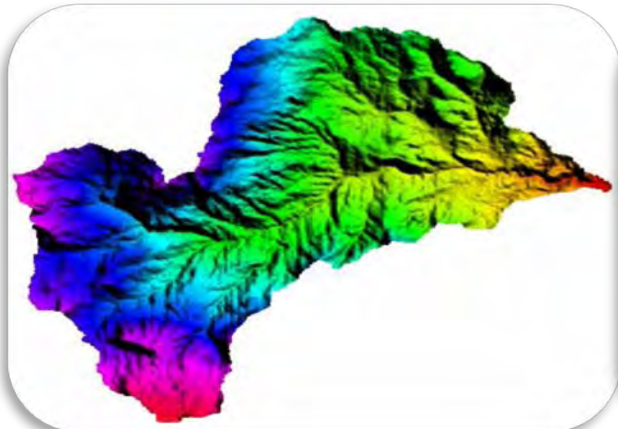
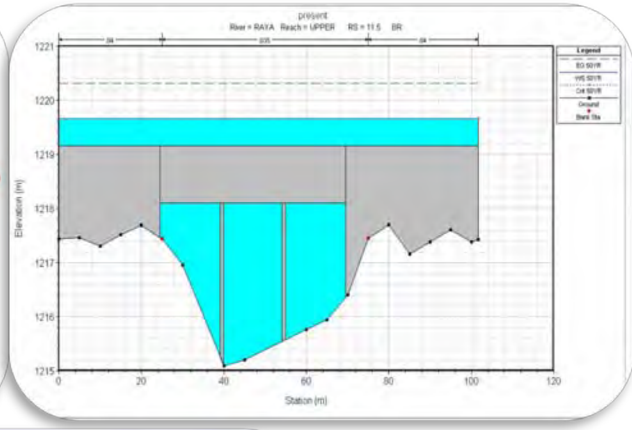
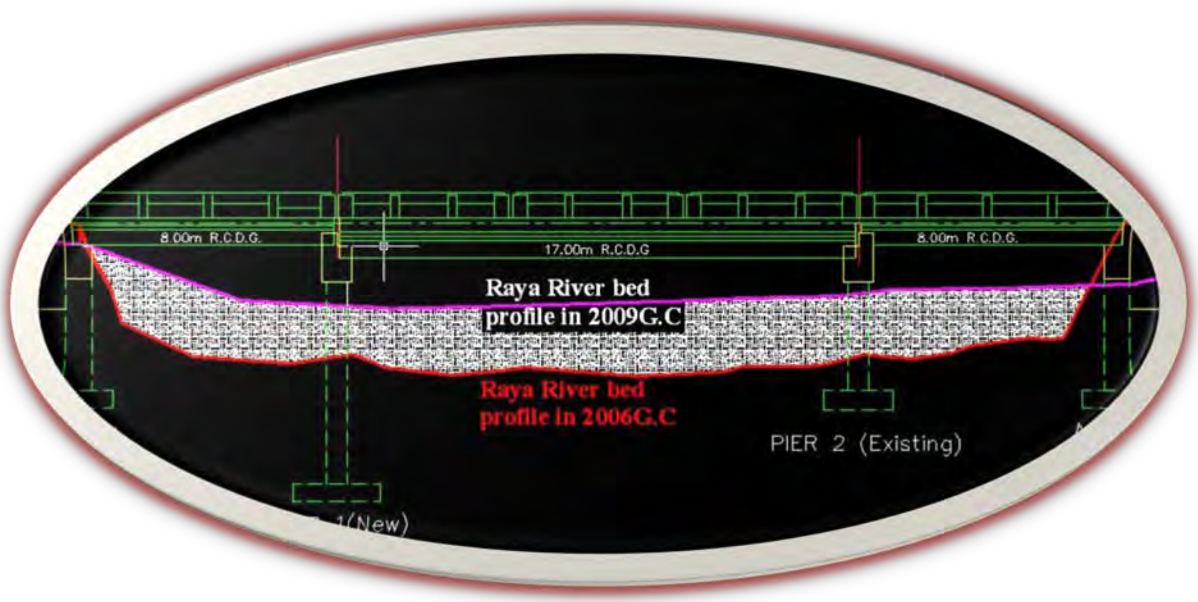
Investigation of Cause of Failures of Highway Cross Drainage Structures

(*Case Study on Raya River Bridge*)







By: Beza Nigussie **JULY 2010**

Investigation of cause of failures of Highway cross drainage Structures (Case study on Raya River Bridge)

Masters of Science Thesis

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Declaration and copy right

Beza Nigussie declares that this thesis is my original work and that it has not been presented and will not presented by me to any other university for similar or any other degree award.

Signature ……

Abstract

Bridges that cross the rivers and valleys are vital components of the road network that contributes greatly to the national development and public daily life. Any damage or collapse of bridge can risk the lives of road users as well as create serious influence to the entire country. Furthermore, the reconstruction of the bridges needs considerable amount of money and time. In fact, Ethiopia has experienced many cases of bridge collapse and their serious consequence over decades.

The main factors for the failure of the drainage structures are due to basin characteristics, stream channel characteristics, flood plain characteristics and meteorological characteristics; and these factors categorized as hydrologic failure, hydraulic failure, failure due to gradation and failure due to orientation of the Structure. Of these categories of bridge failures the Raya river bridge is categorized in the form of failures due to gradation.

Hec- Ras and other supporting software's were used to analyze the cause of the failure of the Raya river bridge. DEM data, surveying data at the bridge cross section, land use data and other supporting data's were used to estimate the amount of sediment deposition or long term river bed level rise (aggradation) at the bridge location. The analyses of the data's shows that there is a clear reduction of flow area or opening size at the bridge location due to long term river bed level rise or aggradations around the bridge crossing location resulted from sediment accumulation around the bridge location. The obtained results shows that the main cause of Raya river bridge failure is due to reduction of flow area or opening size at the bridge location due to deposition of sediment which is estimated about 0.588m depth of deposition each year at the bridge location.

Acknowledgements

First of all I would like to thank the almighty GOD for his unspeakable gift, help and protection and I am heartily thankful to St. Virgin Mary and all Saints supporting and protecting me during my work.

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Lastly! I offer my regards and thanks to all the Staff members of Beza Consult, AEC Consult, ERA Bridge Department and those who supported me in any aspect for the completion of the Study.

Beza N.

July, 2010, Addis Ababa Ethiopia

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List of Abbreviations and Definitions

AACRA	Addis Ababa City Road Authority
AEC	Associate Engineering Consult
BMS	Bridge Management System
CN	Curve Number
DEM	Digital Elevation Model
DG	Deck Girder
D/S	Downstream
ERA	Ethiopian Roads Authority
FHWA	Federal Highway Administration
GIS	Geographic Information System
HEC	Hydraulic Engineering Circulars
HWM	Highest Water Mark
PC	Preistresed Concrete
RC	Reinforced Concrete
RCDG	Reinforced Concrete Deck Girder
SCS	Soil conservation service
U/S	Upstream

Glossary

Bed load: Sediment that is transported in a stream by rolling, sliding, or skipping along the bed or very close to it; considered to be within the bed layer (contact load).

Bed slope: The inclination of the channel bottom.

Bridge opening: The cross-sectional area beneath a bridge that is available for conveyance of water.

Channelization: Straightening or deepening of a natural channel by artificial cutoffs, grading, flow-control measures, or diversion of flow into an engineered channel.

Check dam: A low dam or weir across a channel used to control stage or degradation.

Cross section: A section normal to the trend of a channel or flow.

Discharge: Volume of water passing through a channel during a given time.

Drainage basin: An area confined by drainage divides, often having only one outlet for discharge (catchment, watershed).

Frequency: The number of times a flood of a given magnitude can be expected to occur on average over a long period of time.

Frequency analysis is the estimation of peak discharges for various recurrence intervals. Another way to express frequency is with probability. Probability analysis seeks to define the flood flow with a probability of being equaled or exceeded in any year.

Hydraulic Roughness: A composite of the physical characteristics that influence the flow of water across the earth's surface, whether natural or channelized. It affects both the time response of a catchment area and drainage channel, as well as the channel storage characteristics.

Infiltration: A complex process of allowing runoff to penetrate the ground surface and flow through the upper soil surface. The infiltration curve is a graph of the time distribution at which this occurs.

Interception: The storage of rainfall on foliage and other intercepting surfaces during a rainfall event is called interception storage.

Peak Discharge: Sometimes called peak flow. The maximum rate of flow of water passing a given point during or after a rainfall event.

Rainfall Excess: The water available to runoff after interception, depression storage and infiltration has been satisfied.

River training: Engineering works with or without the construction of embankment, built along a stream or reach of stream to direct or to lead the flow into a prescribed channel. Also, any structure configuration constructed in a stream or placed on, adjacent to, or in the vicinity of a stream bank that is intended to deflect currents, induce sediment deposition, induce scour, or in some other way alter the flow and sediment regimes of the stream.

Sediment load: Amount of sediment being moved by a stream.

Stage: The elevation of the water surface above some elevation datum.

Time of Concentration: The time it takes a drop of water falling on the most remote point hydraulically in the catchment area to travel through the catchment area to the outlet.

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1. Introduction

1.1. General

Adequate drainage is essential in the design of highways since it affects the highways serviceability and usable life. For the highway designer, the primary focus of hydrology is the water that moves on the earth's surface and in particular that part that ultimately crosses transportation arterials (i.e., highway stream crossings). A secondary interest is to provide interior drainage for road ways, median areas and interchanges. The drainage designs involves providing facilities that collect, transport and remove the water from the highway.

Hydrologists have been studying the flow or runoff of water overland for many decades, and some rather sophisticated theories have been proposed to describe the process unfortunately most of these attempts have been only partially successful, not only because of the complexity of the process and the many interactive factors involved, but also because of the stochastic nature of rainfall and other source of water. However for many of these surface runoff factors, complete functional descriptions of their individual effects exist only in empirical form. Their qualitative analysis requires extensive field data, empirically determined coefficients and sound judgment and experience.

This case study is based on Hydrology and Hydraulics report for the design reconstruction /replacement / of Raya River Bridge on Addis Ababa - Arbaminch main road section over Raya River around Wajifo town which is 428 km from Addis Ababa. The main reason for this paper is the failure of the existing three span bridges on the Raya River.

The analysis of were done using Arc view 3.2, Global Mapper 8.0, Excel spread sheet and other for the determination of the catchment , catchment characteristics and peak flood determination for the 50 and 100 years return period based on ERA (Ethiopian Roads Authority) Drainage Design Manual. And HEC – RAS 4.0 and other data's were used for the hydraulic analysis.

Based on the obtained finding's Mitigation Measures were recommended for the Raya River Bridge and also recommendations and solutions for other bridge were given.

1.2. Study area

The study area, Raya River Bridge, is located on Addis Ababa Arbaminch main road at 428 km from Addis Ababa around at the entrance of Wajifo town. It is located at 361221 N and 714059 E or 6^0 27' 29'' N and $37^0$44'42'' E in the semen Omo Reign Boreda Abaya Woreda. Fig 1Raya River Bridge location.

The Raya river originates in the mountains of Chencha at an elevation of 2650m a.m.s.l and drains to the eastern direction through Wajifo town after receiving flows from its tributaries and finally ends in Lake Abaya and the bridge located at the upstream of the lake around 3km.

The Raya river catchment covers 91.253 km^2 area at the bridge crossing location and its elevation varies from 2654 m a.m.s.l at the highest point and 1217 m a.m.s.l at the crossing location. More than 79% of the catchment is cultivated and the remaining 21% were covered by small trees, shrubs and scarcely distributed trees were found. There are different types of soils were found chromic vertisols, dystric and orthic acrisoils are the dominant which covers more than 85% of the total soil coverage.

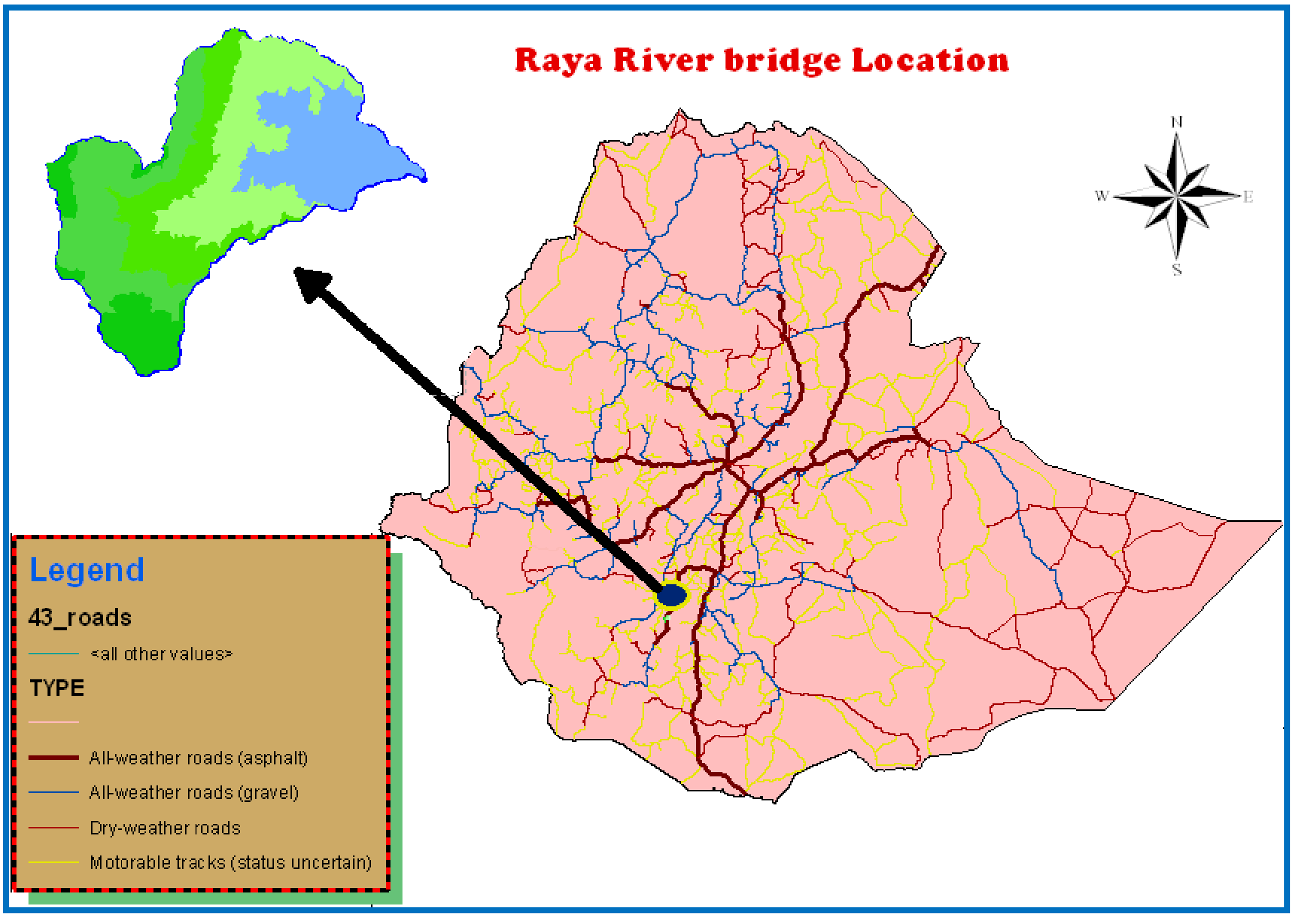


Figure 1: Raya River Bridge Location

1.3. Problem Description

Currently Ethiopian roads Authority were developing a program to manage the existing bridges in the country. Before 2006G.C there is no any means of bridge management system in Ethiopia and which will aggravates the bridge failures because of lack of data's on their conditions. There are a lot of problems were observed on the Raya river bridge the main problems which we have observed that:-

- The failure of the existing multiple span (8m+18m+8m) span bridge along the Addis Ababa – Arbaminch main road. See photo # 1
- Cracks on the pier and abutment of the bridges. See photo # 2
- Aggradation or increasing of river bed elevation. See photo # 3
- Silted up weir or diversion structure at the upstream of the bridge. See photo # 4
- Flooding problems around bridge location.

Photo 1: Raya River Bridge failure (Sep 2009)

Photo 2: cracks on the pier (Sep 2009)

Photo 3: River bed level rise (Sep 2009)

Photo 4: Silted up diversion structure (Sep 2009)

1.4. *Expected causes of the bridge failure*

As per the site visit and the site findings the following points were mentioned as the causes of the existing 8m+18m+8m triple span bridge failure:

- Aggradation or increasing of the river bed elevation which will reduce the clear opening of the bridge water way.
- Construction of weir/ diversion structure at the u/s of the bridge which will reduce the velocity of the flow and aggravates the amount of sediment deposition.
- Channelization work which diverts the flow in one direction, to the Arbaminch side of the river, which makes the flow to concentrate on that side.
- Farmer/local peoples activity to divert the flow to their farm land and
- The bridge is located just at the mouth of the Lake Abaya, which also reduces the flow velocity and it will make it the river to deposit the sediment on the bridge location before the entrance of the lake.

This study will go deeper into scientific analysis to get into the real causes of the problem that caused the failure of the Raya river bridge.

1.5. *Objectives*

The main objective of the study is to investigate the main cause of failure of the Raya River Bridge and to come across to a feasible solution for the problems observed by using hydrologic ,hydraulic and sediment models by using the available data's. This could be achieved through gaining knowledge on bridge scouring problem and developing a tool to access the scour problem specifically on gradation problems on a bridge crossing location. This study also aims to contribute a better basis for Hydrologic and Hydraulic design of bridges to predict the amount of scour level specifically on Aggradation / Degradation or river bed elevation change.

Specific Objectives of this study are:

- To investigate the various failure condition of Raya bridge and to provide scientific basis for each failure conditions
- To recommend design guide lines for new bridges
- To use the outcome for further problem prediction, identification and mitigation measures.

1.6. Significance of the research

In Ethiopia recently lots of road projects were under construction and lot of design works were done for the future expansion of the road network throughout the country by the Federal and Rural Road Authorities. The country has experienced many cases of bridge collapse for many decades but there is no any information for the causes of their failures.

Bridge Scour is one of the major causes of the bridge failures of which gradation or long term elevation change of river bed is also one of the causes of the failure specially on flat areas of the country, on bridge locations where there is large amount of land use changes on the catchment area, on locations of bridges just at the mouth of the entrance to Lakes like Raya, Shefe, Baso, Kulfo rivers and others located at the upstream and downstream of a dam or Reservoirs.

Therefore there is a need to have a proper design of bridges on the above locations to overcome the consequence of bridge failures due to gradation/river bed elevation changes. Most of the time hydrologists are mainly concerned on only for scouring problem on piers and Abutments or contraction scour, but it is also mandatory to analyze the long term effect of aggradation or degradation of river bed which is one of the causes of bridge failure in our country.

There are lots of bridges which are UN functional due to the effect of long term elevation change of river bed/gradation. Some samples were explained to show the significance of analyzing the long-term effect of river bed changes:

a) Segen River Bridge

The Segen river bridge is located on Fissehagenet – Chelelektu – Konso road at around 30kms from the tourist town of Konso. The River carries a lot of sediment in its watercourse and deposits its sediment around the existing bridge and upstream of the bridge due to the flat nature of the topography. The existing bridge at the moment is fully silted up and the entire bridge structure that is both the superstructure and substructure are fully buried under sediment. See photo # 5

b) Baso, Raya, Shefe, Kulfo river bridges

This mentioned bridges and other bridges which are located on Addis Arbaminch main road are vulnerable for completely failure due to the rise in their river bed level and reduction of clear opening height at the crossing locations. See photo # 6&7

Photo 5: Segen River Bridge completely buried under sediment (Aug 2007)

Photo 6: Shefe River Bridge less than 0.9m clear opening height (Jun 2006)

Photo 7: Baso River Bridge less than 0.7m clear opening height (Jun 2006)

2. LITERATURE REVIEW

2.1. Bridges in Ethiopia and Previous failure Cases

2.1.1. Bridges in Ethiopia

Bridges that cross the rivers and valleys are vital components of the road network that contributes greatly to the national development and public daily life. Any damage or collapse of bridge can risk the lives of road users as well as create serious influence to the entire country. Furthermore, the reconstruction of the bridges needs considerable amount of money and time. In fact, Ethiopia has experienced many cases of bridge collapse and their serious consequence over decades.

Presently more than 20,000 km of federal road administrated by ERA and the road network contains about 3,000 bridges and more than 27,000 small drainage structures. Among them about 35% of Ethiopian bridges were constructed more than 60 years ago showing signs of severe deterioration due that they have not been properly maintained since their construction.

Table 1: Condition of bridges in Ethiopia (ERABMS Bulletin 2006)

Road Class	Total Bridges	Good *		Need Repair		Need Replacement	
		bridges	%	Bridges	%	bridges	%
A1	284	250	88	81	28.5	19	6.7
A2	525	505	96	115	21.9	12	2.3
A3	226	220	97	68	30	5	2.2
A4	198	170	86	49	24.7	17	8.6
A5	88	81	92	83	94.3	1	1.1
A6	13	12	92	3	23.1	1	7.7
A7	43	36	84	5	11.6	0	0.0
A8	26	25	96	6	23.1	0	0.0
A9	7	5	71	3	42.9	0	0.0
A10	67	57	85	25	37.3	0	0.0
Link	571	539	94	210	36.8	31	5.4
M. access	405	366	90	123	30.4	13	3.2
0.9	330	323	98	78	23.6	3	
Feeder	172	154	90	38	22.1	5	2.9
Total	**2,955**	**2,743**	**92.8**	**887**	**30**	**107**	**3.6**

Presently, there are 2,955 bridges along the federal road network, 4.7% of the bridges are located on the trunk roads of A1 (A-A – Djibouti) A2 (A-A – Axum), A3(AA-Gondar), A4 (AA- Gimbi) and A5 (AA- Metu) 33.61 % are rated poor conditions that require interventions 30% needs repair and 3.6% replacement. The fact that as many as 35.2% of all the bridges on the A1 road need repair or replacement indicates the seriousness of the bridge conditions in Ethiopia. Almost 1/3 of the bridges were constructed more than 61 years ago. Some bridges are in good condition but they need repair/ rehabilitation due to hydrological problems.

Table 2: Type of Bridges (ERABMS Bulletin 2008)

Type	bridge	%
RC Slab	1,272	43.05
RC Deck Girder	632	21.39
RC Box Girder	5	0.17
RC Arch	16	0.54
PC Deck Girder	5	0.17
PC Box Girder	1	0.03
Masonry Arch	546	18.48
Steel Girder	11	0.37
Steel Truss	6	0.20
Steel Truss and RC DG	1	0.03
RC Box and RC DG	2	0.07
RC Arch and RC DG	1	0.03
Temporary Bridge (Bailey)	51	1.73
RC Box Culver	401	13.57
RC DG and Slab Culvert	5	0.17
Total	**2,955**	**100**

2.1.2. Previous Bridge failure Cases

The main causes of the failure of the drainage structures are due to the following factors:

1) Basin Characteristics: Size, shape, land use, geology, soil type, surface infiltration and storage etc
2) Stream channel Characteristics: geometry and configuration, natural and artificial controls, channel modifications, aggradations, degradation and debris.
3) Flood plain characteristics
4) Meteorological characteristics: precipitation amount and type, storm cell size and distribution, storm direction and time of precipitation (hyetographs).

Based on the above factors we can categorize the causes of the failures of the drainage structures in the following groups:

a) Hydrological failure
b) Hydraulic failure
c) Failure due to aggradations or degradation
d) Orientation or location of structure.

The bridge failures presented below are samples of different types of bridge failures observed in our country.

A) Fafem River Bridge

The Fafem River Bridge is located on Harar Jijiga road project at 68km from the tourist town Harar. The bridge is recently constructed in 2007 G.c and failed within a year in 2008G.c due to flooding. From the observed and collected data the bridge does not have sufficient opening size to accommodate the coming flood on the proposed bridge location.

Photo 8: Failed Fafem River Bridge (Jul 2008)

Photo 9: Fafem river flooding condition (Jul 2008)

B) Guang River Bridge

Guang River Bridge is located on Metema Abederafi gravel road section around 8km from Metema. The bridge is a triple span Girder bridge having span of 72m each 24m span were constructed by nongovernmental organization(NGO) and the bridge serves only for one rainy season and completely failed due to flooding. Based on the local peoples information given the bridge does not have sufficient opening size to accommodate the flood during rainy season.

Photo 10: Failed Guang River Bridge (Jun 2009)

C) Delbena River Bridge

Delbena River Bridge located on the Arbaminch Konso road and it is failed due to flooding. In addition there are also other bridge failures observed on this road section.

Photo 11: Delbena River Bridge (Aug 2006)

Photo 12: Failed Delbena Bridge (Aug 2006)

D) Segen River Bridge

The Segen River Bridge is located on Fesehagenet Konso road around 16km from the tourist town Konso. This bridge is completely buried under sediment and at present it's not functional at all.

Photo 13: Completely buried Segen Bridge (Aug 2007)

E) Garno River Bridge

Garno River Bridge is located on Addis Ababa Gonder main road at 674km from Addis Ababa. This is 12m span Girder Bridge constructed in 1977G.c there is a scouring problem on one of the abutment and it causes failure of the approach slab.

Photo 14: Collapsed approach slab of Garno Bridge (Jul 2006)

Photo 15: Scouring on the abutment of Garno Bridge (Jul 2006)

2.2. Bridge Scour

The most common mobile boundary analysis required of the engineer is likely to be the evaluation of scour impacts on existing or new bridges.

An evaluation of bridge safety against scour is necessary because the bridge location on the stream is fixed, but the stream may scour channel material through the bridge reach and move laterally in the floodplain. The economic life of a bridge is often taken as 50 years following construction, but the actual life could be much longer. Therefore, an adequate evaluation of scour potential is quite important. The analytical tools to address erosion and scour impacts at bridges were largely lacking until the 1960s. Early scour prediction equations and sediment transport models were available, but the analysis of a specific flood event to compute expected scour was seldom performed. This lack of analysis was mainly due to poor understanding of the physical process of bridge scour, the lack of adequate information for all the variables needed for such an analysis, and the inability to accurately model significant geometry changes for short-duration flood events.

HEC – RAS has standard bridge scour analysis as a hydraulic design function within the program. In addition to designing the bridge opening using HEC – RAS, the engineer can now perform a scour analysis within HEC – RAS for the bridge design. The program does not yet provide a long – term sediment transport model and no hydraulic or sediment modeling is done in the scour analysis. Instead, HEC – RAS uses the equations and procedures developed by FHWA to estimate the maximum scour potential at the bridge.

The bridge scour equations used by the FHWA were developed primarily through flume studies using movable – bed physical models. Model testing resulted in predication equations for contraction scour into the bridge and the scour caused by local obstacles at the bridge- the abutments and piers. The equations used by the FHWA have been field tested and found to produce conservative estimates of scour depths (more scour than is expected to occur at the actual bridge).

Scour at bridges can occur in a variety of ways, including long – term aggradation and degradation throughout the river reach containing the bridge, general scour near and within the bridge structure, contraction scour, scour around bridge obstructions (abutments and piers), and scour from lateral movement of the stream channel. These sources of scour are presented in the following sections.

2.3. Aggradation and Degradation

Aggradation and degradation are long term changes in stream bed elevation by natural factors or man's activities. The terms aggradation and degradation are not defined in precisely way by engineers, geologists, and geomorphologists. The difference in the definitions' comes from defining the limits of the perspective used to view the river in time and space. The purpose of this section is to define the terms as they are used in this report and contrast the definitions with terms often used to describe vertical streambed level changes.

Leopold et al. (1964) provide a definition of aggradations and degradation from the viewpoint of the geomorphologist. They also introduce into the definition the terms scour and fill. These are the two terms most likely to be confused with aggradations and degradation.

"With the rise in stage accompanying flood passage through a river reach, there is an increase in velocity and shear stress on the bed. As a result the channel bed tends to scour during high flow. Because sediment is being contributed from upstream, as the shear decrease with the fall of stage the sediment tend to be deposited on the bed or the bed fills. Channel scour and fill are words used to define sedimentation during relatively short periods of time whereas the terms degradation and aggradation apply to similar processes that occur over a longer period of time. Scour and fill involves times measured in minutes, hours, days, perhaps even seasons, whereas aggradation and degradation apply to persistent mean changes over a period of times measured in years."

Contrast this with Simons and Senturk (1977) in an engineering text where the following is provided:" A river is stable when the geometry of a cross section is constant in time. If the bottom level increases, the stream bed is aggrading. If the bottom level decreases, the stream bed is subjected to degradation." Simsons and Sentrurk leave out the important time consideration of time frame.

For the purpose of this report the Leopold et al. (1964) definitions will be adopted. All the bed level changes which occur over the time periods less than a year will be referred to as scour or fill. Aggradation and degradation require long time spans. For example after a single flood event a channel bed moves downward, scour has occurred. If after three years and several flood events the channel bed consistently moves downward, degradation occurred. Degradation and aggradation will be associated with the changes occurring over many channel widths. The perspective in viewing problems will often extend for kilometers both upstream and downstream of a bridge crossing.

The design capacities of bridges in the backwater of a downstream river or reservoir, or those that cross rivers carrying a high concentration of sediment may be compromised by channel and overbank deposition in or near the bridge opening or support structures. This could in turn cause flooding problems upstream of the structure and could also cause overtopping of approach roads and the bridge itself.
Reach aggradation or degradation can be identified by evaluating historic records of the river reach for changes in channel geometry. To estimate an upward or downward trend in stream elevations and the average change per year. This yearly average change can be multiplied by the projected life of the bridge to estimate the long – term aggradation or degradation. A sediment transport model can also give insight into the magnitude of reach aggradation as well as degradation. The engineer can also apply his

or her judgment, supplemented with available information, to estimate the overall lowering or rising of the stream invert through the projected life of the bridge.

2.3.1. Types of gradation problems

i) Aggradation Problem

The highway crossing problem most associated with aggradation, as illustrated in photo # 16 is reduction of flow area. This reduction in flow area results in possible flow over the bridge deck. Traffic is immediately or potentially disrupted. Not only is there a potential disruption of traffic, there is a potential to have the bridge swept away due to an increase in horizontal force and turning movement. Aggradation at bridge crossing also results in expensive maintenance costs. It becomes necessary to excavate the deposited material in the flow area upstream and downstream of the bridge to provide necessary flow area to pass the design flow.

ii) Degradation Problem

As illustrated in photo # 17 the highway crossing problems associated with degradation are the exposure of footings, the exposure of pile bents, and the erosion of the abutments. Degradation also undermines bank protection, results in instability of channel banks, and increases debris problems. Ultimately, the degradation can result in the loss of a bridge and in fact, is responsible for the loss of many bridges throughout the country.

Photo 16: Aggradation on river Segen with inadequate opening (Aug 2007)

Photo 17: Degradation on river Warda exposing the foundation of the abutment (Aug 2007)

2.3.2. Classification of causes

Causes of gradation changes that have an impact on highway crossings can be classified into two basic categories: (a) natural causes and (b) the result of man's activities. An analysis indicates that very few gradation changes were due to natural factors.

Some gradation changes should perhaps be classified as being caused by a combination of both natural and man-induced factors. Their number is so small that a separate category is not warranted. Because man's activities dominate the causes for gradation problems, they will be discussed first.

i) Man's activities

The activities of man are literally changing the face of the earth and hence, the hydrologic basins. Some activities have had far-reaching consequences on streams and have caused or contributed to aggradation and degradation problems at bridges. Construction of a bridge and approach embankments may also have consequences, but they are unlikely to be far-reaching. Man's activities were found to be the major cause of streambed elevation changes.

From an analysis of the case histories, man's activities resulting in gradation problems can be classified into the following categories:

- Channel alteration
- Streambed mining
- Damming and reservoir regulation
- Land use changes,

a) Channel alteration

Straightening, dredging, clearing and snagging artificial constrictions and other alterations of natural channels are the major causes of streambed elevation changes. Straightening of natural channels, principally to improve drainage for agricultural purposes has been widely practiced. Straightened channels have degraded, and degradation is usually accompanied by widening of the channel, unstable banks and serious debris problems. The degradation is attributed to an increase in channel slope that result from shortening of channel length. The increase in channel slope increases the velocity and the shear stress on the bed. As a result the channel bed degrades until the bed becomes armored or the channel widens and begins to meander to reduce the channel slope back to equilibrium, a stable condition. Some degradation has resulted from the abandonment of channels that have been adjusted to the stream regime and the cutting of new channels and failure to stabilize them. In this case, an armored channel is moved to freshly cut alluvium that has less capacity and erosion resistance.

b) Streambed mining /excavation

If sand or gravel is removed from an alluvial channel in quantities that represent a substantial percentage of the bed load in transport, the channel will probably degrade. In addition removal of gravel from pits or trenches in or along the stream may result in a change in flow alignment at the bridge.

c) Dams and reservoir

The effects of dams and reservoirs in a stream are complex and have not been thoroughly investigated. The consequences include clear water release; high, sustained, regulated flows; backwater; low, sustained, regulated flows; dam breach or removal; and high, controlled, irrigation canal releases.

Downstream from reservoirs, channel degradation is to be expected because of removal of sediment load. The total amount of degradation is difficult to predict; if a sand bed channel becomes armored with gravel, the amount may be small. On gravel bed streams aggradation may occur downstream from the dam because the flow releases are insufficient to transport gravel brought in by tributary streams. As pointed out by Kellerhals, Church, and Bray (1976), channel avulsions, which can present a serious threat to many engineering structures, are associated with most aggradation situations.

d) Land Use Changes

Urbanization, agriculture, strip mining and logging/clearing are activities of man that cause gradation problems. Natural vegetation is extremely important in maintaining channel stability. The lateral stability of streams, particularly in regions where agriculture is practiced, has very probably been affected by clearing has occurred more or less gradually over the past hundred years, the magnitude of the effect at a particular crossing site is sometimes difficult to assess.

Mining in upland areas may cause aggradation of channels, which are then subjected to degradation after the mining ceases. Although only about 10 percent of the case histories documented shows gradation problems from land use changes, it is a significant problem. Highway engineers should be aware of land use changes in design of new bridges and maintenance of existing bridges.

ii) Natural causes

It was difficult to isolate case histories with gradation problems solely caused by natural factors because of the extensive activities of man.

a) Alluvial fans

Case histories in the Elk River near piedmont, South Dakota are excellent examples of natural causes. The case history illustrates the impact of locating a high way crossing (bridges) on an alluvial fan.

b) Other factors

Other identified natural causes and complications from gradation problems included natural armoring, braiding, debris, meandering/migration (natural cut offs), recurrent flooding/high stream velocity, channel bed and bank material erodibility and fire. Although problems resulting from natural causes are not as frequent as that resulting from mans activities, it is important to recognize natural causes in both design and maintenance of highway crossings.

2.4. General Scour

General scour includes scour from sources that often cannot be adequately quantified through analytical studies. This category includes scour caused by bend migration, fluctuating downstream water surface elevations that control backwater elevations through the bridge, and channel morphology characteristics, such as scour hole at the junction of two streams. General scour also includes possible scour in the vicinity of the bridge due to the design flood. General scour is often estimated from field inspections, aerial mapping, and the projected worst case for general scour at a bridge. For more critical situations one or more multidimensional numerical model(s) or a physical model of the bridge may be needed to best evaluate general scour.

2.5. Contraction Scour

Contraction scour occurs when a channel's cross – section is reduced by natural or manmade features. Possible constrictions include the construction of long causeways to reduce bridge lengths (and costs), the placement of large (relative to the channel cross section) piers in the channel, abutment encroachment, and the presence of headlands. The reduction of cross sectional area results in an increase in flow velocity due to conservation of flow. This may cause the condition of more sediment leaving than entering the area and thus an overall lowering of the bed in the contracted area. This process is known as "contraction scour."

For design flow conditions that have long durations, such as those crated by storm water runoff in river and streams in relatively flat country, contraction scour can reach near equilibrium depths. Equilibrium conditions exist when the sediment leaving and entering a section of a stream are equal. Laursen's contraction scour prediction equations were developed for these conditions. A summary of Laursen's equations is presented below.

2.5.1. Steady uniform flows

For steady, uniform flow situations one- dimensional computer flow models are usually adequate for estimating design flow velocities. If, in addition, the design flow event is of long duration, such as a riverine storm water runoff event in relatively flat terrain, equilibrium contraction scour equations can estimate design contraction scour depths. Laursen's contraction scour equation [Laursen (1960)] were developed for these situations. However, predictions using these equations tend to be conservative, even for long duration flows, since the rate of erosion decreases significantly with increased contraction scour depth. That is, unless the flow duration is extremely long, equilibrium depths are not achieved. Laursen developed different equations for clear – water and live- bed scour flow regimes. Both equations are designed for situations with relatively simple flow boundaries to facilitate determination of meaningful values for the terms in the equations. A brief summary of the equations are presented herein.

2.5.1.1. Live bed contraction scour equation

The live – bed scour equation assumes that the upstream flow velocities are greater than the sediment critical velocity, V_c.

$$\frac{Y2}{Y1} = \left(\frac{Q2}{Q1}\right)^{\frac{6}{7}} * \left(\frac{W1}{W2}\right)^{K1}$$

$Ys = Y2 - Y0 =$ average contraction scour

Where

$Y1$	=	Average depth in the upstream channel, (m)
$Y2$	=	Average depth in the contracted section after scour, (m)
$Y0$	=	Average depth in the contracted section before scour, (m)
$Q1$	=	Discharge in the upstream channel transporting sediment, (m^3/s)
$Q2$	=	Discharge in the contracted channel, (m3/s)
$W1$	=	Bottom width of the main upstream channel that is transporting bed material, (m)
$W2$	=	Bottom width of the main channel in the contracted section less pier widths, (m)
$K1$	=	Exponent listed in Table 3 below

Table 3: Determination of Exponent, K1

$\frac{V*}{\omega}$	K1	Mode of Bed material Transport
<0.50	0.59	Mostly contact bed material discharge
0.50 to 2.0	0.64	Some suspended bed material discharge
>2.0	0.69	Mostly suspended bed material discharge

V_*	=	$(\frac{\tau o}{\rho})^{0.5}$ shear velocity in the upstream section, (m/s)
ω	=	fall velocity of bed material based on the D_{50}, (m/s) (Figure 2)
g	=	acceleration of gravity (9.81 m/s^2)
τo	=	shear stress on the bed, (pa (N/m2))
ρ	=	Density of water, (kg/m^3)

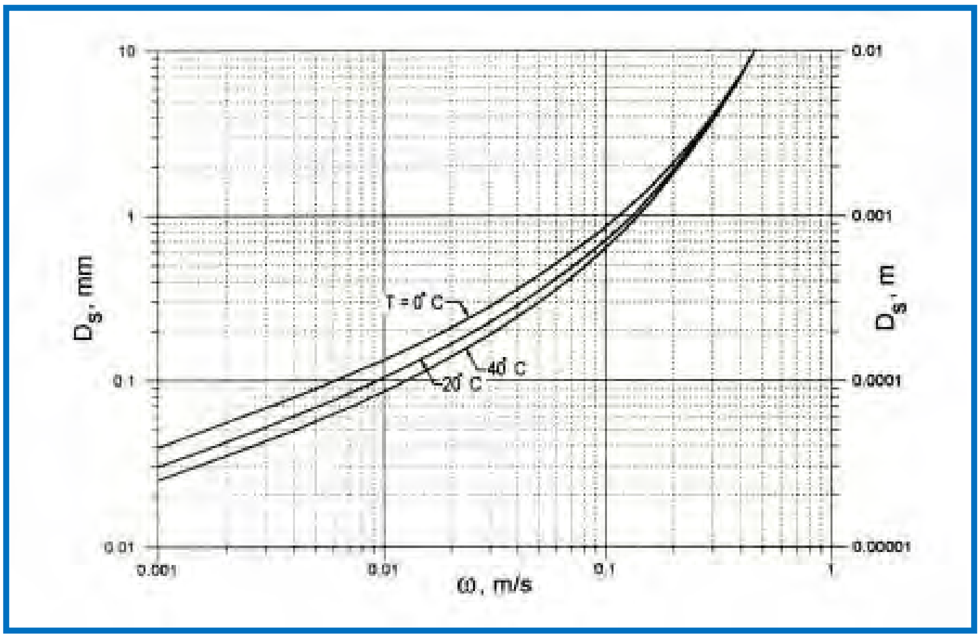


Figure 2: Fall Velocity of Sediment Particles having Specific Gravity of 2.65 (taken from HEC – 18, 2001)

2.5.1.2. Clear water contraction scour

The clear – water scour equation assumes that the upstream flow velocities are less than the sediment critical velocity.

$$Y2 = \left(\frac{Ku * Q^2}{Dm^{\frac{2}{3}}} * W^2\right)^{\frac{3}{7}}$$

Where

Y2	=	average equilibrium depth in the contracted section after contraction scour, (m)
Q	=	Discharge through the bridge or on the set – back overbank area at the bridge associated with the width W, (m3/s)
Dm	=	Diameter of the smallest non – transportable particle in the bed material ($1.25D_{50}$) in the contracted section, (m)
D_{50}	=	Median diameter of bed material (m)
W	=	Bottom width of the contracted section less pier widths, (m)
Y0	=	average existing depth in the contracted section, (m)
Ku	=	0.025 SI units

2.5.2. Unsteady, complex flows

There are many situations where Laursen's contraction scour equations are not appropriate including cases where: a) the flow boundaries are complex b) the flows are unsteady (and/or reversing), and c) the duration of the design flow event is short, etc. these situations usually require the application of two – dimensional, flow and sediment transport models for estimating contraction scour depths. For example, the US Army Corps of Engineers' RMA2 hydraulics model and SED2D sediment transport model. Just what constitutes a short or long duration flow event is not well defined, but is dependent on several factors including site conditions, design flows, and sediment parameters. As such, one must rely on engineering judgment and experience when making these determinations. As a general rule of thumb, if the situation requires a 2D model for the hydraulics it will most likely require a 2D model for computing contraction scour.

2.6. Bed Forms

When cohesion less sediments are subjected to currents and/or surface waves, bed forms can occur. These bed features are divided into several categories (ripples, mega ripples, dunes, sand waves, antidunes, etc.) according to their size, shape, method of generation, etc. since some of these waves – like features can have large amplitudes; they must be accounted for by those responsible for establishing design scour depths. This is particularly true for structures with buried pile caps that may be uncovered by these bed forms. There are a number of predictive equations for estimating bed form height and length in the literature [Tsubaki – Shinohara (1959), Ranga Raju –Soni (1976), Allen (1998), Fredsoe (1980), Yalin (1985) , van Rijn (1993]. One of these formulations is presented below.

The following methods and equations for estimating bed form heights and lengths were developed by Leo C. van Rijn. The details of this work and the work of other researchers can be found in van Rijn (1993).

The first step in van Rijn's procedure establishes the type of bed form that will exist for the flow and sediment conditions of interest. This is accomplished by computing the values of the dimensionless parameters T and D_* and then referring to Table 4. The equations in Table 5 estimate the bed form height and length given the bed form type.

Table 4: Bed Classification for determining Bed Forms

Transport Regime		Particle size $1 \leq D_* \leq 10$	$D_* > 10$
Lower	$3 \leq Tr \leq 10$ $10 \leq Tr \leq 15$ $10 \leq Tr \leq 15$	Mini – Ripples Mega – Ripples and Dunes	Dunes Dunes Dunes
Transition Upper	$15 \leq Tr \leq 25$ $Tr \geq 25$, $Fr < 8$ $Tr \geq 25$, $Fr > 8$	Washed – Out Dunes, Sand Wages (Symmetrical) Sand Waves plane Bed and/or Anti- Dunes	

The expression for Tr,d* and Fr are as follows:

$$T_r = \frac{\tau - \tau c}{\tau c}$$

Where the critical bed shear stress, τc, can be estimated from shield's Diagram in Figure 3.

$$\tau' = \rho * g * \left(\frac{V}{C}\right)^2$$

$$C = 18\,\frac{m1/2}{s} * \log\left(\frac{12yo}{3D90}\right)$$

$$d_* = D_{50} * \left[\frac{(Sg-1)*g}{V^2}\right]^{\frac{1}{3}}$$

sg= $\frac{\rho s}{\rho}$ = mass density of sediment divided by mass density of water,

$V = \frac{\mu}{\rho}$ = kinematic viscosity of water

g = acceleration of gravity

Y_0 = water depth just upstream of structure,

D_{90} = grain diameter of which 90% of sediment has a smaller value, and

F_r = Froude Number = $\frac{V}{\sqrt{g*Yo}}$

Table 5: Bed Form Length and Height (van Rijn, 1993)

Bed Form Classification	Bed Form Height (Δ)	Bed Form Length (λ)
Mega – Ripples [1]	0.02 y0[1-exp(-0.1T)] (10 –T)	$0.5y_0$
Dunes	$0.11y_0\,(\frac{D50}{y0})^{0.3}$[1-exp(-0.5T)] (25-T)	$7.3y_0$
Sand Waves	$0.15\ y_o\,(1- Fr^2)$ { 1- exp[-0.5(T-15)]}	$10y_0$

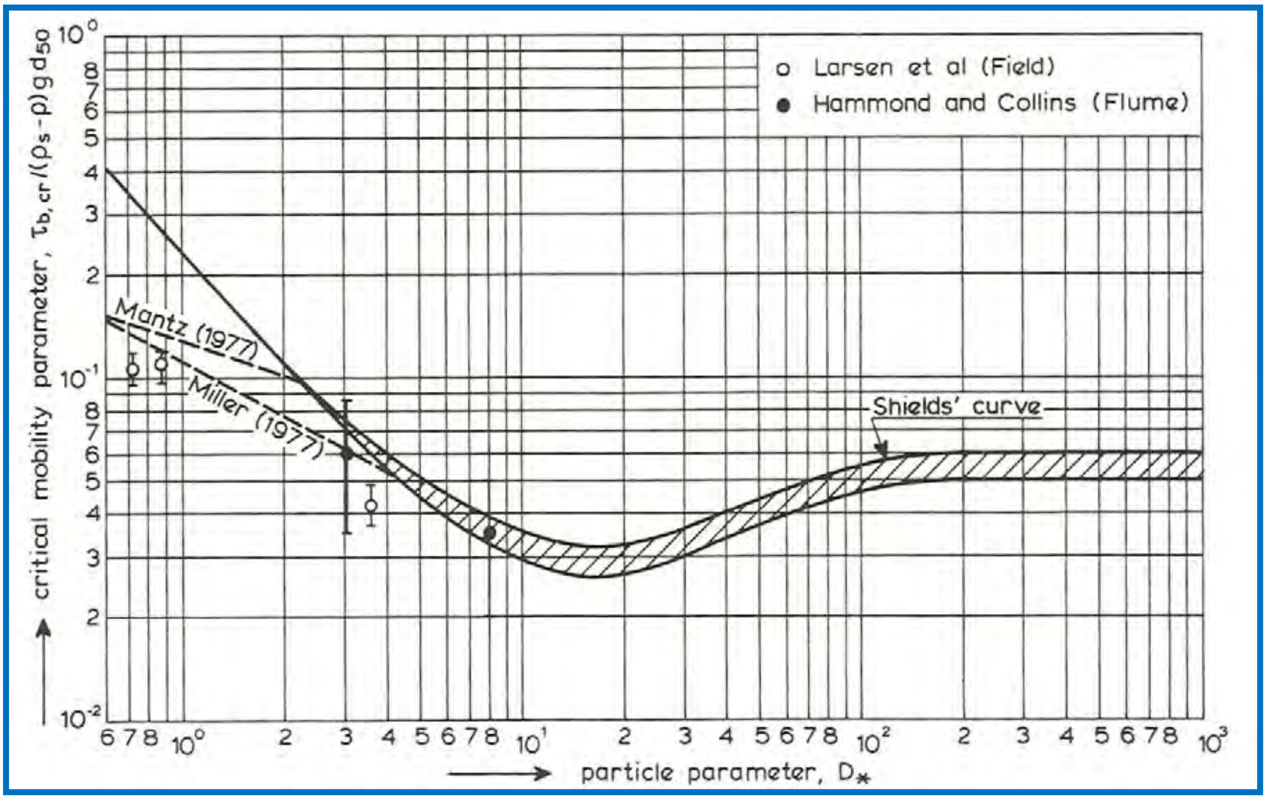


Figure 3: Critical bed shear stresses as a function of sediment particle diameter, shields (1936).

2.7. Local Scour

Local scour occurs at and within the bridge opening itself and is influenced by a variety of parameters relating to the bridge piers and abutments.

2.7.1. Scour at piers

Piers cause the flow to pass around each pier and also move vertically down the pier face toward the channel bottom. Turbulence around piers results in vortex systems and excessive scour, especially during flood events. As flow approaches the pier, it decelerates, theoretically coming to rest at the face of the pier, causing a stagnation pressure. Stagnation pressures are greatest near the water surface, where velocities are

higher than toward the channel bottom. The difference in stagnation pressure creates a downward pressure gradient along the face of the pier, forcing the direction of flow along the pier downward. This velocity down the pier, if great enough, begins to move particles from the bottom of the pier, causing scour at this location. These downward flows around the base of a pier create a “horseshoe vortex” that removes bed material near the pier and footing. Flow moving past the pier also creates a “wake vortex” that aids in transporting scoured bed material downstream.
Velocities of sufficient duration and magnitude can expose and/or undermine the pier footings, which can undermine the pier footings, which can ultimately reduce their bearing capacity. Large scour holes around individual piers can undermine the pier and result in collapse of the pier foundation, leading to the loss of the support structure of a bridge. Pier scour is affected by the number and shape of the piers, the angle of attack of the flow on the pier, the type of pier foundation, and the debris and ice carried by the stream.

2.7.2. Scour at Abutments

Contracting flow may break sharply into the bridge opening at the abutments, causing flow concentration and resulting in abutment scour. Key factors in abutment scour include the abutment shape – vertical or spill through the abutment location in relation to the channel banks, and the incorporation of upstream spur dikes or guide walls.

2.8. Lateral Scour

This type of erosion is caused by the horizontal movement of the channel, without necessarily creating a deeper channel. Meandering streams shift laterally in the floodplain, with the meander loops moving slowly in the downstream direction, potentially causing problems at bridges. Bridges crossing wide floodplains often allow significant floodplain flow through the bridge opening, as well as flow from the channel. If the velocities in the channel cause erosion of the backline, the main channel may shift laterally and relocate into a portion of the floodplain under the bridge superstructure. Because piers located in the floodplain may not be as substantial or as deeply based as piers in the channel, such a situation may result in the loss of one or more piers in the overbank area and potentially the loss of the bridge itself.

3. Methods and Data collection

3.1. Hydrological Model

Many comprehensive hydrologic models have been developed in the past decades due to advances in hydrologic sciences and Geographical information system (GIS). Among them the SCS method of peak discharge estimation (Runoff estimation), developed by the U.S soil conservation service (1972), has been used for this research paper. This is because it is applicable for areas which do not have sufficient rainfall and stream flow records. In addition ERA drainage design manual recommended using SCS method for the peak discharge estimation and most the consultants in the country uses ERA drainage design manuals for the hydrology and hydraulic analysis of bridges.

3.1.1. Soil Conservation Service (SCS) method

This method is developed by the U. S. Soil Conservation Service for calculating rates of runoff and requires the same basic data as the Rational Method: catchment area, a runoff factor, time of concentration, and rainfall. The SCS approach, however, is more sophisticated in that it considers also the time distribution of the rainfall, the initial rainfall losses to interception and depression storage, and an infiltration rate that decreases during the course of a storm. With the SCS method, the direct runoff can be calculated for any storm, either real or fabricated, by subtracting infiltration and other losses from the rainfall to obtain the precipitation excess.

3.1.2. Catchment Area

A catchment area will be determined from topographic maps and field surveys. For large catchment areas it might be necessary to divide the area into sub-catchment areas to account for major land use changes, obtain analysis results at different points within the catchment area, or locate storm water drainage structures and assess their effects on the flood flows. A field inspection of existing or proposed drainage systems has been made to determine if the natural drainage divides have been altered. These alterations could make significant changes in the size and slope of the sub-catchment areas.

3.1.3. Rainfall

The SCS method is based on a 24-hour storm event which has a Type II time distribution. The Type II storm distribution is a typical time distribution which the SCS has prepared from rainfall records. It is applicable for interior rather than the coastal regions and should be appropriate for Ethiopia. To use this distribution it is necessary for the user to obtain the 24-hour rainfall value for the frequency of the design storm desired.

3.1.4. Rainfall – Runoff equation

A relationship between accumulated rainfall and accumulated runoff was derived by SCS from experimental plots for numerous hydrologic and vegetative cover conditions. Data for land-treatment measures, such as contouring and terracing, from experimental catchment areas were included. The equation was developed mainly for small catchment areas for which daily rainfall and catchment area data are ordinarily available. It was developed from recorded storm data that included total amount of rainfall in a calendar day but not its distribution with respect to time. The SCS runoff equation is therefore a method of estimating direct runoff from 24-hour or 1-day storm rainfall.

The equation is: $$Q = \frac{(\mathrm{P}-\mathrm{Ia})^2}{(\mathrm{P}-\mathrm{Ia})+\mathrm{S}}$$

Where: Q = accumulated direct runoff, mm
P = accumulated rainfall (potential maximum runoff), mm
Ia = initial abstraction including surface storage, interception, and infiltration prior to runoff, mm
S = potential maximum retention, mm

The relationship between Ia and S was developed from experimental catchment area data. It removes the necessity for estimating Ia for common usage.
The empirical relationship used in the SCS runoff equation is:

$$\mathrm{Ia} = 0.2^*\mathrm{S}$$

Substituting 0.2*S for Ia, the SCS rainfall-runoff equation becomes:

$$Q = \frac{(\mathrm{P} - 0.2 * \mathrm{S})^2}{(\mathrm{P} + 0.8 * \mathrm{S})}$$

S is related to the soil and cover conditions of the catchment area through the CN. CN has a range of 0 to 100, and S is related to CN by:

$$\mathrm{S} = \frac{25400}{\mathrm{CN}-254}$$

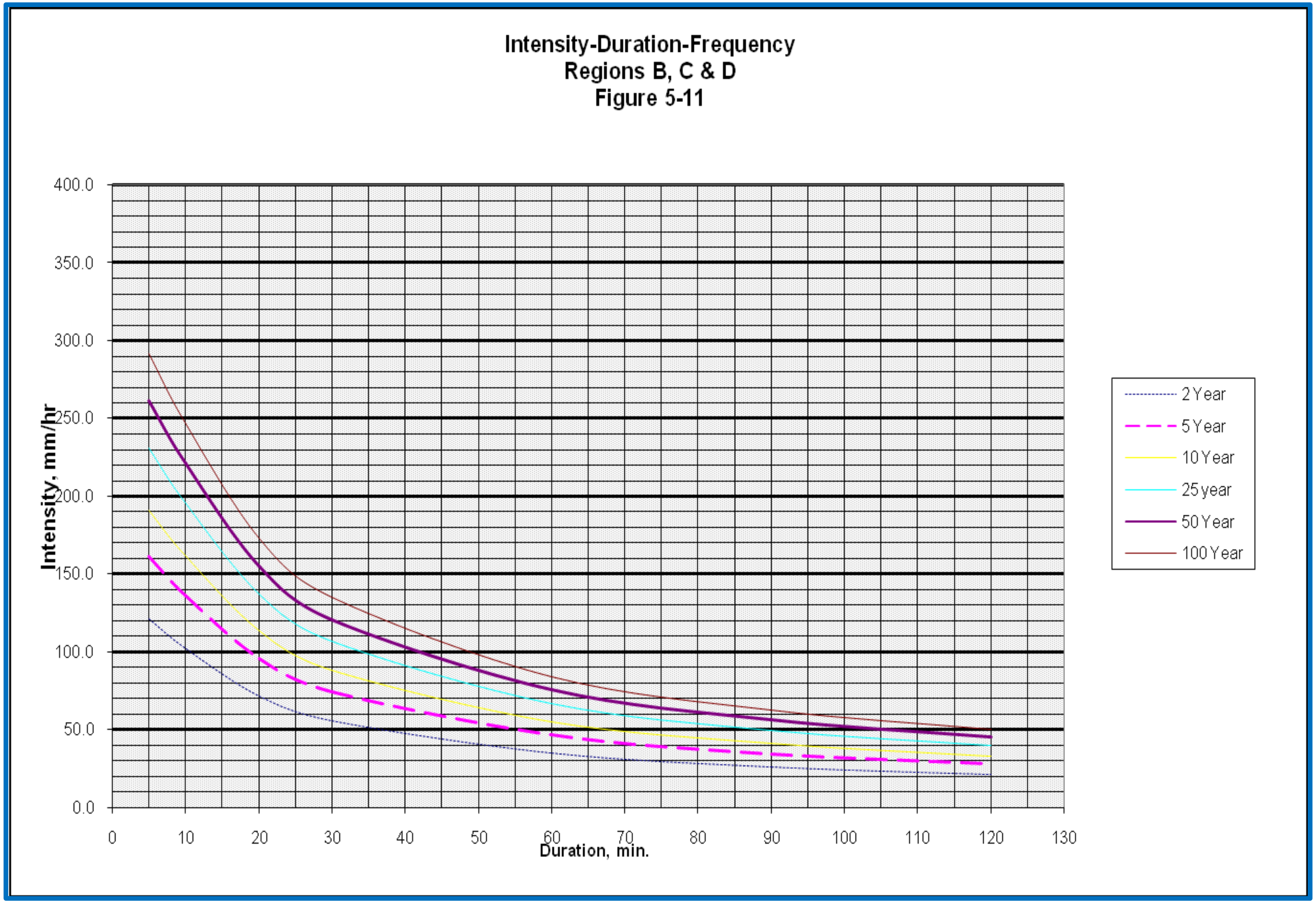


Figure 4: Intensity duration frequency curve for region B (ERA DDM 2002)

3.1.5. Runoff Factors

Runoff is rainfall excess or effective rainfall - the amount by which rainfall exceeds the capability of the land to infiltrate or otherwise retain the rainwater. The principal physical catchment area characteristics affecting the relationship between rainfall and runoff are land use, land treatment, soil types, and land slope.

A. Land Use

Land use is the catchment area cover, and it includes both agricultural and nonagricultural uses. Items such as type of vegetation, water surfaces, roads, roofs, etc. are all part of the land use. Land treatment applies mainly to agricultural land use, and it includes mechanical practices such as contouring or terracing and management practices such as rotation of crops.

The SCS uses a combination of soil conditions and land-use (ground cover) to assign a runoff factor to an area. These runoff factors, called runoff curve numbers (CN), indicate the runoff potential of an area. The higher the CN, the higher is the runoff potential.

B. Hydrologic Soil Groups

Soil properties influence the relationship between rainfall and runoff by affecting the rate of infiltration. The SCS has divided soils into four hydrologic soil groups based on infiltration rates (Groups A, B, C, and D). These shall be given to the effects of urbanization on the natural hydrologic soil group. If heavy equipment can be expected to compact the soil during construction or if grading will mix the surface and subsurface soils, appropriate changes shall be made in the soil group selected. Also runoff curve numbers vary with the antecedent soil moisture conditions, defined as the amount of rainfall occurring in a selected period preceding a given storm. In general, the greater the antecedent rainfall, the more direct runoff there is from a given storm. A five-day period is used as the minimum for estimating antecedent moisture conditions.

C. Runoff Curve Numbers

The ERA Design Manual gives a series of tables related to runoff factors. The tables are based on an average antecedent moisture condition, i.e., soils that are neither very wet nor very dry when the design storm begins. Curve numbers shall be selected only after a field inspection of the catchment area and a review of cover type and soil maps. Care shall be taken in the selection of curve numbers (CN's). Use a representative average curve number, CN, for the catchment area. Selection of overly conservative CN's will result in the estimation of excessively high runoff and consequently excessively costly drainage structures. Selection of conservatively high values for all runoff variables results in compounding the runoff estimation. It is better to use average values and design for a longer storm frequency.

3.1.6. Time of Concentration (Tc)

Time of concentration (Tc) is the time for runoff to travel from the hydraulically most distant point of the catchment area to a point of interest within the catchment area. Tc for the Raya river bridge hydrology is computed by using Kirpich time of concentration formula shown below. Kirpich assumes that the catchment coverage is Agricultural area, well drained soil and steep watershed slope

$$Tc = 0.0078 * \left(\frac{L^{0.77}}{S^{0.385}}\right)$$

Where Tc = time of concentration (min)

L = length of overland flow (m)

S = slope (m/m)

3.1.7. Ia/p Parameter

Ia/p is a parameter that is necessary to estimate peak discharge rates. Ia denotes the initial abstraction and p is the 24 hour rainfall depth for a selected return period. The 24 rainfall depth is taken from ERA drainage design manual for rainfall region B2. For a given 24 hour rainfall distribution Ia/P represents the fraction of rainfall that must occur before runoff begins.

3.1.8. Peak Discharge Estimation

The following equation were used for the estimation of the peak discharge in SCS method

$$q_p = q_u * A * Q$$

Where q_p = peak discharge, m^3/s

q_u = unit peak discharge, $m^3/s/km^2/mm$

A = drainage area, Km^2

Q = depth of runoff, mm

The unit peak discharge is obtained from the following equation, which requires the time of concentration (tc) in hours and the initial abstraction rainfall (Ia/p) ration as input.

$$q_u = \propto * 10^{Co+C1logtc+C2(logtc)^2}$$

Where Co, C1 and C2 = regression coefficients given in table 6 for various Ia/p ratios

$\propto$ = unit conversion factor equal to 0.000431 in SI unit.

Table 6: Coefficients for SCS Peak Discharge Method (highway hydrology manual)

Rainfall Type	Ia/P	C0	C1	C2
I	0.1	2.3055	-0.51429	-0.1175
	0.2	2.23537	-0.50387	-0.08929
	0.25	2.18219	-0.48488	-0.06589
	0.3	2.10624	-0.45695	-0.02835
	0.35	2.00303	-0.40769	0.01983
	0.4	1.87733	-0.32274	0.05754
	0.45	1.76312	-0.15644	0.00453
	0.5	1.67889	-0.0693	0
IA	0.1	2.0325	-0.31583	-0.13748
	0.2	1.91978	-0.28215	-0.0702
	0.25	1.83842	-0.25543	-0.02597
	0.3	1.72657	-0.19826	0.02633
	0.5	1.63417	-0.091	0
II	0.1	2.55323	-0.61512	-0.16403
	0.3	2.46532	-0.62257	-0.11657
	0.35	2.41896	-0.61594	-0.0882
	0.4	2.36409	-0.59857	-0.05621
	0.45	2.29238	-0.57005	-0.02281
	0.5	2.20282	-0.51599	-0.01259
III	0.1	2.47317	-0.51848	-0.17083
	0.3	2.39628	-0.51202	-0.13245
	0.35	2.35477	-0.49735	-0.11985
	0.4	2.30726	-0.46541	-0.11094
	0.45	2.24876	-0.41314	-0.11508
	0.5	2.17772	-0.36803	-0.09525

3.2. Hydraulic Model

The chief aim of this task was to determine the opening sizes of the drainage structures from the rate of flood runoff (discharge) and the volume of runoff that will pass through the bridge.

This method deploys the hydraulic characteristics of the stream influencing the maximum discharge, such as velocity of flow, slope of the stream, cross sectional area of the stream and shape and roughness of the stream. This method will be used for major streams to compute the design flood levels at crossing sites after the design discharges have been estimated by the hydrological methods of either the SCS Unit Hydrograph Method and compared with the observed flood marks. Cross-Sections of the crossing sites are being determined by the survey.

3.2.1. Manning's Formula of Hydraulic Analysis

This method deploys the hydraulic characteristics of the stream influencing the maximum discharge, such as velocity of flow, slope of the stream, cross sectional area of the stream and shape and roughness of the stream. This method is used for the design flood levels at crossing sites after the design discharges have been estimated by the hydrological methods of the SCS Unit Hydrograph Method. Cross-Sections of the crossing sites have been determined by the survey. Accordingly, the following Manning's equation is used for high-water computations:

$$Q = \frac{1}{n} * R^{\frac{2}{3}} * S^{\frac{1}{2}} * A$$

Where:

Q	=	Discharge in [m3/sec]
R	=	Hydraulic mean depth [m] = A/P
A	=	Cross-sectional flow area [m2]
P	=	Wetted perimeter [m]
S	=	Longitudinal bed slope [%]
n	=	Manning's roughness coefficient

3.2.2. HEC-RAS HYDRAULIC MODEL (OVERVIEW)

The main objective of the HEC – RAS program is quite simple to compute water surface elevations at all locations of interest for either a given set of flow data (steady flow simulation) , or by routing hydrographs through the system(unsteady flow simulation).

Basic Data Requirement

The data needed to perform these computations are divided into the following categories: Geometric data; Steady flow data, unsteady flow data and Sediment flow data. Geometric data's are required for any of the analyses performed with HEC – RAS. The other data types are only required if you are going to do that specific type of analysis.

I) Geometric Data:

The basic geometric data consists of establishing the connectivity of the river system; cross section data, reach lengths, energy loss coefficients (friction losses, contraction and expansion losses) and stream junction information. Hydraulic structure data's (bridge, culverts, weirs etc) which are also considered geometric data's.

a) River system schematic

It is required for any geometric data set with in the HEC –RAS system. The schematic defines how the various river reaches are connected, as well as establishing a naming convention for referencing all the other data.

b) Cross section Geometry

Boundary geometry for the analysis of flow in natural stream is specified in terms of ground surface profiles (cross section) and the measured distance between them (reach lengths). Cross sections are located at intervals along a stream to characterize the flow carrying capability of the stream and its adjacent floodplain. Other data that are required for each cross section consists of: downstream reach length, roughness coefficients, and contraction and expansion coefficient.

c) **Reach length**

The measured distances b/n cross sections are referred to as reach lengths. The reach lengths for the left overbank, right over bank and channel are specified on the cross section data.

d) **Energy loss coefficients**

Several types loss coefficients are utilized by the program to evaluate energy looses; (1) Manning's n values or equivalent roughness "K" values for friction loss, (2) contraction and expansion coefficients to evaluate transition losses and (3)Bridge and culvert loss coefficients to evaluate losses related to weir shape, pier configuration, pressure flow and entrance and exit conditions.

Manning' n selection of an appropriate value for Manning's n is very significant to the accuracy of the computed water surface profiles. The value of manning's n is highly variable and depends on a number of factors including: surface roughness; vegetation; channel irregularities; channel alignment; scour and deposition; obstructions; size and shape of the channel; stage and discharge; seasonal changes; temperature; and suspended material and bed load.

II) **Steady flow data**

Steady flow data are required in order to perform a steady water surface profile calculation steady flow data consists of flow regime, boundary conditions and peak discharge information.

3.3. Sedimentation problem and land use changes.

Sediment is fragmental material primarily formed by the Physical and chemical disintegration of rocks from the earth's crust. Such particles range in size from large boulders to colloidal size fragments and vary in shape from rounded to angular. They also vary in specific gravity and mineral composition. Once the sediment particles are detached, they may either be transported by gravity, wind or/and water.

Mainly for this study we concern only on transportation by water. The transported sediment is comprised of bed load; suspended load, and wash load, van rijn (1993) defines them as:

Suspended load: - that part of the total sediment transport which is maintained in suspension by turbulence in the flowing water for considerable periods of time without contact with the Streambed. It moves with practically the same velocity as that of the flowing water.

Bed load: - the sediment in almost continuous contact with the bed carried forward by rolling, sliding or hopping.

Wash load: - that part of the suspended load which is composed of particle sizes smaller than those found in appreciable quantities is transported though the stream without deposition.

3.4. Data Collection

3.4.1. Climatic Data

This includes collecting examining and indicating the effects on the design work for the components of climate such as monthly min, max and average temperatures and length of records, monthly average rainfall intensity, its distribution and length of records, and other important climatic features of the study area. From National Meteorological agency I have found a rainfall record of 12years around Raya river bridge location in Mirab Abaya gauging station. In addition, according to the map shown on National Atlas of Ethiopia the project area is located on a region of moderate mean annual rainfall. The river catchment area is found on hydrologic region of B2 as per the ERA Drainage Manual 2002 and the parameters used for the hydrologic analysis were used from the manual.

3.4.2. Stream flow Data

The main bottle neck in the hydrologic /Hydraulic Analysis of streams and rivers is the lack of data. Since many of the streams in Ethiopia are not gauged, the peak flood discharge that will be used for the drainage design cannot be estimated from recorded stream flow data. Therefore, the peak discharge will be estimated from Rainfall data using Rainfall – Runoff model. The Raya River is also one of the rivers which do not have any stream flow data records.

3.4.3. Topographic Maps and Digital GIS Data

This includes collection of geological maps and topographical map of the area. I have collected topographical map of 1:250,000 and in addition I have soft copy of the complete Digital Elevation Model (DEM) data of the project area on 30mx30m Grid together with GIS files (such as GIS data of Land use, soil types etc).The catchment delineation have been made on the Digital Topographic Map (SRTM 30m*30m Grid digital Elevation Models). The catchments parameters such as average slope, length of the longest water course, difference in elevation b/n the crossing and water divide, the main channel length and its slope are determined from the above listed maps and software's.

3.4.4. Surveying Data Collection

For the hydraulic and sediment analysis of the Raya river bridge I have collected survey data of the river cross section, upstream and downstream of the bridge location. I have collected two sets of survey data's of each were taken in different times. The first cross section data were taken before the failure of the bridge in 2006 G.C which is collected by ACE (Associate consulting Engineers) the other data were collected after the failure of the bridge in 2009 G.C, therefore this two sets of data's were used for the hydraulic analysis and adequacy check of the existing bridge and the newly proposed bridge by the consultants.

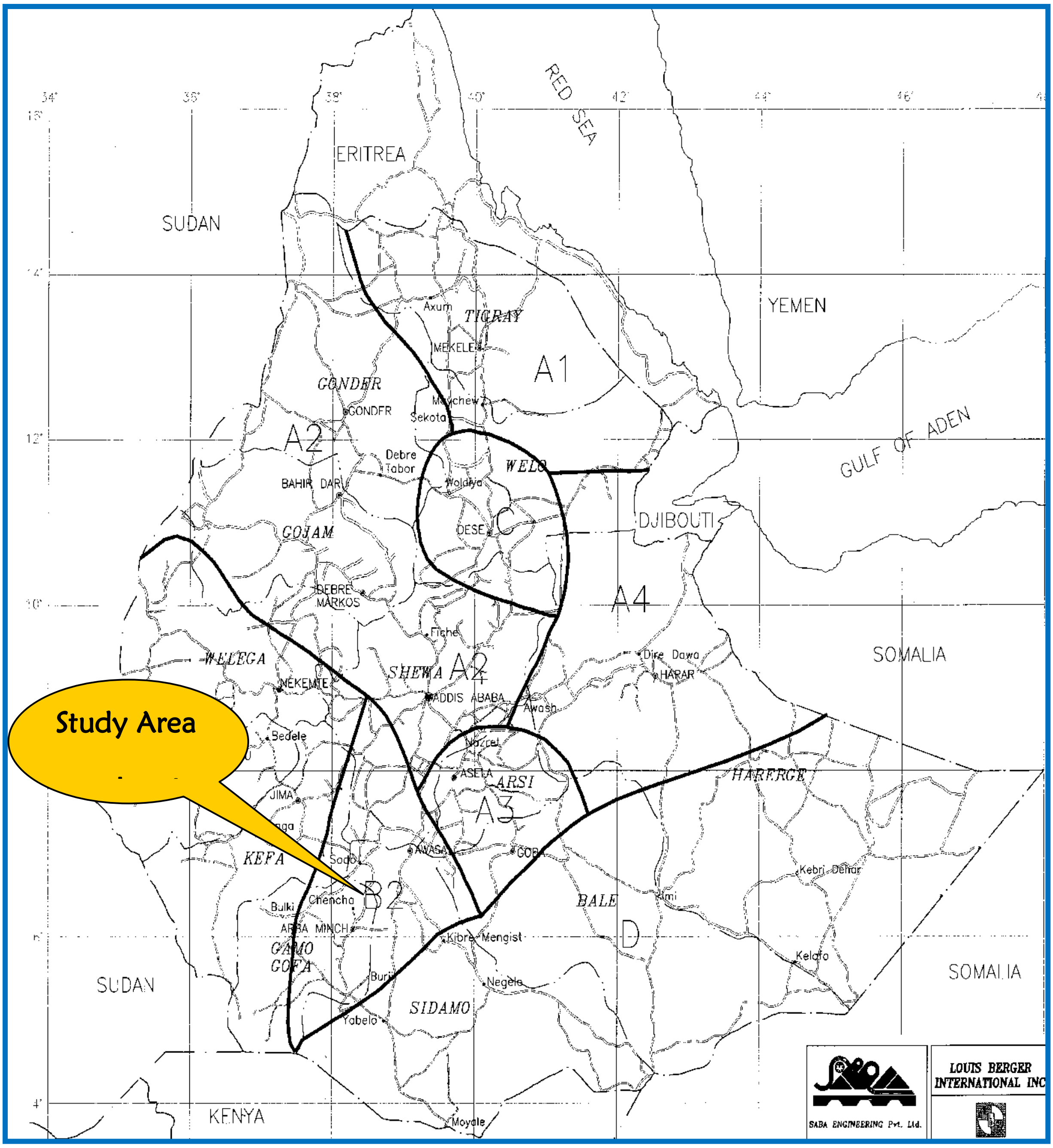


Figure 5: Rainfall regions of Ethiopia (ERA DDM 2002)

4. Analysis and Result

4.1. Hydrologic Analysis

The procedures that are followed in the hydrological analysis of the Raya river includes:-

- Determining the general pattern, identification and description of the catchment.
- Analysis of rainfall data to determine the design storm corresponding the specified return periods.
- Catchment area delineation and computation of catchment parameters like catchment area, stream length, soil type, land use and curve numbers.
- Determining the design and review peak flood discharges. The hydrologic Analysis was done by using the SCS Model.

4.1.1. Return Periods and Rainfall Intensities

For the Raya River, the maximum peak flood computed using the return period recommend in ERA Drainage Design Manual 2002 considering the Road standard and the design life span of the structure, 50 years for Design and 100 year check (Review) return period were adopted. See table 6 Design storm frequency.

The ERA regionalized drainage map of Ethiopia was used to derive the rainfall intensities that were utilized in the SCS Model. Accordingly the project area hydrologic region as per the ERA Drainage Manual 2002 is Region B_2 and the parameters in the Hydrologic Analysis are obtained from the ERA Manual.

4.1.2. Rainfall Analysis and IDF Curve Generation

I have tried to develop tailor made IDF Curve and 24 – Hour Depth Frequency curve for the project location from rainfall data gathered in the area to make comparison with the regionalized ERA IDF Curves, but due to shortage of rainfall data around the project location I have used the parameters from the ERA Drainage Design Manual 2002 for region B_2. Based on the ERA drainage design manual data the 24 hour rainfall depth P is taken as 132 mm for 50 yrs return period and 147mm for the 100 yrs return period were used.

Table 7: Design Storm Frequency by Geometric Design Criteria (ERA, 2002)

Structure Type	Geometric Design Standard			
	DS1/DS2	DS3/DS4	DS5/6/7	DS8/9/10
Gutters and Inlets*	10/5	2	2	-
Side Ditches	10	10	5	5
Ford/Low-Water Bridge	-	-	-	5
Culvert, pipe (see Note) Span<2m	25	10	5	5
Culvert, 2m<span <6m	50	25	10	10
Short Span Bridges 6m<span<15m	50	50	25	25
Medium Span Bridges 15m<span<50m	100	50	50	50
Long Span Bridges spans>50m	100	100	100	100
Check/Review Flood	200	200	100	100

4.1.3. Delineation of Catchments

The catchment delineation were performed in Arc view GIS 3.3 with GIS Hydrology extensions using the Digital Elevation Model generated by the Global Mapper V.8 from the SRTM 30xm 30m Grid digital topographic map which gives generally and usually accurate catchment delineations and which is checked with Georeferenced Topographic Map of 1:250,000 scale. The Raya river catchment covers 91.253 km^2 area at the bridge crossing location and its elevation varies from 2654 m at the highest point and 1217 m at the crossing location. See figure 6

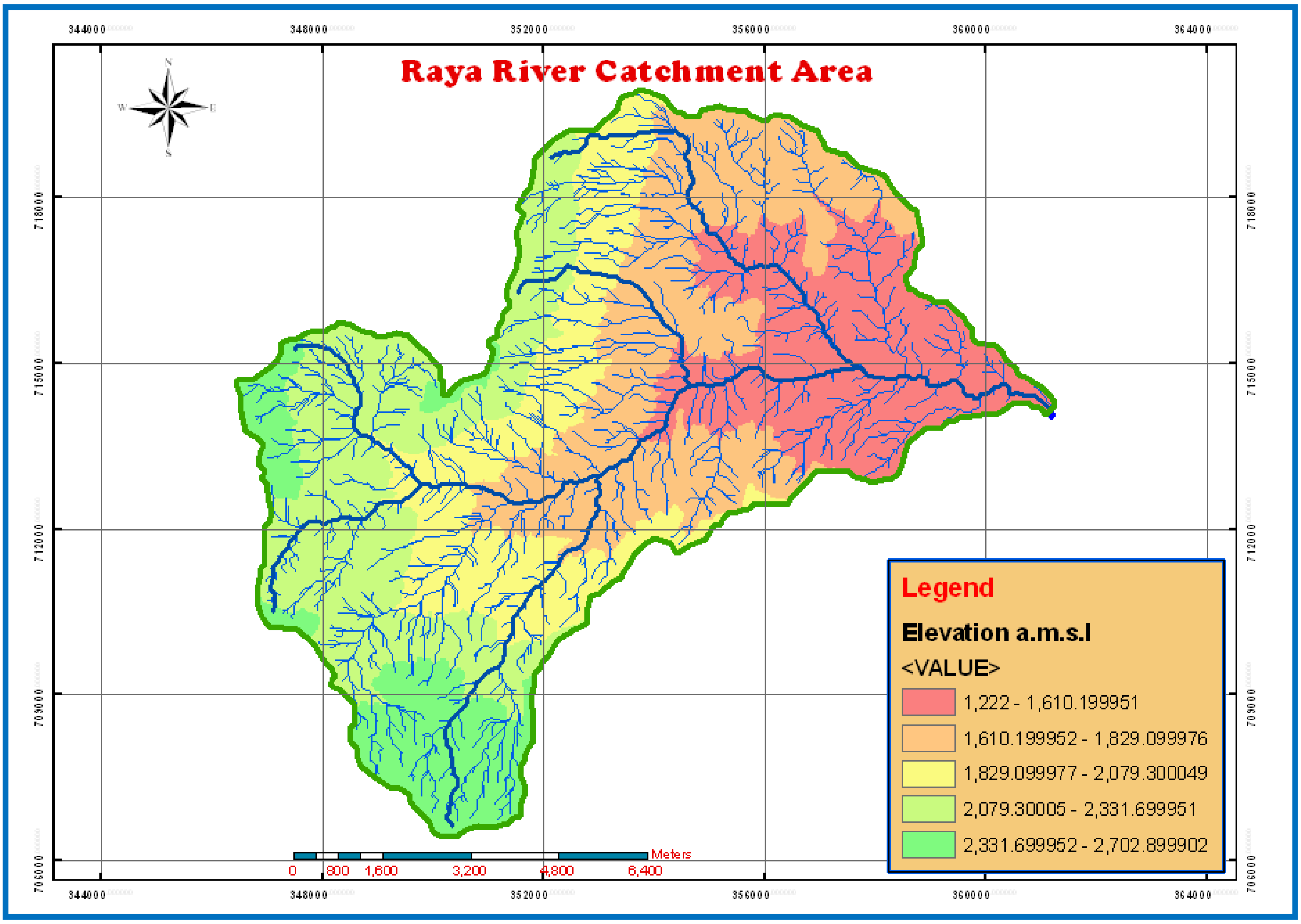


Figure 6: Raya River catchment area

4.1.4. Computation of Catchment Parameters

After the catchment area delineation, catchment properties like stream length are digitized and determined from the stream network generated by Arc view while the land use coverage , soil type and curve number are computed using Arc view spatial analyze from the Digital land use and soil type Digital GIS Map of Ethiopia. More than 79% of the catchment is cultivated and the remaining 21% were covered by small trees, shrubs and scarcely distributed trees were found. See figure 7

Different types of soils were found chromic vertisols, dystric and orthic acrisoils are the dominant which covers more than 85% of the total soil coverage. See figure 8

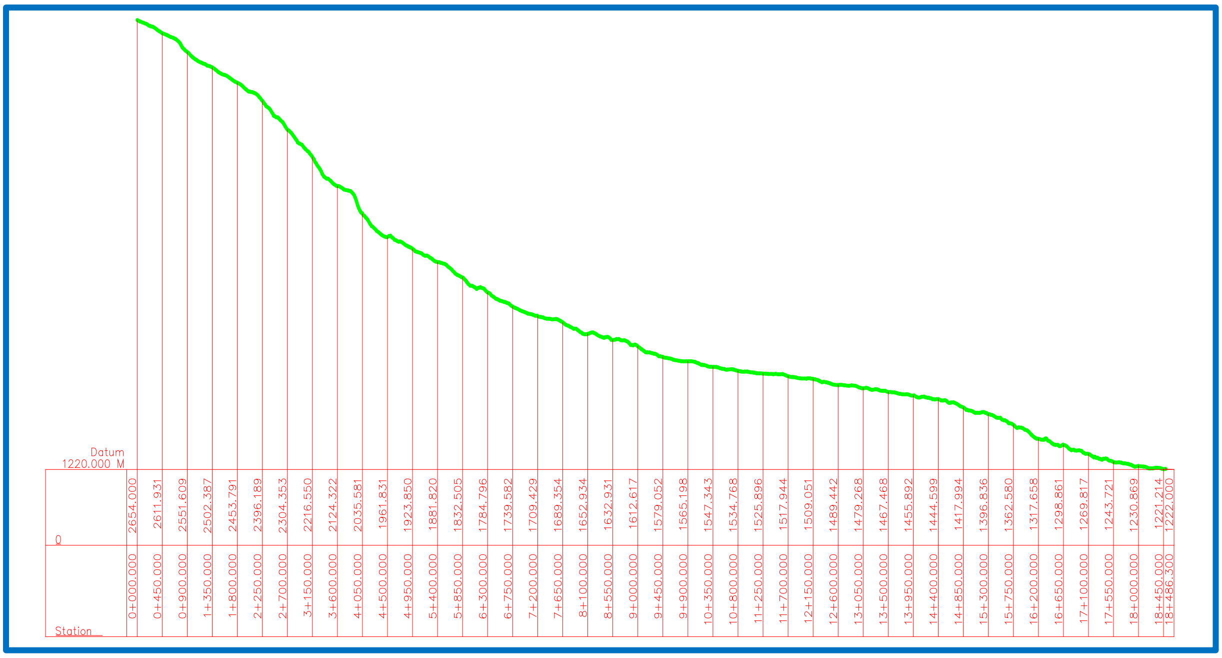


Figure 7: Raya River bed profile

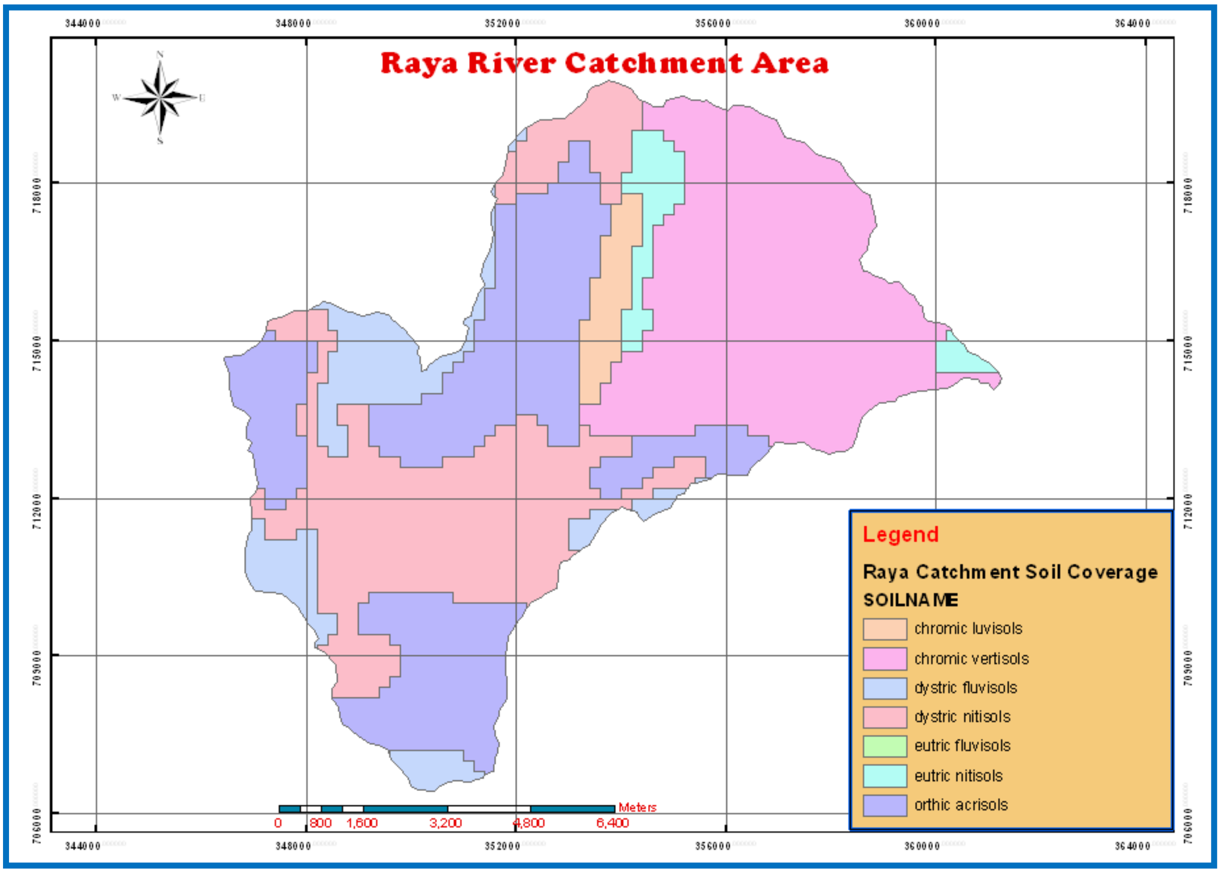


Figure 8: Raya River catchment soil types

4.1.5. Peak Discharge Computation

For the return periods determined in the previous section, the peak design discharge and review peak discharges were computed by using the SCS model discussed in section 3.1. The time of concentration for the Raya river bridge were found 2.03hr using Kirpich formula and the Ia/p ratio for 50 yrs and 100 yrs flood were found 0.145 and 0.13 respectively. Using these values the unit peak discharge were calculated and found 0.092 $m^3/s/km^2/mm$ for the design and 0.093 $m^3/s/km^2/mm$ for the check return period. From the hydrologic analysis result the design peak flood of 50 years return period were found 511.12 m^3/s and 100 years check flood were found 621.90 m^3/s. The detailed calculations of the hydrologic analysis were shown below

Table 8: SCS Peak flood for the design and Check flood

a) Raya River Channel Data

Raya RIVER CHANNEL DATA	Length of Main Channel (L), [m]	18486.30	m
	Length of Channel at 0.3 L, [m]	5545.89	
	Catchment Area, [km2]	91.253	km2
	Crossing Elevation	1221.21	m
	Elevation at 0.3 (L)	1874.40	m
	High Point Elevation	2654.00	m
	Direction of flow	RIGHT TO LEFT	
	Average River Channel Slope	19.10	%
	Terrain Classification	Rolling	

b) Raya River Peak flood Computation

DESIGN FLOOD SCS PARAMETERS	Return Period yrs	50	100
	Time of Concentration TC hours	2.03	2.03
	SCS CN Number for the Whole Catchment	72.70	72.70
	Potential Infiltration S mm	95.39	95.39
	Initial Abstraction Ia mm	19.08	19.08
	Design Storm P (24 Hours Maximum Rainfall) mm	132.00	147.00
	Ia/P =	0.145	0.13
	Direct Runoff q mm	61.21	73.28
	Unit Peak Discharge Qu $m^3/s/km^2/mm$	0.092	0.09
	SCS Q Peak Discharge m^3/s	511.12	621.90

The obtained results were compared with the AEC hydrologic analysis done in 2006 G.C for the upgrading of the Alaba – Arbaminch asphalt road project in the table 9 below. It shows that the peak discharge was undermining by 9.6%.

Table 9: Hydrologic result comparison with AEC

Return period (yrs)	Present Hydrologic Result m3/s	ACE Hydrologic Result m3/s
50	511.12	461.77
100	621.90	-

4.2. Hydraulic Analysis

4.2.1. Determination of Manning roughness coefficient

Manning's 'n' is affected by many factors and its selection in natural channels depends heavily on engineering experience. Based on ERA Drainage design manual guidelines the manning 'n' value for Raya river bridge cross section selected from the table given on ERA drainage design Manual. As shown on the photo the river bed material of Raya river bridge were deposition of material which are cobbles and few boulders, therefore manning's roughness coefficient n=0.04 were adopted for all the river cross-sections for the hydraulic analysis of the Raya river bridge. See Appendix 1 Values of roughness coefficient 'n'.

Photo 18: Raya River Bed Material (Sep 2009)

4.2.2. River Cross – Section Data's

For the Raya river bridge we have used two River cross section data's around the bridge location 40m u/s and D/s of the bridge location. The cross section data's were collected at an interval of 10m to get accurate result and it is interpolated through the river cross section. In addition the bridge cross section data's (Deck, abutment, pier) were collected for the existing bridge of span 34m and the new design bridge having span of 45m. The plan and cross-section data's of the river were shown in the figure below. See Appendix 2 Raya River Survey Data's

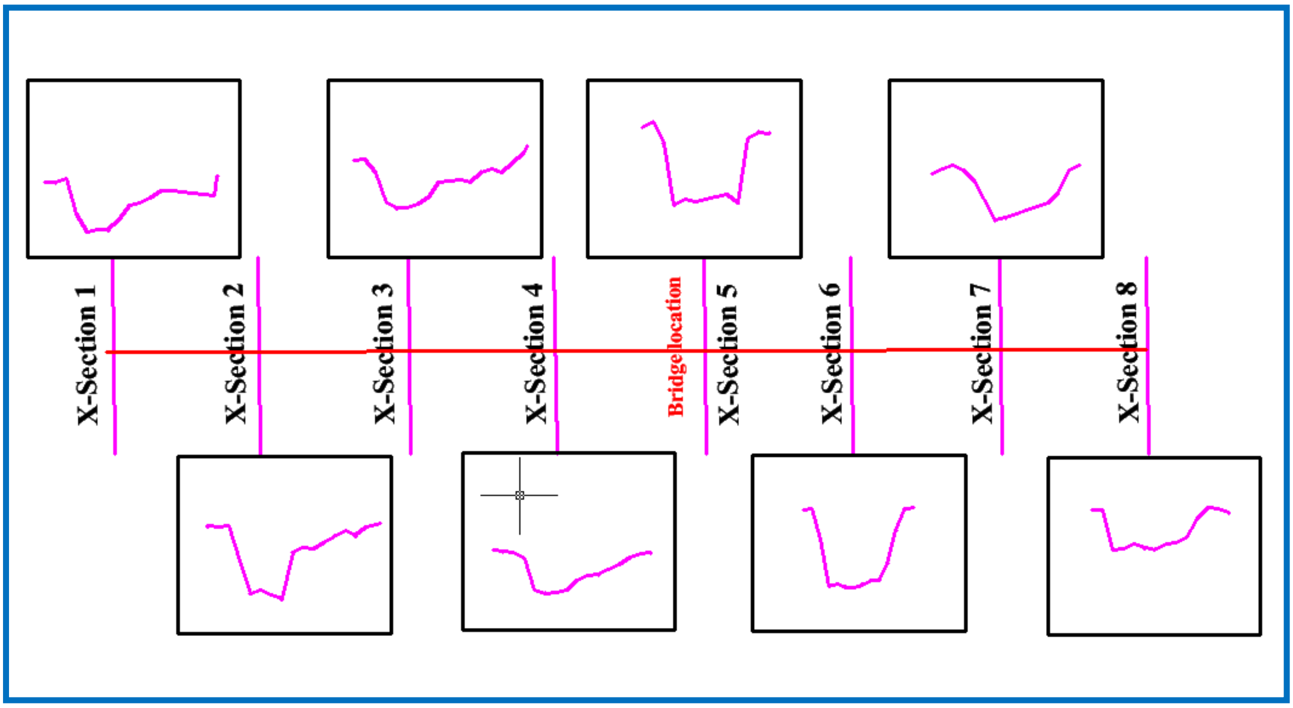


Figure 9: Raya River Cross section data's

4.2.3. Adequacy of the Bridges

The cross section shown above in the figure 9 and using the 50 years and 100 years return period peak discharge obtained in section 4.1, the hydraulic calculation was done. Even though there is no data for calibration and verification the hydraulic profile of the reach around the bridge clearly shows that the computation is consistent and acceptable. Furthermore the geometric data's (cross section) and the manning roughness coefficient n are very close to reality as it was taken from the field survey data's obtained recently. On the basis of this computation, the adequacy of the existing failed bridge dimension, the proposed bridge dimension in 2006G.C and the proposed bridge dimension at present were evaluated for both 50 and 100 years return period peak discharge.

4.2.4. Existing Bridge

The existing 34m clear span (8m+18m+8m) bridge were checked for its adequacy. Based on the Hec- Ras result the existing bridge has been overtopped by both the 50 and 100 years peak discharge. The bridge was overtopped by 0.62m and 0.8m depth for both the design and check flood respectively. This shows that the existing bridge does not have sufficient opening size to accommodate the design and check flood which requires provision of additional opening area to accommodate the coming flood. See figure 10 and 11

Therefore the failure of the existing bridge may have several reasons of which, insufficient opening size of the bridge is the one among several reasons of the failure. The reduction or decrease of clear opening height of the bridge or the reduction of effective flow area due to sediment deposition around the bridge location could be another likely reason for the failure of the bridge. The third reason is the accuracy of the peak discharge calculation during the design.

4.2.5. AEC Proposed Bridge in 2006G.C

AEC newly designed bridge having a clear span of 45m (15m+15m+15m), which is larger opening size as compared to the previous bridge 34m clear span were now started the construction of the bridge at the same location to the previous bridge.

This research has also evaluated the newly proposed bridge. The hydraulic calculation confirmed that the newly proposed bridge was safe during the design period which is in 2006 G.C. figure 12 and 13 clearly demonstrates the feasibility of the bridge during the design period 2006G.C.

4.2.6. AEC Proposed Bridge in 2009G.C

In this section the newly proposed bridge, which is now started its construction was evaluated in 2009G.C survey data. The only new data considered in the evaluation was the current bridge cross section data without changing other parameters used in 2006 G.C like, peak discharge, bridge opening size etc. the bridge which was safe in 2006G.C currently is not safe according to the hydraulic calculation as shown in figure 14 and 15. It is clearly demonstrated that the bridge no longer safe before the completion of its construction.

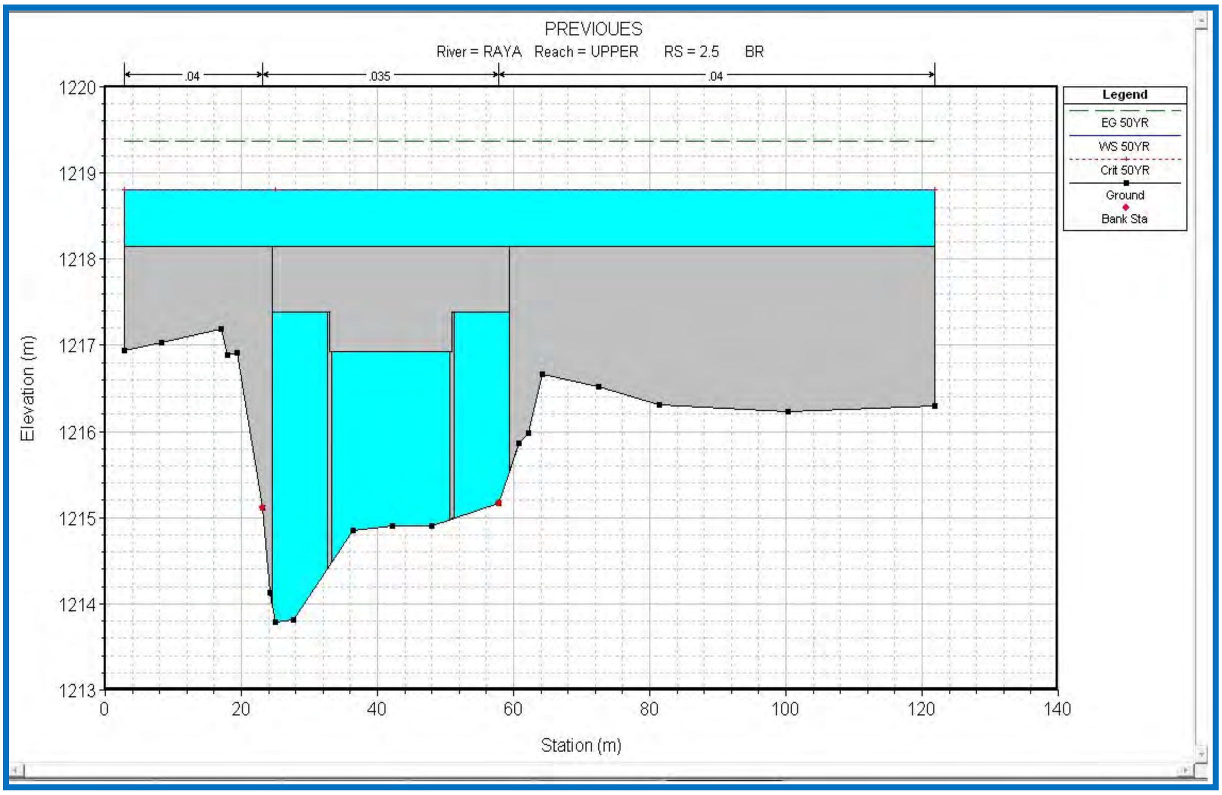


Figure 10: 50 yr peak flood profile for the Existing 34m span bridge

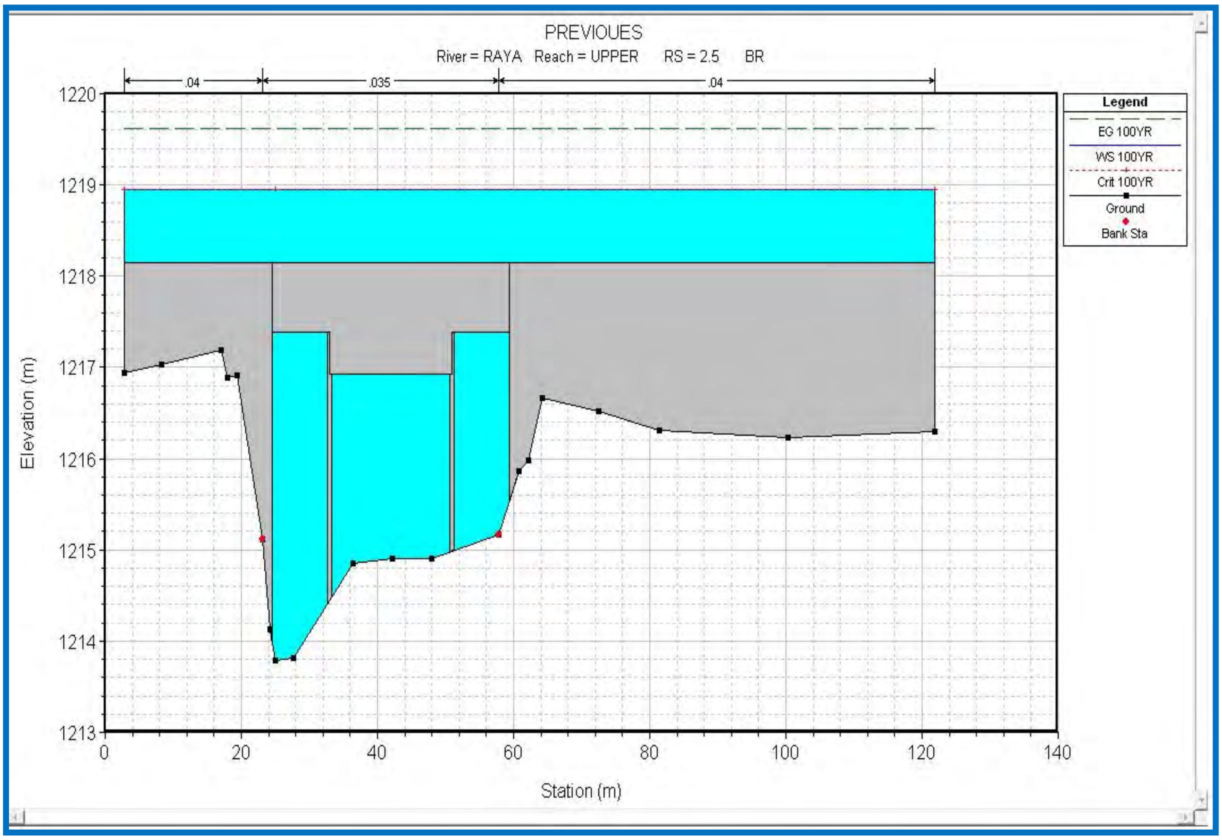


Figure 11: 100 yr peak flood profile for the Existing 34m span bridge

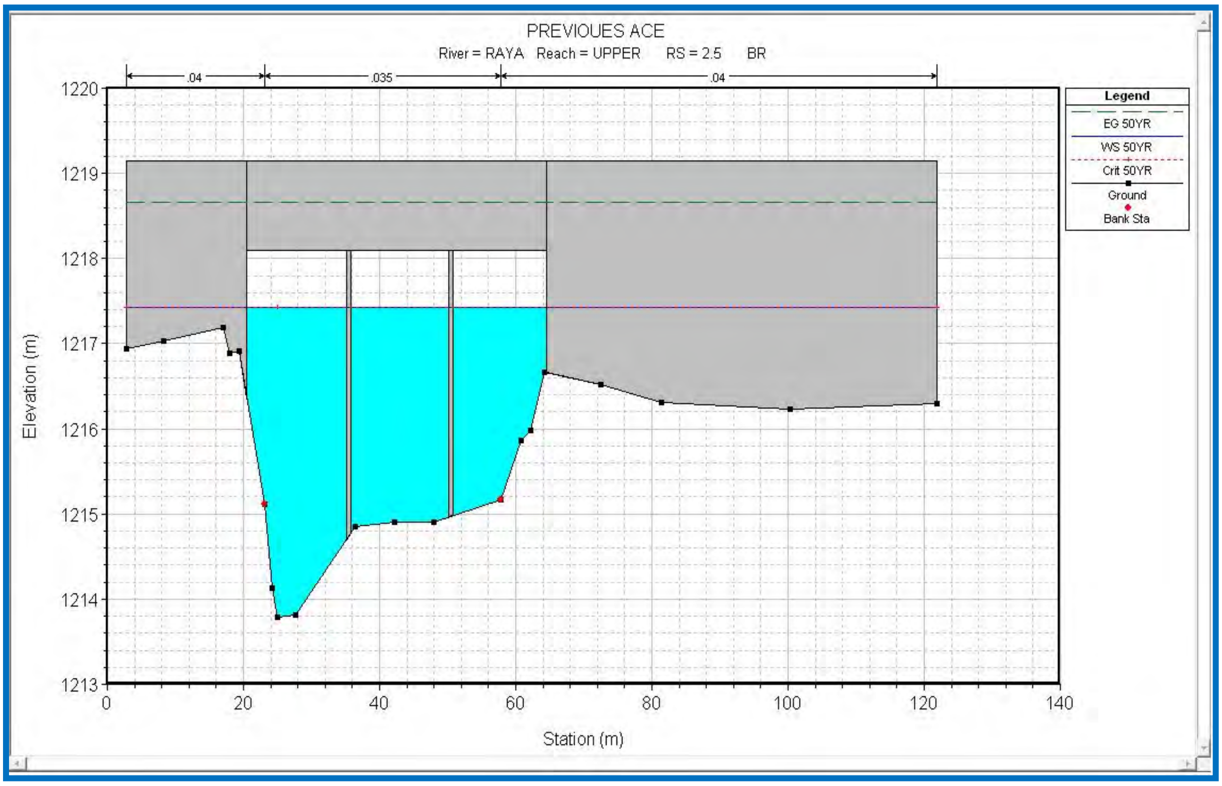


Figure 12: 50 yr peak flood profile for the new AEC 45m span bridge

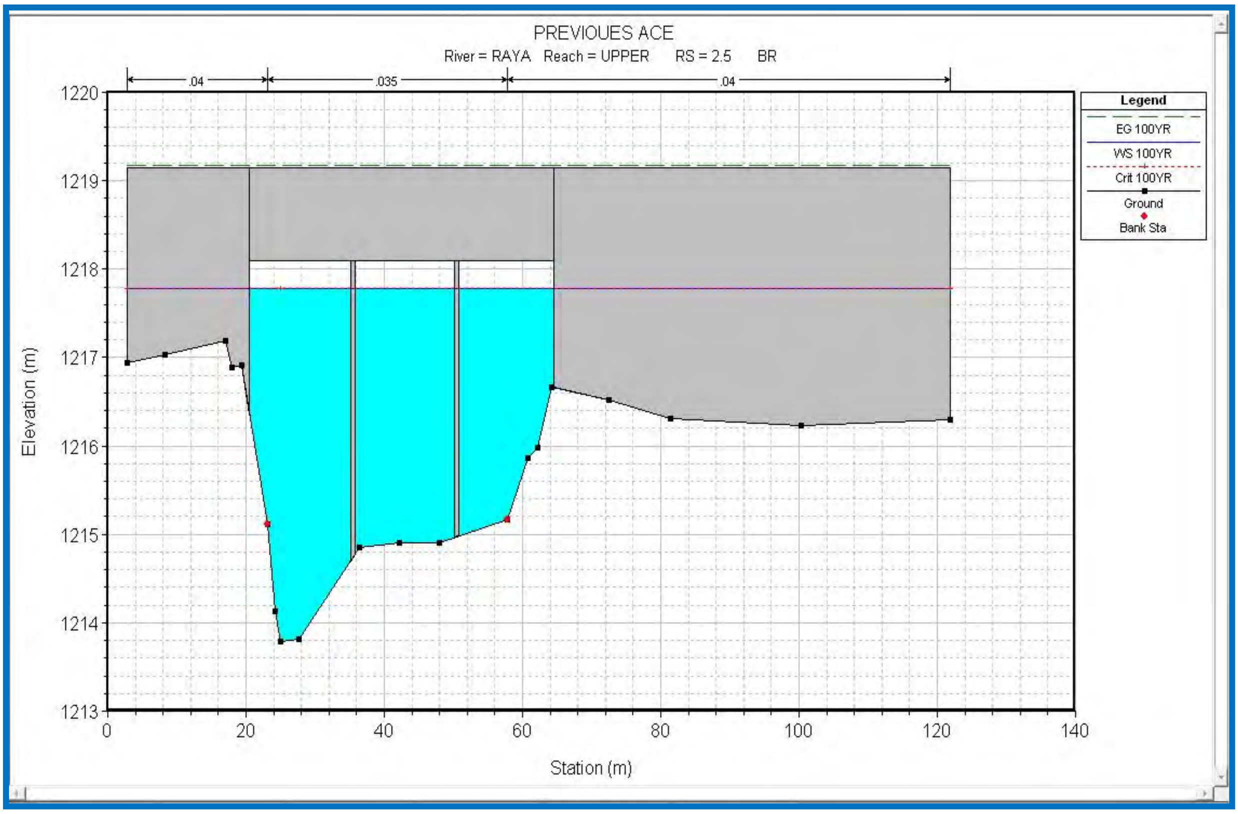


Figure 13: 100 yr peak flood profile for the new AEC 45m span bridge

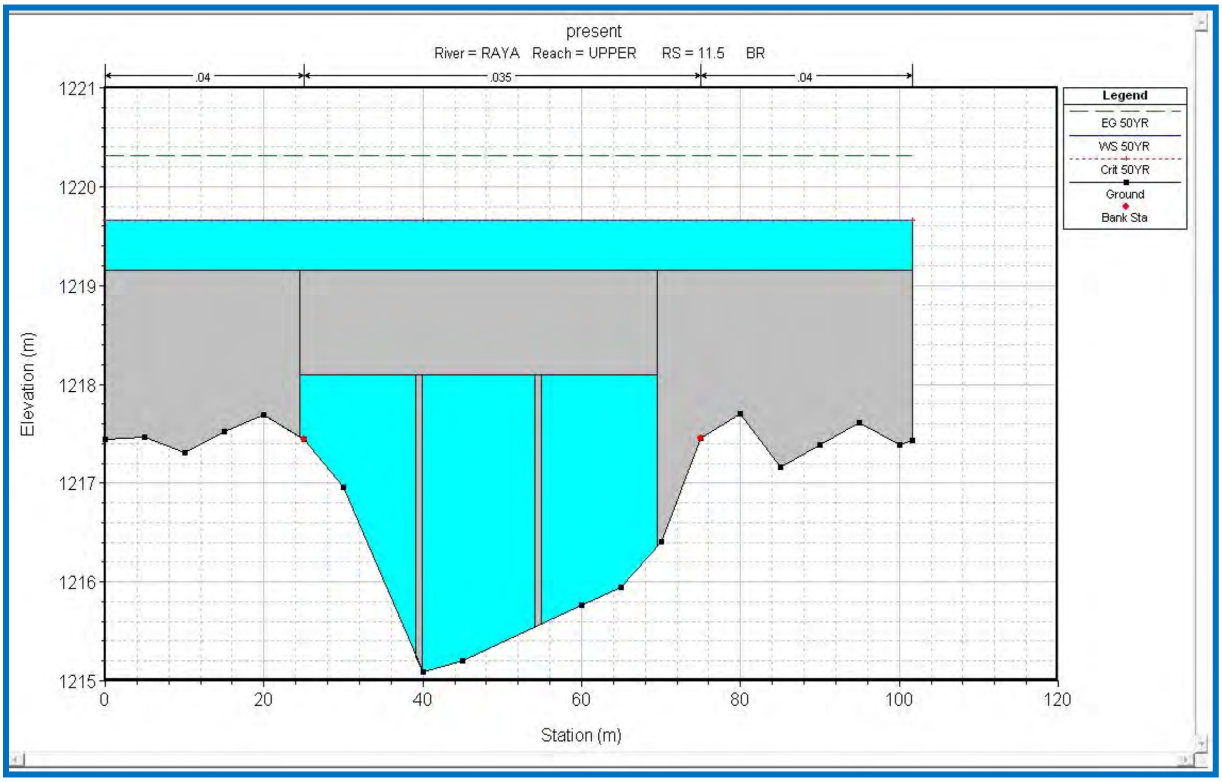


Figure 14: 50 yr peak flood profile using the present river bed level and 45m new bridge proposed

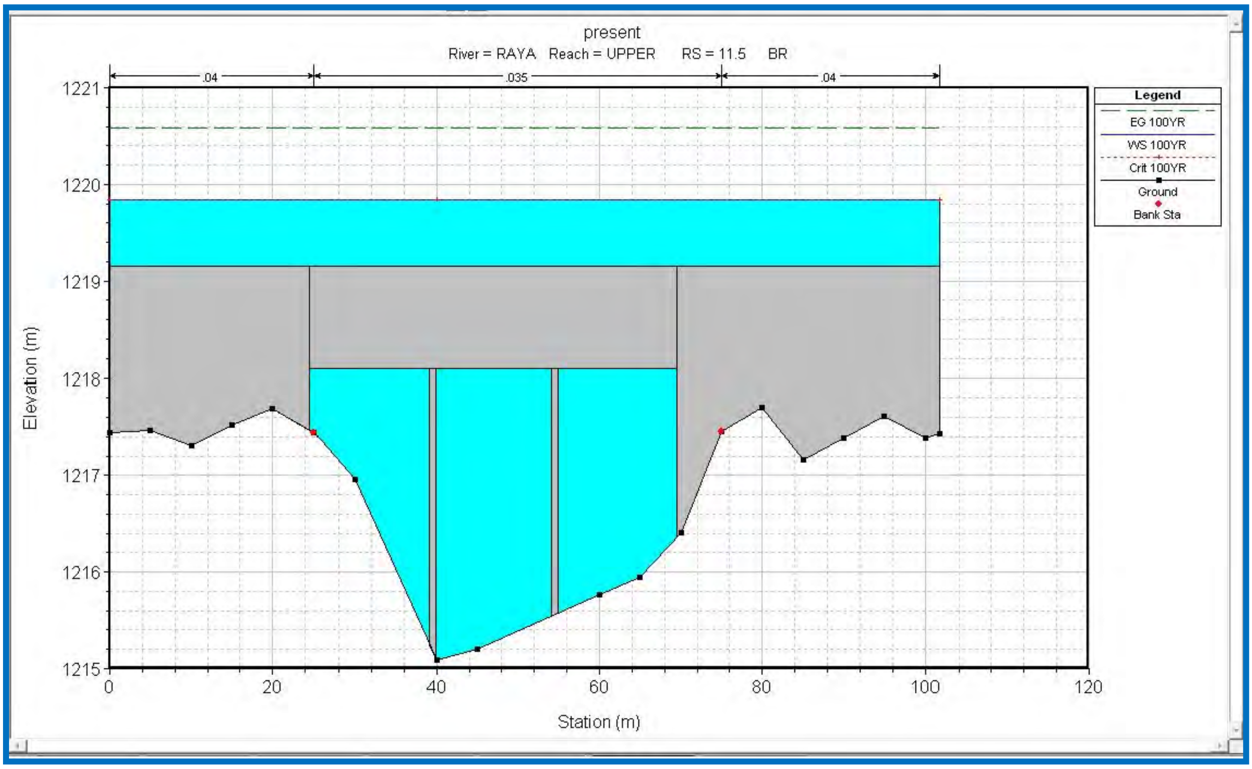


Figure 15: 100 yr peak flood profile using the present river bed level and 45m new bridge proposed

4.3. *Sediment Deposition*

The amount of sediment deposition around the Raya river bridge location were estimated in two ways by using HEC -RAS Sediment model and River bed level changes using the survey data's between 2006 and 2009.

4.3.1. HEC- RAS sediment Transport model

The HEC- RAS sediment transport model performs a mobile bed sediment transport analysis by using Geometric Data's , Quasiy unsteady flow data's, Sediment data's as an input and the analysis results the amount of sediment deposited at the required location with the time base. The HEC- RAs sediment transports Analysis result for the Raya River was shown in the table 10 and figure 16 and 17 below. (Note the units are in feet)

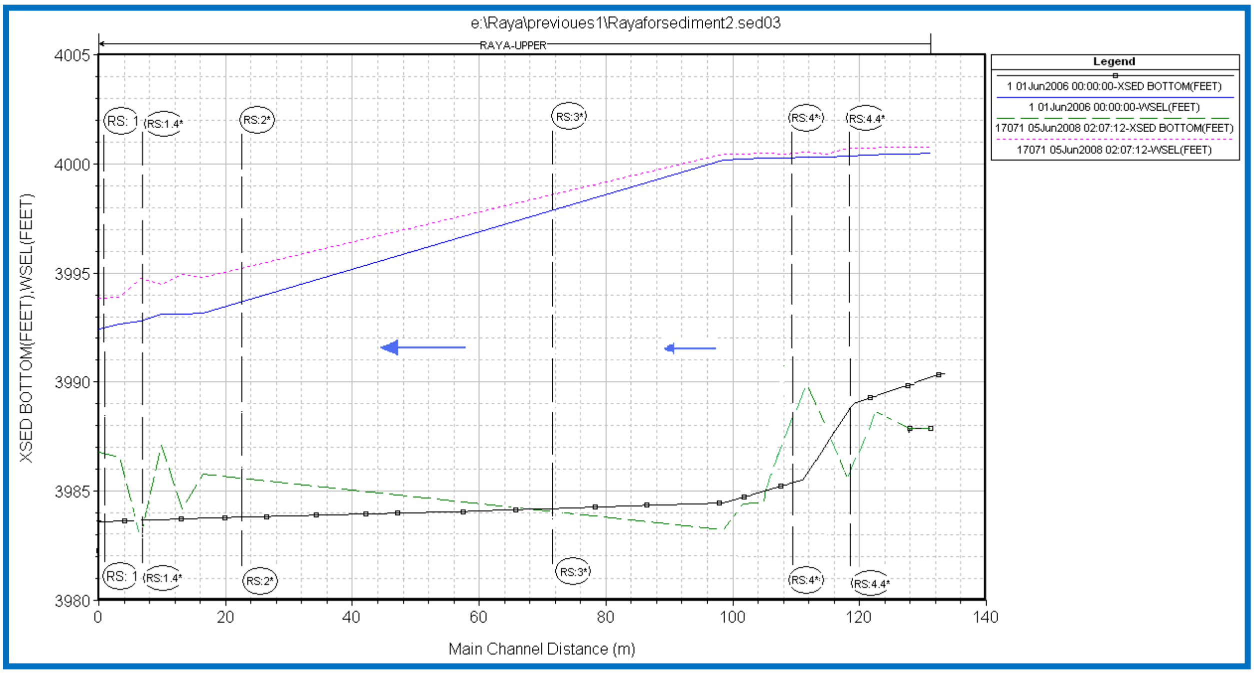
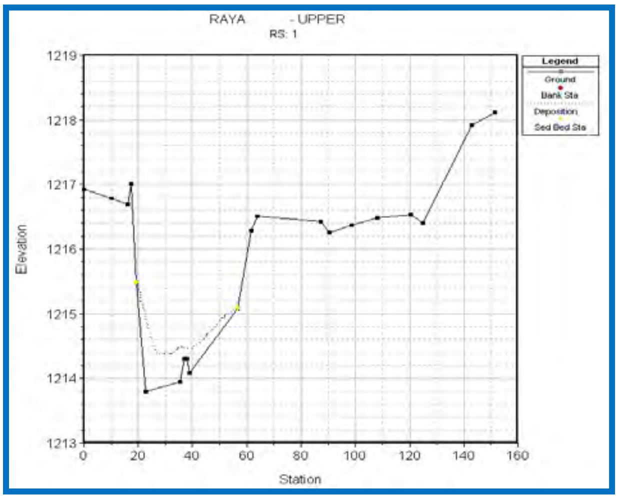
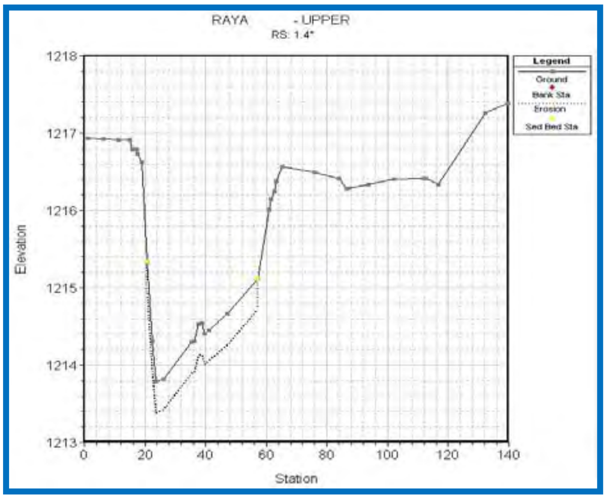


Figure 16: HEC-RAS sediment result showing longitudinal scour and deposition

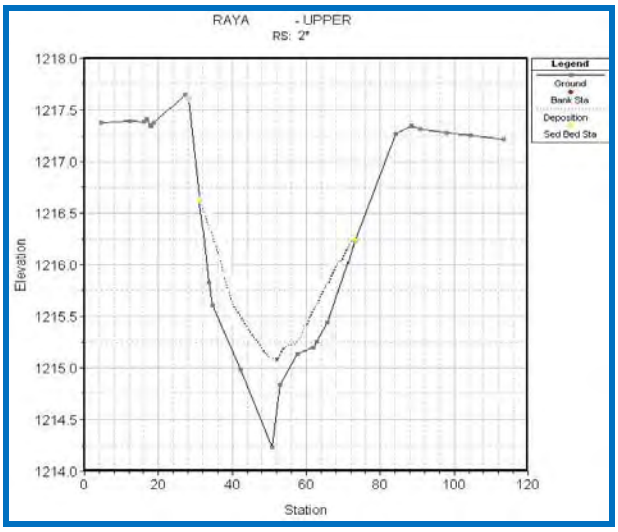
4.3.2. River Bed level rise

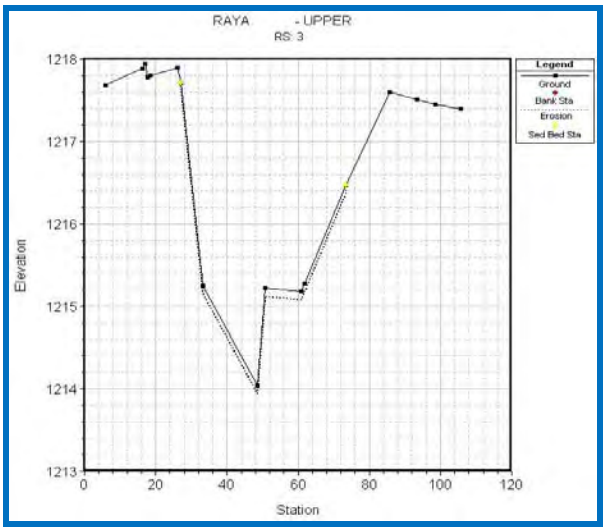
In addition to the result from the HEC- RAS sediment transport model, the amount of sediment deposited around the bridge location were analyzed by using the collected survey data's of the river bed level changes between 2006 and 2009. This has been clearly demonstrates that the cross section area of the bridge was dynamically changed due to the enormous amount of sediment deposition around the bridge location. Based on the obtained cross section data's within the last three years the bridge opening area reduced by 64.64m^2 which is around 24.4m^2 area in each year or 0.588mdepth of deposition yearly. See figure 18



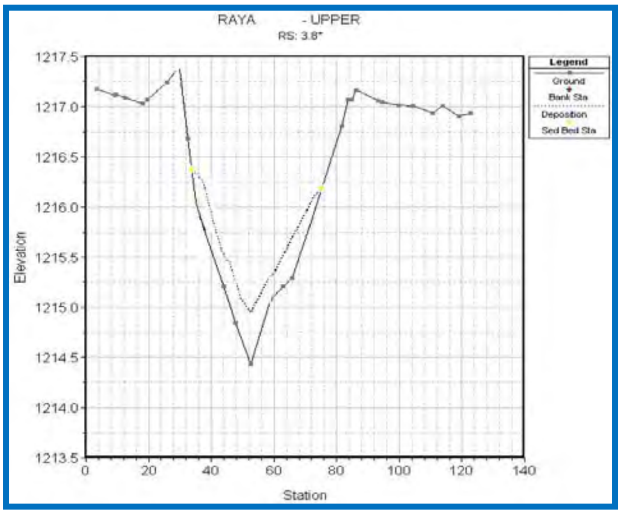


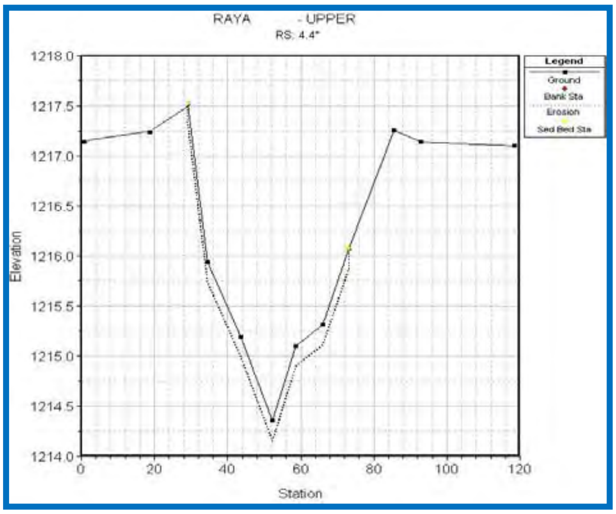
A) Downstream of bridge crossing location





B) At bridge crossing location





C) Upstream of bridge crossing location

Figure 17: HEC-RAS sediment model result showing Scour and Deposition in Cross section

Table 10: HEC – RAS Sediment Model result summary

No	River	Reach	RS	Ch Dist	01Jun2006 01:00- XSED BOTTOM (FEET)	01Jun2006 01:00- WSEL (FEET)	24143 27Apr2008 13:26- XSED BOTTOM (FEET)	24143 27Apr2008 13:26- WSEL (FEET)	Depth of deposition (+) Scour (-) (FEET)	Depth of deposition (+) or Scour (-) (m)
1	RAYA	UPPER	5	3.28	3990.86	4000.48	3987.86	4001.02	-3.00	-0.91
2	RAYA	UPPER	4.8*	3.28	3989.97	4000.45	3987.89	4001.01	-2.09	-0.64
3	RAYA	UPPER	4.6*	3.28	3989.45	4000.43	3988.34	4001.00	-1.11	-0.34
4	RAYA	UPPER	4.4*	3.28	3989.13	4000.40	3988.81	4000.96	-0.32	-0.10
5	RAYA	UPPER	4.2*	3.28	3986.36	4000.37	3986.58	4000.95	0.22	0.07
6	RAYA	UPPER	4	3.28	3985.86	4000.31	3986.92	4000.66	1.06	0.32
7	RAYA	UPPER	3.8*	3.28	3984.69	4000.31	3987.02	4000.75	2.34	0.71
8	RAYA	UPPER	3.6*	3.28	3984.29	4000.28	3987.18	4000.68	2.89	0.88
9	RAYA	UPPER	3.4*	3.28	3984.18	4000.24	3985.52	4000.72	1.34	0.41
10	RAYA	UPPER	3.2*	3.28	3984.07	4000.21	3985.11	4000.67	1.03	0.31
11	RAYA	UPPER	3	82.02	3983.97	4000.17	3983.92	4000.67	-0.05	-0.01
12	RAYA	UPPER	2	3.28	3983.90	3993.14	3984.78	3994.95	0.87	0.27
13	RAYA	UPPER	1.8*	3.28	3983.83	3993.12	3984.87	3995.09	1.04	0.32
14	RAYA	UPPER	1.6*	3.28	3983.74	3993.11	3985.09	3994.67	1.35	0.41
15	RAYA	UPPER	1.4*	3.28	3983.71	3992.81	3982.93	3994.95	-0.78	-0.24
16	RAYA	UPPER	1.2*	3.28	3983.68	3992.64	3986.55	3994.08	2.87	0.87
17	RAYA	UPPER	1	0.00	3983.66	3992.42	3986.80	3994.02	3.15	0.96

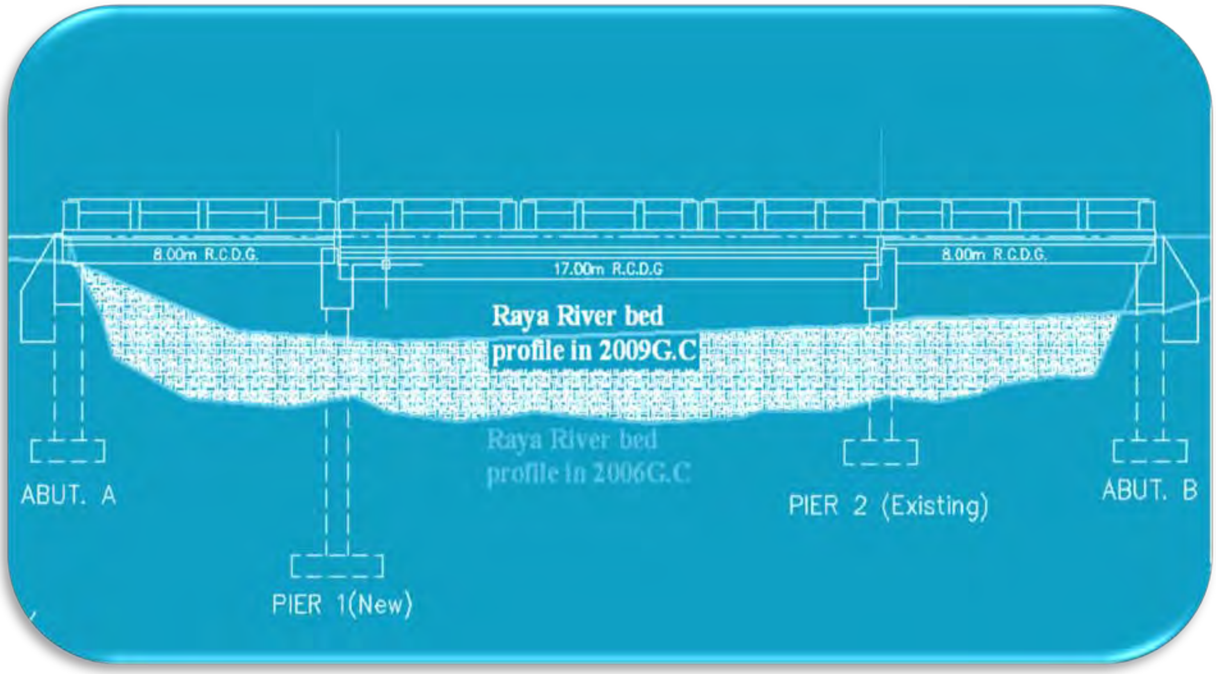


Figure 18: River bed sediment deposition within three years

4.3.3. Causes of sediment deposition

For this specific case there are three major causes expected and each of them were discussed below.

I) U/s structural intervention

As it was mentioned in section 1 there is a diversion structure / weir at the upstream of the bridge crossing location around 150m. In this case the weir or diversion structure located at the u/s of the bridge affects the bridge by reducing the flow velocity that comes to the bridge and this result the sediments to deposit at the bridge crossing location which aggravates the sediment deposition rate on and around the bridge location. The result shows that due to the intervention of the weir the slope of the river bed reduces due to the accumulation of sediment on the weir this results reduction of flow velocity around the bridge location which in turn results to deposit its sediment load on this location.

II) Natural Barrier

The Raya River Bridge is located just at the mouth of Lake Abaya around 3km upstream of the lake. The effect of lake on the bridge location is analyzed by using the change in the river bed profile .At the starting of the catchment is in mountainous and approximately 7.74% and it reduces with increasing of its length and around upstream of the bridge location the slope becomes 3.14% and downstream of the bridge location the slope significantly reduced and becomes flat with a slope of 2.1% finally around the last 4km at the entrance to the lake the slope of the river bed becomes almost 0 % which significantly reduced the velocity of the flow and results the bed load and suspended load sediment to deposit around the bridge location as a result the lake is one of the factors to the river bed level rise or deposition of sediment around the Raya river bridge location.

III) Land use change

Land use change has direct impact on the amount of sediment deposition on river bed. For the Raya River catchment area there is no any clear information about the land use changes. But from the local peoples collected information there is deforestation of the catchment forest coverage for the purpose of agricultural land which increases the amount of sediment deposition on the river bed and also from the data's taken from ministry of agriculture the land use coverage more than 79% of the catchment is cultivated land which adversely affects the amount erosion from the bare land.

5. MITIGATION MEASURES

Sustainable Mitigation measures were required to prolong the life of the bridge and reduce the impact of the failure in the economic sector. The following mitigation measures were recommended for the existing and new bridges constructed in areas were bridges are prone to failure due to enhanced sediment initiation and deposition caused by both natural and human activities.

I) River Training & Erosion Protection

River training works and channelization are highly recommended to control and guide the flow within well-defined banks. Also controlled measures like making the Longitudinal Slope of the river channel a bit steeper may reduce the likelihood of too much sedimentation.

The construction of levees (dykes), channel dredging works, bank stabilizations and bank erosion protection measures may be necessary. Since the bank material of the river is highly erodible, erosion protection measures like grassing of the banks with natural vegetation and ripraps are necessary. These erosion protection measures are highly mandatory especially for those reaches of the river affected by artificial measures and their natural equilibrium disturbed.

II) Periodic maintenance and Dredging work

Rivers like Raya River with heavy siltation problems will tend to restore to their natural equilibrium and undo the artificial intervention measures introduced if they are left to themselves for significant period of time and also the siltation problem cannot be totally eliminated. Hence periodic inspection and maintenance is necessary not to run again in to the same problem.

The Periodic maintenance measures include reinstating breached and weakened banks and dykes, providing erosion protection measures and reinforcing the already in place but damaged protection works in susceptible areas. And if siltation that is over the normally expected amount after mitigation is encountered, dredging and excavation of the silted up material may be necessary for the Raya River Bridge there is a need to perform periodic dredging work within two years interval. Otherwise if this problem happens and is not treated in time, it may get worse, aggravate and will be further exacerbated. So, timely maintenance and intervention measures are very necessary.

It should be emphasized that during excavation and dredging, careful disposal of the spoil material (the dredged material) is necessary as otherwise if it is just dumped on the banks; it ends up back in to the river channel again with very little effort.

III) Removal of Obstruction and bottlenecked Sections

Any bottlenecked section in the river channel should be removed or treated as it causes flow constriction and backwater effects that make favorable grounds for siltation. If the siltation caused by the bottlenecked sections gets worth, channel aggradation may occur which may aggravate the tendency of the river to overtop its banks and change the direction of its watercourse.

IV) Silt traps and reduction of the silt load

Another good way of treating the massive siltation observed is by reducing the silt load carried by the river before it reaches the Bridge location. Silt Traps and Silting Basins provided a good distance upstream of the Bridge may significantly reduce the silt load and alleviate greatly the possibility of heavy siltation near the bridge structure.

V) Sediment transport modeling

The sediment transport modeling will help to determine the total amount of sediment deposition expected and may help in defining the design & geometric parameters of the bridge, the scope of intervention measures required and the magnitude of maintenance measure required at given intervals.

VI) Extensive works on land use changes

Planting of trees, grasses, and other erosion protection methods on the catchment area of the river to reduce the amount of sediment particles deposited on the bridge crossing location.

VII) Location & Opening size of the bridge

The selected bridge location should be on a straight reach with stable natural banks and a sufficiently pronounced channelized waterway (a gorge like channel is highly recommended). Factors to consider in the determination of the Span Length and the Clear Height of the Bridge are described below.

A) Span length

With regard to the opening size of the bridge, the Span Length should be selected in such a way that the bridge spans from the edges of one bank to another and in no case, the flow should be constricted. If the flow is constricted, backwater affects causing sedimentation that will aggravate progressively with each previous siltation.

B) Clear opening height of the bridge

Once the Span is fixed, the detail full-fledged hydrology must be carried out to determine the High Water Mark for the Design and Review Peak Discharges for the Return Periods recommended. Then using Sediment Transport Modeling, the amount of unavoidable expected sedimentation in the channel and the resulting channel aggradations should be determined. And also sufficient free-board should be provided. The opening height should then be determined by considering among others the High Water Mark, Expected Channel Aggradations as mitigated by periodic maintenance measures and the Free-Board required.
Recommended design guide lines for Rivers which encounters gradation problem.

Table 11: Design guidelines for rivers encountering gradation problems.

Aggrading Rivers	Degrading Rivers
Estimating the amount of rate of sediment deposition around bridge crossing location.	Estimation the amount of scouring at the pier and abutment of the bridge.
Perform sediment transport Analysis.	Removal of Vortex flow formation around pier and abutments.
Analyzing the effect of natural or manmade barriers around the bridge, upstream and downstream of the bridge.	Estimating future land use changes in the catchment area of the river.
Estimating future land use changes in the catchment area of the river.	Analyzing the effect of natural or manmade barriers at the upstream or downstream of the bridge.
Providing Opening sizes which is suitable to accommodate the estimated amount of sediment deposition.	Analyzing the effect of upstream mining and presence of reservoir on the river.
If the rate of deposition is beyond the equilibrium recommend the amount and frequency of dredging works required around the bridge location.	

6. SUMMARY, CONCLUSION AND RECOMMENDATION

6.1. Summary

This study evaluated the failure case of the Raya river bridge with the view to under the behavior from the hydraulics point of view. The study evaluated the three cases the existing failed bridge, the proposed bridge in 2006 and 2009G.C. and identified the main cause of the failure of the bridge. It has been informed that the newly proposed bridge which is now under construction which is safe during the design period but currently it's overtopped and it needs design review.

6.2. Conclusion

The following conclusions were drawn from the results of the investigation:

The failure of the Raya river bridge was resulted from the change in the property of the flow of the river around the bridge crossing location. As the clear opening area of the bridge water way decreases the property of the flow changed from normal flow condition to pressurized flow as result the flood over floats one of the super structure of the bridge resulting collapse of the Raya river bridge. The specific failure cause that results the change in the property of the flow are mentioned below.

- Clear opening height reduction or flow area reduction at the bridge location due to long term river bed level rise or Aggradation due to sediment deposition.
- Sediment deposition at the bridge crossing location which is estimated about $24.4m^3$ or 64.64 tones of sediment deposition per meter width in each year.
- The presence of weir or diversion structure at the upstream of the bridge location which aggravates the rate of sediment deposition at the bridge location and upstream of it.
- Reduction of the slope due to improper location of the bridge at the entrance to the Lake Abaya which increases the rate of sediment deposition around the bridge location.

6.3. Recommendation

The following recommendations were drawn from this study

a) To get accurate estimation of peak flood in the study area there is a need to meteorological and flow data around the bridge location.

b) This study does not look to the dynamics of the morphology of the channel, future studies should focus to consider the channel as movable channel.

c) Furthermore sediment concentration flow data collection is also required to estimate the exact amount of sediment deposition around the bridge.

d) In our country lots of bridge failures were experienced and researchers have to do a lot of works in this topic.

REFERENCE

AASHTO, 1992. "Hydraulic Analyses for the Location and Design of Bridges Volume VII-I Highway Drainage Guidelines" AASHTO Task Force on Hydrology and Hydraulics.
Addis Ababa City Roads Authority. (AACRA - 2003). "Drainage Design Manual", Ethiopia

Baker, R.E. (1986). "Local Scour at Bridge Piers in Non-uniform Sediment." Report No.402, Department of Civil Engineering, University of Auckland, Auckland, NewZealand.

Chow, V. T. (1964). "Handbook of Applied Hydrology", McGraw-Hill, New York.

D. Fiddes, J.A. Forsgate and A.O. Grigg, "The Prediction of Storm Rainfall in East Africa", Transport and Road Research Laboratory, Department of Environment (TRRL Laboratory Report 623)

Einstein, H. A. (1950). "The Bed-Load Function for Sediment Transportation in Open-Channel Flows." U.S. Department of Agriculture, Soil Conservation Service, Technical Bulletin No. 1026.

Ethiopian Roads Authority. (2001). "Drainage Design Manual", Federal Democratic Republic of Ethiopia

Gray, W. Brunner. (2006)."HEC RAS, River Analysis System User's Manual" U.S Army corps of Engineers Hydrologic Engineering Center, 609 second street Davis, CA 95616

HEC-18, (1995). "Evaluating Scour at Bridges", Federal Highway Administration.

Louisville, (1998). "What is Bridge Scour?" Department of Civil Engineering, University of Louisville. < http://vortex.spd.louisville.edu> (June.15, 2009)

Melville, B.W. (1975). "Local scour at bridge sites." Report no. 117, University of Auckland, School of Engineering, Auckland, New Zealand.

Melville, B.W., and Sutherland, A.J. (1988). "Design method for local scour at bridge piers." Journal of Hydraulic Engineering, 114(10), 1210-1226.

Soil Conservation Service, (1972). "Soil Conservation Service National Engineering Handbook."U.S. Department of Agriculture, Soil Conservation Service, Washington, D.C.

U.S. Department of Transportation, (2002). "Highway Hydrology Hydraulic Design Manual" Series Number 2, Federal Highway Administration.

U.S. Department of Transportation, 2002." Evaluating Scour at Bridges Hydraulic Engineering Circular No. 18" Federal Highway Administration.

Type of Channel and Description	Minimum	Normal	Maximum
EXCAVATED OR DREDGED			
a. Earth, straight and uniform			
1. Clean, recently completed	0.016	0.018	0.020
2. Clean, after weathering	0.018	0.022	0.025
3. Gravel, uniform section, clean	0.022	0.025	0.030
4. With short grass, few weeds	0.022	0.027	0.033
b. Earth, winding and sluggish			
1. No vegetation	0.023	0.025	0.030
2. Grass, some weeds	0.025	0.030	0.033
3. Dense Weeds or aquatic plants in deep channels	0.030	0.035	0.040
4. Earth bottom and rubble sides	0.025	0.030	0.035
5. Stony bottom and weedy sides	0.025	0.035	0.045
6. Cobble bottom and clean sides	0.030	0.040	0.050
c. Backhoe-excavated or dredged			
1. No vegetation	0.025	0.028	0.033
2. Light brush on banks	0.035	0.050	0.060
d. Rock cuts			
1. Smooth and uniform	0.025	0.035	0.040
2. Jagged and irregular	0.035	0.040	0.050
e. Channels not maintained, weeds and brush uncut			
1. Dense weeds, high as flow depth	0.050	0.080	0.120
2 Clean bottom, brush on sides	0.040	0.050	0.080
3. Same, highest stage of flow	0.045	0.070	0.110
4. Dense brush, high stage	0.080	0.100	0.140
NATURAL STREAMS			
1 Minor streams (top width at flood stage < 30 m)			
a. Streams on Plain			
1. Clean, straight, full stage, no rims or deep pools	0.025	0.030	0.033
2. Same as above, but more stones and weeds	0.030	0.035	0.040
3. Clean, winding, some pools and shoals	0.033	0.040	0.045
4. Same as above, but some weeds and stones	0.035	0.045	0.050
5. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
6. Same as 4, but more stones	0.045	0.050	0.060
7. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
8 Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
b. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
1. Bottom: gravel, cobbles, and few boulders	0.030	0.040	0.050
2. Bottom: cobbles with large boulders	0.040	0.050	0.070
2 Flood Plains			
a. Pasture, no brush			
1. Short grass	0.025	0.030	0.035
2. High grass	0.030	0.035	0.050

Type of Channel and Description	Normal	Maximum
b. Cultivated area		
1. No crop	0.030	0.040
2. Mature row crops	0.035	0.045
3. Mature field crops	0.040	0.050
c. Brush		
1. Scattered brush, heavy weeds	0.050	0.070
2. Light brush and trees in winter	0.050	0.060
3. Light brush and trees, in summer	0.060	0.080
4. Medium to dense brush, in winter	0.070	0.110
5. Medium to dense brush, in summer		
d. Trees	0.100	0.160
1. Dense willows, summer, straight		
2. Cleared land with tree stumps, no sprouts	0.150	0.200
3. Same as above, but with heavy growth of spouts	0.040	0.050
4. Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.060	0.080
5. Same as above, but with flood stage reaching branches	0.100	0.120
3 Major Streams (top width at flood stage > 30 m). The n value is less than that for minor streams of similar description, because banks offer less effective resistance.	0.120	0.160
a. Regular section with no boulders or brush		
b. Irregular and rough section		
4 Various Open Channel Surfaces		
a. Concrete		
b. Gravel bottom with:	--	0.060
Concrete	--	0.100
Mortared stone		
Riprap	0.020	
c. Natural Stream Channels		
Clean, straight stream		
Clean, winding stream		
Winding with weeds and pools		
With heavy brush and timber		
d. Flood Plains		
Pasture		
Field Crops		
Light Brush and Weeds		
Dense Brush		
Dense Trees		

Inlet Topography Raya Bridge				Outlet Topography Raya Bridge			
Point	**Northing**	**Easting**	**Elevation**	**Point**	**Northing**	**Easting**	**Elevation**
1	713981.261	361195.517	1219.038	1	713982.160	361203.905	1218.828
2	713994.411	361199.408	1219.439	2	713990.577	361205.933	1219.022
3	714003.245	361201.842	1219.771	3	713998.100	361207.929	1219.405
4	714009.468	361203.792	1220.137	4	714005.053	361209.802	1219.546
5	714015.596	361205.315	1219.929	5	714011.509	361211.860	1219.792
6	714018.473	361206.125	1219.199	6	714016.601	361213.295	1218.969
7	714021.409	361207.000	1218.360	7	714019.629	361214.107	1219.030
8	714021.409	361207.019	1218.361	8	714023.104	361215.069	1218.531
9	714027.369	361208.647	1215.701	9	714026.496	361215.993	1215.645
10	714034.238	361210.581	1215.758	10	714034.381	361218.195	1215.569
11	714040.271	361212.331	1215.438	11	714042.442	361220.555	1215.222
12	714046.904	361214.204	1215.258	12	714046.871	361221.807	1215.183
13	714053.853	361216.280	1215.517	13	714052.125	361223.505	1215.186
14	714062.341	361218.803	1215.274	14	714060.345	361225.709	1214.956
15	714064.222	361219.107	1219.838	15	714065.979	361228.427	1219.818
16	714072.437	361221.502	1220.048	16	714071.299	361229.291	1219.710
17	714085.215	361225.161	1219.411	17	714083.396	361232.796	1219.269
18	714093.752	361227.479	1219.239	18	714089.697	361234.483	1219.085
19	714105.306	361230.772	1218.846	19	714097.976	361236.963	1218.952
20	714105.895	361228.677	1218.546	20	714097.560	361238.796	1218.436
21	714094.998	361225.589	1218.528	21	714088.809	361236.057	1218.545
22	714088.233	361223.773	1218.627	22	714081.918	361234.117	1218.592
23	714079.889	361221.509	1218.775	23	714073.874	361231.567	1218.874
24	714071.094	361219.075	1219.260	24	714065.739	361229.112	1219.474
25	714064.262	361217.260	1219.117	25	714061.827	361228.394	1218.862
26	714061.176	361216.402	1216.405	26	714059.191	361227.540	1214.909
27	714054.788	361214.567	1215.415	27	714057.456	361226.934	1214.767
28	714048.962	361212.943	1215.159	28	714055.523	361226.398	1215.108
29	714043.039	361211.226	1215.319	29	714051.376	361225.264	1215.252
30	714038.399	361209.995	1215.682	30	714045.203	361223.424	1215.109
31	714027.798	361207.015	1215.818	31	714041.573	361222.396	1215.238
32	714020.817	361205.104	1218.625	32	714034.583	361220.451	1215.479
33	714014.289	361203.244	1219.190	33	714026.650	361218.037	1215.633
34	714005.223	361200.673	1219.153	34	714022.722	361216.911	1218.187
35	713997.856	361198.532	1219.111	35	714018.640	361215.668	1218.665
36	713990.492	361196.446	1218.998	36	714015.797	361214.960	1218.731
37	713980.823	361193.700	1218.798	37	714010.052	361213.271	1218.849
38	713981.272	361190.716	1217.564	38	713996.031	361209.023	1218.570
39	713991.487	361193.663	1217.627	39	713985.881	361206.074	1218.458
40	714006.321	361198.448	1218.513	40	713976.812	361204.997	1217.646
41	714019.314	361202.363	1218.646	41	713985.306	361207.581	1217.610
42	714028.748	361205.027	1215.681	42	713994.002	361210.066	1217.626
43	714038.695	361207.937	1215.525	43	714005.689	361213.655	1217.748
44	714049.855	361211.106	1215.149	44	714011.170	361215.521	1218.003
45	714055.123	361212.504	1215.341	45	714015.722	361216.868	1218.301
46	714060.336	361214.068	1216.840	46	714022.022	361218.911	1218.061
47	714064.331	361215.120	1218.639	47	714025.785	361219.918	1215.647
48	714070.038	361216.693	1218.740	48	714034.008	361222.243	1215.427
49	714078.323	361219.268	1218.488	49	714043.503	361225.030	1215.102
50	714085.194	361221.313	1218.355	50	714050.749	361227.204	1215.341
51	714101.446	361226.034	1218.211	51	714056.227	361228.752	1214.896
52	714110.650	361228.813	1218.595	52	714058.555	361229.300	1214.883
53	714092.630	361221.190	1217.730	53	714059.958	361229.764	1217.843
54	714079.118	361217.362	1217.993	54	714063.825	361230.712	1218.745

55	714069.634	361214.680	1218.244	55	714065.481	361231.413	1218.467
56	714063.304	361212.832	1218.205	56	714077.338	361234.346	1218.047
57	714047.543	361208.347	1215.098	57	714091.627	361238.165	1218.049
58	714039.670	361206.043	1215.424	58	714096.633	361241.938	1217.673
59	714034.349	361204.548	1215.946	59	714076.701	361236.258	1217.665
60	714018.695	361200.109	1218.377	60	714068.676	361234.065	1217.876
61	714006.912	361197.213	1218.009	61	714061.024	361232.022	1217.444
62	713991.820	361193.172	1217.477	62	714058.757	361231.296	1214.737
63	713980.886	361190.422	1217.458	63	714055.888	361230.686	1215.051
64	713980.805	361187.498	1217.327	64	714050.062	361228.958	1215.603
65	714008.265	361194.957	1217.487	65	714044.619	361227.391	1215.119
66	714016.047	361197.168	1218.086	66	714043.234	361227.018	1215.049
67	714027.887	361200.782	1215.922	67	714036.334	361225.136	1215.329
68	714039.884	361204.082	1215.407	68	714032.090	361223.693	1215.497
69	714051.172	361207.269	1215.069	69	714025.658	361221.837	1215.600
70	714056.692	361208.853	1215.359	70	714021.834	361220.699	1217.301
71	714063.822	361210.974	1217.717	71	714017.120	361219.347	1217.737
72	714079.268	361215.419	1217.415	72	714010.136	361217.193	1217.035
73	714092.366	361219.332	1217.599	73	714005.720	361215.609	1216.746
74	714103.409	361222.596	1218.079	74	713993.926	361212.158	1216.811
75	714104.412	361220.321	1217.999	75	713984.001	361209.341	1216.636
76	714084.430	361214.706	1217.264	76	713983.469	361211.544	1216.277
77	714065.754	361209.318	1217.370	77	713993.033	361214.355	1216.243
78	714062.313	361208.225	1217.229	78	714000.067	361216.414	1216.373
79	714057.313	361206.857	1215.345	79	714010.667	361219.485	1216.616
80	714052.388	361205.604	1215.057	80	714018.280	361221.815	1217.188
81	714043.415	361203.005	1215.295	81	714021.696	361222.830	1217.453
82	714037.359	361201.251	1215.512	82	714025.089	361223.767	1215.568
83	714027.830	361198.530	1215.922	83	714033.515	361226.250	1215.494
84	714016.653	361195.505	1217.634	84	714037.762	361227.524	1215.290
85	714006.751	361192.814	1217.298	85	714042.102	361228.807	1215.017
86	713989.770	361188.122	1217.491	86	714046.529	361229.967	1215.255
87	713981.500	361185.898	1217.308	87	714049.605	361230.938	1215.464
88	713981.816	361182.629	1217.428	88	714056.566	361232.845	1215.018
89	713990.549	361185.549	1217.492	89	714060.239	361234.070	1215.259
90	713998.780	361187.895	1217.231	90	714062.857	361235.016	1217.124
91	713998.787	361187.892	1217.231	91	714073.017	361236.988	1217.270
92	713998.784	361187.893	1217.231	92	714082.346	361239.906	1217.129
93	714012.276	361191.779	1217.361	93	714092.166	361242.376	1217.453
94	714027.558	361196.285	1216.038	94	714088.833	361244.293	1217.192
95	714036.554	361198.861	1215.575	95	714072.829	361240.094	1216.711
96	714041.391	361200.389	1215.437	96	714065.165	361237.838	1216.848
97	714057.850	361205.017	1215.336	97	714062.550	361236.952	1217.276
98	714065.152	361207.288	1217.460	98	714060.852	361236.404	1215.219
99	714077.042	361210.673	1217.144	99	714055.655	361234.750	1215.036
100	714086.789	361213.514	1217.286	100	714049.600	361233.037	1215.303
101	714103.656	361218.253	1218.745	101	714045.634	361231.888	1215.264
102	714092.860	361212.395	1216.768	102	714040.796	361230.475	1214.968
103	714075.303	361207.726	1217.147	103	714033.465	361228.271	1215.442
104	714065.619	361205.072	1217.467	104	714028.201	361226.737	1215.479
105	714058.449	361203.032	1215.319	105	714024.177	361225.573	1215.617
106	714051.894	361201.142	1215.113	106	714021.680	361224.822	1216.554
107	714041.744	361198.304	1215.430	107	714018.105	361223.701	1216.814
108	714036.378	361196.761	1215.656	108	714010.153	361221.217	1216.713
109	714028.283	361194.441	1215.861	109	713997.532	361217.440	1216.246
110	713999.874	361187.265	1217.216	110	713988.704	361214.818	1216.368

111	713980.575	361182.047	1217.444	111	713982.636	361212.931	1216.239
112	713981.656	361178.703	1217.561	112	713981.867	361215.291	1216.266
113	713995.444	361182.797	1217.297	113	713987.603	361216.985	1216.314
114	714012.160	361187.617	1217.780	114	713997.057	361219.744	1216.340
115	714028.181	361192.288	1215.867	115	714009.396	361223.479	1216.848
116	714035.689	361194.449	1215.752	116	714016.097	361225.434	1216.843
117	714042.462	361196.364	1215.435	117	714020.965	361226.847	1216.414
118	714052.574	361199.220	1215.147	118	714023.099	361227.370	1216.058
119	714059.047	361201.180	1215.309	119	714025.301	361228.108	1215.445
120	714066.811	361203.319	1217.272	120	714029.693	361229.110	1215.397
121	714076.988	361206.488	1217.157	121	714032.392	361230.164	1215.423
122	714089.741	361210.404	1217.498	122	714037.111	361231.478	1215.150
123	714105.681	361213.539	1217.934	123	714041.267	361232.756	1214.954
124	714086.989	361207.192	1217.361	124	714045.082	361233.802	1215.215
125	714069.118	361201.834	1217.062	125	714048.793	361234.908	1215.376
126	714065.722	361200.929	1217.245	126	714053.032	361236.114	1215.141
127	714059.573	361199.142	1215.295	127	714056.385	361237.099	1215.031
128	714053.059	361197.236	1215.187	128	714060.611	361238.425	1215.171
129	714044.811	361194.944	1215.299	129	714061.688	361238.713	1216.185
130	714042.464	361194.396	1215.446	130	714063.937	361239.385	1217.006
131	714037.625	361192.927	1215.739	131	714068.847	361240.629	1216.835
132	714035.794	361192.511	1216.006	132	714082.311	361244.384	1216.871
133	714031.257	361191.196	1215.990	133	714074.000	361244.515	1217.087
134	714030.546	361190.992	1215.927	134	714069.464	361242.922	1216.819
135	714027.520	361190.203	1216.021	135	714063.739	361241.229	1216.886
136	714022.927	361189.038	1216.685	136	714061.987	361240.607	1217.005
137	714009.620	361185.265	1217.298	137	714060.646	361240.310	1215.124
138	713991.332	361180.449	1217.283	138	714056.460	361239.102	1214.889
139	713981.055	361177.059	1217.643	139	714050.924	361237.601	1215.064
140	713981.785	361174.872	1217.676	140	714048.440	361236.840	1215.256
141	713997.608	361179.351	1217.182	141	714044.081	361235.546	1215.127
142	714010.096	361182.757	1216.986	142	714040.092	361234.438	1214.916
143	714020.880	361185.913	1216.532	143	714036.715	361233.350	1215.053
144	714025.181	361187.221	1216.375	144	714032.378	361232.209	1215.305
145	714027.552	361187.979	1216.039	145	714028.719	361231.122	1215.324
146	714031.265	361188.852	1216.040	146	714023.863	361229.701	1215.504
147	714033.314	361189.587	1216.158	147	714022.087	361229.359	1216.015
148	714037.493	361190.605	1215.904	148	714017.946	361228.031	1216.618
149	714039.476	361191.257	1215.634	149	714014.357	361227.073	1217.214
150	714043.194	361192.423	1215.378	150	714006.466	361224.829	1216.855
151	714053.045	361195.259	1215.125	151	713998.997	361222.044	1216.391
152	714059.978	361197.253	1215.317	152	713992.101	361219.385	1216.392
153	714065.548	361199.033	1217.291	153	713985.892	361218.366	1216.346
154	714069.780	361200.318	1217.061	154	713985.811	361220.120	1216.444
155	714082.009	361204.981	1217.365	155	713998.754	361225.167	1216.810
156	714088.329	361206.169	1217.398	156	714006.732	361227.059	1217.019
157	714106.438	361211.423	1217.886	157	714013.501	361228.362	1217.327
158	714106.947	361211.123	1218.015	158	714017.332	361230.158	1216.650
159	714092.679	361205.044	1217.459	159	714021.752	361231.333	1215.819
160	714085.516	361202.693	1217.281	160	714023.163	361231.722	1215.403
161	714070.348	361198.163	1217.149	161	714025.496	361232.451	1215.268
162	714066.910	361197.224	1217.277	162	714031.336	361234.085	1215.271
163	714061.587	361195.616	1215.592	163	714036.373	361235.453	1215.155
164	714060.143	361195.266	1215.285	164	714040.152	361236.599	1214.864
165	714052.957	361193.134	1215.102	165	714043.183	361237.532	1215.032
166	714043.892	361190.594	1215.349	166	714047.477	361238.658	1215.316

167	714039.883	361189.499	1215.619	167	714050.091	361239.482	1215.044
168	714037.428	361188.936	1216.023	168	714055.772	361241.057	1214.884
169	714033.612	361187.849	1216.347	169	714056.610	361241.453	1215.152
170	714032.332	361187.358	1216.134	170	714059.538	361242.192	1215.047
171	714026.238	361185.786	1216.132	171	714060.270	361242.382	1215.119
172	714024.200	361185.192	1216.406	172	714061.864	361242.790	1217.697
173	714017.892	361183.149	1216.439	173	714065.151	361243.749	1217.002
174	714013.999	361182.234	1216.846	174	714070.056	361244.933	1217.149
175	714010.456	361181.261	1216.814	175	714074.918	361246.206	1216.706
176	713995.131	361177.383	1217.296	176	714080.259	361250.186	1216.884
177	713982.886	361173.484	1217.650	177	714070.873	361247.364	1216.880
178	713983.535	361171.377	1217.684	178	714065.486	361245.807	1216.870
179	713993.754	361174.160	1217.337	179	714063.682	361245.467	1217.643
180	714006.115	361177.781	1216.850	180	714060.924	361244.724	1215.162
181	714013.271	361179.666	1216.459	181	714058.124	361243.852	1215.204
182	714019.424	361181.496	1216.235	182	714055.366	361243.074	1215.048
183	714024.573	361182.935	1216.633	183	714054.446	361242.771	1214.924
184	714027.200	361183.674	1216.144	184	714053.046	361242.386	1215.079
185	714031.939	361185.084	1216.148	185	714047.374	361240.709	1215.240
186	714034.991	361185.826	1216.265	186	714043.544	361239.633	1215.139
187	714040.153	361187.412	1215.704	187	714040.327	361238.850	1214.828
188	714045.324	361188.801	1215.375	188	714035.778	361237.555	1215.091
189	714055.582	361191.877	1215.114	189	714031.245	361236.112	1215.225
190	714060.611	361193.286	1215.294	190	714026.632	361234.801	1215.108
191	714062.610	361193.842	1215.654	191	714023.243	361233.848	1215.266
192	714067.079	361195.124	1217.473	192	714021.971	361233.611	1215.795
193	714069.637	361195.975	1217.276	193	714020.830	361233.130	1216.193
194	714081.210	361199.265	1217.292	194	714018.333	361232.543	1216.704
195	714081.228	361199.239	1217.294	195	714001.231	361227.751	1216.644
196	714089.567	361201.853	1217.406	196	713992.562	361225.145	1216.779
197	714100.447	361205.758	1217.789	197	713985.047	361221.694	1216.641
198	714101.194	361204.103	1217.866	198	713987.562	361226.390	1216.635
199	714092.441	361200.951	1217.425	199	713997.946	361229.087	1217.034
200	714081.618	361197.573	1217.269	200	714001.985	361230.596	1217.168
201	714071.265	361194.473	1217.281	201	714016.341	361234.016	1217.224
202	714067.614	361193.235	1217.580	202	714019.259	361234.621	1216.608
203	714062.528	361191.708	1215.572	203	714022.758	361235.529	1215.568
204	714061.019	361191.395	1215.333	204	714023.817	361235.786	1215.138
205	714054.433	361189.502	1215.077	205	714026.104	361236.493	1215.055
206	714044.664	361186.557	1215.393	206	714030.129	361237.882	1215.131
207	714040.841	361185.506	1215.736	207	714034.433	361238.966	1215.168
208	714036.098	361184.242	1216.071	208	714037.474	361239.848	1214.839
209	714034.280	361183.746	1216.332	209	714040.300	361240.595	1214.819
210	714026.934	361181.490	1216.240	210	714044.676	361242.051	1215.266
211	714024.330	361180.832	1216.500	211	714046.924	361242.638	1215.267
212	714020.926	361179.625	1216.715	212	714047.952	361242.889	1215.033
213	714014.628	361177.744	1216.976	213	714051.248	361243.813	1215.113
214	714007.318	361175.691	1216.696	214	714054.128	361244.612	1214.980
215	713997.908	361173.020	1217.199	215	714056.484	361245.291	1215.253