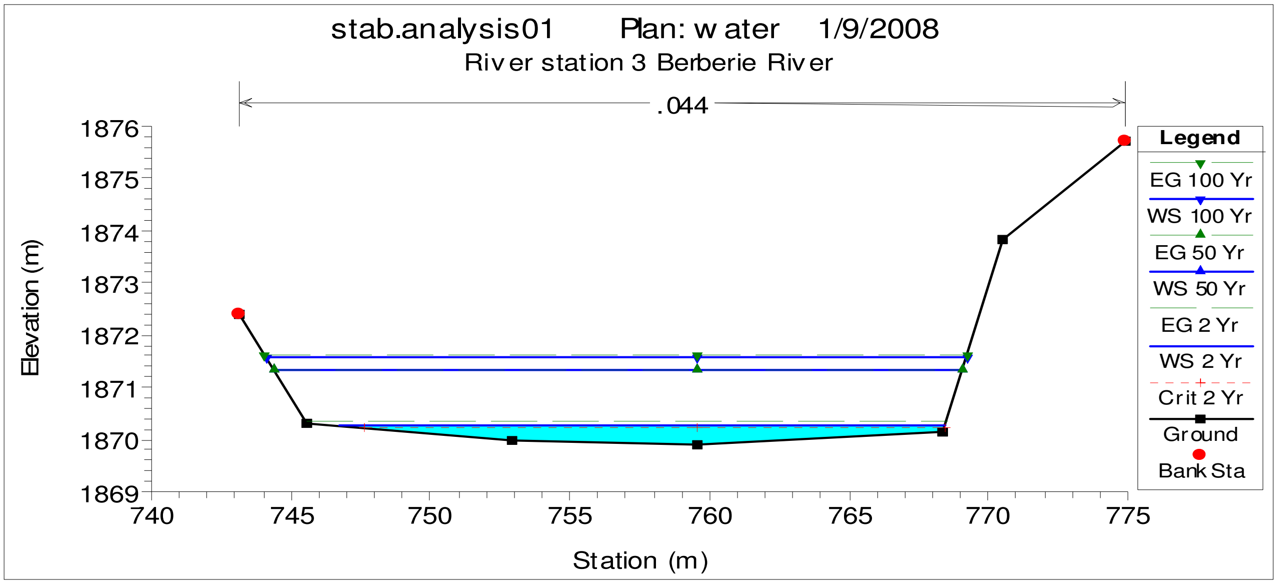

Figure 4-14: Cross section plot at river station 3 of Beriberi River

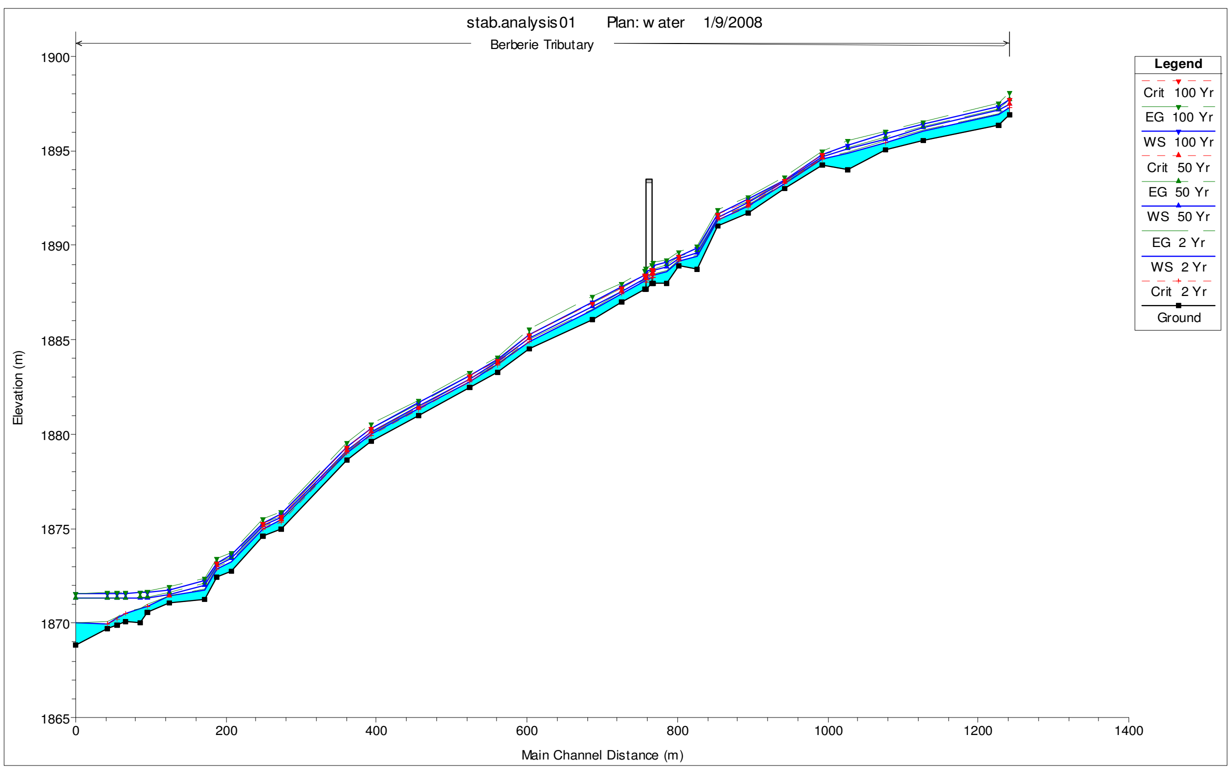

Figure 4-15: Water surface profile plots for the tributary reach

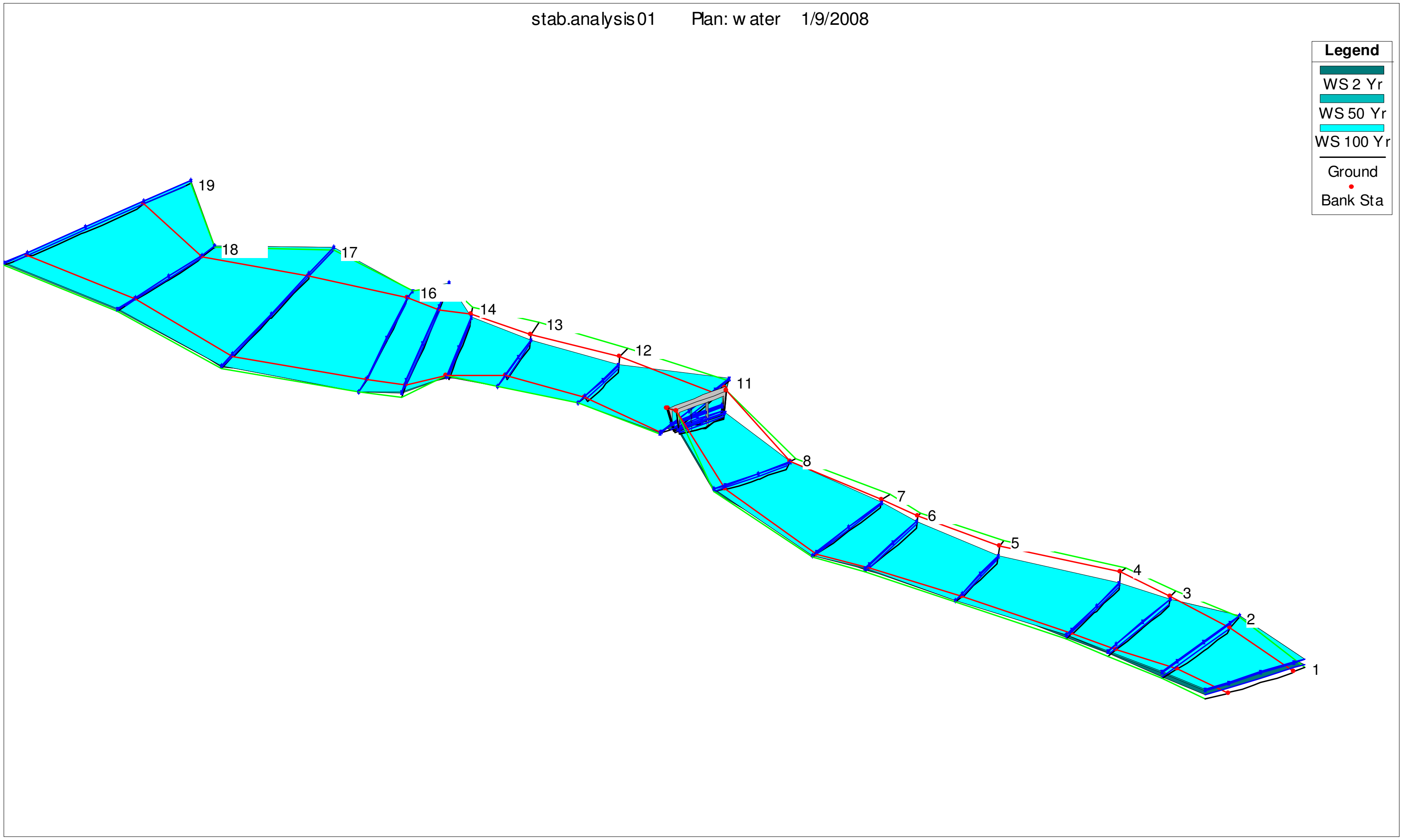

Figure 4-16: x-y-z perspective plots for 2, 50, 100 Yr discharge profiles

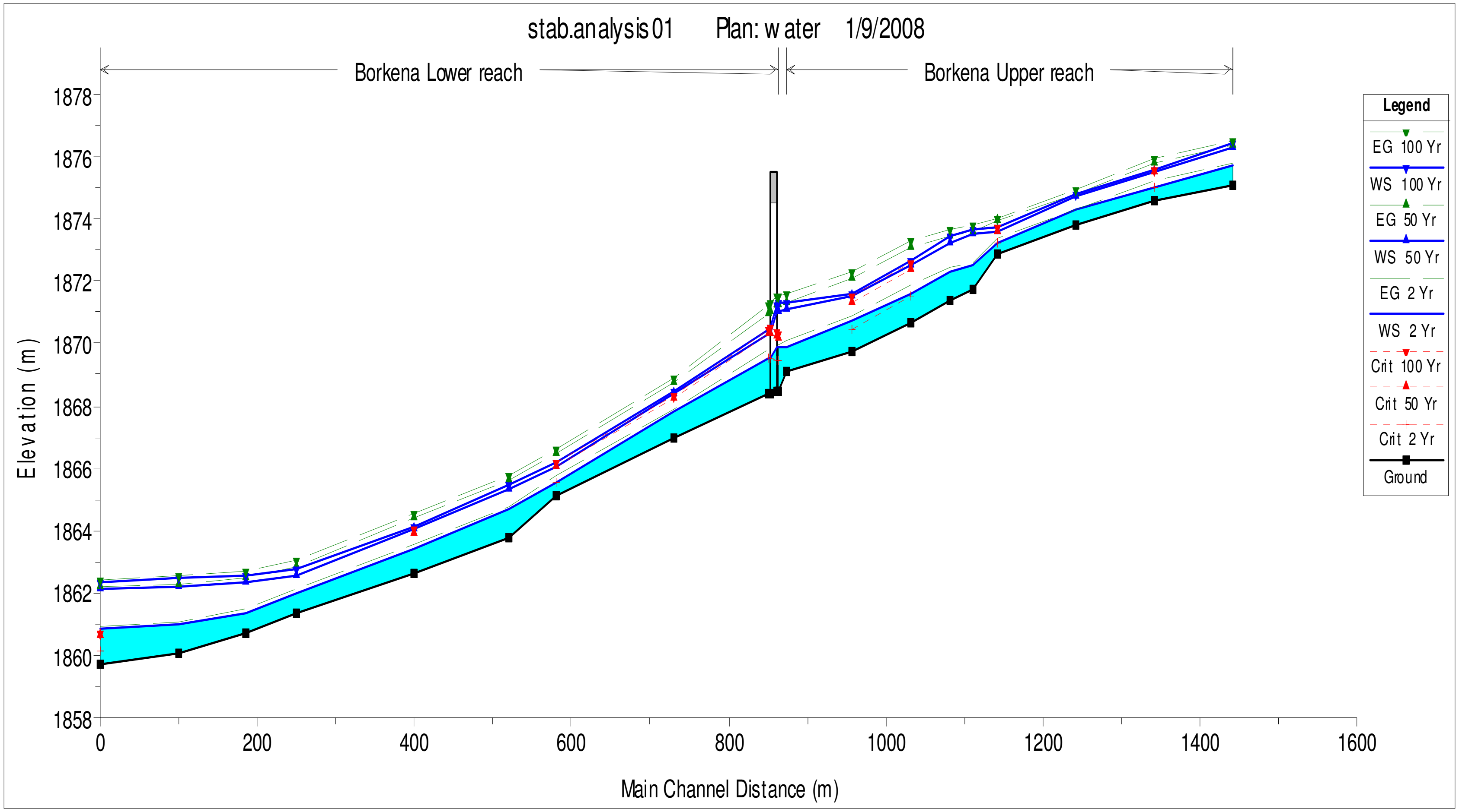

Figure 4-17: Water surface profile plots

4.4. *Discussion on Results*

4.4.1. Aggradations

It is shown that aggradations are observed in stations 4,3,2,1 in the tributary and in all the reaches of Borkena River. This reflects an excess of sediment load relative to the available transport energy. This is manifested in the development of mid channel bars, loss of channel cross section, increased frequency of over bank flooding, increased width to depth ratios ,increased lateral migration rates, reduced sinuosity, increased slope and tendency to wards braiding . Aggradations problem for the Borkena River could probably result from;

- Increased sediment yields from the up stream catchments as much of the catchments is densely populated which favors deforestation
- Increased sediment yields from mass wasting events such as land slides or debris flows as most part of the catchments is with in the grabbed high land mountains.
- Loss of bank stability due to reduced vegetative reinforcement, as the banks of the river are poorly vegetated because of uncontrolled continual man made destructions for farm extensions and fuel wood interests.

Thus while the channel is responding towards equilibrium through this process it affects the near by town infrastructures and the lives of people, so this process of aggradations need to be stabilized.

The first measure that must be provided to arrest the bed aggradations is by controlling erosion in the water shed or upstream reaches. More over grade control structures can be used to enhance vertical bed stability. For example channelization works which include excavating and cleaning channels, constructing cutoffs to increase the local slope, constructing flow control structures to reduce and control the local channel width can help increase the sediment transport capacity of the channel and reduce aggradations and control the lateral widening of the river.

4.4.2. Degradation

Erosion to an extent of 0.04 m 1.5m to is observed on stations 31, 10,11,12,26 in the tributary reach. This channel incision, or down cutting, is a response to some disturbance in which there is an increase in flow energy, usually through an increase in either slope or discharge. The incision process ultimately results in the development of a new channel profile at a lower elevation that has a lower slope and a regional balance with incoming sediment load. Although the causes of channel incision are highly variable, the response of these channels follows a predictable pattern that includes a series of evolutionary stages (Schumm et al, 1984).So for its eventual recovery the channel must pass a process that traces destabilization, down cutting, and widening etc. And this affects properties and lives of people on the adjoining areas.

The destabilization of the Beriberi River may result from:

- An increase in discharge due to deforestation, and urbanization as the catchment is highly degraded.
- Flow concentration by dikes and embankments. Guide walls are being constructed and it is for the new constricted cross section that the model is seen at stations 23, 22, 21, and 20.The guide wall is intended to protect erosion of at toe of the banks, and is about 1.5 m height. But as far as its design does not consider the sediment transport, the channel will under go a process to minimize its power and will tend to widen the cross section through the mass wasting process and finally over fill the guide walls, or it may continue to degrade and erode away the guide walls.
- A decrease in the size of the bed material (loss of erosion resistance in the channel bed), as the river passes cutting through the low land plain of the town in which finer material dominates the area even to a certain depth.

It is analyzed that bed degradation is observed and also stated that it causes catastrophic bank failures when critical thresholds of bank heights and angle are expected. Disastrous events due to bank failures during big floods have been reported repeatedly. Thus the proper measures should be selected to reduce the flow energy through flow modifications or grade control structures. Grade control can be achieved through the placement of large rocks at or near grade imbalances.

4.4.3. Bank Stability and Over Flooding

It is shown that the banks along the tributary reach are unstable due the scouring attacks of the shear and high velocity of the flow .Besides from the geotechnical point of view since the channel is incised the banks are vertical and mass failure of banks due to this phenomena is likely to happen.

The banks along the reaches of the Borkena River are also less resistance even to the minimum shear induced by the flow, apart from this the banks along this reach are shallower that over flooding still will be the problem which is resulted from the complex processes of aggradational problems.

Mass failure of the banks at the tributary reach particularly at stations where significant aggradations and erosion is observed is likely to happen and this is a series threat to the settlement areas adjoining this reach. And the conveyance capacity of the reaches in the Borkena River for the 100 and 50 Yr return periods is quite less that the water surface even extends to a greater area apart from the flood plains.

Thus to prevent the loss of lands and properties proper and sustainable stabilization measures must be employed. At the upper reach of the Borkena River dikes to a height greater than the observed 100 Yr flood must be provided at left and right banks of staions19, 18, 17, 16 &15, and at the lower reach dikes must also be constructed along the banks starting from station 8 and down stream. Bank stabilization measures such as use of stone revetments and the likes can be proposed to stabilize the banks together with the proposed bed stabilization measures.

For the banks in the tributary reach hard structures like reinforced concrete walls must be used on stations 33, 32, 26, 2, 1 etc. But as river change dynamics are so complex to predict it is not enough to set stabilization measures at these stations only and since this is completely an urban channel it is recommendable to stabilize the whole reach using the hard walls.

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5. CONCLUSION AND RECOMMENDATION

Using the existing channel characteristics such as channel dimensions, flow conditions, and sediment characteristics, hydraulic calculations are performed on Borkena and Berberie river channels crossing the Kombolcha town, and based on this calculation sediment transport continuity computation for analysis of vertical channel bed changes is made for each channel reach. The HEC-RAS 4.0 beta version is applied and results indicate that the channel beds are not stable. And as vertical stability is a prerequisite for lateral stability and as the banks are assessed not stable to support the bed instability, the river reaches are generally unstable.

The channel reaches pass through the highly populated and dynamic part of the town. The lateral widening of the rivers that result from aggradations and series bank failures due to scouring problems can cause destruction of near by structures and loss of important areas. Thus it is recommended that the proposed stabilization measures should be implemented with further engineering, economical and hydraulic analysis for effective and sustainable stabilization of the rivers.

The characteristics of stability and instability is best achieved through geomorphic assessment which is based on under standing of the geomorphic evolution of the channel as well as sediment transport dynamics, thus to effectively analyze its problem of instability a means to get timely based measured data on hydrological, hydraulic, geomorphic and sediment characteristics of the river must be developed.

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Appendix-1

Geometric Data

Reach Name	Upper Reach	Station		280.00	289.00	330.00	337.86	375.46	397.66	422.66	450.00	455.46	472.40	480.90
		Elevation		1875.83	1875.68	1875.59	1875.13	1875.08	1875.10	1875.08	1875.16	1875.65	1875.75	1875.90
Station Number	19	Down stream lengths	Left bank	97.40										
			Main Channel	100.00										
			Right bank	110.00										
		Expansion and contraction losses			E=0.3	C=0.1								

Reach Name	Upper Reach	Station		327.66	346.00	350.96	374.36	392.16	416.56	428.96	431.76	456.00
		Elevation		1875.25	1875.11	1874.63	1874.61	1874.64	1874.60	1874.68	1874.93	1875.16
Station Number	18	Down stream lengths	Left bank	94.00								
			Main Channel	100.00								
			Right bank	105.60								
		Expansion and contraction losses			E=0.3	C=0.1						

Reach Name	Upper Reach	Station		244.26	262.66	263.80	291.36	312.36	334.26	354.46	376.36	403.20	404.90	426.06
		Elevation		1874.35	1874.18	1873.83	1873.83	1873.80	1873.83	1873.78	1873.85	1873.85	1874.08	1874.11
Station Number	17	Down stream lengths	Left bank	117.50										
			Main Channel	100.00										
			Right bank	93.80										
		Expansion and contraction losses			E=0.3	C=0.1								

Reach Name	Upper Reach	Station		317.86	330.26	338.96	362.06	376.26	392.06	414.85	432.16	446.46	459.26	462.06	484.6
		Elevation		1873.70	1873.61	1872.95	1872.96	1872.88	1872.91	1872.88	1872.98	1872.96	1873.03	1873.46	1873.5
Station Number	16	Down stream lengths	Left bank	46.60	30.00	25.50									
			Main Channel	30.00											
			Right bank	25.50											
		Expansion and contraction losses			E=0.3	C=0.1									

Reach Name	Upper Reach	Station		271.76	293.46	295.96	325.46	349.68	377.46	408.46	414.46	434.46
		Elevation		1872.89	1872.65	1872.09	1871.85	1871.76	1871.92	1871.94	1872.49	1872.63
Station Number	15	Down stream lengths	Left bank	37.00								
			Main Channel	30.00								
			Right bank	28.00								
		Expansion and contraction losses			E=0.3	C=0.1						

Reach Name	Upper Reach	Station		232.01	240.08	245.66	275.86	300.00	311.00	332.00	339.00	340.44
		Elevation		1874.39	1874.14	1871.75	1871.56	1871.71	1871.41	1871.72	1873.80	1874.02
Station Number	14	Down stream lengths	Left bank	57.00								
			Main Channel	50.00								
			Right bank	43.00								
		Expansion and contraction losses			E=0.3	C=0.1						

Reach Name	Upper Reach	Station		238.20	247.30	250.96	267.46	279.16	281.79	286.14
		Elevation		1873.93	1873.84	1870.68	1871.05	1871.03	1872.22	1872.38
Station Number	13	Down stream lengths	Left bank	92.00						
			Main Channel	75.00						
			Right bank	69.60						
		Expansion and contraction losses			E=0.4	C=0.1				

Reach Name	Upper Reach	Station		193.23	204.15	207.46	219.46	229.96	241.56	244.74	249.78
		Elevation		1873.71	1873.58	1869.72	1869.96	1869.72	1869.90	1871.33	1871.51
Station Number	12	Down stream lengths	Left bank	91.00							
			Main Channel	84.00							
			Right bank	82.70							
		Expansion and contraction losses			E=0.3	C=0.1					

Reach Name	Upper Reach	Station		148.60	180.00	186.10	203.10	226.90	242.20	243.90	283.80
		Elevation		1870.63	1870.54	1869.28	1869.13	1869.17	1869.30	1870.89	1871.03
Station Number	11	Down stream lengths	Left bank	21.00							
			Main Channel	19.00							
			Right bank	19.00							
		Expansion and contraction losses		E=0.3	C=0.1						

Reach Name	Lower Reach	Station		120.00	123.62	136.31	155.88	160.37	169.02	198.13	198.13	200.00
		Elevation		1875.70	1875.37	1869.07	1868.80	1868.48	1868.99	1868.93	1875.36	1875.65
Station Number	10	Down stream lengths	Left bank	9.00								
			Main Channel	9.00								
			Right bank	9.00								
		Expansion and contraction losses		E=0.5	C=0.3							

Reach Name	Lower Reach	Station		125.00	127.92	149.96	149.96	157.55	169.60	182.76	200.98	202.50
		Elevation		1875.70	1875.69	1868.48	1868.56	1868.39	1868.75	1869.40	1875.16	1875.65
Station Number	9	Down stream lengths	Left bank	122.00								
			Main Channel	122.00								
			Right bank	120.50								
		Expansion and contraction losses		E=0.5	C=0.3							

Reach Name	Lower Reach	Station		55.46	63.29	69.36	95.55	108.15	119.86	137.06	153.66	157.04	172.26
		Elevation		1868.69	1868.57	1867.09	1867.13	1866.96	1867.15	1867.09	1867.29	1867.60	1867.79
Station Number	8	Down stream lengths	Left bank	152.40									
			Main Channel	150.00									
			Right bank	150.00									
		Expansion and contraction losses		E=0.3	C=0.1								

Reach Name	Lower Reach	Station		0.00	16.55	14.56	60.86	119.16	151.16	155.14	165.12
		Elevation		1866.72	1866.68	1865.21	1865.11	1865.20	1865.54	1865.71	1865.74
Station Number	7	Down stream lengths	Left bank		65.40						
			Main Channel		60.00						
			Right bank		60.00						
		Expansion and contraction losses				E=0.3	C=0.1				

Reach Name	Lower Reach	Station		20.16	28.46	32.26	75.06	104.73	140.96	144.95	154.85
		Elevation		1866.59	1866.53	1864.04	1863.75	1864.38	1864.44	1864.66	1864.70
Station Number	6	Down stream lengths	Left bank		120.70						
			Main Channel		120.00						
			Right bank		118.90						
		Expansion and contraction losses				E=0.3	C=0.1				

Reach Name	Lower Reach	Station		44.90	54.51	61.66	90.11	123.66	151.76	154.74	172.86
		Elevation		1866.49	1866.31	1862.68	1862.62	1862.94	1863.06	1863.45	1863.65
Station Number	5	Down stream lengths	Left bank		152.00						
			Main Channel		150.00						
			Right bank		150.00						
		Expansion and contraction losses				E=0.3	C=0.1				

Reach Name	Lower Reach	Station		30.40	42.64	46.36	61.60	85.12	110.26	139.44	162.66	166.23	179.71
		Elevation		1865.25	1865.18	1861.43	1861.34	1861.46	1861.45	1861.45	1861.63	1861.86	1861.88
Station Number	4	Down stream lengths	Left bank		67.00								
			Main Channel		65.00								
			Right bank		65.00								
		Expansion and contraction losses				E=0.3	C=0.1						

Reach Name	Lower Reach	Station		35.06	48.90	52.06	71.21	92.06	116.26	147.36	170.96	172.26	191.78
		Elevation		1863.13	1862.98	1860.89	1860.70	1860.78	1860.94	1860.82	1860.99	1861.26	1861.37
Station Number	3	Down stream lengths	Left bank		82.10								
			Main Channel		85.00								
			Right bank		87.06								
		Expansion and contraction losses				E=0.3	C=0.1						

Reach Name	Lower Reach	Station		36.76	57.86	62.36	80.90	102.22	125.83	145.03	160.86	165.86	196.96
		Elevation		1862.02	1861.26	1860.15	1860.13	1860.03	1860.17	1860.06	1860.25	1860.62	1860.85
		Down stream lengths	Left bank		93.20								
Station Number	2		Main Channel		100.00								
			Right bank		107.67								
		Expansion and contraction losses				E=0.3	C=0.1						

Reach Name	Lower Reach	Station		53.56	67.83	69.96	91.68	106.88	125.14	140.03	156.26	160.06	191.96
		Elevation		1860.14	1860.09	1859.72	1859.69	1859.71	1859.68	1859.73	1859.74	1859.84	1859.92
		Down stream lengths	Left bank		0.00								
Station Number	1		Main Channel		0.00								
			Right bank		0.00								
		Expansion and contraction losses				E=0.3	C=0.1						

Reach Name	Tributary	Station		340.85	342.03	345.65	351.57	355.89	357.24
		Elevation		1908.68	1896.89	1896.00	1896.20	1897.02	1904.08
		Down stream lengths	Left bank		19.14	slope of banks	Right bank		84.30
Station Number	34		Main Channel		14.12		Left bank		80.00
			Right bank		14.04				
		Expansion and contraction losses				E=0.4	C=0.1		

Reach Name	Tributary	Station		358.03	358.20	365.80	367.30	383.00	393.58	394.88
		Elevation		1907.74	1905.20	1903.66	1897.32	1896.35	1897.02	1904.34
		Down stream lengths	Left bank		139.36	slope of banks	Right bank		76.70	
Station Number	33		Main Channel		100.28		Left bank		80.00	
			Right bank		90.63					
		Expansion and contraction losses				E=0.3	C=0.2			

Reach Name	Tributary	Station		462.30	463.90	473.30	475.80	496.05	499.10	500.10	504.29
		Elevation		1902.26	1901.34	1901.04	1895.80	1895.56	1896.05	1900.08	1901.26
		Down stream lengths	Left bank		76.87	slope of banks	Right bank		64.50		
Station Number	32		Main Channel		50.77		Left bank		76.10		
			Right bank		41.30						
		Expansion and contraction losses				E=0.3	C=0.2				

Reach Name	Tributary	Station		394.04	395.86	401.90	409.10	417.23	418.90
		Elevation		1902.46	1895.16	1895.40	1895.06	1895.20	1900.66
Station Number	31	Down stream lengths	Left bank		42.87	slope of banks	Right bank		76.00
			Main Channel		49.75		Left bank		73.00
			Right bank		61.56				
		Expansion and contraction losses				E=0.5	C=0.2		

Reach Name	Tributary	Station		355.96	357.12	360.04	365.80	371.57	372.68
		Elevation		1901.57	1894.79	1894.57	1894.00	1894.90	1899.07
Station Number	30	Down stream lengths	Left bank		71.03	slope of banks	Right bank		80.30
			Main Channel		50.54		Left bank		75.10
			Right bank		35.36				
		Expansion and contraction losses				E=0.3	C=0.1		

Reach Name	Tributary	Station		379.08	379.70	384.80	386.50	400.96	408.24	415.21	416.35
		Elevation		1900.44	1898.73	1897.50	1894.44	1894.24	1894.44	1894.35	1896.74
Station Number	29	Down stream lengths	Left bank		71.03	slope of banks	Right bank		61.00		
			Main Channel		50.54		Left bank		64.50		
			Right bank		35.36						
		Expansion and contraction losses				E=0.5	C=0.1				

Reach Name	Tributary	Station		432.70	434.70	444.60	446.70	458.20	467.58	478.51	498.30	500.60
		Elevation		1901.50	1898.00	1897.00	1893.24	1893.00	1893.10	1893.20	1893.27	1896.49
Station Number	28	Down stream lengths	Left bank		57.36	slope of banks	Right bank		61.00			
			Main Channel		47.88		Left bank		64.50			
			Right bank		42.90							
		Expansion and contraction losses				E=0.3	C=0.1					

Reach Name	Tributary	Station		415.45	418.00	426.80	439.05	446.24	448.00	454.90	456.93
		Elevation		1897.52	1892.40	1891.83	1891.69	1892.00	1897.73	1899.00	1899.62
Station Number	27	Down stream lengths	Left bank		41.35	slope of banks	Right bank		84.30		
			Main Channel		39.85		Left bank		80.00		
			Right bank		40.42						
		Expansion and contraction losses				E=0.5	C=0.1				

Reach Name	Tributary	Station		415.45	416.00	420.90	422.00	428.93	439.05	446.24	448.30	455.70	457.06
		Elevation		1899.62	1898.27	1897.20	1891.30	1891.12	1891.00	1891.30	1896.74	1897.09	1898.82
Station Number	26	Down stream lengths	Left bank		25.30	slope of banks	Right bank		84.30				
			Main Channel		28.64		Left bank		80.00				
			Right bank		40.16								
		Expansion and contraction losses				E=0.5	C=0.1						

Reach Name	Tributary	Station		280.00	289.00	330.00	337.86	375.46	397.66	422.66	450.00	455.46	472.40	480.90
		Elevation		1875.83	1875.68	1875.59	1875.13	1875.08	1875.10	1875.08	1875.16	1875.65	1875.75	1875.90
Station Number	25	Down stream lengths	Left bank		97.40	slope of banks	Right bank		79.40					
			Main Channel		100.00		Left bank		69.30					
			Right bank		110.00									
		Expansion and contraction losses				E=0.4	C=0.08							

Reach Name	Tributary	Station		440.91	441.40	447.60	449.20	463.10	476.10	476.67	485.50	486.55
		Elevation		1894.33	1892.29	1891.40	1889.07	1888.93	1888.98	1890.24	1890.49	1891.13
Station Number	24	Down stream lengths	Left bank		17.12	slope of banks	Right bank		55.50			
			Main Channel		16.38		Left bank		65.70			
			Right bank		17.49							
		Expansion and contraction losses				E=0.4	C=0.1					
Reach Name	Tributary	Station		442.02	443.89	453.20	463.00	471.12	472.58			
		Elevation		1893.57	1888.81	1888.67	1888.00	1888.75	1890.77			
Station Number	23	Down stream lengths	Left bank		14.78	slope of banks	Right bank		55.50			
			Main Channel		16.90		Left bank		65.70			
			Right bank		20.10							
		Expansion and contraction losses				E=0.3	C=0.2					

Reach Name	Tributary	Station		451.28	452.67	459.61	468.89	472.28	473.03	
		Elevation		1893.20	1888.35	1887.98	1888.00	1890.20	1893.00	
		Down stream lengths	Left bank		9.77	slope of banks	Right bank		74.00	
Station Number	22		Main Channel		12.32		Left bank		75.00	
			Right bank		10.31					
		Expansion and contraction losses				E=0.5	C=0.3			

Reach Name	Tributary	Station		453.04	455.20	459.16	467.00	473.70	475.65	477.34
		Elevation		1893.93	1888.00	1887.68	1887.84	1887.90	1891.13	1893.67
		Down stream lengths	Left bank		29.52	slope of banks	Right bank		70.00	
Station Number	21		Main Channel		30.79		Left bank		56.40	
			Right bank		40.26					
		Expansion and contraction losses				E=0.5	C=0.3			

Reach Name	Tributary	Station		477.91	479.00	485.00	491.26	498.00	502.12	503.36
		Elevation		1890.26	1887.20	1887.40	1887.26	1887.00	1887.30	1890.26
		Down stream lengths	Left bank		39.22	slope of banks	Right bank		70.40	
Station Number	20		Main Channel		38.65		Left bank		67.30	
			Right bank		39.16					
		Expansion and contraction losses				E=0.3	C=0.1			

Reach Name	Tributary	Station		498.60	499.87	504.40	512.76	520.43	521.50	
		Elevation		1894.22	1886.50	1886.04	1886.27	1890.22	1893.80	
		Down stream lengths	Left bank		80.17	slope of banks	Right bank		80.70	
Station Number	19		Main Channel		83.42		Left bank		73.40	
			Right bank		90.08					
		Expansion and contraction losses				E=0.3	C=0.1			

Reach Name	Tributary	Station		561.80	562.70	567.90	569.33	580.48	588.20	589.47
		Elevation		1889.54	1888.48	1887.50	1884.91	1884.54	1884.69	1890.14
		Down stream lengths	Left bank		44.35	slope of banks	Right bank		61.10	
Station Number	18		Main Channel		42.25		Left bank		76.90	
			Right bank		49.49					
		Expansion and contraction losses				E=0.3	C=0.1			

Reach Name	Tributary	Station		610.70	612.00	620.60	629.03	638.70	650.30	651.50	665.90	665.63
		Elevation		1886.59	1883.60	1883.25	1883.59	1883.72	1883.37	1885.60	1886.76	1888.99
		Down stream lengths	Left bank		47.19	slope of banks	Right bank		66.50			
Station Number	17		Main Channel		38.04		Left bank		61.70			
			Right bank		26.98							
		Expansion and contraction losses				E=0.4	C=0.3					

Reach Name	Tributary	Station		646.30	647.18	650.00	657.80	669.24	679.20	683.90	690.00	691.23
		Elevation		1887.63	1886.00	1882.48	1883.00	1882.50	1882.50	1886.32	1886.89	1888.53
		Down stream lengths	Left bank		71.70	slope of banks	Right bank		61.60			
Station Number	16		Main Channel		66.53		Left bank		53.10			
			Right bank		60.44							
		Expansion and contraction losses				E=0.3	C=0.2					

Reach Name	Tributary	Station		657.51	659.50	665.80	676.09	682.00	690.00	691.10
		Elevation		1886.03	1881.20	1881.10	1881.23	1881.00	1881.40	1886.43
		Down stream lengths	Left bank		63.29	slope of banks	Right bank		67.60	
Station Number	15		Main Channel		63.84		Left bank		77.70	
			Right bank		64.30					
		Expansion and contraction losses				E=0.3	C=0.2			

Reach Name	Tributary	Station		692.28	693.40	701.20	710.00	716.30	717.54
		Elevation		1886.70	1880.00	1879.69	1879.60	1880.30	1887.60
		Down stream lengths	Left bank		33.53	slope of banks	Right bank		80.50
Station Number	14.00		Main Channel		31.43		Left bank		80.40
			Right bank		28.66				
		Expansion and contraction losses				E=0.3	C=0.2		

Reach Name	Tributary	Station		697.16	701.20	706.49	714.67	721.70	725.14
		Elevation		1885.57	1878.70	1878.67	1878.93	1878.63	1886.77
		Down stream lengths	Left bank	89.47	slope of banks	Right bank		59.60	
Station Number	13		Main Channel	88.70		Left bank		67.10	
			Right bank	87.64					
		Expansion and contraction losses			E=0.3	C=0.1			

Reach Name	Tributary	Station		707.14	709.00	716.10	719.40	731.46	750.20	754.30
		Elevation		1883.28	1879.90	1879.27	1875.00	1875.48	1874.95	1881.38
		Down stream lengths	Left bank	17.85	slope of banks	Right bank		52.30		
Station Number	12		Main Channel	24.20		Left bank		57.50		
			Right bank	30.18						
		Expansion and contraction losses			E=0.4	C=0.2				

Reach Name	Tributary	Station		708.88	709.70	716.20	718.70	727.94	745.60	747.97
		Elevation		1882.01	1879.80	1878.90	1874.93	1874.61	1875.14	1879.41
		Down stream lengths	Left bank	43.72	slope of banks	Right bank		57.80		
Station Number	11		Main Channel	41.40		Left bank		61.00		
			Right bank	41.65						
		Expansion and contraction losses			E=0.2	C=0.1				

Reach Name	Tributary	Station		728.44	729.20	739.40	742.40	755.80	768.20	769.90	776.70	776.91
		Elevation		1880.62	1878.67	1877.05	1873.08	1872.76	1873.30	1876.86	1878.71	1879.92
		Down stream lengths	Left bank	24.00	slope of banks	Right bank		52.90				
Station Number	10		Main Channel	18.69		Left bank		64.50				
			Right bank	15.64								
		Expansion and contraction losses			E=0.2	C=0.1						

Reach Name	Tributary	Station		732.06	733.30	742.70	745.20	758.80	768.20	768.80	775.70	776.80
		Elevation		1879.85	1877.88	1876.20	1872.90	1872.45	1873.00	1875.77	1878.00	1879.55
		Down stream lengths	Left bank	15.14	slope of banks	Right bank		52.90				
Station Number	9		Main Channel	16.84		Left bank		77.80				
			Right bank	20.09								
		Expansion and contraction losses			E=0.3	C=0.1						

Reach Name	Tributary	Station		734.53	735.00	742.90	746.79	758.32	765.23	770.86	772.23	
		Elevation		1879.35	1877.84	1876.40	1871.24	1871.26	1872.00	1876.26	1878.25	
Station Number	8	Down stream lengths	Left bank	43.40	slope of banks	Right bank		53.00				
			Main Channel	47.07		Left bank		55.50				
			Right bank	46.41								
		Expansion and contraction losses			E=0.3	C=0.1						

Reach Name	Tributary	Station		742.95	744.54	752.40	754.70	765.30	777.80	780.00	789.00	788.81
		Elevation		1878.66	1877.00	1874.86	1871.26	1871.06	1871.17	1874.55	1876.89	1878.00
Station Number	7	Down stream lengths	Left bank	36.47	slope of banks	Right bank		57.40				
			Main Channel	29.13		Left bank		56.90				
			Right bank	23.07								
		Expansion and contraction losses			E=0.3	C=0.2						

Reach Name	Tributary	Station		757.11	759.00	768.90	770.70	786.42	792.30	795.70	807.60	809.51
		Elevation		1877.97	1877.00	1874.70	1870.88	1870.57	1870.80	1874.87	1875.75	1877.17
Station Number	6	Down stream lengths	Left bank	11.11	slope of banks	Right bank		64.80				
			Main Channel	9.70		Left bank		50.10				
			Right bank	8.29								
		Expansion and contraction losses			E=0.4	C=0.2						

Reach Name	Tributary	Station		755.54	758.00	768.70	770.00	782.13	790.60	798.00	800.60	803.61
		Elevation		1874.41	1873.60	1872.93	1870.60	1870.41	1870.00	1870.60	1875.32	1876.91
Station Number	5	Down stream lengths	Left bank	21.77	slope of banks	Right bank		60.80				
			Main Channel	18.64		Left bank		53.00				
			Right bank	16.83								
		Expansion and contraction losses			E=0.3	C=0.1						

Reach Name	Tributary	Station		752.51	753.04	757.60	766.33	775.80	777.60	781.80	782.15	
		Elevation		1873.91	1873.00	1870.50	1870.10	1870.50	1873.62	1876.00	1877.20	
Station Number	4	Down stream lengths	Left bank	11.81	slope of banks	Right bank		60.00				
			Main Channel	12.02		Left bank		73.80				
			Right bank	14.49								
		Expansion and contraction losses			E=0.3	C=0.1						

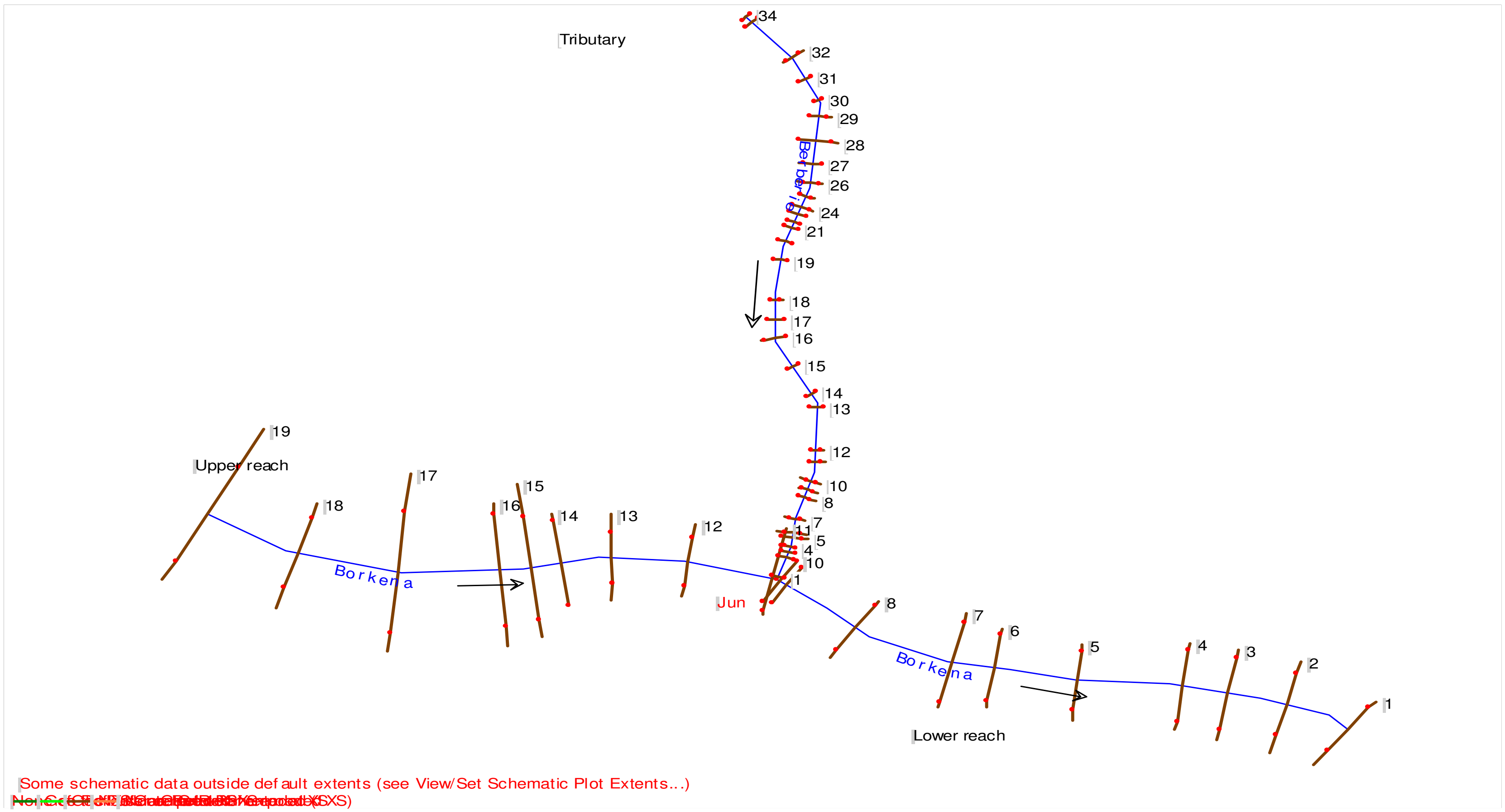
Reach Name	Tributary	Station		744.14	745.60	752.90	759.56	768.40	772.85	773.94
		Elevation		1872.40	1870.32	1870.00	1869.90	1870.14	1873.82	1875.70
		Down stream lengths	Left bank		12.58	slope of banks	Right bank		54.90	
Station Number	3		Main Channel		12.61		Left bank		60.00	
			Right bank		13.44					
		Expansion and contraction losses				E=0.3	C=0.1			

Reach Name	Tributary	Station		744.94	745.75	748.30	760.10	768.00	769.80	770.78
		Elevation		1873.69	1872.62	1869.80	1869.69	1869.82	1872.86	1874.19
		Down stream lengths	Left bank		43.72	slope of banks	Right bank		52.90	
Station Number	2		Main Channel		41.40		Left bank		53.60	
			Right bank		41.65					
		Expansion and contraction losses				E=0.3	C=0.1			

Reach Name	Tributary	Station		731.50	732.00	735.97	742.59	748.45	751.91	752.38
		Elevation		1870.65	1869.00	1868.85	1868.96	1868.87	1869.41	1870.07
		Down stream lengths	Left bank		0.00	slope of banks	Right bank		73.14	
Station Number	1		Main Channel		0.00		Left bank		54.60	
			Right bank		0.00					
		Expansion and contraction losses				E=0.3	C=0.1			

Appendex-2

River schematics and Geometric data



Appendix-3 Annual Report of Daily Data: instantaneous Daily

Flow, from Minister of Water Resources

Annual Report of Daily Data: Instantaneous Daily Flow

Station Number:033 Year: 1989

Latitude: 11:3:^{O}N Longitude: 39:44:^{O}E

	January	February	March	April	May	June	July	August	September	October	November	December
1	0.71	0.49	0.49	2.74	0.71	0.59	0.49	0.96	3.19	0.96	0.49	0.39
2	0.71	0.49	0.49	1.57	0.71	0.59	0.49	0.96	1.93	0.71	0.49	0.39
3	0.71	0.49	0.49	1.57	0.71	0.59	0.49	3.19	2.52	0.59	0.49	0.49
4	0.71	0.71	0.49	1.75	0.71	0.59	0.49	5.93	1.93	0.59	0.49	0.49
5	0.71	0.71	0.49	1.25	0.59	0.49	0.49	44.64	3.19	0.49	0.49	0.49
6	0.59	0.83	0.39	0.96	0.59	0.49	0.96	18.49	2.52	0.39	0.49	0.71
7	0.59	0.83	0.71	0.83	0.59	0.49	0.71	11.84	5.93	0.39	0.49	0.71
8	0.59	0.71	0.71	0.83	0.59	0.83	0.83	5.32	3.19	0.71	0.49	0.71
9	0.59	0.71	1.1	0.71	0.59	0.71	0.71	1.25	3.19	0.71	0.49	0.83
10	0.59	0.71	0.96	0.71	0.59	0.71	0.71	1.25	3.68	0.71	0.49	0.96
11	0.59	0.71	0.59	0.71	0.59	0.71	0.71	0.71	1.57	0.71	0.49	0.96
12	0.59	0.71	0.59	2.52	0.59	0.71	0.71	0.71	1.25	0.59	0.49	0.83
13	0.59	0.71	0.96	0.71	0.59	0.71	0.74	0.71	0.96	0.59	0.49	0.71
14	0.59	0.59	1.25	0.83	0.71	0.59	0.71	0.71	0.83	0.59	0.49	0.71
15	0.59	0.59	0.83	0.83	1.57	0.59	0.71	0.83	0.83	0.59	0.49	0.83
16	0.71	0.59	0.96	0.83	1.1	0.59	3.93	0.83	9.41	0.49	0.49	0.83
17	0.71	0.59	0.71	0.83	0.96	0.59	1	0.83	1.93	0.49	0.49	0.83
18	0.71	0.59	0.71	0.83	0.96	0.59	5.03	1.25	0.83	0.49	0.49	0.83
19	0.71	0.59	0.59	0.71	0.83	0.49	1.75	1.25	0.83	0.49	0.49	0.83
20	0.71	0.59	0.49	0.71	0.71	0.49	1.25	0.96	0.83	0.49	0.49	0.71
21	0.71	0.59	0.49	96	0.71	0.49	1.25	21.75	0.83	0.49	0.49	0.71
22	0.71	0.49	0.49	0.83	0.71	0.49	0.96	2.74	0.83	0.49	0.49	0.71
23	0.71	0.49	0.49	0.83	0.71	0.49	5.32	1.75	0.96	0.49	0.39	0.71
24	0.71	0.49	0.49	1.1	0.59	0.49	2.12	1.4	7.92	0.49	0.39	0.59
25	0.71	0.49	0.59	2.74	0.59	0.49	1.25	19.55	2.32	0.49	0.39	0.59
26	0.59	0.49	2.25	3.68	0.59	0.49	0.96	10.59	3.93	0.49	0.31	0.59
27	0.59	0.49	0.83	0.96	0.59	0.49	0.96	2.74	3.19	0.49	0.31	0.59
28	0.59	0.49	3.68	83	0.59	0.49	0.96	1.57	1.57	0.49	0.31	0.59
29	0.59		5.03	0.71	0.59	0.49	0.96	1.75	1.57	0.49	0.31	0.59
30	0.59		1.57	0.71	0.59	0.49	0.96	3.19	0.96	0.49	0.39	0.59
31	0.49		1.75		0.59		0.96	1.25		0.49		0.49
Maximum	0.71	0.83	5.03	3.68	1.57	0.83	11	44.64	9.41	0.96	0.49	44.64

Latitude: 11:3 ^{O}N Longitude: 39:44:^{O}E

Yr.1990

	January	February	March	April	May	June	July	August	September	October	November	December
1	0.49	0.71	0.49	0.83		0.71	1.75	2.74	18.78	3.61	21.24	
2	0.49	0.71	0.39	0.96		0.71	1.57	1.75	9.97	3.88	23.93	0.59
3	0.49	0.71	0.39	0.96		0.71	1.75	1.75	8.64	23.93	19.97	0.59
4	0.49	0.59	0.71	0.96		0.71	1.75	1.57	6.72	9.51	18.78	0.59
5	0.39	0.59	0.83	0.96		0.71	1.57	1.4	5.25	5.84	15.39	0.59
6	0.39	0.59	0.71	0.96		0.83	1.57	1.75	5.55	4.15	12.34	0.59
7	0.39	0.59	0.49	0.96		0.83	1.75	2.32	4.42	3.61	7.05	0.59
8	0.39	0.59	0.49		0.71	0.83	1.57	6.89	4.7	3.88	3.61	0.59
9	0.39	0.59	0.59		0.71	0.83	1.75	13.6	3.35	3.61	2.63	0.59
10	0.27	0.59	0.59		0.71	0.83	1.75	91.34	3.88	3.61	3.08	0.59
11	0.39	0.71	0.71		0.71	1.25	1.75	21.75	3.35	4.42	2.86	0.59
12	0.39	0.71	0.71		0.71	1.25	1.57	21.75	3.08	4.42	2.63	0.59
13	0.39	0.71	0.71		0.71	1.57	1.57	21.75	3.08	3.88	2.26	0.59
14	0.39	0.83	0.71		0.71	1.75	1.75	20.09	3.35	3.61	2.07	0.59
15	0.39	0.59	0.71		0.71	1.93	1.75	20.09	6.13	3.61	1.88	0.59
16	0.39	0.71	0.71		0.71	2.12	1.75	20.09	5.84	2.86	1.88	0.59
17	0.39	0.71	0.71		0.71	1.93	1.75	18.49	15.39	3.35	1.57	0.59
18	0.39	0.49	0.71		0.71	1.25	1.75	17.46	7.05	2.86	1.88	0.49
19	0.39	0.49	0.71		0.71	1.25	5.32	17.46	5.26	2.26	1.88	0.49
20	0.39	0.59	0.71		0.71	1.25	17.46		5.26	2.26	2.26	0.49
21	0.39	0.71	0.71		0.71	1.25	8.65		4.98	2.44	1.72	0.49
22	0.39	0.71	0.71		0.59	1.4	12.71		6.13	2.26	1.57	0.49
23	0.39	0.59	0.71		0.59	1.57	12.71		5.26	2.63	1.88	0.49
24	0.49	0.59	0.71		0.71	1.57	17.46		4.42	2.86	2.26	0.49
25	0.49	0.49	0.71		0.71	1.57	21.75		4.15	3.08	2.26	0.49
26	0.49	0.49	0.71		0.71	1.1	78.76		4.15	7.81	1.88	0.49
27	0.59	0.59	0.71		0.71	0.96	18.49		5.55	10.44	1.88	0.49
28	0.59		0.71		0.71	2.74	12.71		4.15	10.91	1.72	0.49
29	0.59		0.71		0.71	1.75	5.32		5.26	10.44	1.57	0.49
30	0.59		0.83		0.83	1.75	3.19		3.88	9.07	1.57	0.49
31	0.71				0.83		2.74			28.55		0.49
Maximum	0.7	0.83	0.83	0.96	0.83	2.74	78.76	91.34	18.78	28.55	23.93	91.34

Latitude:11:3:^{O}N Longtude:39:44:^{O}E

Yr.1991

	January	February	March	April	May	June	July	August	September	October	November	December
1	0.49	0.59	0.96	0.59	0.83	0.39	0.71	24.05	1.75	0.71	0.71	0.59
2	0.49	0.59	0.96	0.59	0.71	0.39	0.71	20.09	1.25	0.83	0.71	0.49
3	0.49	0.59	1.57	0.59	0.71	0.39	0.71	21.19	1.25	0.83	0.59	0.49
4	0.49	0.49	0.83	0.59	0.71	0.39	0.71	19.55	1.1	0.96	0.59	0.49
5	0.49	0.49	0.83	0.59	0.59	0.39	0.71	9.41	1.1	1.25	0.59	0.49
6	0.49	0.49	0.83	0.59	0.59	0.39	0.71	8.65	1.1	1.25	0.59	0.49
7	0.49	0.49	0.96	0.59	0.59	0.39	0.83	13.6	1.1	0.96	0.59	0.49
8	0.49	0.49	0.96	0.59	0.59	0.39	0.83	6.89	1.1	0.83	0.59	0.49
9	0.49	0.49	0.83	0.59	0.59	0.49	0.96	9.41	0.83	0.83	0.59	0.49
10	0.39	0.49	0.83	0.71	0.59	0.49	1.25	10.19	0.83	0.83	0.59	0.49
11	0.39	0.49	0.83	0.71	0.59	0.49	1.25	10.19	22.89	0.71	0.59	0.49
12	0.39	0.59	0.83	0.71	0.59	0.49	1.4	91.34	17.97	0.71	0.59	0.49
13	0.39	0.59	0.83	0.71	0.59	0.49	0.96	17.46	8.65	0.71	0.59	0.49
14	0.39	0.59	0.83	0.71	0.59	0.49	4.19	14.06	3.93	0.71	0.59	0.49
15	0.39	0.59	0.96	0.71	0.59	0.49	2.74	2.74	2.96	0.79	0.59	0.49
16	0.39	0.59	0.96	0.83	0.59	0.59	5.32	1.25	2.52	0.71	0.59	0.49
17	0.39	0.83	0.59	0.83	0.59	0.59	30.27	0.96	0.96	0.71	0.59	0.49
18	0.39	0.83	0.59	0.96	0.59	0.59	19.55	0.96	5.93	0.71	0.71	0.49
19	0.39	0.83	0.59	0.96	0.49	0.59	20.63	0.96	3.68	0.71	0.71	0.49
20	0.39	0.83	0.59	0.96	0.49	0.59	13.6	0.96	1.25	0.71	0.71	0.49
21	0.39	0.83	0.59	0.96	0.49	0.59	10.59	5.93	1.25	0.71	0.71	0.49
22	0.39	0.83	0.59	0.96	0.49	0.59	13.15	40.07	0.96	0.71	0.71	0.49
23	0.39	0.83	0.59	0.96	0.49	0.59	14.52	15.96	0.96	0.71	0.71	0.49
24	0.39	1.25	0.59	0.96	0.49	0.59	17.46	12.71	0.96	0.71	0.71	0.49
25	0.49	1.25	0.59	0.96	0.49	0.71	20.63	5.03	0.96	0.71	0.71	0.49
26	0.59	1.1	0.59	0.96	0.49	0.71	17.97	12.27	0.96	0.71	0.71	0.49
27	0.59	1.1	0.59	0.96	0.49	0.71	22.31	17.46	0.83	0.71	0.71	0.49
28	0.59	1.1	0.59	0.83	0.49	0.71	19.55	9.41	0.83	0.71	0.71	0.49
29	0.59		0.59	0.83	0.49	0.71	19.55	7.92	0.83	0.71	0.71	0.49
30	0.59		0.59	0.83	0.49	0.59	25.25	17.46	0.71	0.71	0.59	0.49
31	0.59				0.49		28.34	9.41		0.71		1.26
Maximum	0.59	1.25	1.57	0.96	0.83	0.71	30.27	91.34	22.89	1.25	0.71	1.26

Station

Latitude:11:3:^{O}N Longtiude:39:44:^{O}E

Yr.1992

	January	February	March	April	May	June	July	August	September	October	November	December
1	0.49	0.83	6.56	0.83	0.96	0.83	0.59	7.92				0.00
2	0.49	0.83	2.74	0.83	0.96	0.83	0.59	4.19				
3	0.49	2.74	0.96	0.96	0.71	0.83	0.59	2.96				
4	0.49	3.43	0.96	0.96	0.71	0.83	0.59	1.75				
5	0.71	2.74	0.96	0.83	0.83	0.83	0.71	1.4				
6	0.71	1.57	1.57	1.1	1.25	0.83	0.71	1.4				1.25
7	0.71	2.32	0.96	2.52	1.1	0.83	0.71	1.75				1.25
8	0.71	2.74	0.96	2.74	0.96	0.71	0.71	28.34				0.96
9	0.71	4.19	0.96	2.12	0.96	0.71	0.71	10.19				0.96
10	0.71	12.71	0.71	3.19	0.96	0.71	0.83	2.74				0.96
11	0.71	11.42	0.71	4.46	0.96	0.71	0.83	3.68				0.83
12	0.71	9.02	0.71	2.74	0.96	0.71	0.96	3.68				0.83
13	0.71	3.19	0.71	2.12	0.96	0.71	0.96	5.93				0.83
14	0.71	1.93	0.71	5.03	0.83	0.71	0.96	3.19				0.96
15	0.71	1.25	0.71	14.06	0.83	0.71	1.25	3.19				1.1
16	0.71	0.83	0.71	7.57	0.83	0.71	0.96	23.47				1.25
17	0.71	0.83	0.71	15.96	0.83	0.71	1.57	14.06				0.83
18	0.96	0.83	0.71	6.24	1.1	0.71	1.57	7.92				0.71
19	0.96	0.96	0.71	6.56	1.1	0.71	5.32	7.23				0.71
20	1.1	0.96	0.71	2.32	1.25	0.71	1.93	2.96				0.71
21	1.25	1.1	0.71	0.96	1.57	0.71	3.68	21.75				0.71
22	1.25	0.96	0.71	0.96	1.57	0.71	4.74	3.19				0.83
23	1.57	0.83	0.96	0.96	1.57	0.71	3.19					1.57
24	1.75	0.71	0.96	0.96	1.4	0.71	4.46					0.96
25	1.75	0.96	0.96	0.96	1.75	0.71	3.46					0.96
26	1.93	1.93	1.75	0.83	1.57	0.71	21.75					0.83
27	3.43	7.92	1.57	0.83	0.96	0.71	11.84					0.96
28	1.25	6.24	1.57	0.96	0.96	0.71	4.46					0.96
29	1.25	5.93	1.4	0.96	0.96	0.71	12.71					0.96
30	1.25		1.4	0.83	0.83	0.59	1.4					0.83
31	0.96		1.4		0.83		1.93					0.83
Minimum	3.43	12.71	6.56	15.96	1.75	0.83	21.75	28.34				1.57

Latitude:11:e:^{O}N Longitude:39:44:^{O}E

Yr.1993

	January	February	March	April	May	June	July	August	September	October	November	December
1	0.83	0.49	0.23	0.23	1.25	0.83	0.49	1.57	3.19	2.32	1.25	0.71
2	0.83	0.49	0.17	0.31	1.1	0.83	0.49	1.4	1.93	2.32	0.96	0.71
3	0.83	0.49	0.17	0.23	1.25	0.83	0.49	1.25	1.57	3.19	0.96	0.71
4	1.1	0.49	0.17	0.23	1.25	0.83	0.49	1.25	1.57	2.32	0.96	0.71
5	0.83	0.71	0.17	0.23	1.25	0.96	0.49	1.25	1.93	2.32	0.96	0.71
6	0.83	0.59	0.31	0.83	1.75	0.83	0.49	0.96	4.74	2.32	0.96	0.71
7	0.83	0.59	0.31	1.57	1.4	0.83	0.49	0.96	2.32	2.12	0.96	0.71
8	0.83	0.59	0.31	1.57	2.74	1.1	0.49	0.96	2.52	2.12	0.96	0.71
9	0.83	0.59	0.31	1.1	1.1	0.93	0.59	0.96	2.32	2.12	0.96	0.71
10	0.83	0.59	0.39	1.4	1.1	0.83	0.59	0.96	2.32	2.12	0.96	0.71
11	0.83	0.59	0.39	7.92	0.96	0.71	0.71	0.83	2.12	2.12	0.96	0.71
12	0.83	0.59	0.17	5.32	0.96	0.71	0.71	0.96	1.93	2.12	0.96	0.71
13	0.83	0.39	0.17	4.74	2.12	0.71	1.57	1.1	1.93	2.12	0.96	0.71
14	0.83	0.39	0.17	2.12	3.43	0.71	0.83	1.57	1.75	2.12	0.96	0.71
15	0.83	0.39	0.17	3.68	5.62	0.59	1.57	1.25	1.75	2.12	0.96	0.71
16	0.83	0.39	0.17	2.32	1.93	0.59	1.75	1.25	3.19	2.12	0.83	0.71
17	0.96	0.39	0.23	1.75	0.96	0.59	3.93	0.83	7.23	2.12	0.83	0.71
18	0.96	0.39	0.17	2.32	0.83	0.59	3.19	0.83	3.68	2.12	0.83	0.59
19	0.83	0.39	0.17	1.75	0.83	0.49	4.74	0.83	2.52	2.74	0.83	0.59
20	0.83	0.39	0.17	1.93	1.75	0.49	4.74	0.96	2.52	2.32	0.83	0.59
21	0.83	0.39	0.23	2.32	1.57	0.49	3.43	1.57	2.32	2.32	0.83	0.59
22	0.83	0.39	0.17	3.43	0.96	0.49	4.19	1.25	2.32	2.12	0.83	0.59
23	0.83	0.49	0.17	1.93	0.83	0.49	20.63	2.32	2.32	2.12	0.83	0.59
24	0.83	0.59	0.23	2.12	5.93	0.49	5..93	74.76	2.12	2.12	0.83	0.59
25	0.96	0.49	0.17	2.74	1.57	0.49	1.93	40.07	2.12	2.32	0.83	0.59
26	0.71	0.49	0.17	3.19	1.1	0.49	1.93	14.52	2.12	2.12	0.83	0.59
27	0.39	0.96	0.23	7.92	0.96	0.49	1.25	5.03	2.12	2.12	0.83	0.59
28	0.39	0.23	0.31	3.19	0.83	0.49	17.97	6.24	2.12	2.12	0.83	0.59
29	0.39		0.31	1.93	0.83	0.49	5.03	6.24	2.12	2.32	0.83	0.59
30	0.39		0.17	1.75	0.83	0.49	1.4	5.93	2.32	2.32	0.83	0.59
31	0.39		0.17		0.83		3.43	6.56		1.4		0.59
Maximum	1.1	0.96	0.39	7.92	5.93	1.1	20.63	74.76	7.23	3.19	1.25	74.76

Lontiude:11:3:^{O}N Longitude: 39:44:^{O}E

Yr.1994

	January	February	March	April	May	June	July	August	September	October	November	December
1	0.59	0.39	0.39	0.59	0.39	0.11	0.96	14.7	7.65	1.71	1.35	1.35
2	0.59	0.39	0.39	0.59	0.59	0.11	0.96	22.37	10.8	1.71	1.35	1.35
3	0.59	0.39	0.39	0.59	0.31	0.11	1.57	16.74	9.57	2.72	1.12	1.35
4	0.59	0.39	0.39	0.59	0.31	0.11	2.32	8.71	11.45	2.86	1.19	1.35
5	0.59	0.39	0.39	0.49	0.31	0.11	1.93	6.21	11.45	1.81	1.27	1.35
6	0.59	0.39	0.39	0.49	0.39	0.11	1.25	8.71	6.91	1.81	1.35	1.35
7	0.59	0.39	0.39	0.31	0.39	0.11	1.4	9.57	11.45	1.71	1.35	1.35
8	0.59	0.39	0.49	0.23	0.31	0.31	3.68	8.71	5.36	1.71	1.35	1.35
9	0.59	0.39	0.49	0.23	0.39	0.31	7.92	5.78	3.9	1.71	1.91	1.35
10	0.59	0.39	0.49	0.23	0.39	0.31	3.93	5.16	3.27	1.71	2.12	1.35
11	0.59	0.39	0.49	0.23	0.31	0.39	18.49	5.99	7.9	1.71	1.81	1.35
12	0.59	0.39	0.49	0.23	0.31	0.39	10.19	8.99	4.06	1.71	1.91	1.35
13	0.59	0.39	0.49	0.23	0.31	0.39	19.55	11.79	2.99	1.71	2.01	1.35
14	0.59	0.39	0.49	0.23	0.31	0.39	15.96	29.09	2.35	1.52	1.91	1.35
15	0.59	0.39	0.96	0.31	0.39	0.71	17.46	11.45	3.13	1.52	1.71	1.35
16	0.59	0.39	0.96	0.31	0.31	0.71	9.41	5.16	3.42	1.52	1.52	1.35
17	0.59	0.39	0.59	0.23	0.23	0.71	19.55	7.15	3.13	1.52	1.35	1.35
18	0.49	0.39	0.49	0.23	0.23	0.71	11.42	5.57	2.72	1.52	1.35	1.35
19	0.49	0.39	0.49	0.23	0.23	0.71	161.01	57.77	2.47	1.43	1.71	1.19
20	0.49	0.39	0.71	0.23	0.23	0.71	158.22	11.12	2.14	1.43	1.61	1.19
21	0.49	0.39	0.71	0.96	0.23	0.71	22.37	6.91	1.91	1.35	8.44	1.19
22	0.39	0.39	2.12	1.75	0.23	0.83	24.48	5.78	1.81	1.35	5.57	1.19
23	0.39	0.39	0.71	0.59	0.31	0.83	17.61	5.78	5.57	1.35	2.86	1.19
24	0.39	0.39	0.96	0.39	0.31	0.83	29.09	5.78	4.78	1.35	2.02	1.19
25	0.39	0.39	1.4	0.31	0.31	0.83	7.39	52.24	2.99	1.35	2.01	105
26	0.39	0.39	0.71	0.31	0.31	0.71	40.7	56.83	1.91	1.35	1.71	105
27	0.39	0.39	0.71	0.31	0.23	1.57	18.96	16.74	1.81	1.35	1.52	105
28	0.39	0.39	0.59	0.31	0.17	1.1	21.86	8.17	1.81	1.35	1.52	105
29	0.39		0.59	0.31	0.17	1.25	61.67	9.28	1.71	1.35	1.52	105
30	0.39		0.59	0.39	0.17	1.25	29.09	106.03	1.71	1.35	1.52	105
31	0.39		0.59		0.17		15.1	19.89		1.35		105
Minimum	0.59	0.39	2.12	1.75	0.59	1.57	161.01	106.03	11.45	2.86	8.44	1.35

Yr. 1995

Laqtitude:11:3:^{O}N Longitude 39:44:^{o}E

	January	February	March	April	May	June	July	August	September	October	November	December
1	0.62	0.45	15.34				0.83	8.17	1.15	0.75	0.12	0.08
2	0.62	0.45	15.34				1.15	7.89	0.98	0.49	0.1	0.08
3	0.62	0.45	15.34				1.07	26.37	0.75	0.3	0.1	0.08
4	0.62	0.45	11.6				0.98	17.01	2.19	0.27	0.1	0.08
5	0.62	0.45	8.45				0.98	11.95	3.87	0.27	0.1	0.08
6	0.62	0.45	8.45				0.98	7.89	2.48	0.23	0.1	0.08
7	0.62	0.45	8.45				0.98	6.58	1.8	0.2	0.1	0.08
8	0.62	0.56	8.45				0.98	6.34	1.92	0.14	0.1	0.08
9	0.62	0.75	5.87				0.98	5.2	1.15	0.14	0.1	0.08
10	0.56	0.75	5.87				0.83	3.3	0.9	0.14	0.08	0.08
11	0.56	0.75	5.87				1.15	2.83	0.55	0.14	0.08	0.08
12	0.56	0.69	5.87				0.98	3.47	0.82	0.14	0.08	0.08
13	0.56	11.6	5.87				0.9	3.64	0.68	0.14	0.08	0.08
14	0.56	11.6	5.87				0.9	2.67	0.68	0.14	0.08	0.08
15	0.56	11.6	5.87				0.83	5.42	0.55	1.68	0.08	0.08
16	0.5	8.45	5.87				0.98	6.83	0.49	1.15	0.08	0.08
17	0.5	5.87	5.87				0.9	91.93	0.49	0.68	0.08	0.08
18	0.5	5.87	15.34s				1.76	96.28	0.98	0.61	0.08	0.08
19	0.5	8.45	43.95				2.53	15.22	0.68	0.39	0.08	0.08
20	0.5	8.45	17.45				2.83	125.12	0.55	0.23	0.08	0.08
21	0.5	8.45	14.54				3.14	16.17	0.55	0.14	0.08	0.08
22	0.5	8.45	22.14				1.76	52.97	0.9	0.14	0.08	0.08
23	0.5	8.45	11.6				2.13	13.87	0.61	1.06	0.08	0.08
24	0.5	8.45	24.73				3.14	8.21	0.39	0.68	0.08	0.08
25	0.5	8.45	19.71			1.15	2.98	5.67	0.23	0.35	0.08	0.08
26	0.5	24.73				1.07	3.14	1.92	0.2	0.27	0.08	0.08
27	0.5	19.71				0.98	3.82	1.35	0.17	0.14	0.08	0.08
28	0.5	15.34				0.83	2.67	2.48	0.14	0.14	0.08	0.08
29	0.45					0.83	11.26	1.8	0.14	0.12	0.08	0.08
30	0.45					0.83	17.01	0.75	0.14	0.12	0.08	0.08
31	0.45						11.26	1.8		0.12		0.08
Maximum	0.62	24.73	43.95			1.15	17.01	125.12	3.87	1.68	0.1	0.8

Latitude : 11:3:^{0}N Longitude 39.44:^{O}E

Yr.1996.00

	January	February	March	April	May	June	July	August	September	October	November	December
1.00	1.12	1.12	0.79	0.79	1.05	1.91	1.52	3.27	10.18	0.91	0.58	0.49
2.00	1.12	1.12	0.79	0.79	0.91	1.05	1.52	2.72	21.35	0.85	0.53	0.49
3.00	1.12	1.12	0.79	0.79	0.91	0.98	1.52	2.47	11.12	0.79	0.53	0.49
4.00	1.12	0.98	0.79	0.79	0.91	0.98	1.91	4.41	7.65	0.79	0.53	0.49
5.00	1.12	0.98	0.79	0.79	0.85	0.98	2.12	4.06	5.57	0.68	0.53	0.49
6.00	1.12	0.98	0.79	0.79	0.79	5.36	2.01	3.27	6.44	0.68	0.53	0.45
7.00	1.12	1.27	0.79	0.79	0.79	3.90	2.12	35.61	5.57	0.68	0.53	0.45
8.00	1.12	1.27	1.05	0.79	0.79	3.13	3.58	15.50	4.41	0.68	0.53	0.45
9.00	1.12	1.27	0.91	0.79	0.79	2.47	4.24	72.14	3.90	0.68	0.49	0.45
10.00	1.12	1.27	0.85	0.79	1.35	1.91	5.99	165.34	3.73	0.68	0.49	0.45
11.00	1.12	0.85	0.85	0.79	1.35	1.71	8.44	127.07	3.73	0.68	0.49	0.45
12.00	1.12	0.85	0.85	0.79	1.81	1.52	19.42	23.41	3.73	0.68	0.49	0.45
13.00	1.12	0.79	0.85	0.79	1.91	1.52	13.19	5.36	3.42	0.68	0.49	0.45
14.00	1.12	0.79	0.85	0.79	2.59	1.52	5.16	5.16	2.35	0.68	0.49	0.45
15.00	1.12	0.79	0.85	1.35	5.99	1.52	5.78	12.83	2.01	0.58	0.58	0.45
16.00	1.12	0.79	0.85	1.71	5.99	2.01	3.27	6.44	1.61	0.58	0.58	0.45
17.00	1.12	0.79	0.79	1.12	2.35	2.01	2.99	3.58	1.52	0.58	0.58	0.45
18.00	1.12	0.79	0.79	1.12	1.91	2.01	5.16	2.86	1.35	0.58	0.68	0.45
19.00	1.12	0.79	0.79	1.05	2.86	1.91	15.10	18.50	1.35	0.58	0.68	0.45
20.00	8.71	0.79	0.79	0.98	2.86	1.52	8.44	19.93	1.27	0.58	0.68	0.45
21.00	5.57	0.79	0.79	0.98	2.59	1.52	3.42	11.12	1.27	0.58	0.63	0.45
22.00	2.35	0.79	0.79	0.98	2.23	1.52	2.59	11.45	1.19	0.58	0.58	0.45
23.00	1.35	0.79	0.79	0.98	2.12	1.43	3.13	11.12	0.98	0.58	0.58	0.45
24.00	1.35	0.79	0.79	0.98	2.12	1.43	8.44	14.31	0.79	0.58	0.58	0.45
25.00	1.35	0.79	0.79	0.91	1.91	1.43	8.99	21.86	0.79	0.58	0.53	0.45
26.00	1.35	0.79	0.79	0.91	2.23	1.52	14.31	14.31	0.79	0.58	0.53	0.45
27.00	1.35	0.79	0.79	0.91	2.99	1.52	8.17	9.57	0.79	0.58	0.53	0.45
28.00	1.35	0.79	0.79	2.72	2.59	1.52	6.44	7.90	0.79	0.58	0.53	0.45
29.00	1.19	0.79	0.79	1.52	2.12	1.52	5.16	2.72	1.19	0.58	0.53	0.45
30.00	1.19		0.79	1.27	4.97	1.52	4.41	2.59	0.91	0.58	0.53	0.45
31.00	1.19		0.79		2.86		3.90	14.70		0.58		0.45
Maximum	8.71	1.27	1.05	2.72	5.99	5.36	19.42	165.34	21.35	0.91	0.68	0.49

Latitude 11:3:^{O}N Longitude 39:44:^{O}E

Yr.1997	January	February	March	April	May	June	July	August	September	October	November	December
1.00	0.45	0.45	0.25	0.49	0.27	0.20	0.91	0.98	1.71	1.12	2.23	1.43
2.00	0.45	0.45	0.25	0.49	0.27	0.20	0.73	1.27	1.35	1.05	2.01	1.35
3.00	0.45	0.45	0.25	0.45	0.27	0.20	8.99	1.05	1.19	1.05	1.61	1.35
4.00	0.45	0.45	0.25	0.41	0.27	0.20	5.99	1.19	1.12	0.98	1.35	1.19
5.00	0.45	0.45	0.25	0.34	0.27	0.20	7.9	1.27	1.43	0.79	1.19	1.19
6.00	0.45	0.45	0.25	0.31	0.27	0.20	10.18	1.19	2.59	0.74	0.98	1.19
7.00	0.45	0.41	0.25	0.31	0.25	0.25	7.90	7.90	2.01	0.73	0.98	1.19
8.00	0.45	0.41	0.25	0.27	0.25	0.45	8.17	7.15	1.61	0.73	1.19	1.12
9.00	0.45	0.41	0.25	0.27	0.25	0.53	6.91	8.99	3.13	0.73	1.43	1.05
10.00	0.45	0.41	0.25	0.27	0.22	0.49	6.91	41.46	2.59	0.73	1.43	0.79
11.00	0.45	0.41	0.25	0.27	0.22	0.41	4.24	15.90	2.35	0.63	4.41	0.79
12.00	0.45	0.41	0.25	0.27	0.22	0.37	2.86	21.35	2.12	0.53	2.86	0.79
13.00	0.45	0.41	0.17	0.27	0.22	0.27	2.23	30.33	2.01	0.53	1.91	0.79
14.00	0.45	0.41	0.53	0.27	0.22	0.27	3.73	13.56	2.59	0.53	1.35	0.73
15.00	0.45	0.41	0.53	0.25	0.22	0.27	4.24	18.50	1.91	0.53	1.35	0.73
16.00	0.45	0.41	1.12	0.25	0.22	0.25	9.57	14.31	1.52	0.63	1.19	0.68
17.00	0.45	0.41	1.19	0.25	0.22	0.25	14.31	10.80	0.98	0.68	1.05	0.68
18.00	0.45	0.27	0.68	0.25	0.22	0.25	13.56	7.90	0.85	1.05	0.98	0.68
19.00	0.45	0.27	0.58	0.25	0.22	0.25	10.80	5.57	0.79	1.35	4.78	0.63
20.00	0.45	0.25	0.63	0.25	0.22	0.27	7.90	3.73	0.79	3.13	2.86	0.63
21.00	0.45	0.25	0.63	0.25	0.22	0.27	5.57	2.59	0.79	3.42	4.78	0.63
22.00	0.49	0.25	0.53	0.25	0.22	0.45	3.73	5.36	0.79	2.72	12.48	0.58
23.00	0.49	0.25	0.53	0.25	0.20	0.45	2.47	3.13	0.79	2.23	5.16	0.58
24.00	0.49	0.25	0.53	0.41	0.20	0.41	4.06	6.21	0.79	5.16	18.96	0.53
25.00	0.45	0.22	0.53	0.31	0.20	0.37	11.79	9.57	0.79	3.27	8.44	0.53
26.00	0.45	0.25	0.53	0.27	0.20	0.37	7.90	6.44	0.68	4.06	5.57	0.53
27.00	0.45	0.25	0.53	0.27	0.20	0.45	3.73	4.41	1.71	2.01	2.35	0.53
28.00	0.45	0.25	0.53	0.27	0.20	0.41	2.35	19.42	1.35	1.61	1.81	0.53
29.00	0.45		0.53	0.27	0.20	0.53	1.71	2.72	1.35	0.12	1.61	0.53
30.00	0.45		0.49	0.27	0.20	0.68	1.27	2.12	1.27	3.13	1.43	0.49
31.00	0.45		0.49				1.05	2.59		2.72		0.49
Maxiumu	0.49	0.45	1.19	0.49	0.27	0.68	14.31	41.46	3.13	5.16	18.96	41.46

Yr.1998.00

Latitude 11:3:^{O}N Longitude 39:44:^{O}E

	January	February	March	April	May	June	July	Augest	Septemeber	October	Novembe	December
1.00	0.49	1.35	0.49	0.41	0.53	0.20	0.22	14.31	6.91	1.61	0.91	0.73
2.00	0.49	0.73	0.45	0.45	0.53	0.20	0.25	8.99	4.78	1.52	0.91	0.73
3.00	0.49	0.73	0.45	0.45	0.49	0.20	0.25	5.78	3.73	1.43	0.85	0.73
4.00	0.49	0.58	0.53	0.49	0.49	0.20	0.25	4.78	5.16	1.43	0.85	0.73
5.00	0.49	0.49	0.53	0.49	0.45	0.20	0.34	3.42	8.44	1.52	0.85	0.73
6.00	0.49	0.49	0.68	0.49	0.45	0.20	0.41	5.16	6.91	2.12	0.85	0.73
7.00	0.58	0.45	0.63	0.49	0.45	0.20	0.37	2.47	3.13	1.43	0.85	0.73
8.00	0.58	0.41	0.58	0.49	0.45	0.20	0.37	4.44	2.59	1.35	0.85	0.73
9.00	0.53	0.41	0.49	0.49	0.45	0.20	0.58	57.77	2.59	1.71	0.85	0.73
10.00	0.53	0.41	0.45	0.49	0.45	0.20	2.59	13.56	4.41	2.23	0.85	0.73
11.00	0.53	0.41	0.41	0.49	0.45	0.20	1.19	34.24	2.47	1.71	0.85	0.73
12.00	0.53	0.41	0.41	0.22	0.34	0.20	2.35	7.90	1.91	2.72	0.85	0.73
13.00	0.53	0.41	0.41	0.22	0.27	0.20	1.71	4.24	1.71	2.59	0.85	0.73
14.00	0.53	0.41	0.41	0.22	0.27	0.20	0.91	31.60	1.52	2.12	0.85	0.73
15.00	0.53	0.41	0.41	0.22	0.27	0.20	0.58	37.02	1.52	1.71	0.79	0.73
16.00	0.53	0.41	0.41	0.22	0.27	0.22	0.68	6.44	1.43	1.52	0.79	0.73
17.00	0.53	0.41	0.41	0.22	0.27	0.22	0.91	12.13	1.71	1.27	0.79	0.73
18.00	0.49	0.41	0.41	0.25	0.27	0.22	0.79	5.36	1.71	1.19	0.79	0.73
19.00	0.49	0.41	0.41	0.25	0.25	0.22	8.99	4.41	1.43	1.12	0.79	0.73
20.00	0.49	0.41	0.41	0.25	0.25	0.20	19.42	14.31	2.12	1.12	0.73	0.73
21.00	0.49	0.41	0.41	0.25	0.22	0.22	5.99	3.42	1.91	1.19	0.73	0.73
22.00	0.49	0.41	0.37	0.25	0.22	0.20	1.35	58.73	2.86	1.52	0.73	0.73
23.00	0.45	0.41	0.37	0.25	0.22	0.20	51.35	4.78	2.35	1.19	0.73	0.73
24.00	0.41	1.19	0.37	0.25	0.22	0.20	13.19	4.59	12.83	1.12	0.73	0.73
25.00	0.41	0.73	0.37	0.25	0.20	0.20	8.71	10.18	9.87	1.05	0.73	0.73
26.00	0.41	0.58	0.37	0.25	0.20	0.20	10.48	3.90	3.27	1.05	0.73	0.73
27.00	0.41	0.49	0.37	1.52	0.20	0.20	135.2	11.45	2.59	0.98	0.73	0.73
28.00	0.41	0.49	0.37	0.79	0.20	0.20	40.7	22.88	2.12	0.91	0.73	0.68
29.00	0.41		0.37	0.58	0.20	0.20	58.73	15.10	3.42	0.91	0.73	0.68
30.00	0.41		0.37	0.53	0.20	0.20	107.45	8.44	2.01	0.91	0.73	0.68
31.00	0.41		0.41		0.20		131.91	6.67		0.91		0.68
Maxium	0.58	1.35	0.68	1.52	0.53	0.22	135.2	58.73	12.83	2.72	0.91	0.73

Yr.1999

Latitude:11:3:^{0} N longitude

	january	February	March	April	May	June	July	August	September	October	November	December
1.00	0.68	0.53	0.49	0.45	0.68	0.37	1.19	3.42	5.16	1.12	1.43	0.79
2.00	0.68	0.53	0.49	0.45	0.49	0.37	2.12	2.12	3.58	10.8	1.35	0.79
3.00	0.68	0.53	0.49	0.45	0.49	0.37	1.35	1.91	1.61	1.71	1.19	0.79
4.00	0.68	0.53	0.49	0.41	0.58	0.37	6.44	3.90	15.1	1.71	1.19	0.79
5.00	0.68	0.53	0.49	0.41	0.41	0.37	13.19	4.78	10.18	1.91	1.12	0.79
6.00	0.68	0.53	0.49	0.41	0.41	0.37	1.05	3.27	2.59	3.13	1.05	0.79
7.00	0.68	0.53	0.49	0.41	0.41	0.37	9.87	1.81	7.65	2.72	1.05	0.79
8.00	0.68	0.53	0.49	0.41	0.41	0.37	1.27	15.50	10.18	2.72	1.05	0.79
9.00	0.79	0.53	0.49	0.41	0.41	0.37	2.35	4.24	4.06	6.44	0.98	0.79
10.00	1.05	0.53	0.49	0.41	0.41	0.37	0.68	3.90	39.2	2.86	0.98	0.79
11.00	0.79	0.53	0.49	0.41	0.41	0.37	0.68	2.86	3.9	22.37	0.91	0.79
12.00	0.73	0.53	0.49	0.41	0.41	0.37	0.79	55.89	3.27	6.91	0.91	0.73
13.00	0.73	0.53	0.49	0.41	0.41	0.37	1.19	6.91	10.18	4.02	0.91	0.73
14.00	0.68	0.53	0.49	0.41	0.41	0.37	1.19	3.73	3.42	2.86	0.91	0.79
15.00	0.68	0.53	0.49	0.41	0.41	0.41	21.86	2.86	2.99	3.42	1.52	0.79
16.00	0.68	0.49	0.49	0.41	0.41	0.41	47.9	14.31	3.58	3.42	0.91	0.79
17.00	0.68	0.49	0.49	0.41	0.41	0.45	2.59	19.42	3.13	7.9	0.91	0.79
18.00	0.68	0.49	0.49	0.41	0.37	0.45	3.27	8.71	2.72	15.1	0.91	0.79
19.00	0.68	0.49	0.49	0.41	0.37	0.45	3.13	5.57	2.12	10.8	0.85	0.79
20.00	0.68	0.49	0.49	0.41	0.37	0.45	2.12	47.06	1.71	13.93	0.85	0.79
21.00	0.68	0.49	0.45	0.45	0.37	0.45	1.19	6.21	1.71	5.16	0.85	0.79
22.00	0.68	0.49	0.14	0.45	0.37	0.45	5.99	11.79	1.52	3.73	0.85	0.79
23.00	0.68	0.49	0.41	0.45	0.37	0.45	49.61	8.99	1.35	2.59	0.85	0.79
24.00	0.68	0.49	0.41	0.45	0.37	0.45	3.73	15.50	1.35	2.35	0.85	0.79
25.00	0.68	0.49	0.41	0.45	0.37	0.45	2.23	0.63	1.35	2.12	0.85	0.79
26.00	0.68	0.49	0.41	0.41	0.37	0.45	4.41	3.42	1.35	1.91	0.85	0.85
27.00	0.68	0.49	0.41	0.41	0.37	0.45	11.12	11.45	1.35	1.81	0.85	0.85
28.00	0.63	0.49	0.41	0.41	0.37	0.41	9.57	4.41	1.35	1.71	0.85	0.85
29.00	0.58		0.45	0.41	0.37	0.58	24.48	5.57	1.19	1.52	0.85	0.85
30.00	0.58		0.45	0.49	0.41	0.68	7.39	8.17	1.19	1.52	0.79	0.85
31.00	0.58		0.45		0.37		5.99	21.35		1.52		0.85
Maximum 31.00	1.05	0.53	0.49	0.49	0.68	0.68	49.61	55.89	39.20	22.37	1.52	0.85

2000

Latitude:11:3:oN logitude :39:44:OE

	january	February	march	April	May	jule	july	August	september	october	Novemebr	December
1.00	0.50	0.31	0.20	0.17	0.20	0.14	0.17	66.95	129.40	1.34	0.98	0.45
2.00	0.50	0.31	0.20	0.17	0.20	0.14	0.20	51.81	148.45	1.25	0.90	0.45
3.00	0.50	0.31	0.20	0.17	0.27	0.14	0.20	75.9	55.17	1.15	0.69	0.45
4.00	0.50	0.31	0.20	0.17	0.27	0.12	0.20	74.87	20.66	1.15	0.69	0.45
5.00	0.50	0.31	0.20	0.17	0.23	0.12	0.20	129.4	69.86	1.15	0.69	0.45
6.00	0.50	0.31	0.20	0.17	0.23	0.12	0.20	10.59	18.78	1.15	0.69	0.45
7.00	0.50	0.31	0.20	0.14	0.20	0.12	0.23	238.44	8.45	1.15	0.69	0.45
8.00	0.45	0.23	0.20	0.14	0.27	0.12	0.23	8.45	36.82	2	0.83	0.45
9.00	0.45	0.23	0.20	0.14	0.36	0.12	0.90	2.83	80.08	4.18	0.75	0.45
10.00	0.45	0.23	0.20	0.14	0.45	0.12	2.26	14.15.	33.54	4.18	1.15	0.45
11.00	0.45	0.23	0.20	0.14	0.20	0.12	0.83	12.3	16.17	2.53	1.15	0.45
12.00	0.45	0.23	0.20	0.14	0.20	0.12	0.62	80.08	6.83	1.54	0.98	0.56
13.00	0.45	0.20	0.20	0.14	0.20	0.12	1.76	65.05	4.18	1.25	0.98	0.62
14.00	0.45	0.20	0.20	0.14	0.20	0.12	0.62	9.03	4.38	1.15	0.90	0.62
15.00	0.45	0.20	0.20	0.20	0.17	0.12	0.44	13.02	4.18	0.83	0.83	0.69
16.00	0.40	0.20	0.20	0.20	0.17	0.12	0.66	8.45	3.14	0.83	0.75	0.69
17.00	0.40	0.20	0.14	0.20	0.17	0.12	0.27	17.01	2.83	0.83	0.75	0.69
18.00	0.40	0.20	0.14	0.20	0.17	0.12	0.23	55.17	2.53	0.75	0.75	0.62
19.00	0.40	0.20	0.14	0.20	0.17	0.12	0.20	9.33	2.26	0.75	0.69	56.00
20.00	0.40	0.20	0.14	0.20	0.17	0.12	4.99	13.02	2.83	0.75	0.69	0.56
21.00	0.40	0.17	0.14	0.20	0.17	0.12	2.53	4.18	2.83	0.75	0.69	0.50
22.00	0.40	0.17	0.14	0.20	0.17	0.12	0.83	17.01	1.76	0.69	0.69	0.50
23.00	0.40	0.17	0.14	0.23	0.17	0.12	10.27	98.16	1.54	0.69	0.69	0.45
24.00	0.36	0.17	0.14	0.23	0.17	0.12	9.64	14.15	1.34	0.62	0.62	0.45
25.00	0.36	0.17	0.14	0.20	0.17	0.12	2.53	5.87	1.34	0.62	0.56	0.45
26.00	0.36	0.17	0.14	0.20	0.17	0.12	47.00	4.00	1.15	0.62	0.45	0.45
27.00	0.36	0.17	0.14	0.20	0.17	0.14	40.29	7.62	1.07	0.62	0.45	0.45
28.00	0.36	0.20	0.14	0.20	0.17	0.17	5.42	4.99	4.18	0.62	0.45	0.45
29.00	0.36	0.20	0.14	0.20	0.17	0.00	4.38	3.30	2.53	0.28	0.45	0.45
30.00	0.31		0.14	0.20	0.17	0.17	22.14	2.26	1.76	2.67	0.45	0.45
31.00	0.31		0.14		0.14		2.53	138.00		1.34		0.45
Maximum	0.50	0.31	0.20	0.23	0.45	0.17	47.00	238.44	148.45	4.38	1.15	0.69

2001

Latitude:11:3^{o}N longitude :39:44:^{O}E

	January	February	March	April	May	June	July	August	September	October	November	December
1:00	0.45	0.36	0.23	0.36	0.23			8.45	2.53	1.88	0.27	0.23
2:00	0.45	0.36	0.23	0.27	0.23			87.73	2	1.54	0.27	0.23
3:00	0.45	0.36	0.23	0.27	0.75			8.45	3.14	1.25	0.27	0.23
4:00	0.45	0.36	0.23	0.27	0.56			4.78	2.13	0.98	0.27	0.23
5:00	0.45	0.36	0.23	0.27	0.45			17.45	5.42	0.83	0.27	0.23
6:00	0.45	0.45	0.23	0.27	0.45			5.2	3.64	0.69	0.27	0.23
7:00	0.45	0.45	0.23	0.27	0.45			23.67	2.53	0.56	0.27	0.23
8:00	0.45	0.5	0.23	0.27	0.45			8.45	4.18	0.56	0.27	0.23
9:00	0.45	0.5	0.23	0.27	0.45			30.43	5.42	0.56	0.27	0.23
10:00	0.45	0.5	0.36	0.23	0.45			27.49	5.87	0.5	0.27	0.23
11:00	0.45	0.62	0.36	0.23	0.45			69.86	2.98	0.45	0.27	0.23
12:00	0.45	0.62	0.31	0.23	0.45			16.17	2	0.45	0.27	0.2
13:00	0.45	0.56	0.31	0.23	0.4			9.03	1.65	0.45	0.23	0.2
14:00	0.45	0.56	0.31	0.23	0.4			7.35	3.82	0.45	0.23	0.2
15:00	0.45	0.5	0.31	0.23	0.4			24.73	1.88	0.45	0.23	0.2
16:00	0.45	0.45	0.31	0.23	0.9			10.92	1.54	0.45	0.23	0.2
17:00	0.4	0.45	0.31	0.23	0.69			5.64	1.34	0.45	0.23	0.2
18:00	0.4	0.36	0.31	0.23	0.4			4.58	1.07	0.31	0.23	0.2
19:00	0.4	0.27	0.27	0.23	2.39			4	5.42	0.31	0.23	0.2
20:00	0.4	0.23	0.36	0.23				10.27	3.47	0.27	0.23	0.2
21:00	0.36	0.23	0.83	0.23				2.67	2	0.27	0.23	0.2
22:00	0.36	0.23	0.98	0.23				2.53	19.71	0.27	0.23	0.2
23:00	0.36	0.23	1.34	0.23				3.14	2.83	0.27	0.23	0.2
24:25:00	0.36	0.23	0.75	0.23				4.58	2.26	0.27	0.23	0.2
25:00:00	0.36	0.23	1.07	0.23				2.67	1.76	0.27	0.23	0.2
26:00:00	0.36	0.23	0.9	0.23				2.53	1.34	0.27	0.23	0.2
27:00:00	0.36	0.23	0.83	0.23				1.76	1.65	0.27	0.23	0.2
28:00:00	0.36	0.23	0.69	0.23				1.54	1.34	0.27	0.23	0.2
29:00:00	0.36		0.56	0.23				1.44	0.98	0.27	0.23	0.2
30:00:00	0.36		0.45					1.34	0.9	0.27	0.23	0.2
31:00:00	0.36		0.45					4.18		0.27		0.2
Maximum	0.45	0.62	1.34	0.36	0.16			87.73	19.71	188	0.27	0.23

Appendix -4

Estimation of run-off coefficient of Berberie River

(Total Catchment Area= 18km^2)

Land use/ cover and land slope	Percentage of land slope with respect to its land use	Average soil texture for each land use	Value of c	Weighted value of C
Wood land and forest flat 0-10%				
Flat	1.90		0.30	0.01
Rolling 5-10%	11.40	Clay	0.35	0.04
Hilly Mountainous>10%	24.70		0.53	0.12
Pasture				
flat 0-5	1.50	Silty Loam	0.30	0.005
Rolling 5-10%	1.50		0.35	0.01
Hilly Mountainous>10%	7.00		0.42	0.03
Cultivated		Sandy loam		
Flat 0-5%	5.40		0.30	0.02
Rolling 5-10%	12.60		0.40	0.05
Hilly Mountainous>10%	18.00		0.50	0.09
Urban Areas		30% of Area impervious		
Flat 0-5%	7.20		0.40	0.03
Rolling 5-10%	8.80		0.50	0.04
	$\sum \% = 100$			$\sum c = 0.45$

Estimation of run-off coefficient of Borkena River

(Total Catchment Area= 70km^2)

Land use/ cover and land slope	Percentage of land slope with respect to its land use	Average soil texture for each land use	Value of C	Weighted value of C
Wood land and forest				
Flat 0-5%	31.00		0.30	0.130
Rolling 5-10%	1.30	Clay	0.35	0.010
Hilly Mountainous>10%	12.00		0.50	0.070
Pasture				
Flat 0-5	8.00	Silty Loam	0.30	0.030
Rolling 5-10%	1.70		0.35	0.010
Hilly Mountainous>10%	1.60		0.42	0.010
Cultivated		Sandy loam		
Flat 0-5%	16.00		0.30	0.0065
Rolling 5-10%	14.10		0.40	0.080
Hilly Mountainous>10%	8.30		0.50	0.050
Urban Areas		30% of Area		
Flat 0-5%	3.60	impervious	0.40	0.020
Rolling 5-10%	2.40		0.50	0.017
	$\sum \% = 100$			$\sum c = 0.48$

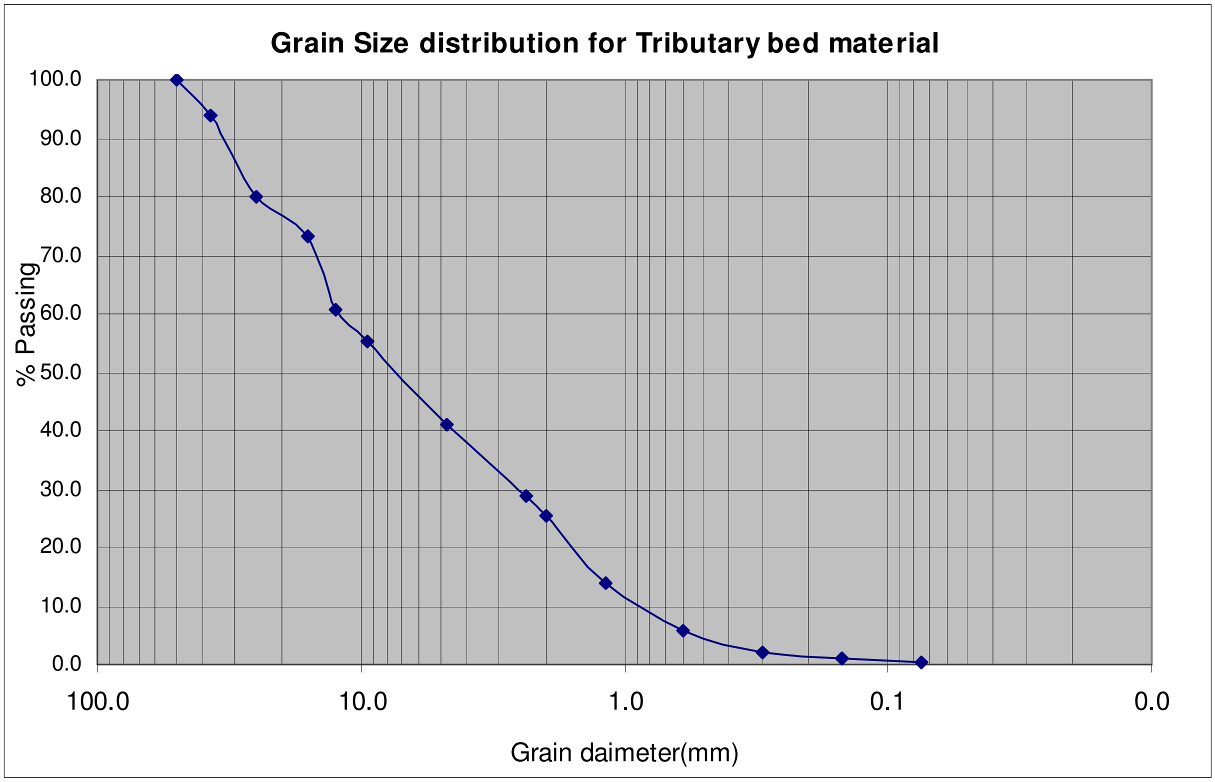
Estimation of run-off coefficient of Berberie River

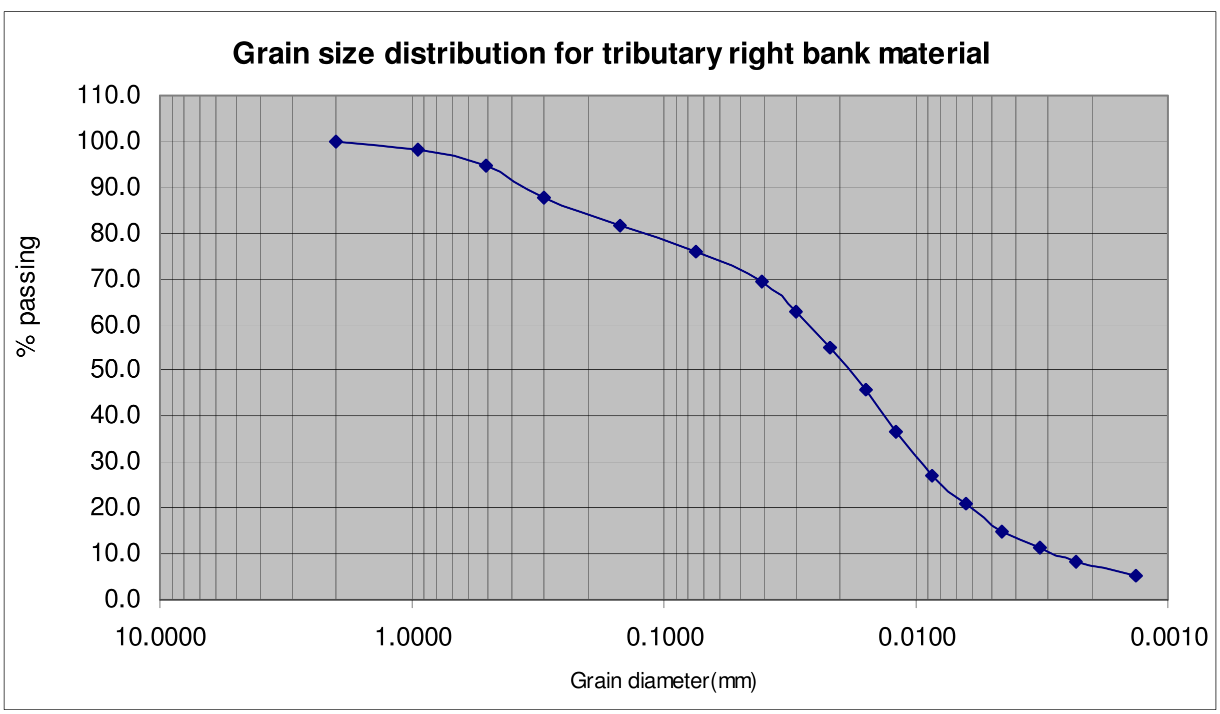
(Total Catchment Area= 281km^2)

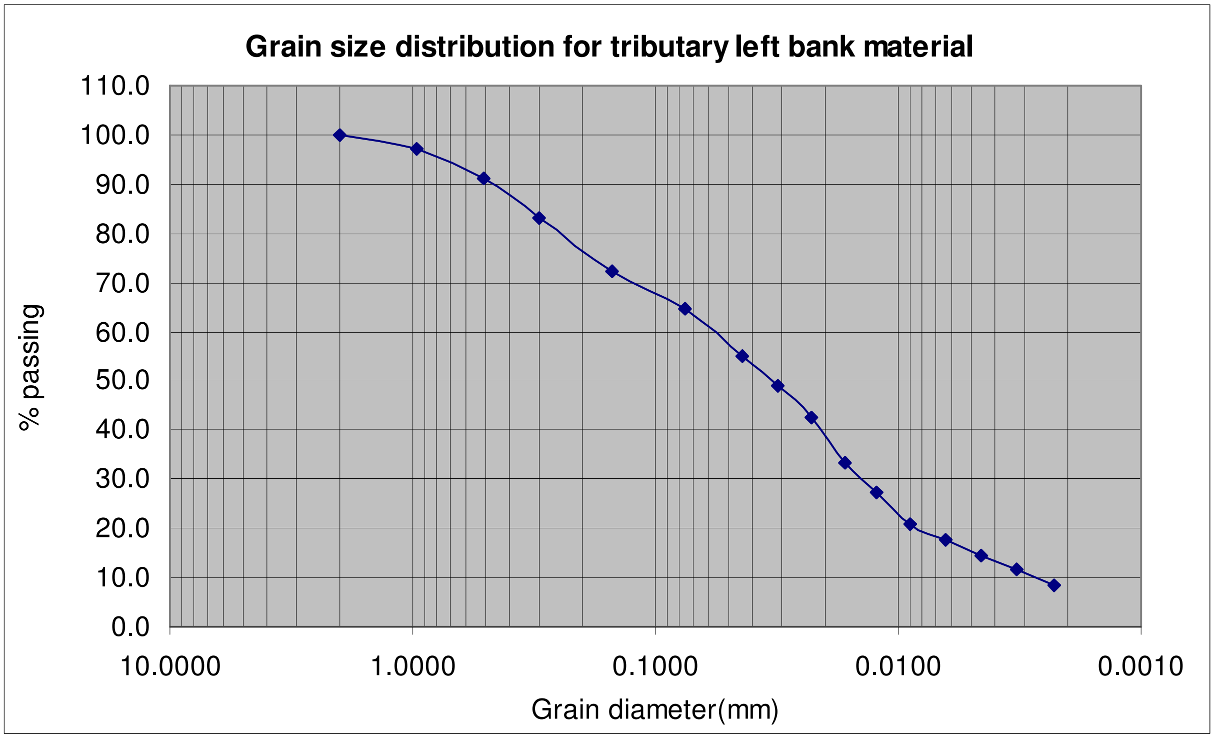
Land use/ cover and land slope	Percentage of land slope with respect to its land use	Average soil texture for each land use	Value of c	Weighted value of C
Wood land and forest flat 0-10%				
Flat 0-5%	13.98		0.30	0.04
Rolling 5-10%	0.69	Clay	0.35	0.002
Hilly Mountainous>10%	32.93		0.50	0.16
Pasture				
flat 0-5	1.50	Silty Loam	0.30	0.005
Rolling 5-10%	1.50		0.35	0.01
Hilly Mountainous>10%	5.80		0.42	0.02
Cultivated		Sandy loam		
Flat 0-5%	4.20		0.30	0.01
Rolling 5-10%	10.20		0.40	0.04
Hilly Mountainous>10%	15.60		0.50	0.08
Urban Areas		30% of Area		
Flat 0-5%	6.00	impervious	0.40	0.02
Rolling 5-10%	7.60		0.50	0.04
	$\sum \% = 100$			$\sum c = 0.44$

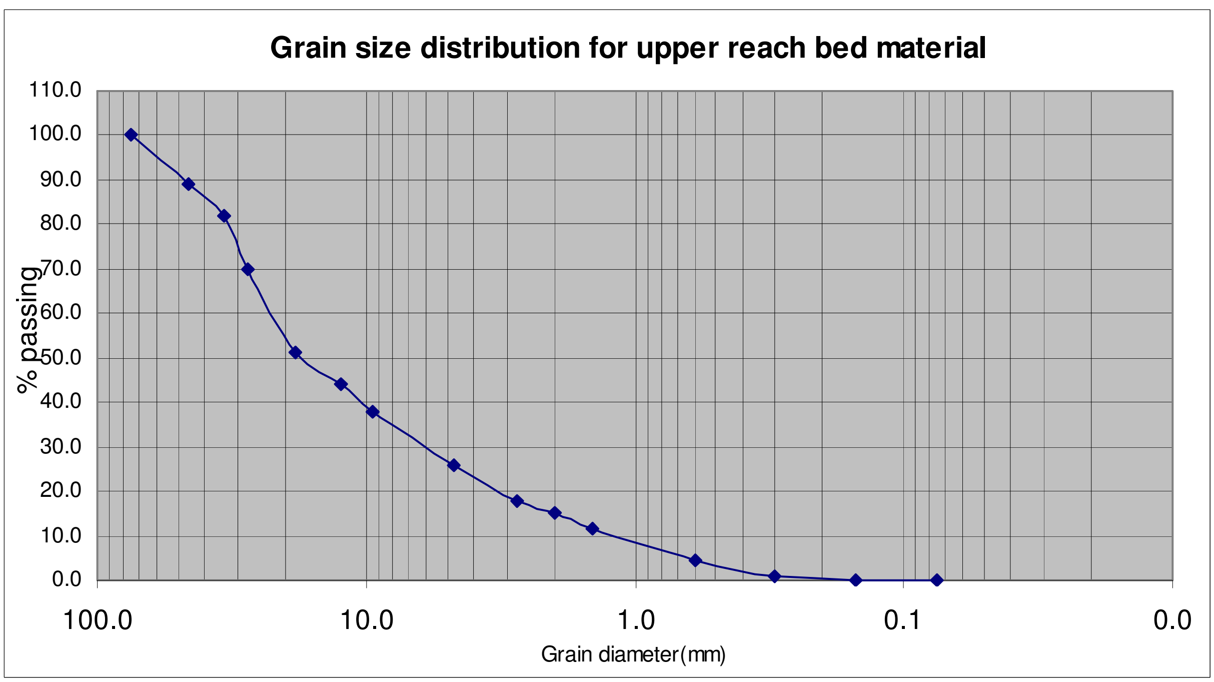
Appendex-5

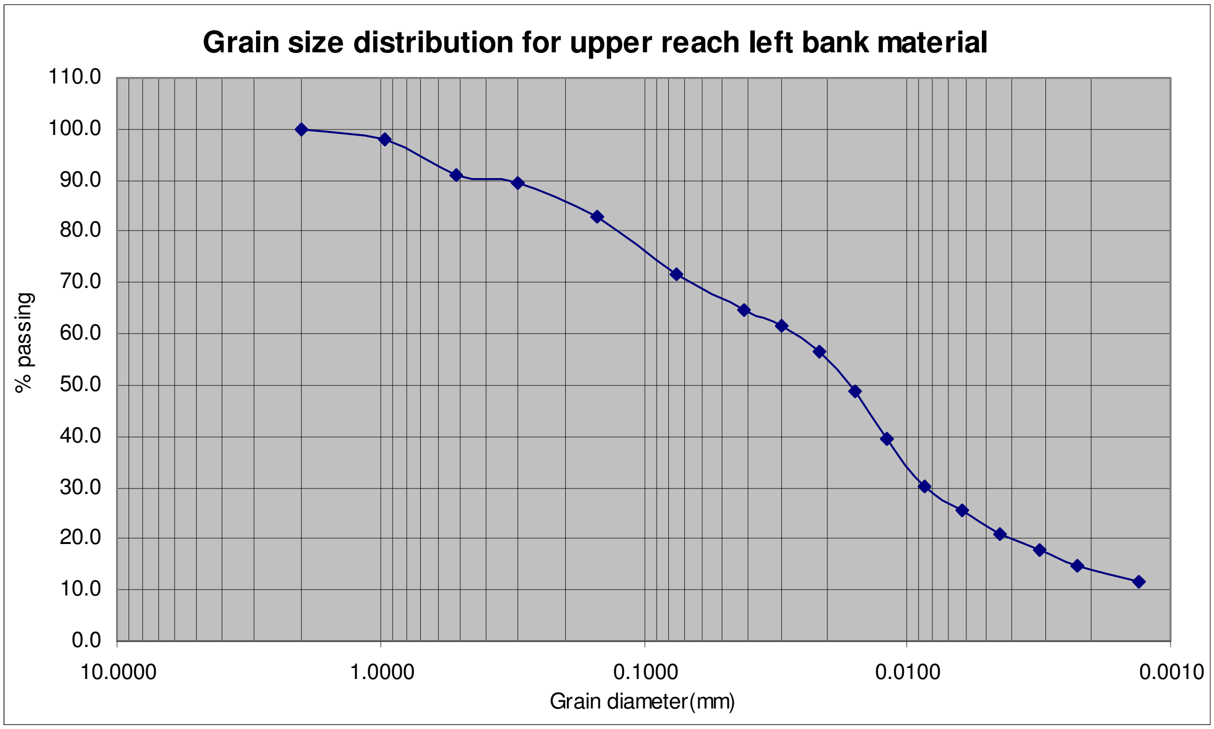
Grain Size Distribution Plots

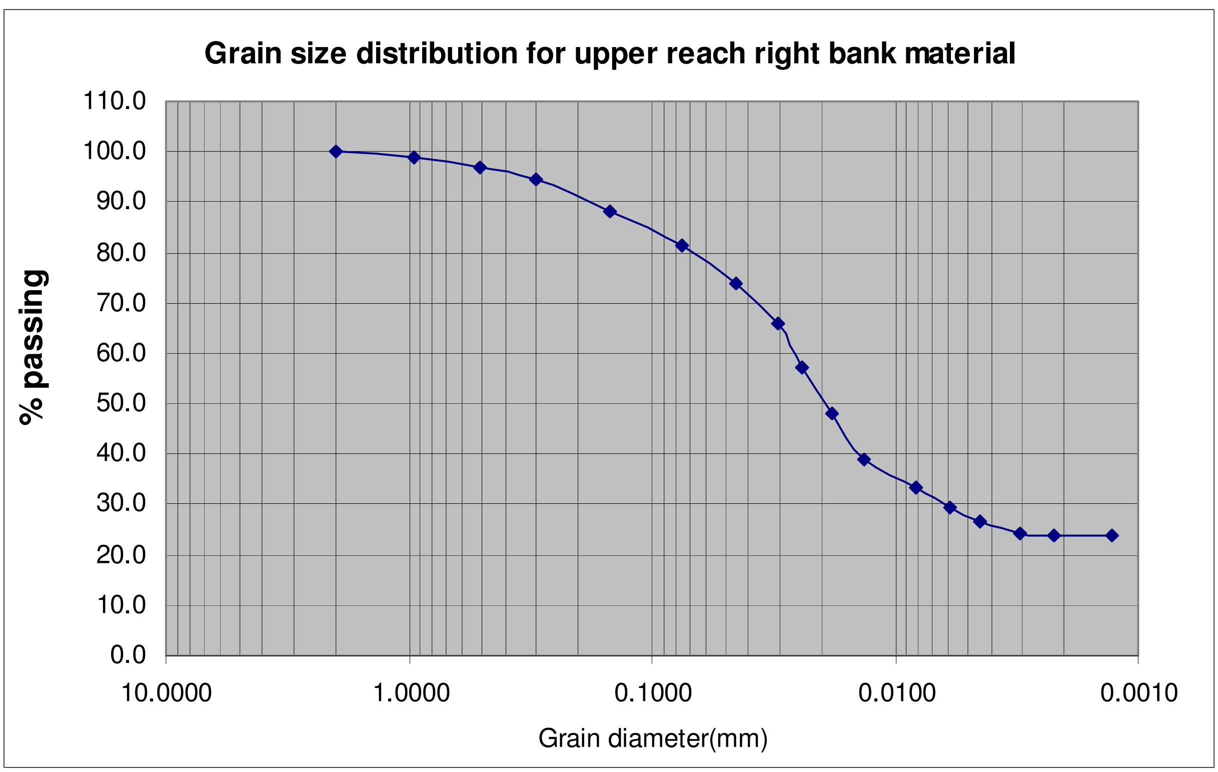


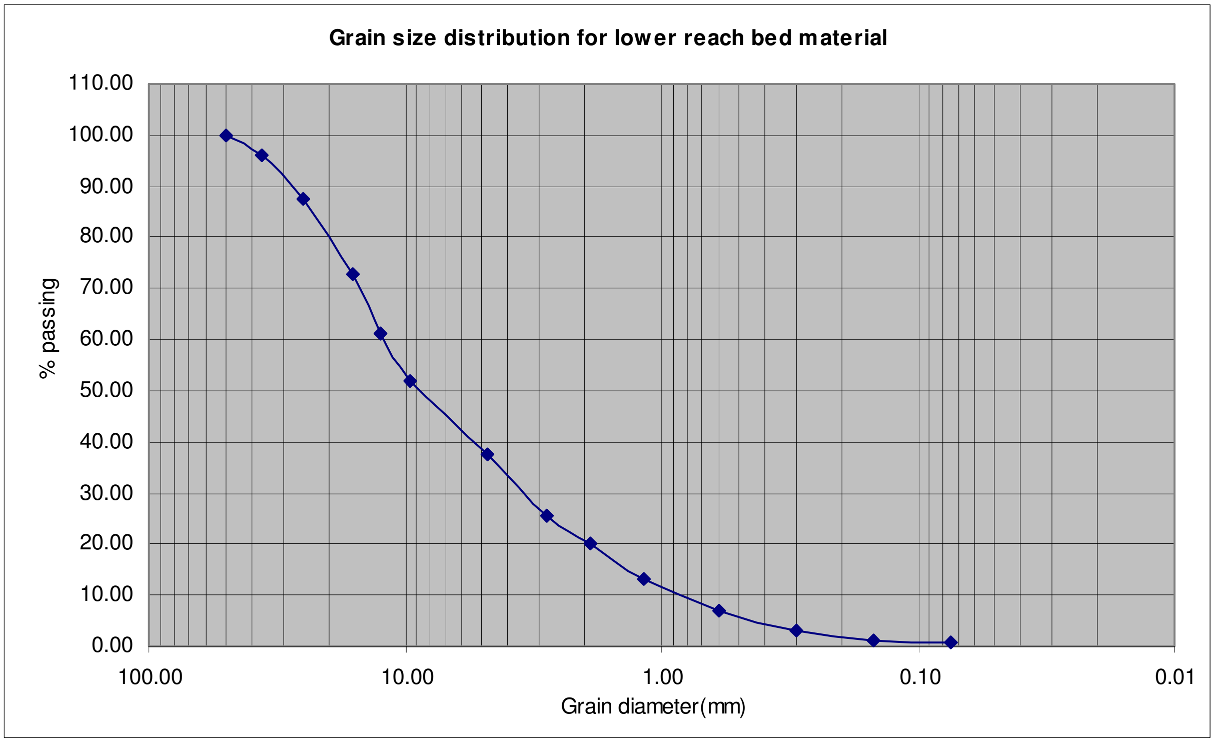


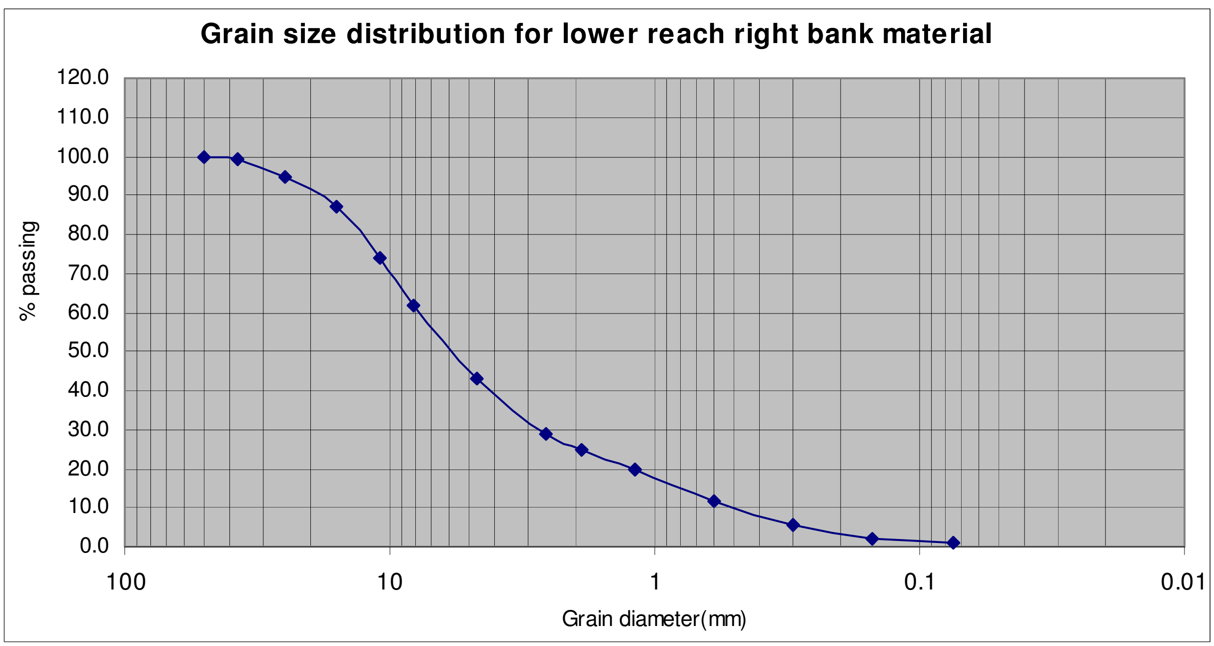

Grain size distribution for tributary left bank material
% passing
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
10.0000
1.0000
0.1000
0.0100
0.0010
Grain diameter(mm)

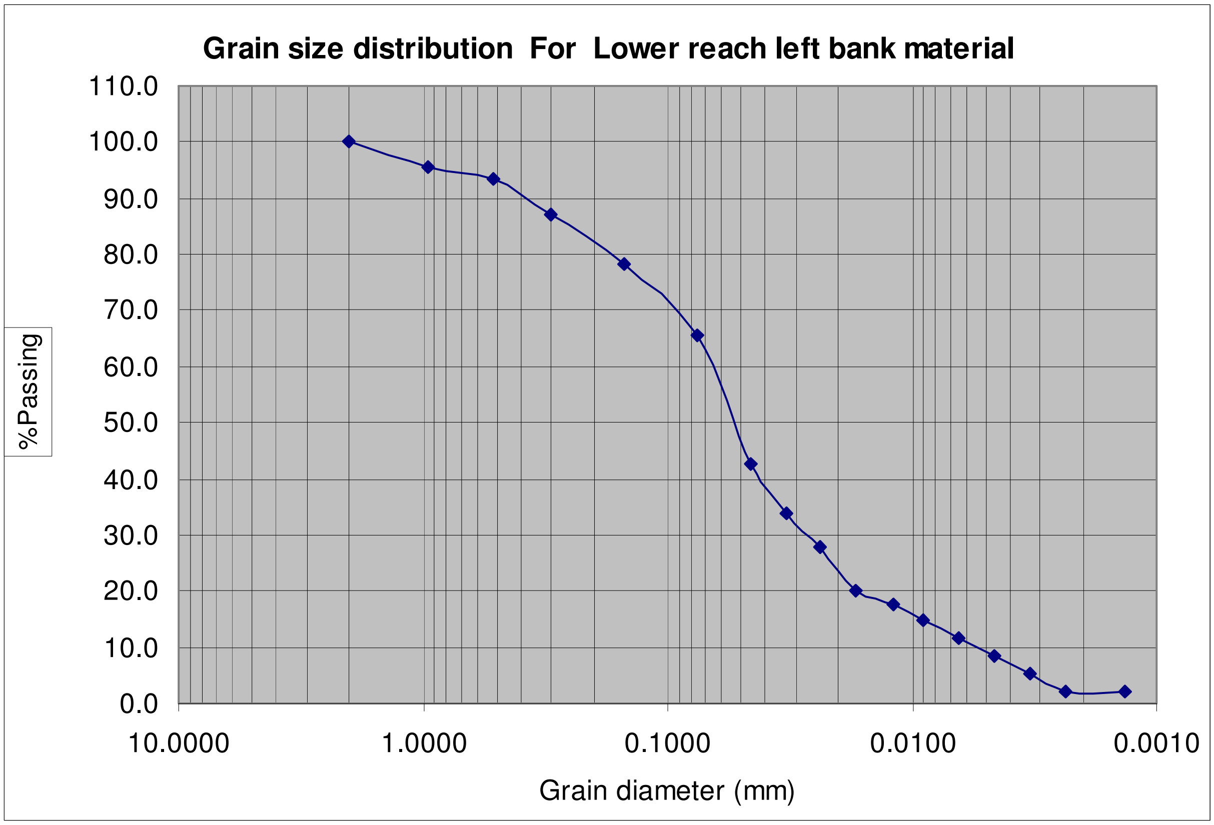

Grain size distribution for upper reach bed material
% passing
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
100.0
10.0
1.0
0.1
0.0
Grain diameter(mm)


Grain size distribution for upper reach left bank material
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
% passing
10.0000
1.0000
0.1000
0.0100
0.0010
Grain diameter(mm)


Grain size distribution for upper reach right bank material
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
% passing
10.0000
1.0000
0.1000
0.0100
0.0010
Grain diameter(mm)


Grain size distribution for lower reach bed material
110.00
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
% passing
100.00
10.00
1.00
0.10
0.01
Grain diameter(mm)


Grain size distribution for lower reach right bank material
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
% passing
100
10
1
0.1
0.01
Grain diameter(mm)


Grain size distribution For Lower reach left bank material
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
%Passing
10.0000
1.0000
0.1000
0.0100
0.0010
Grain diameter (mm)