



ADDIS ABABA UNIVERSITY

Addis Ababa Institute of Technology

School of Civil and Environmental Engineering

**Effect of Sediment Aggradation on the Hydraulic Performance of
River Cross Drainage Structures**

(The case of Mekanisa Bridge on Mekanisa to Gofa Highway Road)

A thesis Submitted to Addis Ababa Institute of Technology, School of Graduate
Studies, Addis Ababa University

In partial Fulfilment of the Requirement for the Degree of Masters of Science in
Civil and Environmental Engineering

Major in Hydraulic Engineering

By

Natnael Hailu

Advisor. Dr.Yilma Seleshi

Addis Ababa

Ethiopia

May 2016

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Declaration

I, the undersigned, declare that the thesis is my original work, and has not been presented for a degree at any university and that all sources of materials used for the thesis have been fully acknowledged.

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Abstract

Mekanisa Bridge is constructed on Little Akaki River in Addis Ababa city as cross drainage structure to connect the Highway Road from Mekanisa Round About to Gofa camp. It was constructed just before six years and currently the Bridge faces a serious problem of sediment aggradation both at the left and right side of the piers and the abutment. Due to sediment aggradation on the Bridge, reduction in the hydraulic performance was observed and flooding both upstream and downstream were also occurred frequently. HEC HMS and HEC RAS software were used to determine both the peak discharge, water surface profile level and sediment transport at the Bridge location based on the current river section profiles. Using the HEC HMS model the 50 year peak discharge of 405.5m³/sec was determined. The discharge which was used to determine the maximum water surface of the Bridge was 497.8m³/sec. From this one can observe no significant difference in peak discharge to cause a problem. But on HEC RAS model the water surface level using 50 year peak discharge was 2213.95m amsl before Bridge inserted into the model and 2214.6m amsl after Bridge inserted into the model. This is significant figure as compared to the maximum water surface level 2211.04m amsl which is used for the actual Bridge design. This clearly shows significant reduction in hydraulic performance of the Bridge and increase bed level at the Bridge location. In addition to this significant bed scour was modeled just upstream of the Bridge and insignificant deposition on the left and right side of the piers and abutments of the Bridge. This is mainly due to reduction in the opening and increase both velocity and sheer force of the water at the Bridge location. Pier layout, agricultural activity along the river reach and bank erosion are the major contributors of sediment at the Bridge crossing. River training work, dredging and retaining walls recommended to tackle sediment transport and deposition at the Bridge location.

Key words:-Bridge, Sediment, HEC-HMS, HEC-RAS, Aggradation, Pier

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List of abbreviations

ERA	Ethiopian Roads Authority
HEC-RAS	Hydraulic Engineering Center River Analysis System
HEC-HMS	Hydraulic Engineering Center Hydrologic Modeling System
amsl	Above mean see level
GIS	Geographical Information System
OGL	Original Ground Level
FHWA	Federal Highway Authority
BMS	Bridge Management System
Hec-GeoHMS	Geographic Hydrologic Modeling System
SCS	Soil Conservation Service
NRCS	Natural Resources Conservation Service
CN	Curve Number
IDF	Intensity Duration Frequency
DEM	Digital Elevation Model
DPF	Design Peak Flood
FAPF	Frequency Analysis Peak Flood
UH	Unit Hydrograph

1. Introduction

1.1 General

Bridges are hydraulic structures which are built on water bodies to transport traffic flow from one side of the river or flood plane to next side. According to *ERA Drainage Design Manual, (1993)* Bridges are defined as structures that transport vehicular traffic over waterways or other obstructions, or part of a stream crossing system that includes the approach roadway over the floodplain, relief openings, and the bridge structure.

Generally bridge design comprises two important aspects; the Hydraulic and the Structural design. In the past different studies conducted in US and UK and the results showed that many bridge failures are due to hydraulic effects. Unfortunately engineers give great attention for the Structural design than the Hydraulic design. Undermining the bridge opening capacity, sediment and debris accumulation and scouring effects are the major problems in bridge hydraulic design and this factors play a great roll behind failures of bridge structure all around the world.

Hydraulic problem on bridge structures is also a great problem in Ethiopia. Many bridge and culvert structures failed due to flooding and scouring. In the norther part of the country most bridge failures are due to scouring effects whereas in the southern and eastern part of the country flooding and overtopping are the major failure types. Mekanisa Bridge is an example to show bridge hydraulic performance reduction due to sediment aggradation under the bridge structure. The bridge is located in flat flood plain area which facilitates flood inundation and sediment deposition. Layout of the bridge with respect to the flow direction and river bends just downstream of the bridge also contributes additional problems on the bridge.

The main objective of this thesis work is to show the effects of sediment aggradation on the hydraulic performance of bridge structures and the consequences of bridge construction in flat flood plains areas without considering sediment aggradation effects.

Different soft wares were used to model the actual field events. This will help to understand the real world problems in very simple forms.

Generally, HEC- HMS and HEC-RAS soft wares are used to model the Hydrology and the Hydraulics of the study area respectively and will be discussed in detail in the coming chapters.

1.2 Objective

1.2.1 General objective

- The general objective of this study is to investigate the effect of sediment aggradation on the hydraulic performance of **Mekanisa Bridge** from Hydrologic and Hydraulic perspective.

1.2.2 Specific objective

- To evaluate the current Bridge opening capacity or the Hydraulic performance of the Bridge.
- To evaluate the design discharge at the Bridge location.
- To evaluate the rate of sedimentation, and
- To identify the dominant causes of sediment aggradation on the Bridge and provide possible mitigation measures.

1.3 Description of the Study area

1.3.1 Location of the study area

The study area is located in Little Akaki River catchment which is part of Akaki River catchment and it covers a total catchment area of 202Km². It approximately bounded between the geographic coordinate of 38°35'52.97"E to 38°44'0.62"E longitude and 9°8'10.99"N to 8°58'1.47"N latitude.

Akaki River catchment is found in the North Western part of Awash River Basin and its border divides the Awash River Basin and Abay River Basin. Some part of it located in the Western Ethiopian Highlands of the Shewan plateau, and the rest is located in the Western margin of the Ethiopian Rift valley. The capital city Addis Ababa and other small towns such as Akaki, Sendafa, Burayu and small farm villages are also found in this catchment. The two main rivers namely the Big Akaki and the Little Akaki joins together and flow to the Awash River as a tributary.

Akaki Watershed

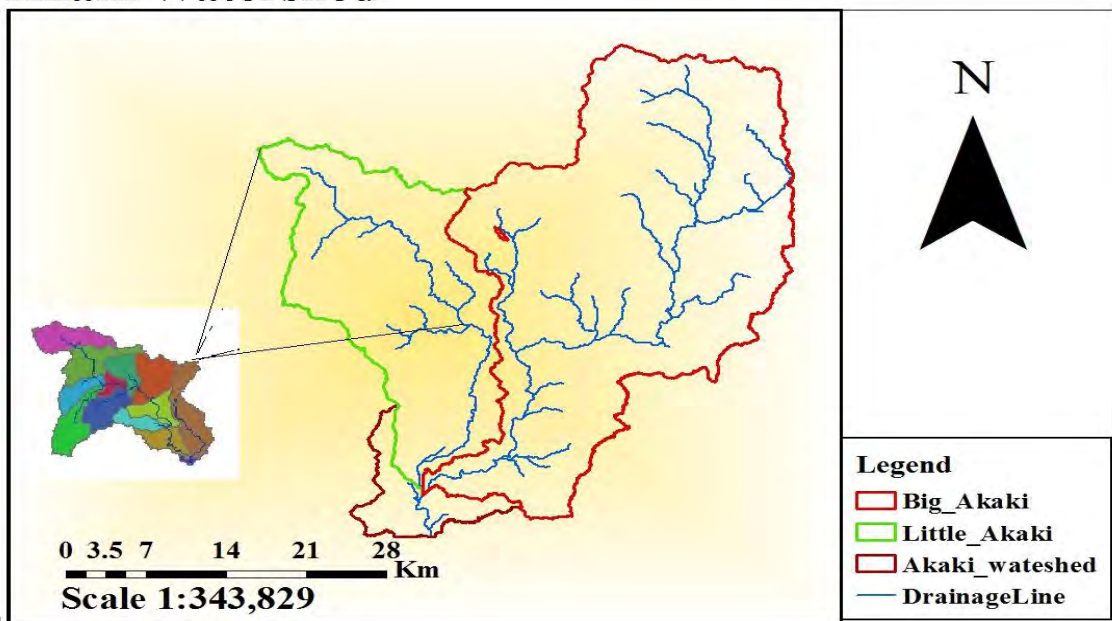


Figure 1. Location of Akaki Catchment.

The total catchment area of the Akaki river basin, including Addis Ababa, is divided into two major sub-catchments. These are the Big Akaki River (Eastern) locally known as Tiliku Akaki sub-catchment and the Little Akaki River (Western) locally known as Tinishu Akaki sub-catchment. Big Akaki River catchment covers a total area of 897 Km² whereas Little Akaki River catchment covers a total area of 410 Km² and in total Akaki catchment covers about 1369 Km² including Aba Samuel reservoir.

1.3.2 Location of the Bridge

Mekanisa Bridge is constructed in Addis Ababa, "Nifas-Silk Lafto" sub city. It is constructed on Mekanisa River as a cross drainage structure on the road that joins Mekanisa Round About (Gofa Mazoria) to Gofa Camp. The River is part of Little Akaki River which finally joins Aba Samuel Reservoir. Little Akaki has different names as it passes through different places across the city like 'Mekanisa River' as it passes through Mekanisa. Little Akaki river originates from highlands of Addis Ababa located on the northern part of city having an elevation about 3000m *amsl* and finally at the bridge crossing site the elevation becomes about 2215m *amsl*. The Bridge is located at 8°57'52.11"N latitude and 38°44'5.57"E longitude as shown in the *Figure.2* below.



Figure 2. Location of Mekanisa Bridge.

1.3.3 Climate of the study area

The study area shares the same climatic condition as that off Akaki watershed. In general the climate of the area can be categorized broadly into two seasons which include the Dry season from October to May, and the Wet season which extends from June to September, with intermittent rainfall in the dry months. The aerial average annual catchment rainfall and potential evapotranspiration are 1100 and 1226 mm, respectively.

The seasonal variation of rainfall distribution within the study area is due to the annual migration of the Intertropical Convergence Zone, a low pressure zone marking the convergence of dry tropical easterlies and moist equatorial westerlies across the catchment.

The highest and lowest mean maximum temperature over record periods is 25c in Dry season and 20c in Wet season, while the variation of mean monthly temperature values fall in the range of 7c to 12c throughout the year. In general, the climate of the study area can be categorized as warm temperate zone.

1.3.4 Topography

The topography of the study area is undulating and form plateau in the Northern, Western and Southwestern parts of the project area, while gentle morphology and flat land areas characterize the Southern and South-Eastern parts of the project

area. The watershed of the study area is defined within 202 km² area, including the water flow contributing areas of the watershed in the Oromia region.

Topography

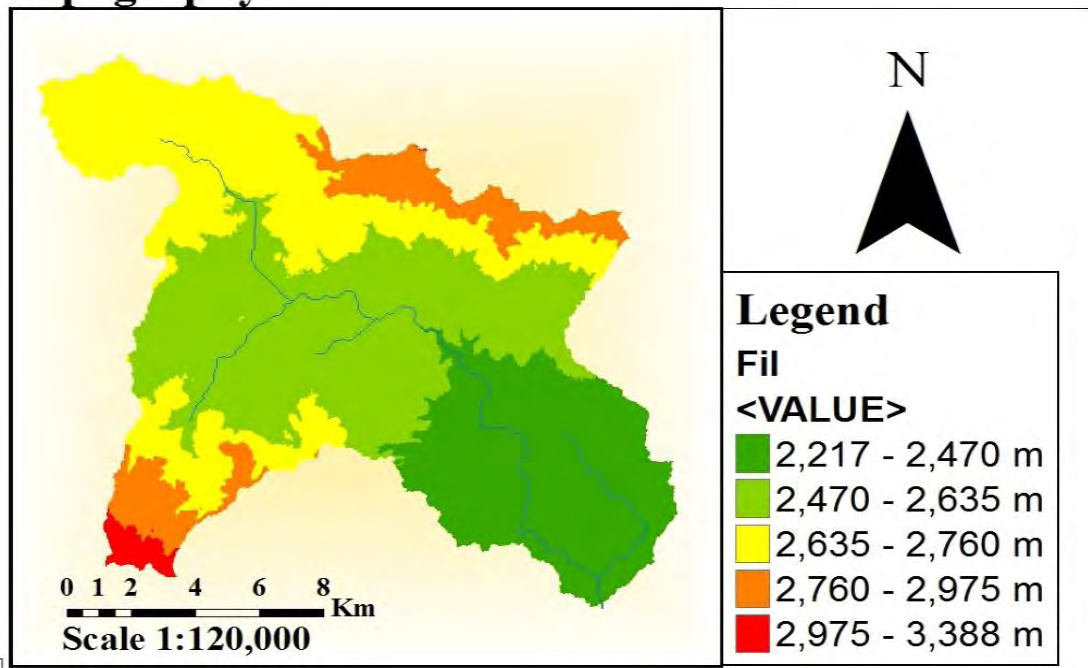


Figure 3. Topography of the study area.

1.3.5 Land Use and land cover

Using GIS software and analysing the shape files, the general land use and land cover of the study area can be classified as urban area, agricultural land, water bodies, forests and grass land. In the Northern part of the catchment which is on the Entoto Mountain, the land is covered in Forest, dominantly eucalyptus trees and the top of the mountain range is relatively flat that facilitates infiltration of precipitation into the ground. As the slope gets sharper towards the city a relatively higher runoff coefficient is expected.

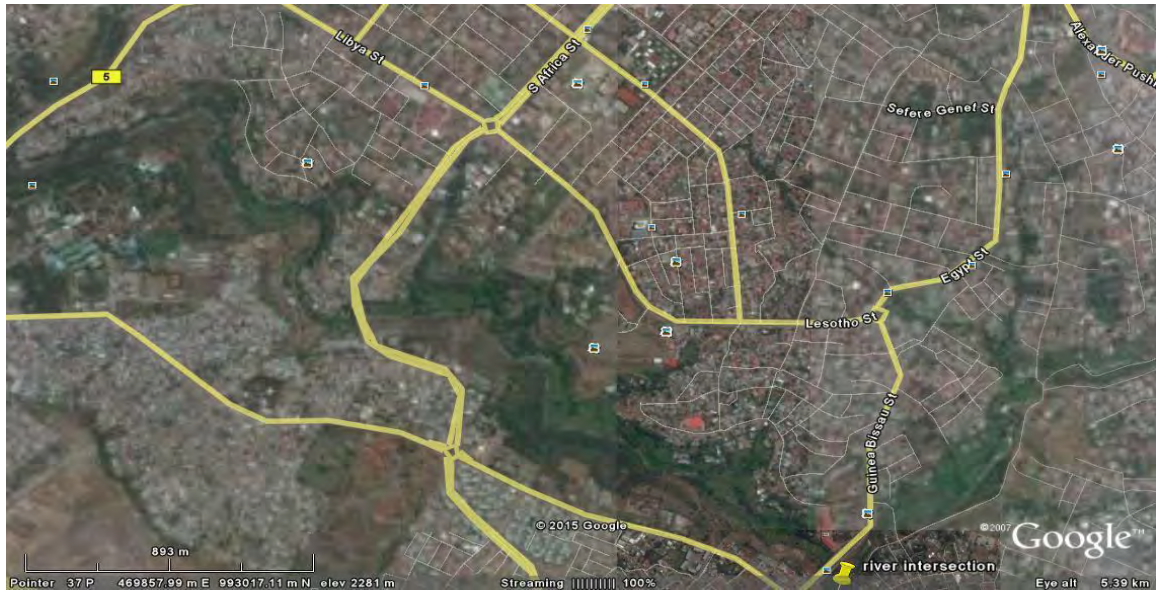


Figure 4. Land use Land cover

Residential areas are found in and around the city which are generally characterized as paved surface that cause small infiltration and most of the rainfall that comes is converted into surface runoff and drains into networks of rivers. The rest of the catchment is dominantly covered by agricultural lands.

1.3.6 Soil Type

After analysing the shape file of the soil in GIS, the general soil type of the study area is categorized as Group B and Group D. According to *ERA Drainage Design Manual, (2013)* Group B soils are categorized as Silt loam or loam and this type of soils have a moderately low runoff potential due to moderate infiltration rates. These soils primarily consist of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. In the same way Group D soils are categorized as Clay loam, silty clay loam, sandy clay, silty clay or clay. Group D soils are the type of soils which has high runoff potential due to very slow infiltration rates. These soils primarily consist of clays with high swelling potential, soils with permanently-high water tables, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious parent material.

Soil

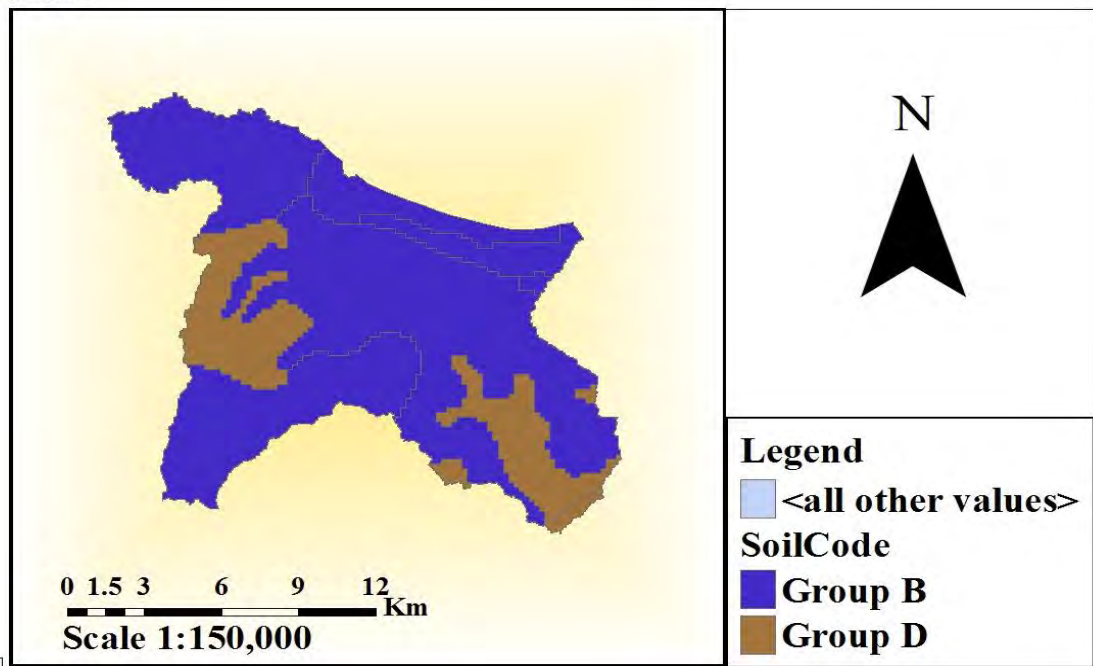


Figure 5. Soil type of the study area.

1.3.7 Hydrology and drainage

The two major Rivers in the Akaki catchment are the Little Akaki River, which flows through the Western part of the city and Big Akaki River, which flows through the Eastern part of the city. Major perennial rivers such as Big and Small Akaki and Kebena River start from the Entoto ridge and drains to the South passing through the center of the city of Addis Ababa.

In the Project area the streams drain towards South from the Entoto ridge; Southeast direction from Mt. Wechecha; and other elevated areas of the central parts of the city.

The perennial streams in the Akaki catchment are Little Akaki, Big Akaki, Bantyku, Kurtume, Kebena and Ginfile. Other streams are intermittent in nature. On the top of the mountain streams are dense forming radial drainage pattern, whereas in most parts of the city core they form dendrite drainage pattern. Towards the South almost all streams or big tributaries crossing the city in different direction join either Little Akaki or Big Akaki River. The two rivers flow on either side of Addis Ababa and complete their courses entering Lake Abba Samuel.

1.3.8 Reservoirs

There are about six man-made reservoirs in the Akaki River Catchment. These are: Gefersa I, II and III, Lega Dadi, Dire and Abba Samuel Lake. The first four are serving for drinking water supply except Gefersa III which serves as a sediment trap while the last one was constructed for electric power generation (*Dereje Nigussa, 2002*). Aba Samuel Reservoir was constructed for water supply and hydropower generation. Now, it is a non-functional swamp area which retains highly-polluted effluents from the big rivers. Among the five reservoirs, the only reservoir which exists in the study area is the Gefersa reservoir.



Figure 6. Major Reservoirs and Rivers in the study area (Source, *Dereje Nigussa, 2002*).

1.4 Statement of the Problem

Currently Ethiopia is investing millions of birr for the construction of roads and highway structures in order to boost the economic activity of the country. Even though a huge amount of money is invested on the sector, due to gaps in detail study and design problems the country loses a huge amount money each year. This is what we clearly see on the Mekanisa Bridge.

Even though Bridge opening size is designed to convey a design discharge of a given return period, sediment aggradation at bridge cross section will reduce the

opening size and results rise in backwater level (Afflux) and also modification of flow type which facilitates flooding and washing away of bridge structures.

Mekanisa Bridge is one big example to show effects of sediment aggradation on bridge structures. As clearly shown on the figure bellow the bridge piers both at the left side and right side of it submerged in sediment partially or fully.



Figure 7. Current sedimentation level and Bridge condition (August 2015)

This clearly shows reduction in opening size or reduction in clear waterway through the Bridge. Whenever the Bridge opening capacity exceeded by the flood event the Bridge acts as a barrier to the flow which results rise in backwater level and the end result will be flooding, even during low flow season.

For the case of Mekanisa Bridge the 50 year return period design flood level considered was 2211m but on the picture shown below which is taken on August 2015 the water level was about 2211m which is almost equal to the design flood level even with low flooding season and puts the safety of the bridge at risk.



Figure 8. Flood at Mekanisa Bridge on August 2015

Therefore the current opening capacity of the Bridge must be determined and also the sedimentation level and rate must be known to provide possible measures before further damage occurs on the Bridge.

1.5 Research questions

The following questions need to be raised and answered in detail to satisfy the objective of this research paper.

- Is the current bridge cross section sufficient enough to pass the 50 year design flood?
- Does the bridge construction have a direct effect on the sediment aggradation and river bed change at the bridge cross section?
- What are the main direct sources of sediment materials, is it the bank erosion, human activity along the river or upper river catchment?
- What are the possible methods that can be used to prevent the problem and to increase the useable life of the bridge?

1.6 Limitation of the study

It was very difficult for me to find the Original Ground Level (OGL) of cross section at different locations of the river during the construction of the bridge. Due to this it is very difficult to compare river bed change and sediment aggradation before and after the Bridge construction. But, based on field observation and photo materials during flooding, it is clear that sediment aggradation and river bed change at the Bridge crossing is serious problem.

Based on the above background this thesis work is limited to the current river cross section and bed material data available on the field.

1.7 Thesis outline and organization

This Thesis paper generally organized into five chapters. Chapter one will describe the general characteristics of the study area. The General and Specific objectives of the study is also described in this chapter. Chapter two includes the Literature Review part. Other scholar's paper works are sited and discussed in order to support the objectives of the study. Chapter three includes the Data collection and analysis part. Results and discussions also presented in chapter four. In this chapter outputs of the models are presented in graphs and figures.

Chapter five also includes the Conclusion and Recommendation part of the thesis work.

2. Literature Review

2.1 Bridge hydraulics

2.1.1 Overview on Hydraulic Design of Bridges

The impacts of Bridge design and construction on the economics of highway design, safety to the traveling public, and the natural environment can be significant. An economically viable and safe Bridge is one that is properly sized, designed, constructed, and maintained. In general, although longer Bridges are more expensive to design and build than shorter bridges, they cause less backwater, experience less scour, and can reduce impacts to the environment. Increased scour from too short Bridge can require deeper foundations and necessitate countermeasures to resist these effects. A properly designed Bridge is one that balances the cost of the Bridge with concerns of safety to the traveling public, impacts to the environment, and regulatory requirements to not cause harm to those that live or work in the floodplain upstream and downstream of the Bridge (*Hydraulic Design Of Safe Bridges, 2012*).

The most common cause of highway Bridge failure is due to the adverse Hydraulic action of the water that passes through it. It is therefore essential that sufficient attention is paid to the prevention of such failures when designing Bridges over rivers, or flood-plains. A Bridge's vulnerability to damage, or loss, as a result of Hydraulic action, scour in particular, needs to be minimised. It is clear that the design of Bridges across watercourses requires a multi-disciplinary approach, involving Structural, Geotechnical as well as specialist Hydrological and Hydraulics expertise. There for all this disciplines must work together in order to minimize the risks of Bridge failures.

According to *Les Hamill, (2004)* the two overall objectives for the Hydraulic design of Bridges are:

- The effect of constructing the Bridge on the existing water regime should be kept to the minimum.
- The Structural design of the Bridge should aim to prevent failure under the various types of hydraulic actions.

Any structure which is going to be constructed on rivers is expected to bring problems on the surrounding environment unless great care is given. Bridges are structures that are built on rivers and the construction of Bridges will have

temporary or long term effect on the surrounding environment. Therefore the negative impact of construction of Bridge structures on rivers should be kept as minimum as possible in order to avoid serious problems.

2.1.2 Flow through Bridge structures

Bridge construction on a river will change the normal river flow pattern under the Bridge temporarily or permanently. If water flows through a constriction that is, a section narrower than the natural river channel, then the water level will increased upstream of the constriction compared with that which would otherwise be. As shown in the *Figure.9* below the backwater will extend upstream to section 0, a point where the constriction has no effect on the water level, and uniform flow exists.

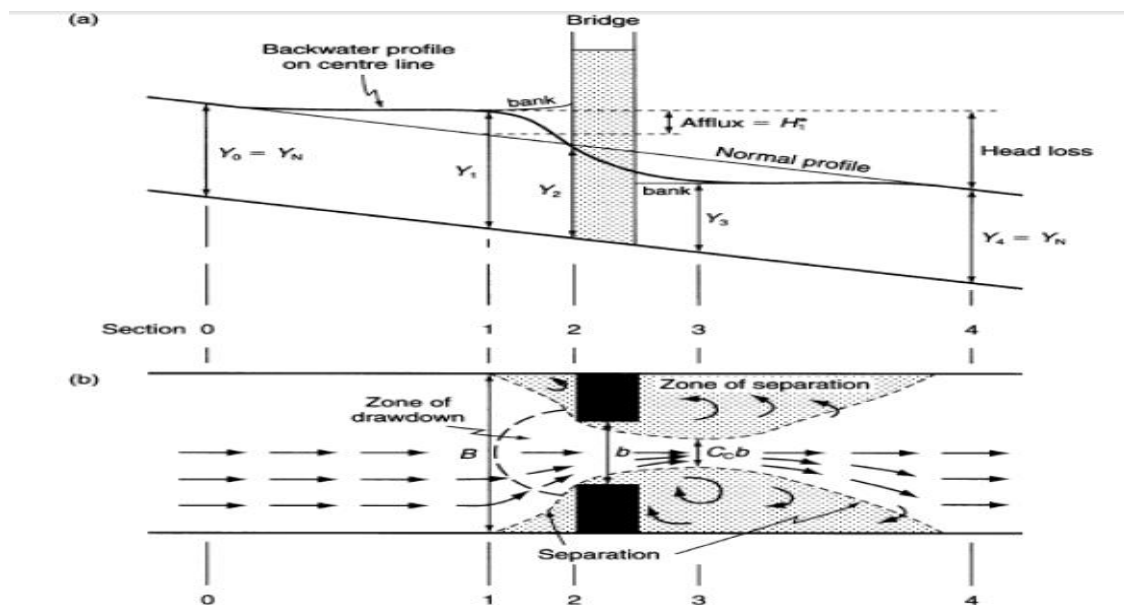


Figure 9. Flow through Bridge structures.

The distance between the constriction and section 0 depends upon such factors as the geometry, roughness and slope of the channel, and can be calculated using a backwater analysis. In the reach affected by the backwater the depth will be greater than normal, so the velocity and energy loss are less than would otherwise occur (*Les Hamill, 2004*). This will in turn facilitates the accumulation of sediment materials, if there exists excess supply of sediment on the upstream side of the river. General mathematical relationships and concepts of flow through bridges will be discussed in detail in the next chapter.

2.1.3 Effect of Bridge construction on River flow

When a Bridge is placed in a river it will reduce the natural channel capacity and acts as an obstacle to the flow. This results a loss of energy as the flow contracts, passes through the Bridge and then, most significantly, re-expands back to the full channel width. To provide the additional head necessary to overcome the energy loss the upstream water level increases above which would not usually experienced without the Bridge. This additional head is called the afflux, and its variation with distance upstream is called the backwater profile. The smaller the opening, the greater the afflux and backwater (*Les Hamill, 2004*).

Hydraulic engineers and designers are faced with a wide variety of choices when determining the capacity or location of a new Bridge or an existing Bridge that is to be replaced (*Hydraulic Design of Safe Bridges, 2012*). One situation where a knowledge of Bridge hydraulics is essential is when a new bridge is to be built that obstructs the main river channel and/or encroaches onto the floodplain. Sometimes the analysis may involve an existing Bridge where flooding already occurs and it is necessary to determine what proportion of this is attributable to the afflux from the structure (*Les Hamill, 2004*).

Sometimes it becomes very difficult to decide whether the construction of a Bridge has a direct effect on the rise in back water level or not. First appearances will lead to a total wrong conclusion. In many situations flooding, in the form of overbank flow, would occur even if the Bridge was not there. According to *Les Hamill (2004)*, a rough guide can be developed to investigating whether or not a Bridge is the primary cause of flooding by comparing the hydraulic capacity of the main river channel without the Bridge (Q_R) with the capacity of the Bridge waterway (Q_w) and the design flood (Q_{DF}).

- If $Q_R < Q_w$ the Bridge is relatively blameless;
- If $Q_R < Q_{DF}$ inundation of the floodplains would occur without the bridge;
- If $Q_w < Q_R$ the Bridge forms an obstacle to flow and may cause or exacerbate flooding;
- If $Q_w < Q_{DF}$ the waterway is under designed;
- If $Q_w > Q_{DF}$ the waterway is overdesigned or has a margin of safety.

Although the above relationships are fairly logical, the extent of any flooding actually induced by the Bridge will depend upon such factors as the height of the

banks and their freeboard, whether normal or abnormal stages exist, the Froude number, and the severity of the contraction (*Les Hamill, 2004*).

2.2 Sediment Aggradation problems on Bridges

Sediment aggradation is the process of increase in bed level elevation due to sediment material deposition on the bed of river channel. In simple words aggradation can be defined as a persistent mean change to channel bed elevation. Sediment aggradation occurs whenever there is excess supply of sediment from the upstream side of the river and existence of any obstruction like Bridge structures which have a direct effect on the flow velocity. According to *Brian P. Schultz, (2012)* bed aggradation occurs when flow is slower: before, under, and after the Bridge section compared to the rest of the stream channel. When sediment is carried by slower moving river in the vicinity of a Bridge, it settles down onto the bed of the stream. In more detailed definition aggradation occurs when the bed-material load supplied to a reach of river from upstream exceeds the river's capacity to transport it. Rivers that are in a regime, namely, those where there is no net change in channel morphology over a period of years, maintain a long-term sediment transport balance (*Brown, et.al. 1981*).

In contrast, any systematic increase in bed-material load or reduction in transport capacity causes long term change. Increased supply causes aggradation to migrate downstream, whereas a reduction in transport capacity causes deposition to move upstream. As bed-material transport preferentially follows the locus of the maximum velocity filament, there will be some parts of the cross section where bed-material load is minimal. These sections will still be prone to bed scour, particularly where increased backwater exacerbates contraction effects (*Brown, et.al. 1981*).

Deposition of bed sediment in a reach of a stream channel can be the result of instability in the stream channel system. Channel widening and other modifications, backwater effects, change in slope along with change in the surrounding watershed can lead to an unstable channel in the vicinity of the bridge resulting in sediment deposition, or aggradation (*Jessica T. Newlin, 2007*). The presence of rigid structures and continued maintenance to a stream channel to clear the deposition also facilitates long-term, systematic sediment aggradation condition at a Bridge crossing (*Jessica T. Newlin, 2007*).

2.3 Causes of Sediment Aggradation at Bridge Locations

2.3.1 Bridge pier alignment with respect to flow direction

The design of the piers and abutments has direct effect on the Bridge Hydraulic capacity or performance. The placement of Bridge piers in the channel or in the floodplain of a natural rivers will cause an additional backwater due to the pier obstruction to the flow. Roadways should be aligned perpendicular to channel and floodplain flows. According to *FHWA, (1978)* skewed crossings with angles of up to 20 degrees produces no objectionable flow patterns. (*FHWA, 2012*) had developed a computer model to show the effect of skew angle on the Hydraulic performance of a bridge. According to their model output 25 degree skew angle will result increase in water surface elevation just upstream of the bridge which implies sediment deposition will also be possible just upstream side of the bridge. Based on the above fact bridge skewness will also contribute to sediment accumulation at Mekanisa Bridge since the skew angle is about 40° with the river flow.



Figure 10. Angle of Skewness at Mekanisa Bridge

2.3.2 Human activities at Bridge location or along the River

Humans have made many land-use changes that have disturbed the natural conditions under which river systems developed. These changes include agricultural activities, urbanization, and commercial development of land resources. Of these, the widespread use of land and associated practices for agriculture is the most significant. The removal of the protective vegetation and the loosening of the soil during cultivation results in a speeding up of the erosion process.



Figure 11. Small scale Agricultural activity near Mekanisa Bridge on the Left River over Bank.

The streams and rivers draining through these agricultural areas suddenly overloaded with sediment, producing an imbalance in the equilibrium between sediment and water discharge.

Another important land-use change that affects river systems is urbanization. The most significant long-term urbanization effect on river morphology and system development is the resultant increase in peak discharges. The increase in discharge comes from the reduction in overland flow resistance produced by the greatly increased impervious land-area. The reduced resistance increases overland flow velocities, reducing peaking times and increasing peak discharges. The response of the river system to these changes is to degrade and reshape those channels immediately downstream of the urbanized area (S. A. Brown, 1981).

2.4 Effects of Aggradation on Hydraulic performance of Bridges

Sediment aggradation in stream channel can pose a serious problems on highway cross drainage structures especially on Bridges. The process of sediment aggradation in the vicinity of Bridge can causes the Bridge waterway opening size to be reduced. Sediment aggradation can partially or fully block waterway opening and result a serious problem. Each Bridge is designed to convey a certain magnitude flood, or design flood, through the bridge waterway opening. When the waterway opening becomes partially or fully blocked by sediment, the Bridge will no longer be able to pass the design flood through the opening. This can cause

flooding upstream of the Bridge and more frequent overtopping of the Bridge deck; both of which present a public safety hazard and can increase the risk of Bridge failure (*Brian P. Schultz, 2012*).



Figure 12. Sediment level under Mekanisa Bridge (Top), flooding just downstream of the Bridge (Middle) and flooding of Office and Dormitories at Mekane Eyesus Seminary compound just upstream of the Bridge (Bottom).

In addition, reduction in the design flood capacity or the hydraulic performance of the Bridge will increase hydraulic loading on the Bridge's superstructure and promote further sedimentation in the raised backwater.

2.5 Overview of Bridge problems related to Hydraulics in Ethiopia

Stream crossing systems should be designed for: minimum cost subject to criteria, desired level of hydraulic performance up to an acceptable risk level, mitigation of impacts on the stream environment, and accomplishment of social, economic and environmental goals (*ERA Drainage Design Manual, 1993*).

In recent years Ethiopia gives great emphasis for the development of road construction sector. Both the federal and city government invest huge amount of money for the construction of new road projects in addition to expansion and maintenance of old road networks throughout the country. Bridges are one of the most important structures in road construction. Proper design of Bridges both Structural and Hydraulic design determines the usable life of roads. Unfortunately, most of the time Engineers give great emphasis on the Structural design than the Hydraulic design for highway structures especially for Bridges. But in real world problems related to Hydrologic and Hydraulic design of Bridges play a great roll in the total failure of Bridge structures.

In Ethiopia most of Bridge failures are due to problems related to Hydrologic or Hydraulic designs. Inadequate Hydraulic design and less Hydrological studies will lead to narrow waterway openings, pier and abutment scouring, sediment aggradation, upstream flooding and debris accumulation which is clearly shown in *Figures below*.



Figure 13(a) Sediment Aggradation on Segen Bridge (Right) and Baso Bridge (Left) with inadequate opening size. (Source: Beza Nigussie, 2010).



Figure 13(b). Bridge Abutment scouring on river Warda (Left) and Garno Bridge (Right). Source (Beza Nigussie, 2010).



Figure 13(c). Faheem River Bridge failure due to flooding (Left) and flooding at Mekanisa Bridge on Little Akaki River due to narrowing of opening (Right). Source (Beza Nigussie, 2010) and Field visit.

2.6 Major types of Bridge failures

The end result of reduction in Hydraulic performance of a Bridge is the total failure. The most common cause of Highway Bridge failure is due to adverse Hydraulic action. It is therefore essential that sufficient attention is paid to the prevention of such failures when designing Bridges over rivers or flood-plains (Les Hamill, 2004). Bridge's vulnerability to sever damage or a complete loss, as a result of Hydraulic action, including sedimentation and scour, needs to be minimised as

much as possible. According to *Beza Nigussie (2010)*, the main causes of failure of drainage structures are due to the following factors:

- Basin Characteristics: Size, shape, land use, geology, soil type, surface infiltration and storage.
- Stream channel Characteristics: geometry and configuration, natural and artificial controls, channel modifications, aggradations, degradation and debris.
- Flood plain characteristics.
- Meteorological characteristics: precipitation amount and type, storm distribution, storm direction and time of precipitation

According to *Beza Nigussie, (2010)* causes of failures of drainage structures can be categorized into the following groups based on the above factors;

- Hydrological failure,
- Hydraulic failure,
- Failure due to aggradations or degradation, and
- Failure due to orientation or location of structure.

2.6.1 Hydrological failure of Bridges

Traditionally, Bridge design mainly focuses on the crossing site location. Historical records examined and flood flows determined. A Bridge opening capable of passing the peak flood is designed. The stream channels are occasionally straightened or modified in some way to accommodate the required structure. In streams flowing over bedrock this approach is adequate but in alluvial streams it may prove inadequate (*S. A. Brown, 1981*).

Hydrological failures mainly associated with the determination of the peak discharge that the Bridge is capable to pass without having significant problems. Less input data, error in data analysis and selection of inappropriate modelling methods will lead to undermining or over estimation of peak discharges which will result reduction or over design of Bridge opening size. Over design results increase in total cost of the structure whereas reduction in opening size will result in total failure of the Bridge during peak flow seasons of the year. In order to avoid

this, a detail Hydrological study needs to be carried out in the catchment where the bridge is going to be constructed.

2.6.2 Hydraulic failure of Bridges

The major damage on Bridges at river crossing occurs during high flood seasons. Many researchers studied the Hydraulic design of Bridges in order to investigate major causes of failure of different river Bridges around the world. *Smith (1976, 1977)* studied 143 Bridge failures that occurred throughout the world between 1847 and 1975. From the study it is possible to understand that almost half of the failures were due to floods.

Flood events have a great potential to wash the foundation and the superstructure of a large number of Bridges structures. When there is excess flow in the stream and when this excess flow exceed the design flood the flow will bypass the bridge and the most severe consequences will be scour and foundation failure (*Les Hamill, 2004*).

In a survey conducted in *USA* of 224 Bridges in the country it was discovered that 106 sites (47%) had Hydraulic problems as a result of lateral stream erosion. Accumulation of debris was a problem at 26 sites (12%), with many more experiencing some form of scour (*Les Hamill, 2004*).

In Ethiopia it is very difficult to put in number Bridge failures due to hydraulic actions. But it is very clear that Bridge failures due to problems related to Hydraulic design exists through the country. Currently *ERA* is using Bridge Management System (*BMS*) software to manage Bridges and culverts throughout Ethiopia. Currently around 4000 Bridges and their status data is collected and stored in the system which will help to narrow the information gap.

2.7 Major causes of Hydraulic failures of Bridges

Generally evidences suggest that there are three principal factors involved in Bridge failures related to Hydraulics which occurs either singly or in combination which include an inadequately sized opening, scour, and accumulation of debris and sediment (*Les Hamill, 2004*).

2.7.1 Inadequately sized openings

Bridge opening size has a significant effect on the Hydraulic performance of the Bridge structure. Whenever the opening size under the Bridge span gets smaller then it acts as a barrier to the flow and causes the inundation of a large residential or commercial areas on upstream side then the Bridge can hardly be considered to be adequate, even if it survives the flood event. Inadequate size of Bridge opening may be a result of error during design phase or river morphology change due to the construction of Hydraulic structures on the main channel.

The construction of hydraulically inefficient Bridge could cause flooding upstream, or it magnifies the problems which already exists. Consequences of hydraulically inefficient Bridge could be extremely damaging and expensive if a large number of properties or factories were flooded, so it is important to make sure that a hydraulically efficient structure is designed and the backwater level calculated accurately.

2.7.2 Scour

Usually the openings of a Bridge are less than the full width of the river. Due to this water accelerates as it approaches and passes through the waterways. Consequently the velocity is higher than it would otherwise be, and this can cause scour and undermining of the foundations of the Bridge. The narrower the openings the larger the velocity, and the finer the material the more easily it can be transported. A study conducted in 1973 showed that of 383 Bridge failures caused by catastrophic floods, 25% involved pier damage and 72% involved abutment damage (*Les Hamill, 2004*). A more extensive study in 1978 showed that scour at Bridge piers was just as significant as scour at the abutments. In 1985, in Pennsylvania, Virginia and West Virginia, 73 Bridges were destroyed by flooding, including scour. During the floods in spring 1987, 17 Bridges in New York and New England were damaged or destroyed by scour (*Les Hamill, 2004*).



Figure 14. Pier and Foundation scour of a Bridge. (Source ERA)

Scour can further be classified as Local and General scour. General scour occurs in a confined section of a river and results in a lowering of the bed level across the width of the river. It is caused by a reduction in flow area resulting in an increased average velocity and bed shear stress. Hence, there is an increase in stream power at the contraction; more bed material is transported through the contracted section than is transported into the section. As the bed level is lowered, the velocity decreases, shear stress decreases, and equilibrium is restored when the transport rate of sediment through the contracted section is equal to the incoming rate (S. A. Brown, 1981).

Local scour occurs in the bed of the channel around the base of piers, embankments, and similar obstructions and is due to the action of vortex systems induced by obstructions to the flow. Local scour occurs in conjunction with or in the absence of degradation, aggradation, and general scour (S. A. Brown, 1981). Local scour does not normally occur over the entire channel width. The basic mechanism causing local scour is the vortex of fluid resulting from the pileup of water on the upstream edge and subsequent acceleration of flow around the nose of the pier or embankment. The action of the vortex is to erode bed materials away from the base region. If the transport rate of sediment away from the local region is greater than the transport rate into the region, a scour hole develops. As the depth is increased, the strength of the vortex is reduced, the transport rate is reduced, equilibrium is re-established, and scouring ceases (S. A. Brown, 1981).

2.7.3 Debris accumulation and Sediment Aggradation

Build-up of trash and debris against Bridge components can significantly affect the hydraulic performance of Bridges. Difficulties are normally associated with small single span Bridges which tend to be more easily blocked than large multi-span structures. This may result in large increase in water level upstream and associated flooding. Debris may partially restrict the flow leading to significant scour around piers or abutments threatening the safety of the structure (*The Design of Highway Bridges for Hydraulic Action, 1994*).

Bridge piers, particularly those in the centre of the main channel, can collect large quantities of debris, which significantly reduces the Hydraulic performance. This should be taken into consideration at the design stage (*Les Hamill, 2004*).

Debris which are caught against or between piers can result in enhanced Hydraulic forces by increasing the effective pier width. The extent of these force is not easily predicted and usually be most severe when the river is in flood (*The Design of Highway Bridges for Hydraulic Action, 1994*).

Like that of debris accumulation, sediment aggradation at Bridge cross section also results a serious problem on the overall Hydraulic performance of a Bridge. The main effect of channel bed aggradation and fill is to reduce bridge clearance. However, aggradation may continue to the extent where new hazards like meanders cut off and channel pattern change will also generate.

In addition, aggradation may lead to bank erosion as bar formation changes flow paths, and decreased channel capacity will increase flooding with the potential for damage to the bridge and its approaches (*Jean-Louis Briaud et.al, 2001*). In addition, aggradation may lead to bank erosion as bar formation changes flow paths, and decrease in channel capacity will increase flooding with the potential for damage to the bridge and its approaches (*Jean-Louis Briaud et.al, 2001*).



Figure 15. Debris and Sediment accumulation on piers at Mekanisa Bridge

Even if the Hydraulic analysis is carried out diligently, flooding may be much worse than predicted as a result of debris. The debris does not always have to be caught on the bridge to cause problems: debris that obstructs the river channel either upstream or downstream of the structure may be sufficient to change the water levels at the site significantly and thus change the Hydraulic performance of the Bridge. Alternatively, the blockage may cause the river to change course (*Les Hamill, 2004*).

Aggradation at bridge crossings also results expensive maintenance costs; it becomes necessary to excavate the deposited material in the flow area upstream and downstream of the bridge to provide the necessary flow area to pass the design flow (*S. A. Brown, 1981*).

Generally hydraulic design of bridge should consider all factors discussed before in order to prevent social and economic problems.

2.8 Overview of Software and Models

Different models and soft wares were used for different purposes in this thesis work. But the basic software and models used are the ArcGIS, HEC-GeoHMS, Hydrologic model (HEC-HMS) and the Hydraulic model (HEC-RAS). Basin processing was carried out using ArcGIS in combination With HEC-GeoHMS software. General hydrological problems and hydrological parameters were modelled using the HEC-HMS (*Hydrologic Modeling System*) software. Final outputs from HEC-HMS software then exported to the HEC-RAS (*River Analysis System*) software, which is capable of modelling wide range of hydraulic problems. Different mathematical formulas used in the software and their relationships are discussed in detail in this section.

2.9 Hydrologic Modelling (HEC-HMS)

HEC-HMS (Hydrologic Modelling System) is an open source software developed by the U.S. Army Corps of Engineering's Hydrologic Engineering Center. HEC-HMS is designed to simulate the rainfall-runoff processes of watershed systems. It is designed to be applicable in a wide range of geographic areas for solving the widest possible range of problems. This includes large river basins water supply and flood hydrology, and small urban or natural watershed (*HEC-HMS user's manual, 2013*). Runoff hydrographs produced by the program used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecast, future urbanization impact, reservoir spillway design, flood damage reduction, flood plain regulation, and system operation (*HEC-HMS user's manual, 2013*).

It is important to mention that HEC-HMS is a software that enables the user to perform hydrological modelling based on a wide selection of common mathematical models used in Hydrology. In HEC-HMS, the rainfall-runoff process in a watershed is represented in a simplified manner as shown in *Figure.16*.

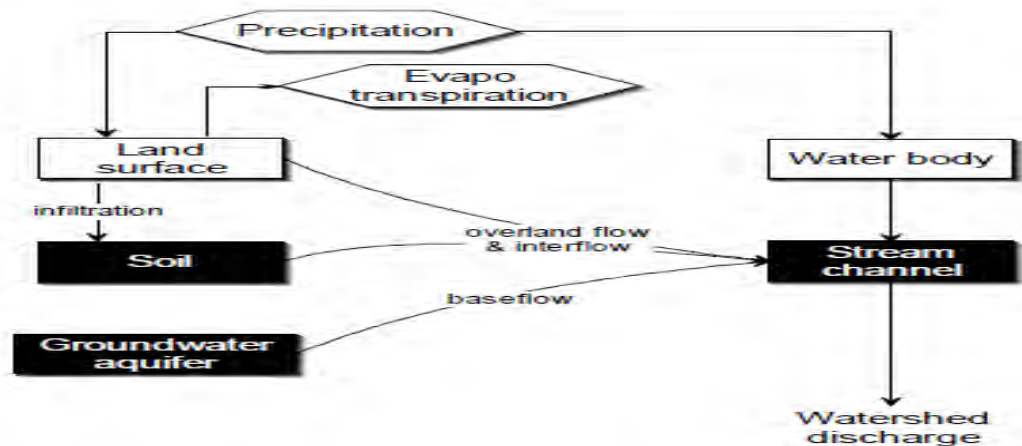


Figure 16. Typical HEC-HMS representation of a watershed. (Source: HEC-HMS user's manual, 2013).

This simplified representation of the runoff process does not account for the storage and movement of water vertically within the soil layer. It is however sufficient to model a flood hydrograph as the result of a storm (*HEC Technical Reference Manual, 2000*). For modeling purposes, this simplified hydrologic cycle is further divided into four major components, which are modeled separately. The models included in the software can thus be categorized as follows:

- **Loss Method:** A model used to compute the runoff volume is often referred to as the loss method since it accounts for the losses that occur during a rainfall event as a result of infiltration and evapotranspiration. For each time interval in the modeling process, the loss method calculates the amount of water that contributes to the runoff in the river (*effective rainfall*).
- **Transform Method:** models of direct runoff are also called transform method, since they convert the effective rainfall over a watershed into a hydrograph at the outlet of the watershed. These models account for the surface roughness and geometry of the watershed.
- **Base flow Method:** Base flow models are used to simulate the fraction of the runoff contributed by groundwater.
- **Routing Method:** If the analysed watershed is divided into sub-watersheds, the flow at the outlet of a certain upstream watershed has to be routed through the river channel in the downstream watershed. The models used to simulate this routing process are therefore called routing methods. They account for the geometry and roughness of the relevant river channel.

2.9.1 Description of Software Components

There are four main components in HEC-HMS software environment which are Basin model, Meteorological model, Control specification, and Time-series data.

- In the Basin model physical characteristics of the watershed and a simplified physical representation of that watershed are presented. The main features of the basin model are Sub-basins, Reaches, Junctions and Sink. The modeling results comprise runoff hydrographs for each sub basin as well as graphical and numerical representations of rainfall, losses and direct runoff for each sub basin and the combination of all sub-basins at the outlet of the watershed.
- The Meteorological model is the representation of the rainfall event that is intended to be modeled.
- The time series data for the model is defined in the time-series data manager component. Flow data, rainfall data, and any other time-series data which are relevant in the model will be inserted here.
- In the control specification section, the computational time step and the date of the simulation run will be defined. This will be used as a time base during computation process.

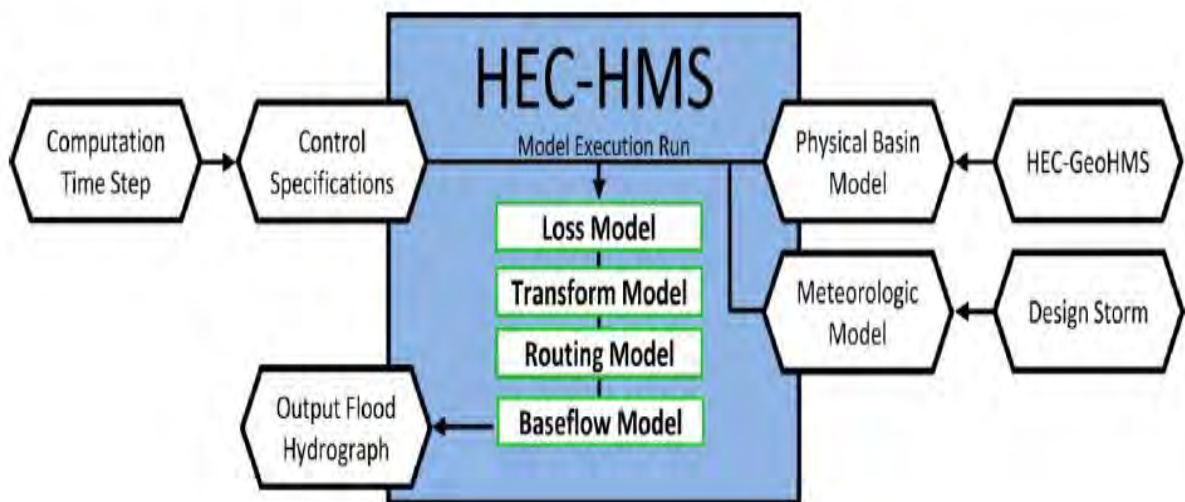


Figure 17. HEC-HMS software components (Source: GIS Based Flood Modelling, 2013)

2.9.2 Description of Hydrologic model components and selection criteria.

During hydrologic model selection different conditions needs to be taken into consideration. Depending on the situation on the ground which is being modeled and the available data on hand, an adequate mathematical model for each model components needs to be chosen. In this study, the hydrologic modeling is performed primarily to generate flood hydrographs with certain statistical return periods resulting from single design storm events with the same statistical return periods which are derived from IDF curves of the study area. Furthermore, the river where the study area is located specifically at the Bridge crossing is found in ungauged catchment. Based on this background, the models shown in *Table.1* below were chosen for each of the four components of the runoff process.

Table.1 List of selected models.

Methods	Selected model
Loss method	NRCS curve number(CN) method
Transform method	NRCS dimensionless UH method
Routing method	Muskingum method
Base flow method	Not considered

- ***Loss method: NRCS Curve Number (CN) method***

HEC-HMS provides different means of determining losses for a given study area or watershed. Based on the data what we have on hand and experience, one can choose the appropriate method for the specific study area. HEC-HMS automatically calculates the effective rainfall which produce runoff in the watershed after it computes the losses based on the data we provide. For the case of this study *NRCS Curve Number (CN) method* is selected since it requires only one unknown input data which is the Curve Number (CN). Curve Number is a function of land use, land cover and soil type. It is relatively easy to find this data inputs with the help of GIS software. In general The SCS runoff equation is widely used in estimating direct runoff because of its simplicity, flexibility, and versatility. The only input parameter needed is CN and the hydrologic data used to estimate

CN are normally available in most un-gaged watersheds. In addition, the equation can be applied to a wide range of watershed conditions.

The U.S. Natural Resource Conservation Service (*NRCS*) formerly known as the Soil Conservation Service (*SCS*) Curve Number method used in this study estimates the effective rainfall as a function of the cumulative rainfall, the land use, land cover, soil type and the antecedent moisture condition of the soil. It was created based on the analysis of a large number of small and gauged agricultural watersheds throughout the USA. Apart from the input precipitation, the method uses a single parameter, the CN to characterize the watershed. The CN quantifies the infiltration capacity and theoretically ranges between 0 (100% of the total rainfall infiltrate) to 100 (100% of the total rainfall changed to runoff). The basic runoff equation of the CN method is shown in *Equation 1*.

According to SCS (1985), the runoff equation is developed based on the concept that the ratio of amount of rainfall infiltrated after runoff begins (*F*) to watershed storage (*S*) was assumed to be equal to the ratio of actual direct runoff to effective rainfall (total rainfall minus initial abstraction). The assumed relationship in mathematical form is:

$$\frac{F}{S} = \frac{Q}{P-I} \quad .Equation.1$$

Where:

F = accumulated infiltration,

S = watershed storage,

Q = actual direct runoff,

P = total rainfall,

I = initial abstraction,

The amount of rainfall infiltrated after runoff begins can be expressed as:

$$F = (P - I) - Q \quad .Equation.2$$

By substituting *Equation 2* into *Equation 1* and solving for *Q* in terms of *P*, *I*, and *S*, Equation (1) becomes:

$$Q = \frac{(P-I)^2}{(P-I)+S} \quad ; P > I \quad .Equation.3$$

The initial abstraction defined by the SCS mainly consists of interception, depression storage, and infiltration occurring prior to runoff. For further

simplification of the equation the relation between I and S was developed by analysing rainfall-runoff data for many small watersheds and the empirical relationship is:

$$I = 0.2 S \quad .Equation.4$$

Substituting Equation (4) into Equation (3) yields:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad .Equation.5$$

Finally S is related to CN using equation:

$$S = \frac{25400}{CN} - 254 \quad .Equation.6$$

- **Transform method: NRCS Unit Hydrograph method**

In this part of the model the excess rainfall which is processed in the loss model will be transformed into runoff at a given point or usually on the watershed outlet. HEC-HMS provides different types of mathematical models for transformation method. In HEC-HMS software mathematical models are available both for gauged and ungauged watersheds.

The concept of unit hydrograph (UH) play important role in transform models. First proposed by *Sherman (1932)*, the unit hydrograph (originally named unit-graph) of a watershed is defined as a direct runoff hydrograph (DRH) resulting from 1 unit of excess rainfall generated uniformly over the drainage area at a constant rate for an effective duration (*Chow, 1988*).

The underlying concept of the UH is that the runoff process is linear, so the runoff from greater or less than one unit is simply a multiple of the unit runoff hydrograph (*HEC, 2010*).

To compute the direct runoff hydrograph with a UH, HEC-HMS uses a discrete representation of excess precipitation, in which a pulse of excess precipitation is known for each time interval. It then solves the discrete convolution equation for a linear system:

$$Q_n = \sum_{m=1}^{n \leq M} P_m U_{n-m+1} \quad .Equation.7$$

Where:

Q_n =storm hydrograph ordinate at time $n * \Delta t$

P_m =rainfall excess depth in time interval $m*\Delta t$ to $(m+1)*\Delta t$; m =total number of discrete rainfall pulses;

U_{n-m+1} = UH ordinate time $(n-m+1)*\Delta t$.

Q_n and P_m are expressed as flow rate and depth respectively, and U_{n-m+1} has dimensions of flow rate per unit depth.

Using the concepts of proportionality and superposition in a unit hydrograph, it is possible to determine the flood hydrograph resulting from any measured or design rainfall for any watershed (*ERA Drainage Design Manual, 2013*).

For the case of this study paper the catchment where the bridge located is ungauged watershed. Due to this it is impossible to develop unit hydrograph from observed rainfall-runoff relationship. Whenever rainfall-runoff data is not available a synthetic unit hydrograph technique is normally employed (*A guide to SCS runoff procedures, 1985*).

A synthetic unit hydrograph relates the parameters of the UH model to watershed characteristics. In this model UH can be generated in the absence of the precipitation and runoff data necessary to derive the UH (*HEC, 2010*). HEC-HMS provides different synthetic UH models for ungauged watershed.

In HEC-HMS software different synthetic UH models are provided. In this thesis paper dimensionless SCS synthetic unit hydrograph is used.

The SCS synthetic unit hydrograph method was derived from observed rainfall-runoff data of natural watersheds with different sizes and geographic locations. The derived unit hydrographs were then made dimensionless and averaged to obtain a standard dimensionless unit hydrograph (*DUH*) as shown in *Figure.18* below (*A guide to SCS runoff procedures, 1985*).

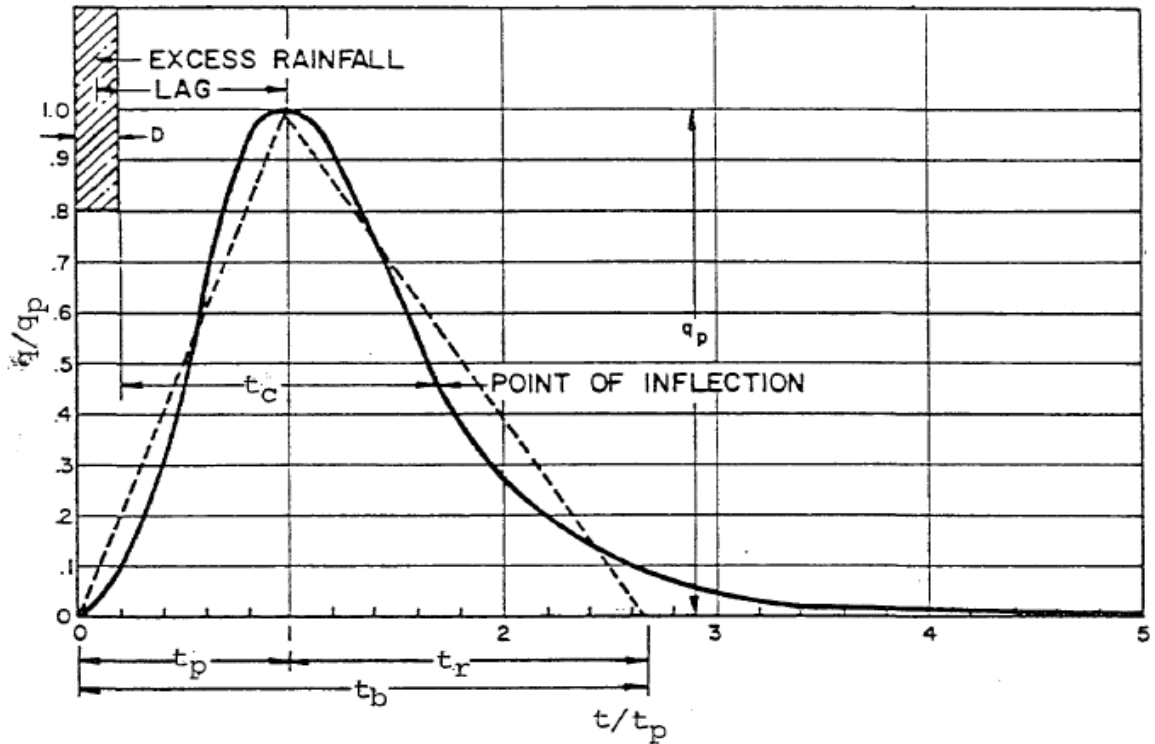


Figure 18.SCS Dimensionless Curvilinear and Triangular Unit Hydrographs (Source: A guide to SCS runoff procedures, 1985)

SCS suggests that UH peak and time of UH peak to be related by:

$$U_p = C \frac{A}{T_p}$$

.Equation.8

Where:

U_p = UH peak discharge

C =conversion constant (2.08 in SI)

A =watershed area

T_p = time to peak UH

In the same way time to peak UH (T_p) can be determined using:

$$T_p = \frac{\Delta t}{2} + t_{lag}$$

.Equation.9

Where:

Δt =excess precipitation duration (also the computational interval in HEC-HMS),

t_{lag} = the basin lag, defined as the time difference between the center of mass of rainfall excess and the peak of the UH.

For adequate definition of the ordinates on the rising limb of the SCS UH, a computation interval, Δt , that is less than 29% of t_{lag} must be used (HEC, 2010).

Lag time is calculated using the SCS lag time equation listed below.

$$t_{lag} = \frac{L^{0.8} * (S+1)^{0.7}}{1900 * S_b^{0.5}} \quad \text{Equation.10}$$

Where:

t_{lag} =lag time in hour

L =longest flow path in the watershed,

S = watershed storage,

S_b = basin slop

When the lag time specified, HEC-HMS solves *Equation 9* to find T_p , and *Equation 8* to find U_p . Knowing U_p and T_p the UH can be found by multiplying the dimensionless UH ordinates, which are included in HEC-HMS software, (HEC, 2010).

All the above formulas are incorporated in HEC-HMS software and by applying the appropriate data input the required final result will be produced in graphs and tables.

- **Routing method: Muskingum method**

Flow routing is a procedure to determine the time and magnitude of flow (i.e., the flow hydrograph) at a point on a watercourse from known or assumed hydrographs at one or more points' upstream (Chow et al., 1988).

HEC-HMS software provides six different models to estimate flow through river channels. All the models require different input parameters although each of them uses the concept of continuity and momentum equations. Based on data requirement and simplicity, Muskingum method is selected for river flow routing.

2.10 Hydraulic Modelling (HEC-RAS)

HEC-RAS (*River Analysis System*) is a hydraulic modelling software developed by the U.S. Army Corps of Engineer's Hydrologic Engineering Center. The software is capable of performing one-dimensional (1-D) steady and unsteady-flow simulations and comprises a graphical user interface, separate hydraulic analysis components, data storage and management capabilities as well as graphics and reporting facilities (*Hydraulic Reference Manual, 2010*).

The HEC-RAS system contains four one-dimensional river analysis components which are: steady flow water surface profile computation, unsteady flow simulation, movable boundary sediment transport computation, and water quality analysis (*Hydraulic Reference Manual, 2010*). One of the great advantage of this software version is all the four models can be computed using a common geometric data representation and common geometric and hydraulic computation routines.

HEC-RAS can handle bridge hydraulics effectively and has many commonly used methods available for predicting sediment transport potential within a stream reach, such as Ackers and White, Meyer Peter and Muller, and Yang equations. For the case of this thesis work, steady flow water surface profile computation and movable boundary sediment transport computation were determined using HEC-RAS 4.1.0.

2.10.1 Steady flow water surface profile computation in HEC-RAS

This component of the model is intended to calculate water surface profiles for steady gradually varied flow. It is also capable of modelling subcritical, supercritical, and mixed flow regime water surface profiles (*Hydraulic Reference Manual, 2010*). The basic computational procedure is based on the solution of the one-dimensional energy equation and momentum equations. Momentum equation is applied in situations where the water surface profile is rapidly varied flow type. This happens where there is hydraulic jump, flow through bridges, and when flow is constricted.

According to *Hydraulic Reference Manual (2010)*, water surface profiles are computed from one cross section to the next by solving the energy equation with

an iterative procedure called the standard step method. The energy equation is written as follows:

$$Z_2 + Y_2 + \frac{a_2 V_2^2}{2g} = Z_1 + Y_1 + \frac{a_1 V_1^2}{2g} + h_e \quad \text{.Equation.11}$$

Where:

Z_1, Z_2 = elevation of main channel inverts

Y_1, Y_2 = depth of water at cross sections

V_1, V_2 = average velocities

a_1, a_2 = velocity weighting coefficient

h_e = energy head loss

This can be further simplified using the figure given below;

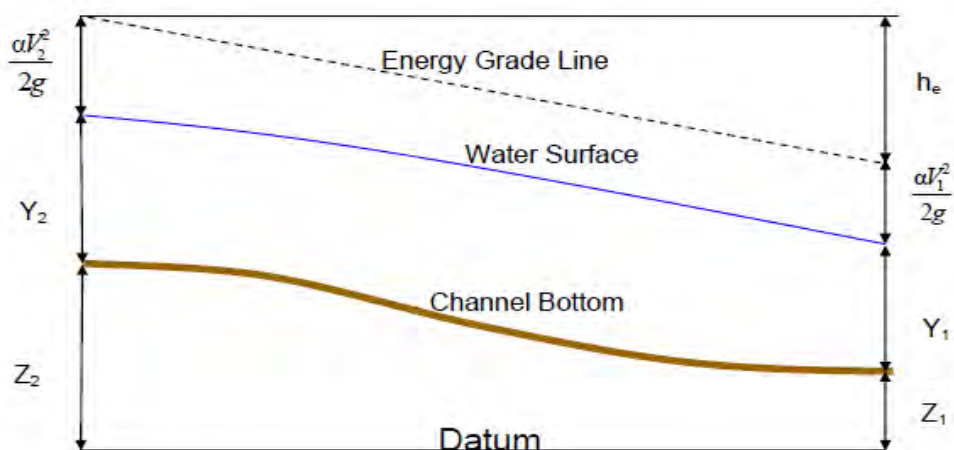


Figure 19. Representation of terms in the energy equation. (Source: Hydraulic Reference Manual, 2010).

The energy head loss (h_e) can be estimated by adding friction head loss (h_f) and contraction/ expansion head loss (h_{ce}). Friction head loss is a product of energy grade line slope (S_f) and length of the channel between each cross section. The energy head loss can be expressed using Equation 12;

$$h_e = L \bar{S}_f + C \left| \frac{a_2 V_2^2}{2g} - \frac{a_1 V_1^2}{2g} \right| \quad \text{.Equation.12}$$

Stream cross sections may not always taken perpendicular to the flow direction. Due to this left and right side of the channel will have different length. For this

reason HEC-RAS considers weighted channel length during computation process and expressed in *Equation.13* below.

$$L = \frac{L_{lob} \bar{Q}_{lob} + L_{ch} \bar{Q}_{ch} + L_{rob} \bar{Q}_{rob}}{\bar{Q}_{lob} + \bar{Q}_{ch} + \bar{Q}_{rob}}$$

...*Equation.13*

Where:

L = discharge weighted reach length

L_{lob}, *L_{ch}*, *L_{rob}*, are left overbank, main channel and right overbank length respectively.

Q_{lob}, *Q_{ch}*, *Q_{rob}*, are discharges at left overbank, main channel and right overbank section of the channel respectively.

The energy grade line and the velocity head can also be determined from manning's equation applying successive iterations:

$$Q = KS_f^{1/2}$$

$$K = \frac{1}{n} AR^{2/3}$$

...*Equation.14*

Where:

Q=discharge in the channel

K=conveyance constant

S_f=friction slop

During computation of contraction and expansion losses the program assumes that as contraction is occurring whenever the velocity head downstream is greater than the velocity head upstream. Likewise, when the velocity head upstream is greater than the velocity head downstream, the program assumes that a flow expansion is occurring (*Hydraulic Reference Manual 2010*).

Equation 12 is used to calculate the energy head loss between the sections. Then using *Equation 11* and the initial boundary condition, a depth for the second cross section is calculated and compared with the initial estimated depth value. These steps are repeated until the calculated depth at the next section (upstream if subcritical or downstream if supercritical flow) is within 0.003 meters of the estimated value.

Whenever there is abrupt change in the velocity of flow HEC-RAS software automatically switches the energy equation into momentum equation. This is mainly because energy equation is not applicable in rapidly varied flow condition which happens when flow changes from subcritical to super critical or vice versa. This condition generally occurs when there is hydraulic jump or when flow passes through hydraulic structures built over the main channel.

Momentum equation starts by solving Newton's second law of motion.

$$F = ma \quad \text{.Equation.15}$$

After considering all horizontal forces acting on a block of water along the bed of the river which are presented in figure, the following equation is developed.

$$P_2 - P_1 + W_x - F_f = Q\rho\Delta V_x \quad \text{.Equation.16}$$

Where:

P_2, P_1 = hydrostatic pressure force at location 1 and 2 respectively

W_x = weight component along x direction

F_f = drag force

Q = discharge between the section

ρ = density of water

ΔV_x = change in velocity between the section

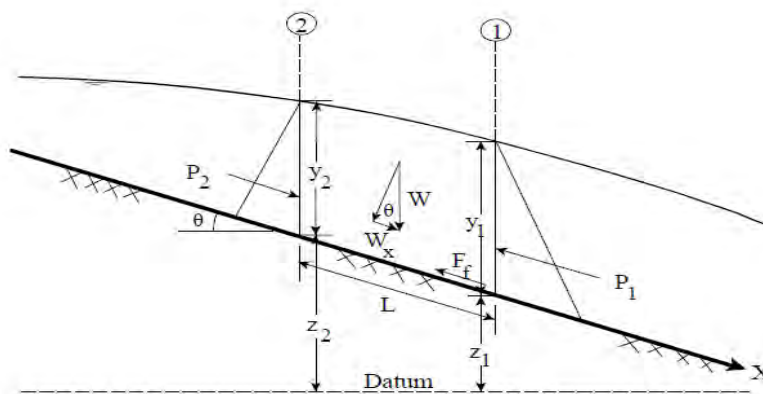


Figure 20. Application of the momentum principle (Source, Hydraulic Reference Manual 2010)

After inserting all variable parameters in Equation 16, a simplified general momentum equation is developed as shown below.

$$\frac{Q_2^2 \beta_2}{g A_2} + A_2 \bar{Y}_2 + \left(\frac{A_1 + A_2}{2} \right) L S_0 - \left(\frac{A_1 + A_2}{2} \right) L \bar{S}_f = \frac{Q_1^2 \beta_1}{g A_1} + A_1 \bar{Y}_1$$

.Equation.17

This simplified momentum equation will be used throughout HEC RAS software to solve problems with or without modification.

2.10.2 Sediment transport modelling in HEC-RAS

This component of the modelling system is intended for the simulation of one-dimensional sediment transport or movable boundary calculations resulting from erosion and deposition over moderate time periods typically years, although applications to single flood events also possible (*Hydraulic Reference Manual, 2010*). The model is designed to simulate long-term trends of erosion and deposition in a stream channel that might result from modifying the frequency and duration of the water discharge and stage, or modifying the channel geometry. This model is suitable to determine the rate of sedimentation at fixed channel cross-sections including Bridge cross-section which is the case of this study.

To model a sediment transport event, HEC-RAS uses a quasi-unsteady flow series. A quasi-unsteady flow series is created from a storm hydrograph by dividing the hydrograph into flow duration steps, in which the flow, stage, temperature, and sediment loading are considered constant. The flow durations are further broken down into computation increments, in which the bed elevation and hydrodynamics are updated after each increment. Finally, computational increment are further subdivided into the bed mixing time step to consider change in the composition of bed material due to removal or addition of materials. Therefore, rather than modelling a constantly changing flow hydrograph, HEC-RAS models a constant flow over the flow duration, and only allows bed elevation and hydrodynamics to change between each computational increment. This approach helps to increase model stability when simulating sediment transport events.

Between each cross section, HEC-RAS solves for sediment continuity using the *Exner Equation*.

The *Exner equation* is used by calculating a sediment transport capacity within the active layer of the channel based on the current hydrodynamics of the cross section.

$$(1 - \lambda_p)B \frac{\partial \eta}{\partial t} = - \frac{\partial Q_s}{\partial x} \quad .Equation.18$$

Where:

B = channel width

η = channel elevation

λ_p = active layer porosity

t = time

x = distance and,

Q_s = transported sediment load

This equation simply states that the change of sediment volume in a controlled section is equal to the difference between the inflowing and out flowing loads. The sediment continuity equation is solved by computing transport capacity through the control volume associated with each cross section. This capacity is compared to the sediment supply entering the control volume. If the capacity is greater than supply there is a sediment deficit which is satisfied by eroding bed sediments. If supply exceeds capacity there is a sediment surplus causing material to deposit (*Hydraulic Reference Manual, 2010*).

HEC-RAS determines transport potential for a single representative soil grain. Transport potential is the hydrodynamic capacity of the water to transport a single grain size sediment material. There are a number of equations developed to determine the transport potential of flowing water based on range of grain size distribution which are available on *HEC-RAS Technical Reference Manual, (2010)*.

After the appropriate transport potential function selected the next step in HEC-RAS will be determining the transport capacity in order to determine single representative sediment transport model of the system. This is done by multiplying the transport potential for each grain class and percentage of that grain class in the bed and summarized in *Equation19* below.

$$T_c = \sum_{j=1}^n \beta_j T_j$$

...Equation.19

Where:

T_c=total transport capacity

n=the number of grain size class

β=percentage of the material in the particular grain size class

Using the output from this Equation and solving the *Exner continuity Equation* *HEC-RAS* solves for *Bed elevation change in stream channels*.

3. Materials and Methods

3.1 Introduction

This chapter in general will try to discuss the materials used in this thesis work and the general procedures followed in order to complete the thesis. It also focuses on the assessment of the data that was collected from government institutions and field survey. Detail description on how the raw data processed and used is also presented. It is necessary to investigate if there is any gaps in the existing data and select the appropriate data filling methods whenever it is necessary. Finally the models and their basic input parameter determination will be discussed in detail.

3.2 Materials and soft wares used

The materials and soft wares used for this research are:-

- ARC-GIS is used to obtain hydrological, physical parameters and spatial information of the sub-catchments of the study area.
- HEC-GeoHMS together with Arc-Hydro tool is used for terrain processing and to subdivide the basin into more manageable form. In addition to this determination of basin characteristics which are used as an input in HEC-HMS model is also processed using this software.
- HEC-RAS software is used to model hydraulics of the bridge and movable bed modelling.
- Digital Elevation Model (DEM) data is used as an input for ARC-GIS software for catchment delineation and estimation of catchment characteristic.
- Hydrological data and is also used during frequency analysis phase.
- Eagle point software is used to generate contour and topographic map at upstream and downstream of the bridge. In addition cross sections were processed and determined using Eagle point software.
- Total station is used to collect elevation and location data at different points.
- Sieve and sieve shaker also used during sieve analysis.

3.3. Data collection

Both primary and secondary data were collected for this thesis work. Both the cross sectional data and soil sample data were collected through field survey which is primary data. The Hydrological data, Bridge as built drawings, Bridge design data and other related data were collected from different government institutions.

3.3.1 Hydrological data

Hydrological data is one of the most important input data parameter used in HEC-HMS model. It includes stream flow data of different time series at gauging stations. Stream flow data is required during the manual calibration phase in HEC-HMS software. The HEC-HMS peak flood output is compared against the observed stream flow frequency analysis results. The project area is located in Little Akaki river catchment which is an Un-gauged catchment. Due to this it is necessary to use Big Akaki flow data to calibrate model parameters and finally transfer hydrological parameters to the project area. For this reason a 24 years daily stream flow data ranging from 01 Jan 1981 to 31 Dec 2004 at Akaki gauging station was collected from Ministry of Water Resource and Energy.

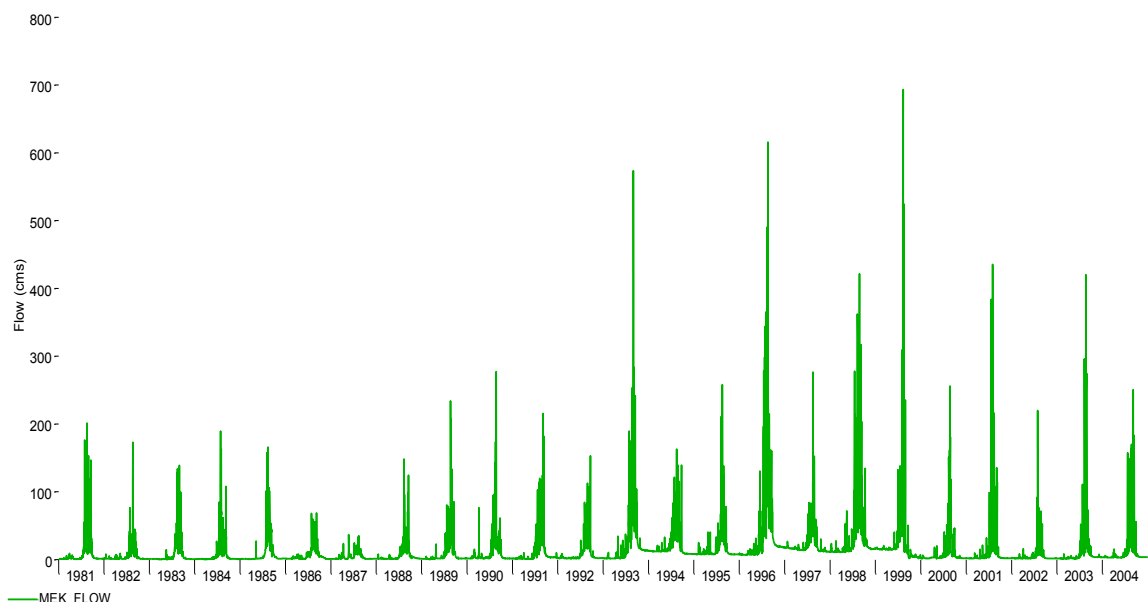


Figure 21. Stream flow data at Akaki gauging station.

3.3.2 River cross section data

Cross section data represents the geometric boundary of the stream. Cross sections are located at relatively short intervals along the stream to characterize the flow carrying capacity of the stream and its adjacent floodplain. Even though it is not a must, it is advisable to take cross section at constant interval. Cross sections are required at representative locations throughout the stream and at locations where changes occur in discharge, slope, shape, roughness; and at hydraulic structures (bridges, culverts, and weirs).

The required information for a cross section consists of: the river, reach and river station identifiers; station points and elevation; downstream reach lengths; Manning's roughness coefficients; main channel bank stations; and contraction and expansion coefficients. The cross section and topographic data was collected from field survey.



Figure 22. Field survey at Mekanisa Bridge.

Point data were collected as shown in the figure above using total station both at upstream and downstream of the bridge. The point data contains information about the location and the elevation of that particular point. After data collection is completed then the point data exported to Eagle Point software for further analysis. Eagle point software is used to generate the contour map of the area and also to generate cross section data at the desired locations. The station number, distance between two cross sections and the elevation data were exported to excel and then to HEC-RAS.

3.3.3 Soil sample and Gradation data

Soil sample and gradation data is the basic input data used in HEC-RAS software during movable bed load transport simulation phase. This data was collected during field surveying. Soil samples under the bridge bed and on the upstream and downstream bank were collected. Finally sieve analysis was carried out in Highway lab at Addis Ababa University and soil sample gradation data were collected. The sieve analysis result both in table and figure are annexed.



Figure 23. Soil sample and sieve analysis

3.3.4 Data for terrain processing

Digital Elevation Model (DEM) is the basic data for terrain processing. DEM includes both elevation and location data of a given area. 30 x 30 DEM data of the interest area was collected from ministry of water resource and energy.

3.4 Data Analysis

3.4.1 General procedures

The general procedure followed to finalize this thesis work started from terrain processing. The Watershed boundary, watershed outlet, and all the River networks including their respective physical parameters were generated in the terrain processing phase. Terrain processing is carried out on Arc-GIS environment in combination with Hec-GeoHMS and Arc Hydro tools. The output from terrain processing then exported to HEC-HMS for further hydrological analysis. After manual calibration the optimal hydrological parameters from Big Akaki catchment were transferred to the project area.

For manual calibration the peak discharge for different return periods (2, 5, 10, 25 and 50 years) on the Big Akaki catchment were determined on HEC-HMS model and then compared with the frequency analysis results. For the frequency analysis: Log Persons III, Log Normal and Extream Value Type I distribution methods were selected.

The probability distribution methods were selected based on their wide application in peak flood determinations. Finally the peak design discharge values for the given return period were transferred to the HEC-RAS software to analyse water surface profile and movable bed load transport. Both sediment transport rate and the maximum water surface level at the Bridge location were determined in HEC-RAS model. Based on the results found on HEC-RAS model, conclusion and recommendations were provided. The flow chart below summarizes the general procedures.

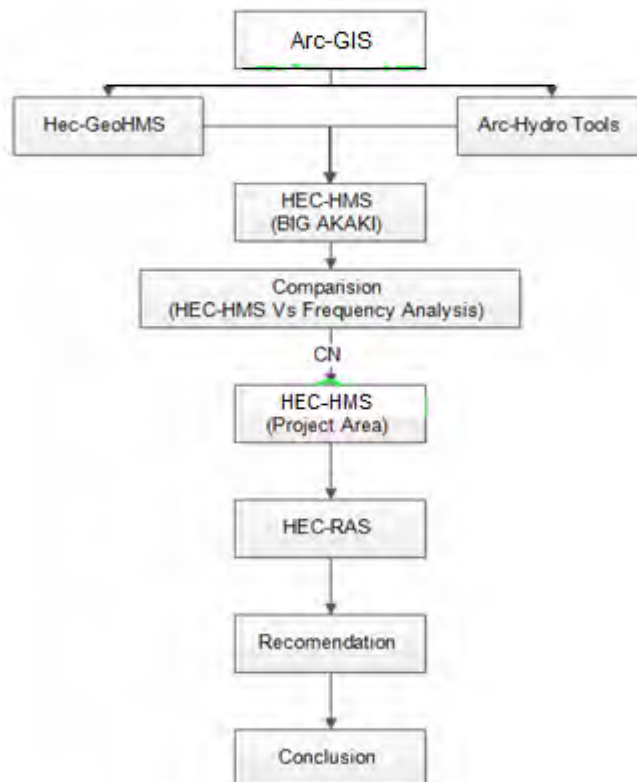


Figure 24. Flow chart for the Methodology

3.4.2 Basin model processing (Arc-GIS and HEC-GeoHMS)

The basin model was created using the HEC-GeoHMS software which is an extension software within the Arc GIS environment. The first major step in creating the basin model was to delineate the stream network and the watershed boundaries of the area of interest. This process is commonly referred to as terrain pre-processing and is entirely based on the input DEM. The GRID files below were created from the DEM by following the step by step procedures in HEC-GeoHMS.

- **Fill Sinks GRID:** This function creates a depression less or hydrologically corrected DEM based on the input DEM. Therefore, the software automatically increases the elevation value of any pit cell to the level of the surrounding terrain. The corrected GRID of the project area is shown in *Figure.25* below.

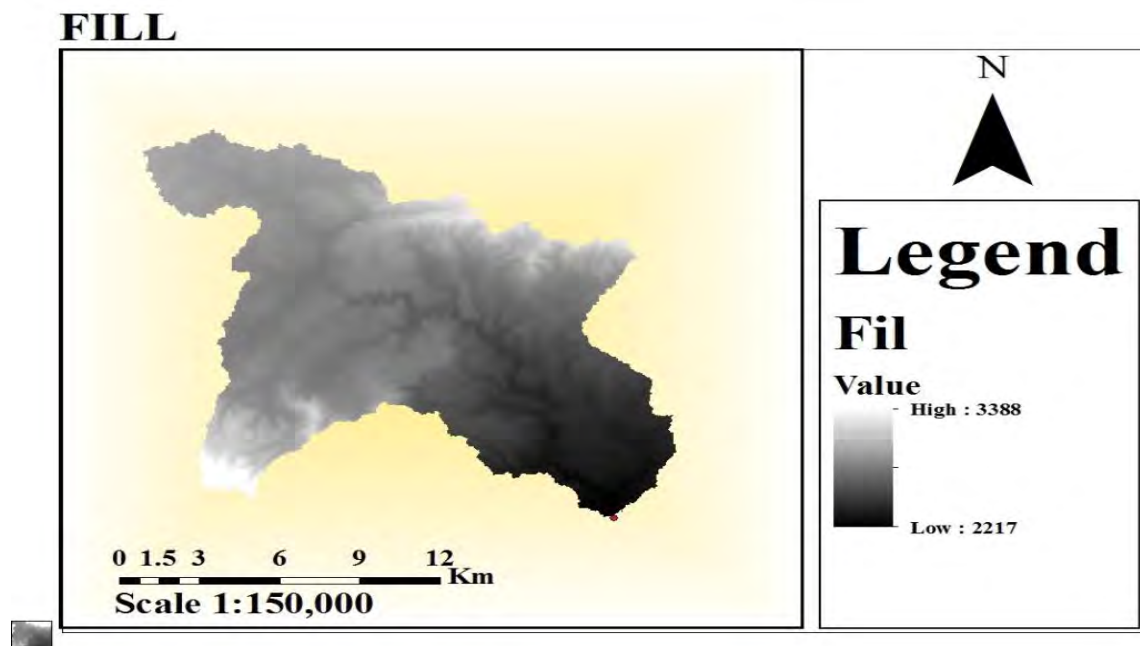


Figure 25.Fill sink GRID

- **Flow Direction GRID:** This GRID is determined based on the Fill Sink GRID output. In the Flow Direction GRID processing, the direction of flow of a drop of water is determined based on elevation of each grid cell. In HEC-GeoHMS each drop of water has eight probability of flow direction based on the elevation where it dropped. Flow direction output is shown in *Figure.26* below.

Flow Direction

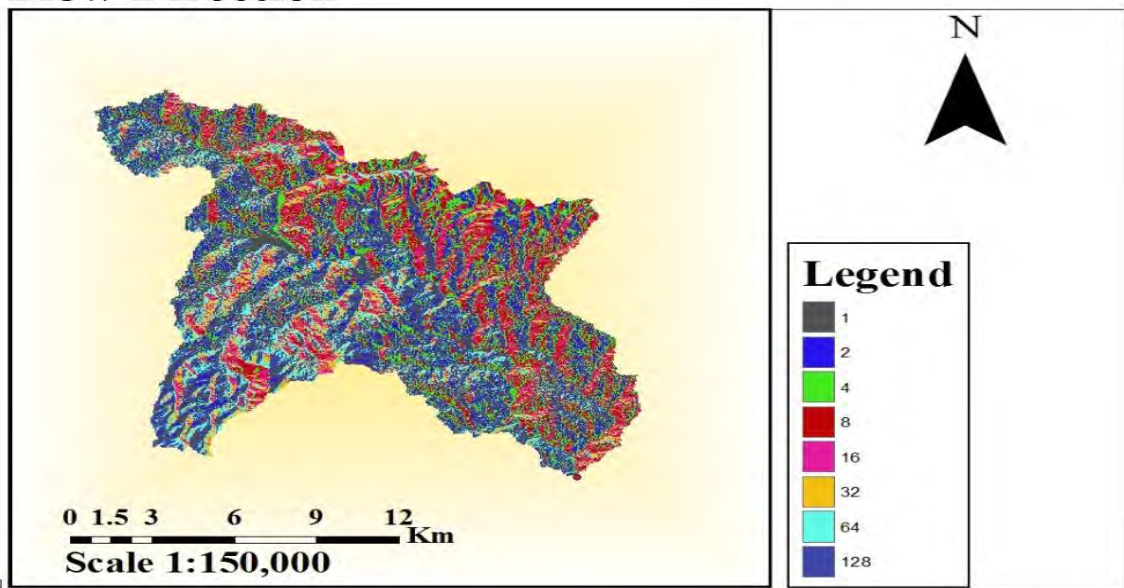


Figure 26. Flow Direction GRID

- **Flow Accumulation GRID:** This GRID is determined from the flow direction GRID and defines the number of upstream cells draining into any given cell in the grid. In these step the concentration of flow is determined. Highly concentrated flow is represented in white colour in the figure below whereas less concentrated flow is represented in dark colour.

Flow Accumulation

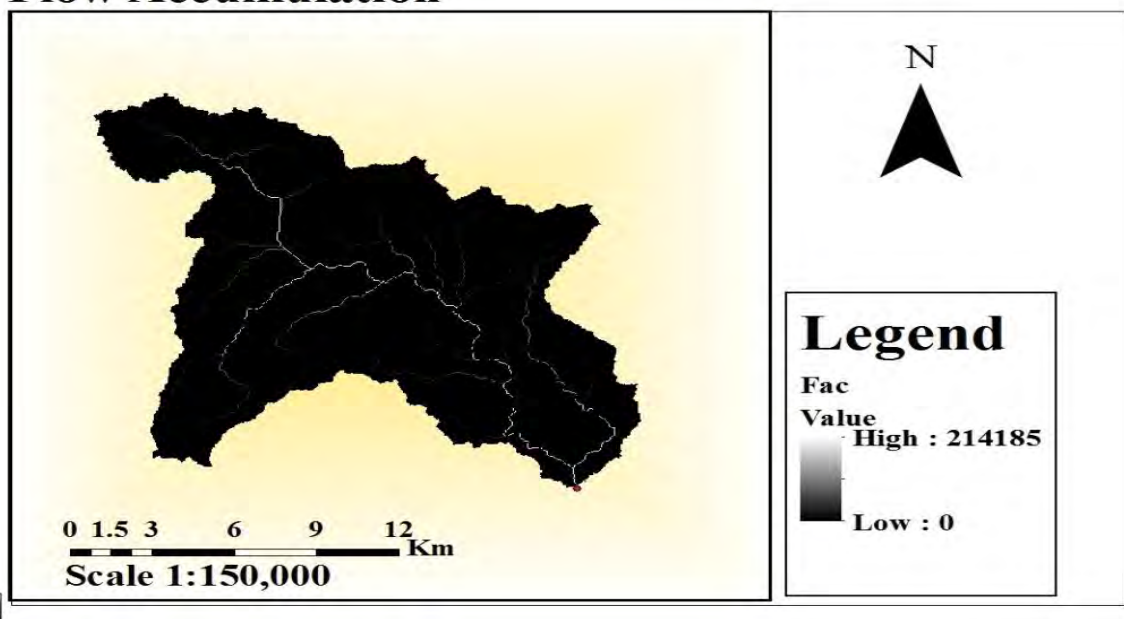


Figure 27. Flow Accumulation GRID

- **Stream Definition GRID:** In this step, the cells that form the stream network are defined based on a threshold number of cells that drain into a given cell. The result is a GRID, in which the stream network is represented by lines of connected grid cells.

Stream Definition

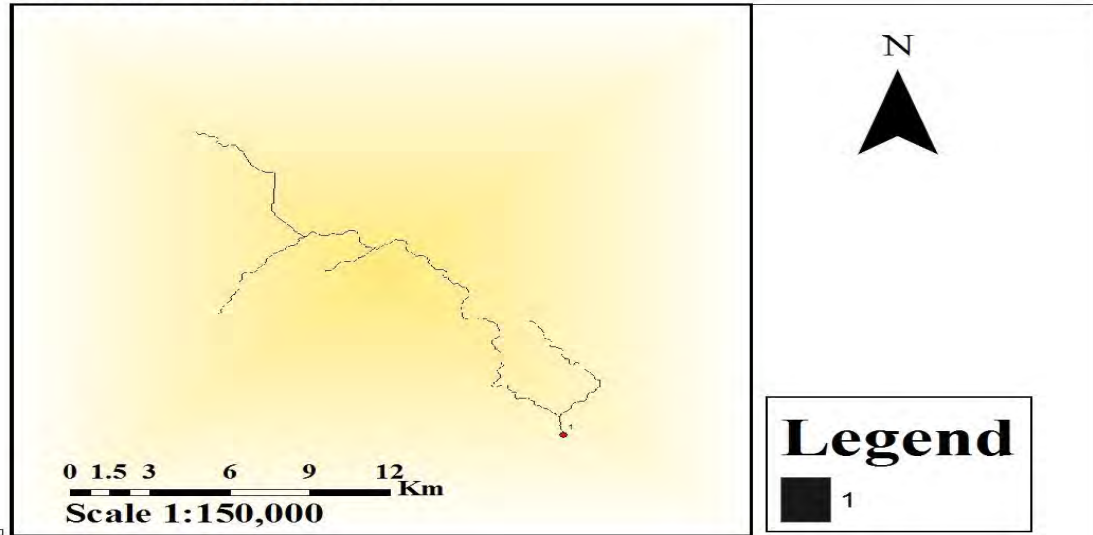


Figure 28. Stream Definition GRID

- **Stream Segmentation GRID:** This GRID is created by splitting the streams as defined in the stream definition GRID at any junction.

Stream Segmentation

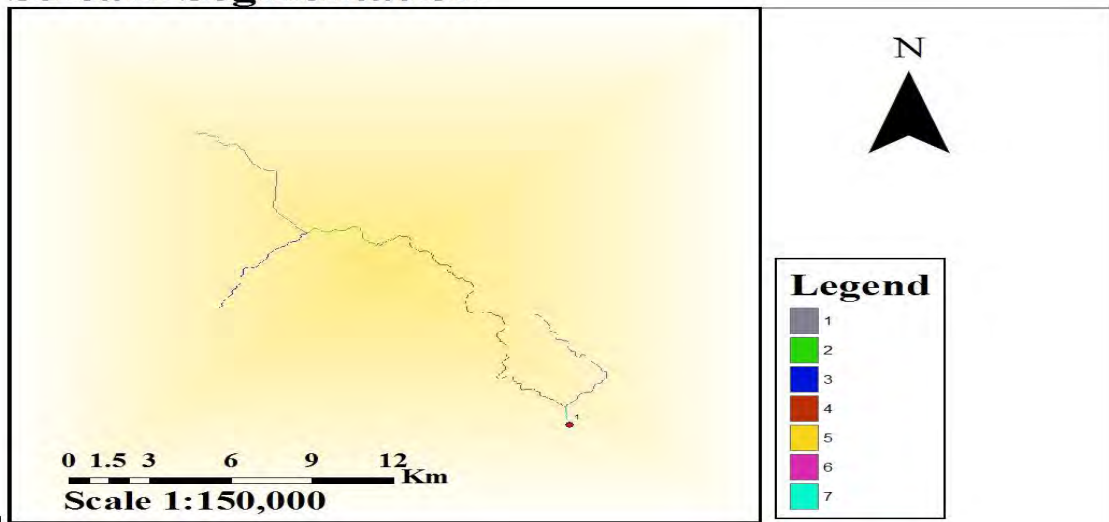


Figure 29. Stream Segmentation GRID

- **Catchment Grid:** For every stream segment defined by the stream segmentation GRID, the corresponding watershed is delineated and stored in a GRID file format as shown in figure below.

Catchment GRID

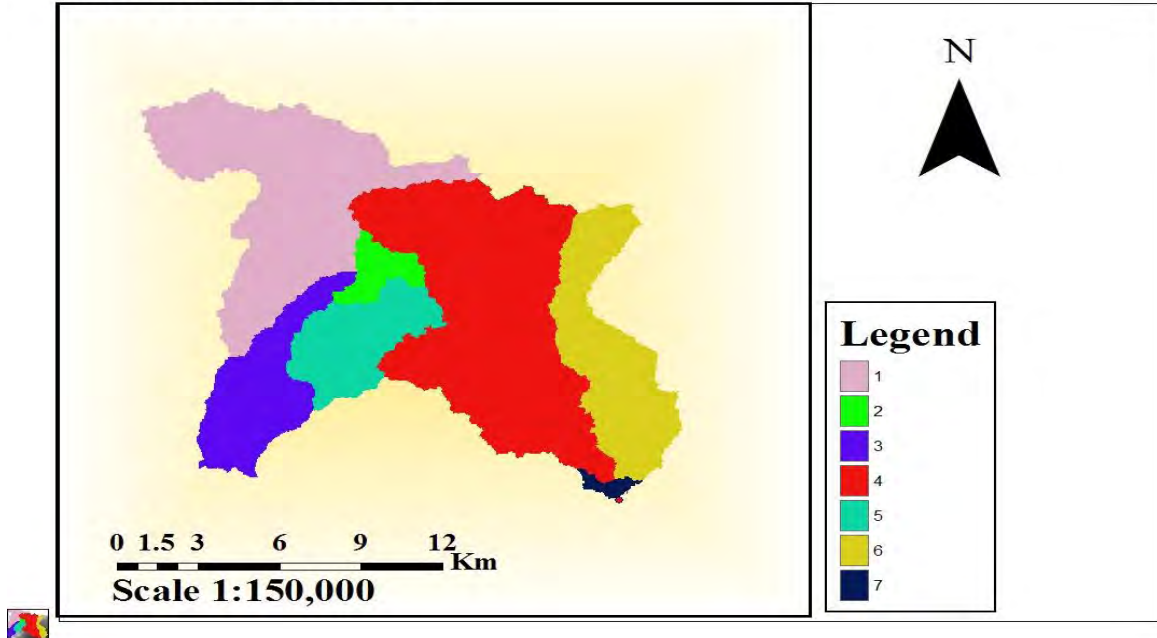


Figure 30. Catchment GRID delineation.

Based on the outcomes of the previous steps, three vector layers were created in order to complete the terrain pre-processing:

- **Catchment Polygons:** This function uses the catchment GRID to delineate the boundaries of each sub basin in the form of a vector layer.
- **Drainage Line:** The stream segments defined by the stream segmentation GRID are transformed into a vector stream layer by this function.
- **Ad joint Catchment:** In this step, the upstream sub basins are aggregated at any stream confluence. This step is not hydrologically relevant but enhances the computational performance in subsequent steps.

After the completion of the terrain pre-processing a project point has to be defined. The project point defines the outlet of the watershed that is intended to be modeled and thus has to be placed on a drainage line. The location of the bridge is considered to be the outlet of the sub catchment for the case of this thesis work.

Based on the outcomes of the terrain pre-processing and the definition of the project point, HEC-GeoHMS delineates the project area and creates all necessary layer files for this area. All the created data is stored in a new geodatabase file.

After completion of pre-processing phase HEC-GeoHMS delineates each sub catchments and produce their parameters.

For the case of this thesis the delineated watershed had a total area of 202 km² and it includes five sub basins. For each of the resulting stream segments and sub basins, a serious of physical parameters were computed based on the corrected DEM in HEC-GeoHMS. These parameters include the lengths and slopes of each river segment as well as the average basin slope, the longest flow path and Area of each sub basin. The data is automatically stored in the attribute table of the river and sub basin layer.

Figure.31 shows all Sub basins, River networks and their physical parameters which were created based on previously described procedures.

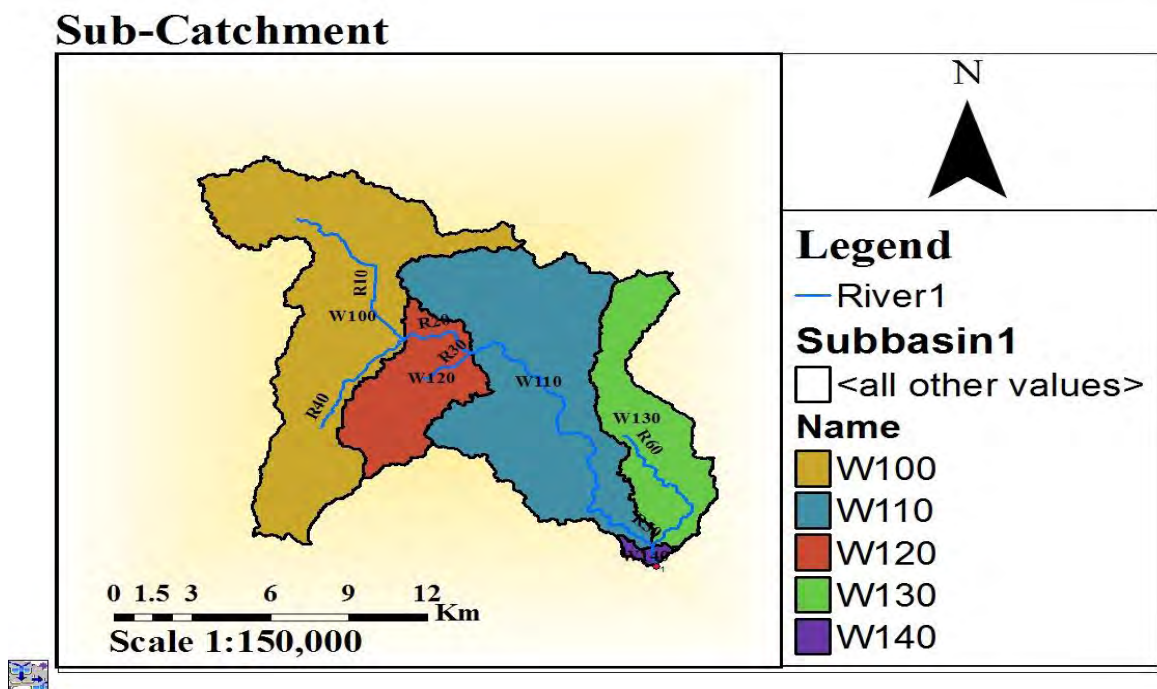


Figure 31. Sub-catchment and River network delineation.

Table 2. Physical parameters of Sub-catchments.

Name	Shape *	Shape_Length	Shape_Area	BasinSlope	Area_HMS
W100	Polygon	89177.0768	76262071.087911	11.051286	76.262071
W110	Polygon	69319.0878	70529690.712192	13.673638	70.529691
W120	Polygon	34445.0282	23559670.246452	12.118992	23.55967
W130	Polygon	47132.0768	29409440.511425	9.673959	29.409441
W140	Polygon	9377.383	1385200.025728	6.103228	1.3852

Table 3. Physical parameters of River network.

Name	Shape *	Shape_Length	Slp	ElevUP	ElevDS	RivLen	ElevUP_HMS	ElevDS_HMS	RivLen_HMS
R10	Polyline	8564.419478	0.0130	2661	2549	8564.419478	2661	2549	8564.419478
R20	Polyline	3597.635333	0.0100	2549	2513	3597.635333	2549	2513	3597.635333
R30	Polyline	2420.880933	0.0198	2561	2513	2420.880933	2561	2513	2420.880933
R40	Polyline	6131.66956	0.0112	2618	2549	6131.66956	2618	2549	6131.66956
R50	Polyline	17010.614629	0.0171	2513	2221	17010.614629	2513	2221	17010.614629
R60	Polyline	8073.010012	0.0178	2365	2221	8073.010012	2365	2221	8073.010012
R70	Polyline	1041.480572	0	2221	2221	1041.480572	2221	2221	1041.480572

3.4.3 Hydrologic Modelling (HEC-HMS)

- **Basin model**

HEC-HMS software incorporates seven basin elements which include sub basin creation tool, reach creation tool, reservoir creation tool, junction creation tool, diversion creation tool, source creation tool and sink creation tool. All basic physical input parameters used in basin modelling including Area of sub catchments, longest flow path, river length, basin slope, river slope were imported directly from Hec-GeoHMS software.

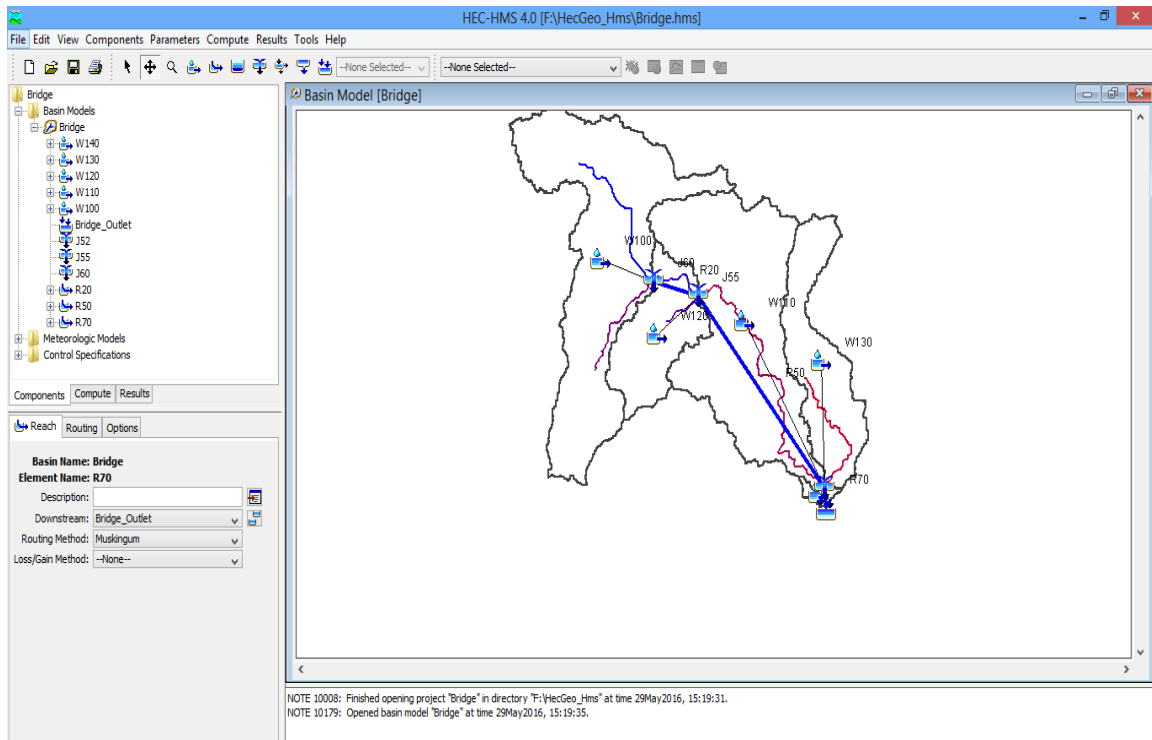


Figure 32. Basin model representation of the project area using HEC-HMS.

For the case of this study SCS CN model was selected for Loss model and SCS Unit Hydrograph method for transform method.

For SCS CN model, the Curve Number (CN) is the basic input data. Basically the Curve Number for the project area derived from the Big Akaki catchment after manual calibration completed. This is based on the fact that both sub catchments located in the same geographic location and shares same physical and hydrological parameters.

The curve number determination for Big Akaki catchment follows the procedures listed below.

- First initial CN values were determined from SCS runoff curve number table (*Annexe 1.A*) and using ArcGIS software.
- After that, the CN values which were obtained from the table inserted into the Big-Akaki HEC-HMS model. Other input parameters were obtained in the same procedure as that off Little Akaki catchment.
- Then the model runs and the peak discharge output for the predefined return periods was compared with the maximum peak discharge results obtained

from frequency analysis results. This process repeated until the peak discharge output of the HEC-HMS result resembles with the peak discharge results of the frequency analysis.

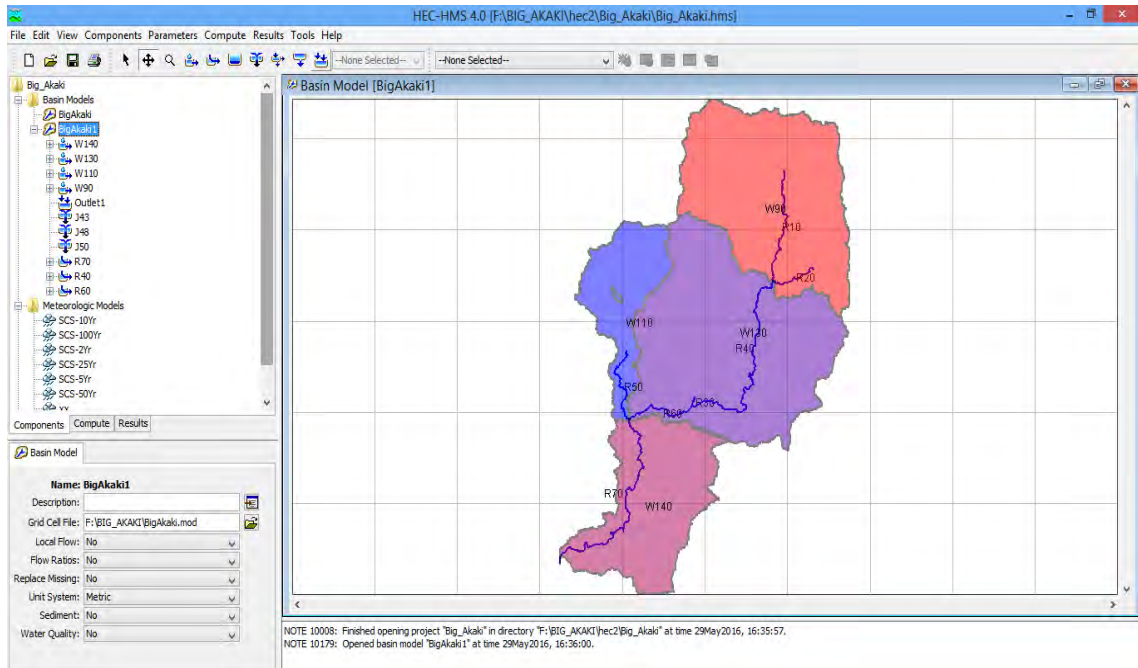


Figure 33. Big Akaki Basin Model representation.

Finally Curve Number values were transferred to the project area HEC-HMS model based on weighted area method and considering similarity between land use and land cover of the sub catchments. Basic input parameters used in HEC-HMS software for the project area are summarized in Table 4.

The formulas used to derive the t_c , t_{lag} and the computation time interval (Δt) were described in detail in chapter two. The rest parameters were imported from Hec-GeoHMS software.

Table 4. Basic input parameters used in HEC-HMS for project area.

Sub-Basin	Area(Km2)	L(m)	L(ft)	CN	S	%slop	t _{lag} (Hr)	T _c (Hr)	t _{lag} (min)	0.29*t _{lag} (min)
W140	1.39	2706.75	8880.31	85.00	1.76	6.10	0.63	1.04	37.55	10.89
W130	29.41	18174.68	59627.49	85.00	1.76	9.67	2.28	3.80	136.83	39.68
W120	23.56	9562.48	31372.58	75.00	3.33	12.12	1.67	2.78	100.15	29.04
W110	70.53	24161.01	79267.44	81.08	2.33	13.67	2.75	4.58	164.75	47.78
W100	76.26	14362.71	47121.18	75.00	3.33	11.05	2.42	4.03	145.23	42.12

Table 5. Basic input parameters used in HEC-HMS for Big-Akaki

Watershed	Area(Km2)	L(m)	L(ft)	CN	S	%slop	t _{lag} (Hr)	T _c (Hr)	t _{lag} (min)	0.29*t-lag
w90	273.78	28985.53	95095.74	78.00	2.82	15.19	3.31	5.52	198.90	57.68
w110	95.367	26928.86	88348.21	85.00	1.76	14.14	2.58	4.31	154.98	44.95
w130	346.34	45062.64	147841.51	80.00	2.50	9.65	5.57	9.28	334.06	96.88
w140	174.65	31333.33	102798.40	75.00	3.33	6.46	5.91	9.85	354.52	102.81

River routing was carried out by using the Muskingum routing method. Muskingum routing method was selected because it requires relatively simple input parameters which can be determined using Arc GIS and HEC-GeoHMS software.

- **Meteorological model**

The meteorological model is the component of the software where precipitation input is spatially and temporally distributed over the river basin. SCS Type2 rainfall distribution method was considered since SCS curve number is developed based on 24 hour SCS storm distribution. ERA, (2013) developed a 24 hour rainfall depth for different hydrological regions in the country displaying similar rainfall pattern as shown in Figure 34. The project area is found in Region A2 and the design storms for different return periods were derived from Table 6.

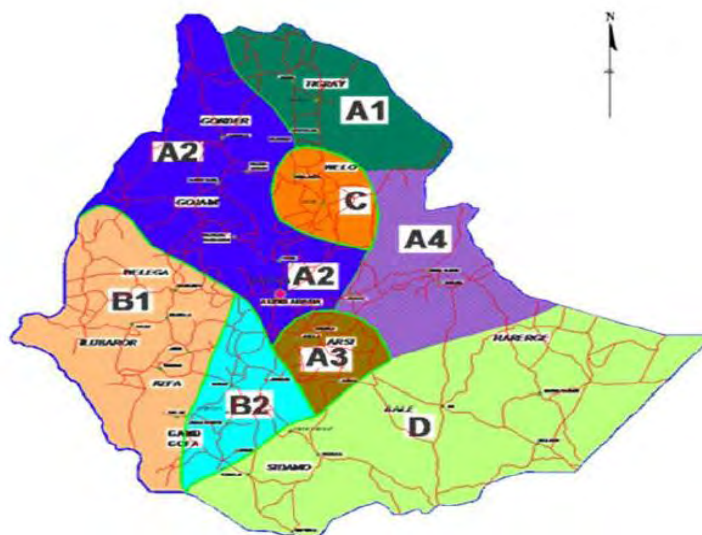


Figure 34. Regional classification based on rainfall distribution (Source: ERA Drainage Design Manual, 2013)

Table 6. 24hr Rainfall depth Vs frequency (Source: ERA Drainage Design Manual, 2013)

Return Period Years	24 hr Rainfall Depth (mm) vs Frequency (yr)							
	2	5	10	25	50	100	200	500
RR-A1	50.30	66.02	76.28	89.13	98.63	108.06	117.48	130.00
RR-A2	51.92	65.52	74.45	85.70	94.07	102.45	110.91	122.27
RR-A3	47.54	59.61	67.66	77.92	85.62	93.34	101.13	111.58
RR-A4	50.39	63.83	72.28	82.55	89.97	97.20	104.32	113.63
RR-B1	58.87	71.26	79.29	89.35	96.84	104.37	112.02	122.41
RR-B2	55.26	69.95	79.68	92.03	101.29	110.61	120.07	132.87
RR-C	56.52	71.04	80.54	92.52	101.48	110.50	119.66	132.06
RR-D	56.23	76.84	90.37	107.46	120.23	133.05	146.00	163.44

From the table, for region A2 the **2, 5, 10, 25** and **50** year return periods were selected for modelling and their respective design storm depths are **51.92mm, 65.52mm, 74.45mm, 85.7mm** and **94.07mm**.

- **Time series data**

Time series data includes both flow and precipitation data. In the HEC-HMS model no time series data was used for modelling, since the parameters used in the model were calibrated manually using Big Akaki flow data. Basically the time series data here is used to determine peak discharges for the predefined return periods using frequency analysis methods. Big Akaki is selected because no gauging station available in the project area and it becomes difficult to find flow data. In addition both Little and Big Akaki shares the same physical and hydrological parameters since they are located in the same geographical positions. After inserting all necessary parameters in the above model sections of the HEC-HMS software then control specification defined.

- **Control specification**

Control specification is the part of the software where the computation time interval (Δt), the Start and Ending time of simulation specified. After that the program runs and the simulated results collected from the result tab both in the form of Table and Graphs.

3.4.4 Hydraulic Modelling (HEC-RAS)

Hydraulic analysis was performed in order to determine the hydraulic performance of the Bridge. In order to insert the geometric data first reach and the name of the river needs to be defined. Once river and reach name defined simple layout of the River plotted on the HEC-RAS window. Then cross section editor window opened. Once the geometry of the cross sections were determined using Eagle Point software then the cross section output transferred to excel software and after that cross section data exported to HEC-RAS geometric data editor. In this part of the software component the elevation of cross sections, the distance between the banks, the manning's roughness coefficient, expansion and contraction coefficients were all inserted. For manning's values 0.03 and 0.04 selected for the flood plain and main channel respectively. This is based on the fact that the river shows clean, winding, some pools and shoals in the main channel and cultivation areas with no crops at the flood plains and the table Annexed at the end of this paper. For contraction coefficient 0.3 and 0.1 were used at the bridge section and for the rest of the river section respectively. In the same way 0.5 and 0.3 were used for expansion coefficient based on the hydraulic reference manual recommendation.

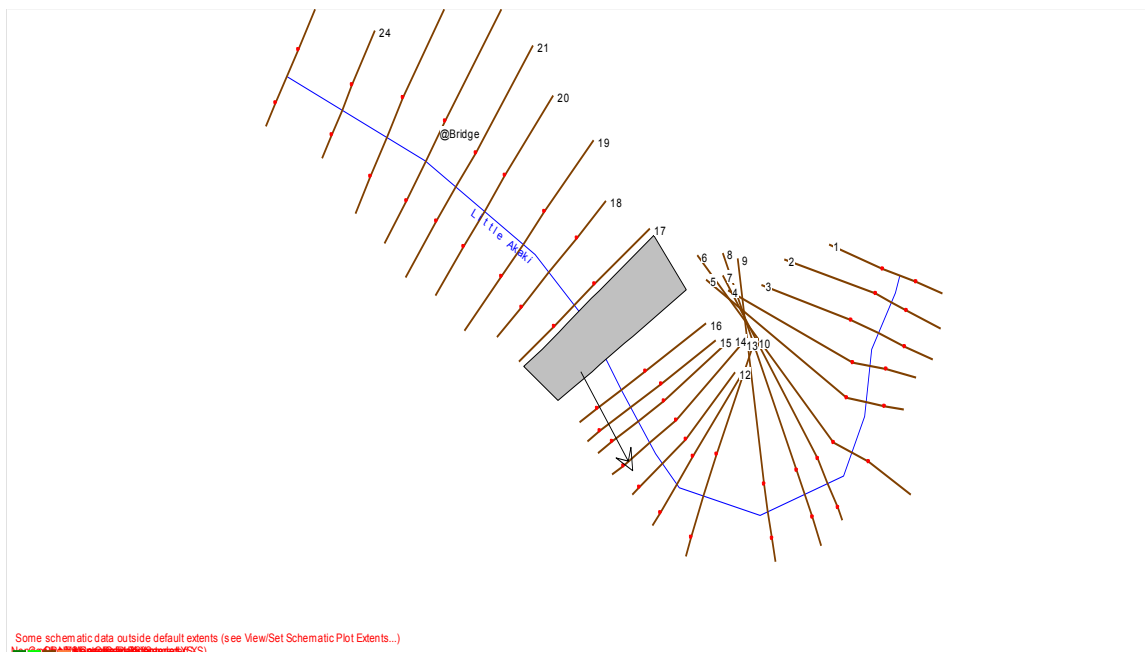


Figure 35. HEC-RAS River reach and Cross Section representation.

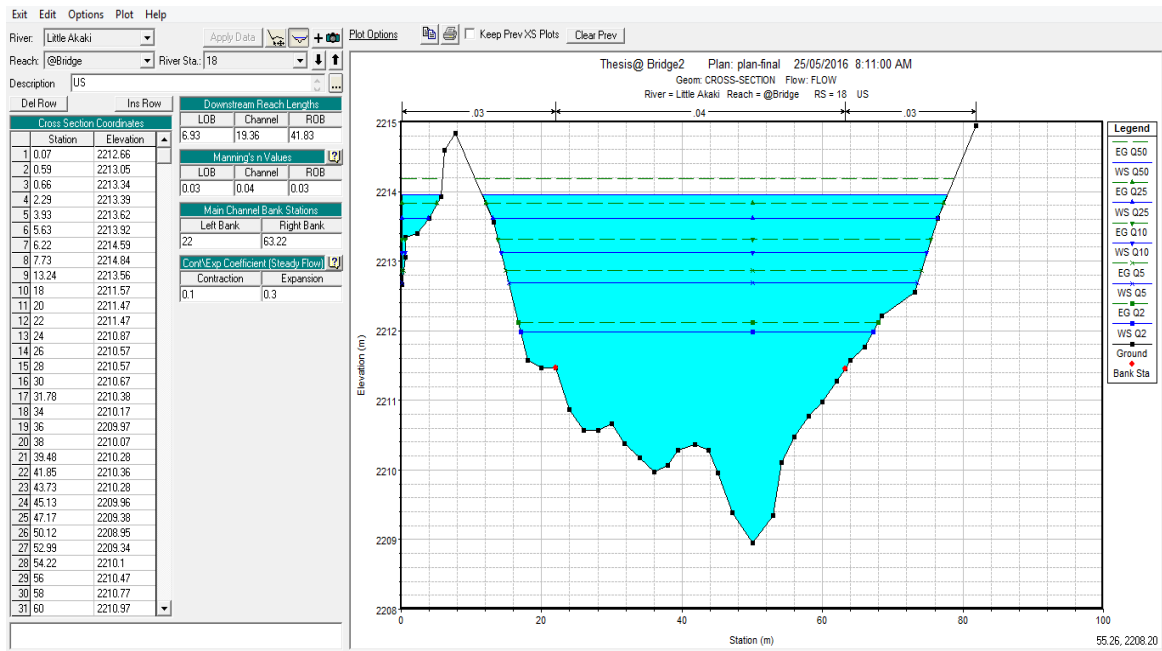


Figure 36. HEC-RAS Geometry editor window.

The bridge cross section and layout is inserted in the bridge and culvert data editor window. All necessary cross section data of the bridge which are used to represent the actual bridge shape were inserted in this part of the software component. The bridge length, the bridge height, high and low chords of the bridge, width of the bridge, pier number, location and finally the abutments were all inserted in this editor. The bridge geometric data are annexed at the end of the paper.

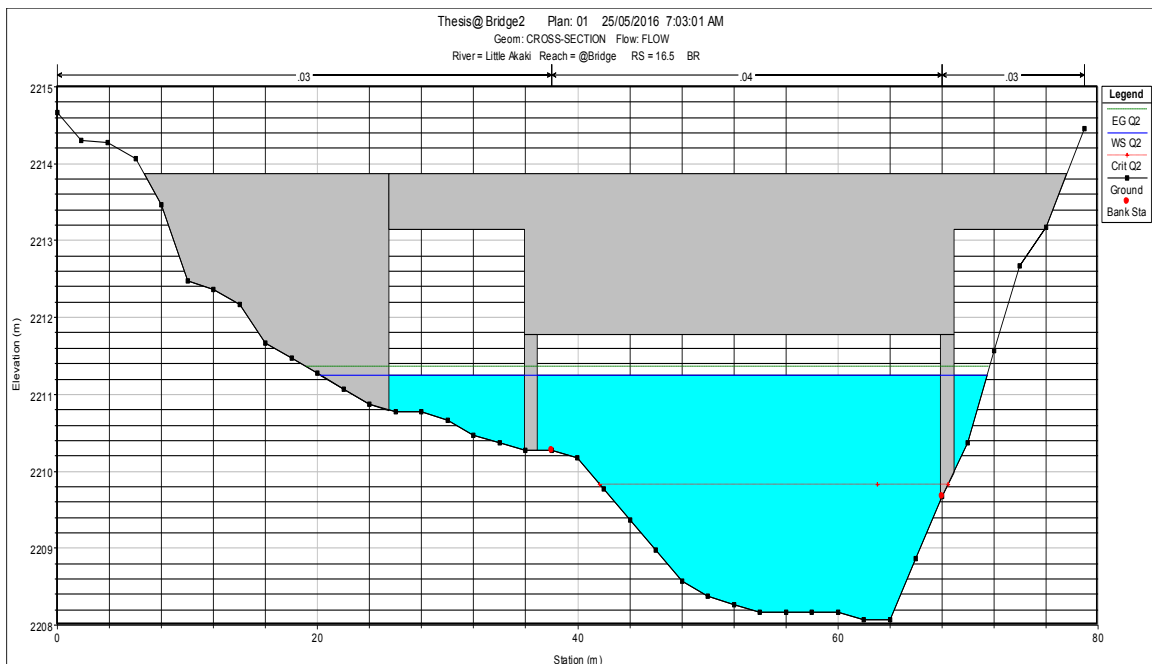


Figure 37. Bridge cross section editor windows.

After completing all the necessary geometric input data then HEC-HMS output results were inserted into the steady flow data editor section. All the design flood values were inserted here and the boundary conditions for the model also selected from the reach boundary condition editor tab. For the case of this study normal depth boundary condition was selected since no observed data was available. Normal depth assumes slope of the river bed is equivalent to the energy grade line of the flowing water. Slope of the river bed is determined by taking river bed elevation difference at up and down stream and dividing it with the length.

Finally from Run tab plan was created and steady flow analysis carried out. The outputs were collected in the view tab. Outputs can be collected both in figure and table from here.

Once results obtained the next step was to determine movable bed load or sediment analysis at specific cross section locations. There are three basic procedures to be followed during sediment analysis phase in HEC-RAS.

- First sediment data inserted into the model using sediment data editor window. Sediment data includes the initial conditions, transport parameters, transport functions, soil sample gradation results.
- For the boundary condition equilibrium load was selected since there is no sediment data on the project area. For the transport parameter *Laursen (Copland)* method was selected since this function is the only function in HEC-RAS to consider soil gradation up to silt range.
- The next necessary step during sediment analysis was to determine and insert the quasi-unsteady flow data. The current version of the HEC-RAS model only capable of modelling sediment transport by converting the unsteady flow hydrograph into a series of blocks so that every sediment calculation remains constant for the defined duration. For the case of this thesis the design peak discharges were used in order to visualize their impact on the Bridge cross section.
- The final step is running the software and collecting both tabulated and graphical outputs of the model.

4. Result and Discussion

In this chapter the out puts of the models described in detail using graphs and figures. Both hydrologic and hydraulic results were compiled here.

4.1 Peak Discharge result using Frequency Analysis at Big-Akaki

Based on 24 years observed flow at Big Akaki outlet the peak discharge for five different return periods were determined using frequency analysis methods. The maximum discharge out of the three frequency analysis results were selected for each return periods and tabulated in *Table.7* below.

Table 7.Frequency analysis result of Big Akaki.

	Log-Normal (m ³ /s)	EV1 (m ³ /s)	Log-PeronIII (m ³ /s)	Qmax (m ³ /s)
Q2 =	227.55	246.59	244.06	246.6
Q5 =	397.21	395.67	401.32	401.3
Q10 =	531.64	494.37	501.37	531.6
Q25 =	725.39	619.08	619.20	725.4
Q50 =	886.61	711.60	699.97	886.6

4.2 Peak discharge result using HEC-HMS at Big-Akaki outlet

After frequency analysis results obtained the next step was to determine peak discharge at Big Akaki outlet using HEC-HMS model. After inserting all necessary parameters which were described in methodology part, varying the curve number (CN) of the sub catchments and finally running the model the following results were observed.

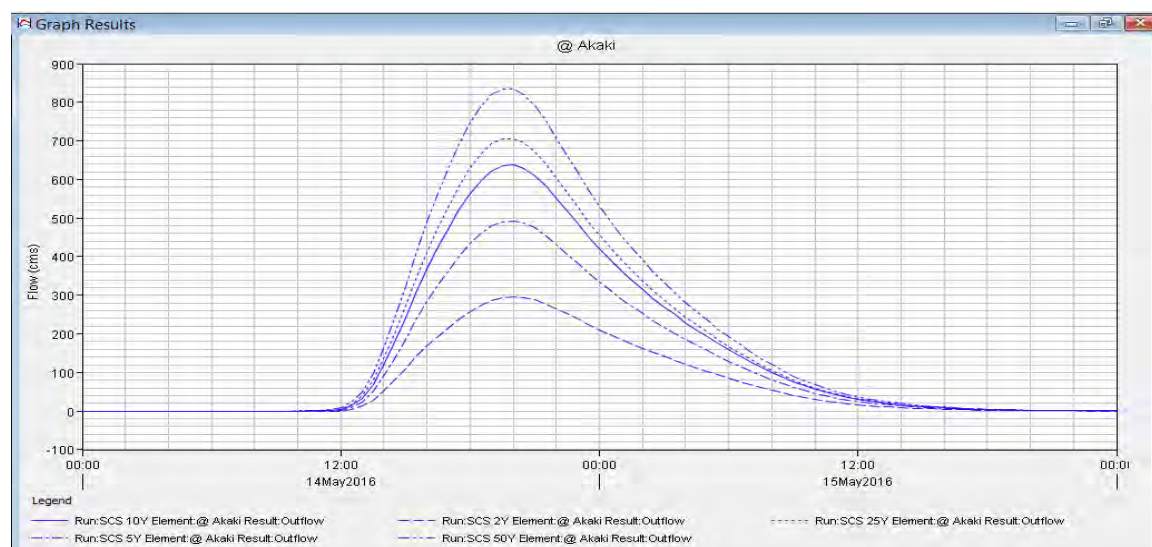


Figure 38.HEC-HMS result at Big Akaki river outlet.

The peak discharge output of HEC-HMS model and the Frequency analysis results are compiled in *Table 8* below.

Table 8. Frequency analysis and HEC-HMS result at Big Akaki outlet.

Return period	Qmax (Frequency Analysis), m³/s	Qmax (HEC-HMS) m³/s
2	246.6	295.8
5	401.3	493.3
10	531.6	637.2
25	725.4	705.9
50	886.6	834.2

Once the Peak discharge output using HEC-HMS model and the Frequency analysis results determined, line of fit between the two plotted using Excel.

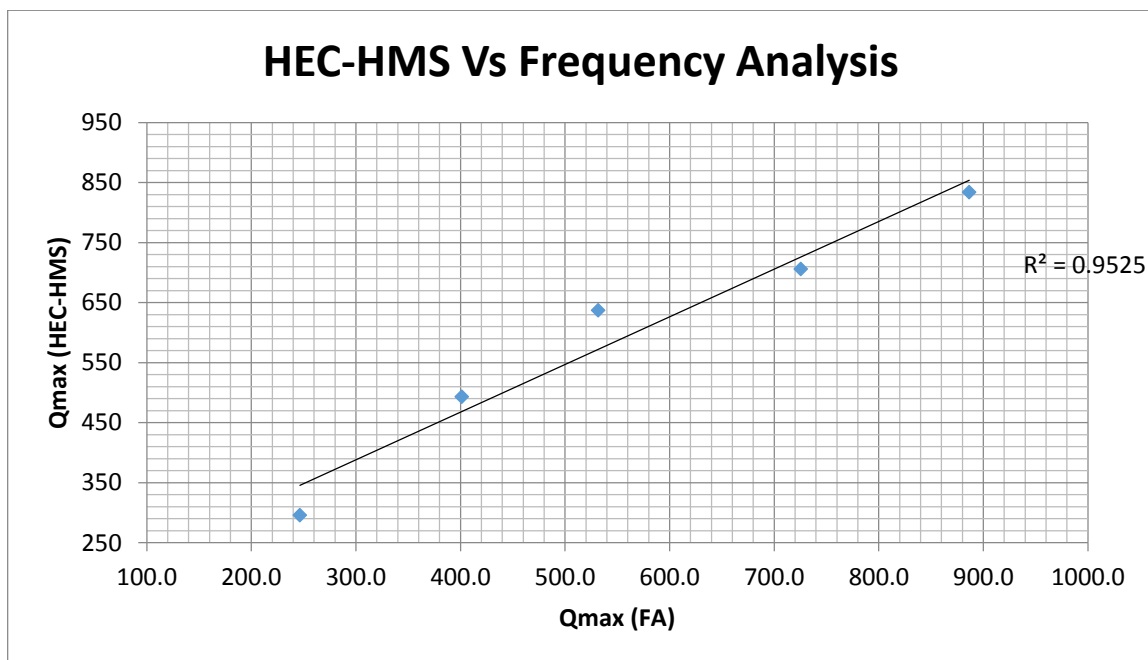


Figure 39. Line of fit between HEC-HMS and Frequency analysis results.

From the above figure it is possible to see good relationship between the simulated output of HEC-HMS model and the frequency analysis results. Therefore it is possible to transfer hydrological parameters from Big Akaki to the project area for further analysis. Base on this fact the curve number (CN) is transported from the Big Akaki catchment to the Project Area.

4.3 Peak discharge result using HEC-HMS at Project Area outlet

The peak discharge determination at the outlet of the project area, which is basically at the Bridge is done with similar procedures used for the Big Akaki. The necessary parameters were inserted into the model and the peak discharge for different return periods were determined and presented in *Figure.40* as follows.

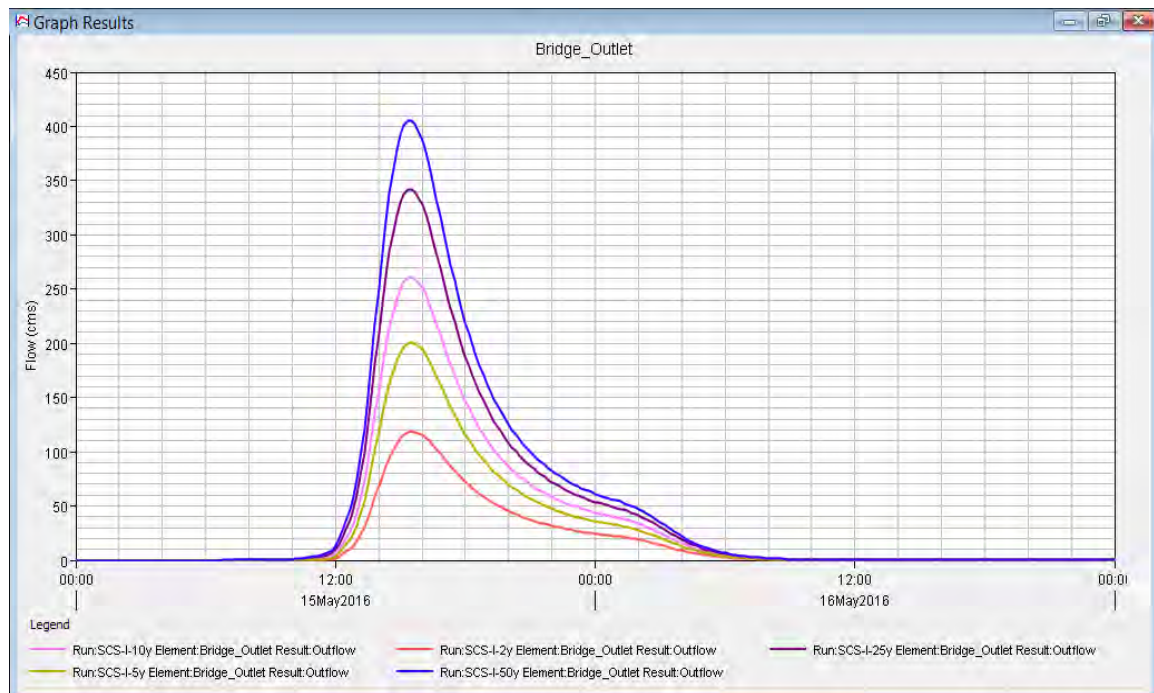


Figure 40. Peak discharge of different return periods at the Bridge.

Based on the outputs of the HEC-HMS model the following peak discharges for different return period were summarized in *Table.9*.

Table 9. Peak discharge at the outlet.

Return period	2	5	10	25	50
Qmax (m3/s)	118.5	200.7	261	342.2	405.5

From the design document the 50 year peak discharge which is used to determine the maximum water level was 497m³/sec. The Curve Number they used for the catchment was 91 and the design storm used was 107mm.

For the case of this study the 50 year peak discharge determined using the model was 405.5m³/s, the average weighted Curve Number is 80 and the 50 year design storm is 94.07mm.

4.4 HEC-RAS water surface profile without the Bridge

The design discharge outputs from HEC-HMS software is used to determine the water surface profile. The 50 year return period design flood water surface profile output of the HEC-RAS model without considering the Bridge is shown in *Figure 41* below.

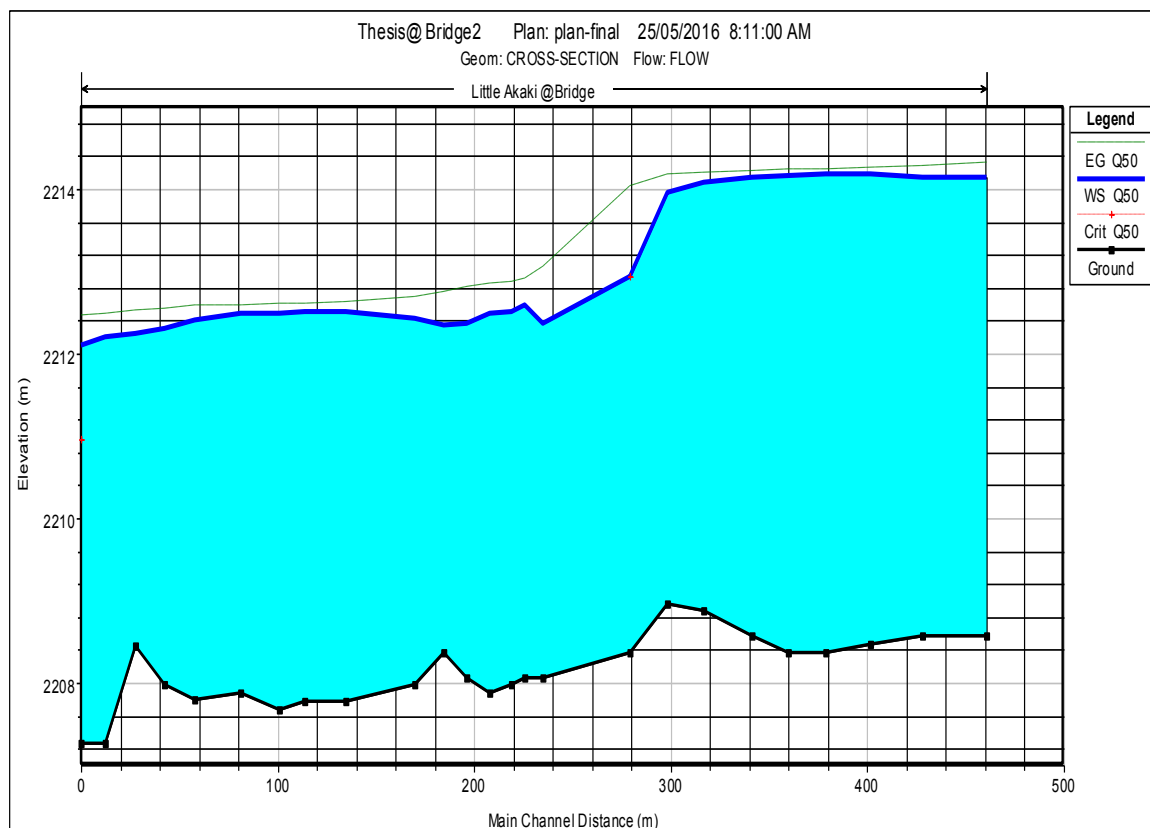


Figure 41. Water surface profile output of HEC-RAS.

From the above *Figure* it is possible to observe that the water surface profile for the 50year design discharge at the upstream side is about 2213.95m amsl without considering the bridge in the model. The simulated water surface elevation is much greater than the maximum design water surface elevation, 2211.04m amsl which is used to determine the bridge height during the design phase. This can be considered as one indication that there exists a bed elevation change in the vicinity

of the bridge. Having this in mind the next step is to insert the bridge and see if there exists further rise in the water surface elevation.

4.5 HEC-RAS water surface profile including the Bridge

After inserting all geometric data from the design document into the model the next step was to determine whether the bridge is overtopped or not with the given design discharge inputs. Water surface profile both at the upstream and downstream of the bridge were computed and presented in *Figure 42(a)*, *(b)*, and *Figure.43* below.

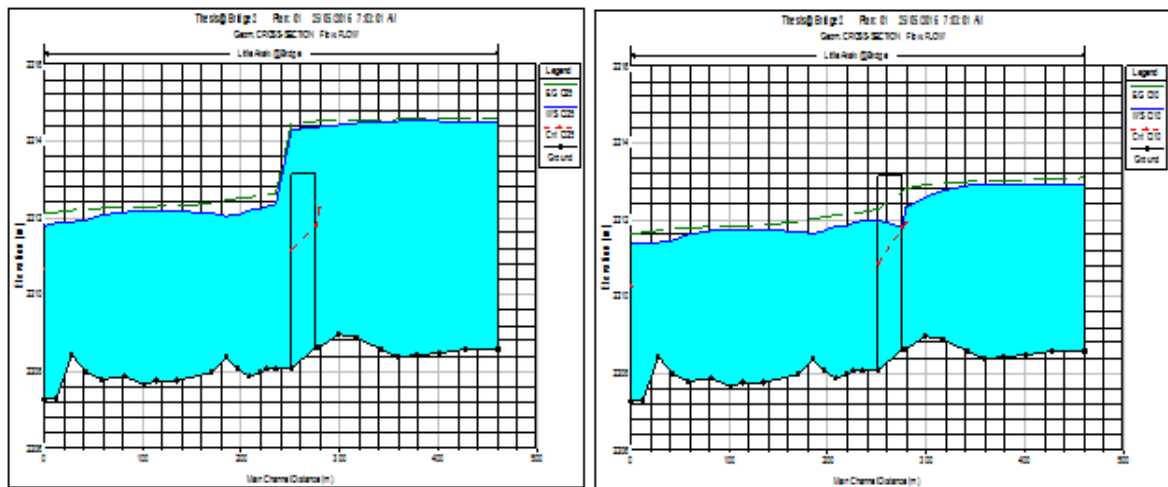


Figure 42(a).Water surface profile for Q25 *Figure 42(b).Water surface profile for Q10*

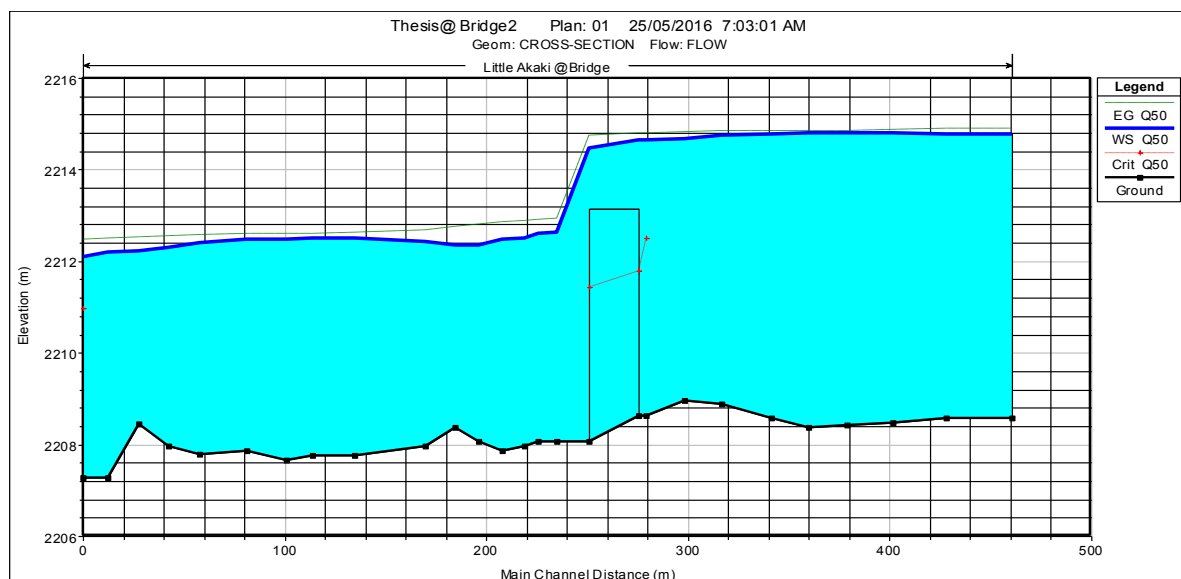


Figure 43.Water surface profile for Q50.

The water surface profile (*Figure.42 (b)*) for the 10 year return period design flood is below the Bridge low chord. Therefore the water can pass through the bridge opening even though it is a pressurized flow type. But the water surface profile (*Figure.42 (a), Figure.43*) for the 25 and 50 year return period is totally above the Bridge high chord. The water surface profile for the 25 and 50 year return period is 2214.2m and 2214.6m *amsl* respectively. The highest elevation (*High chord*) of the Bridge is 2213.87m *amsl* which shows an elevation difference of 0.73m below the water surface level for the Q50 design discharge.

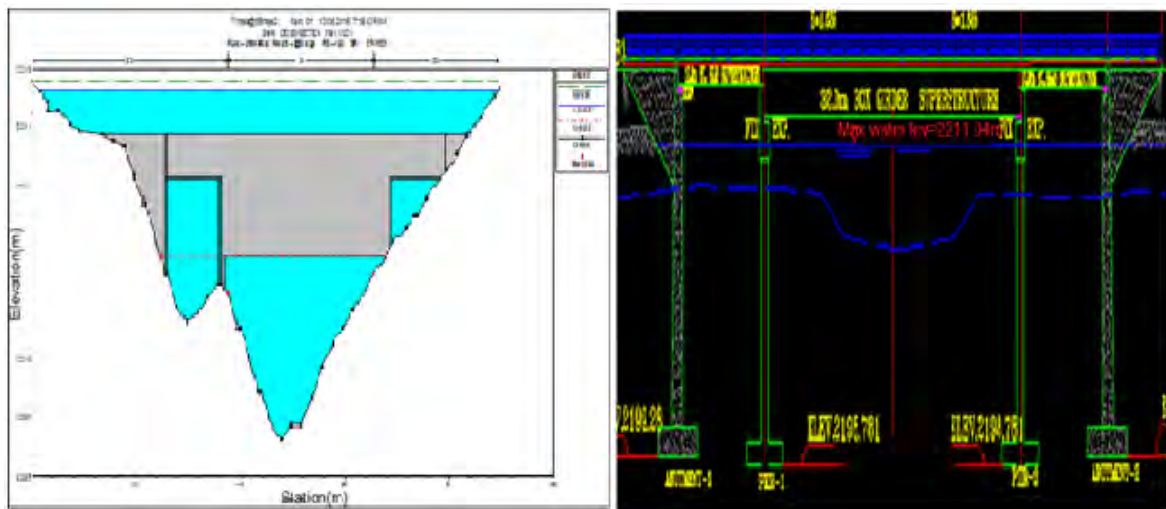


Figure 44. Maximum water surface profile using HEC RAS and design document (Q50)

There is also a 3.54m elevation difference between the maximum water surface elevation which is used in the actual design and the above result. In addition there is 0.65m difference in maximum water surface elevation before and after the bridge inserted into the model which implies the Bridge has a direct contribution on the back water and flooding problems of that area. This clearly shows that the current Bridge opening capacity is not capable to pass even the 25 year design flood event.

4.6 Sediment transport analysis results in HEC-RAS

Based on the current cross section and bed material of the river, HEC-RAS computed the bed elevation change along the river bed. For the purpose of comparison, the less frequent 50 year peak flood and the more frequent 2 year peak flood were used as an input and the following bed elevation change results were determined.

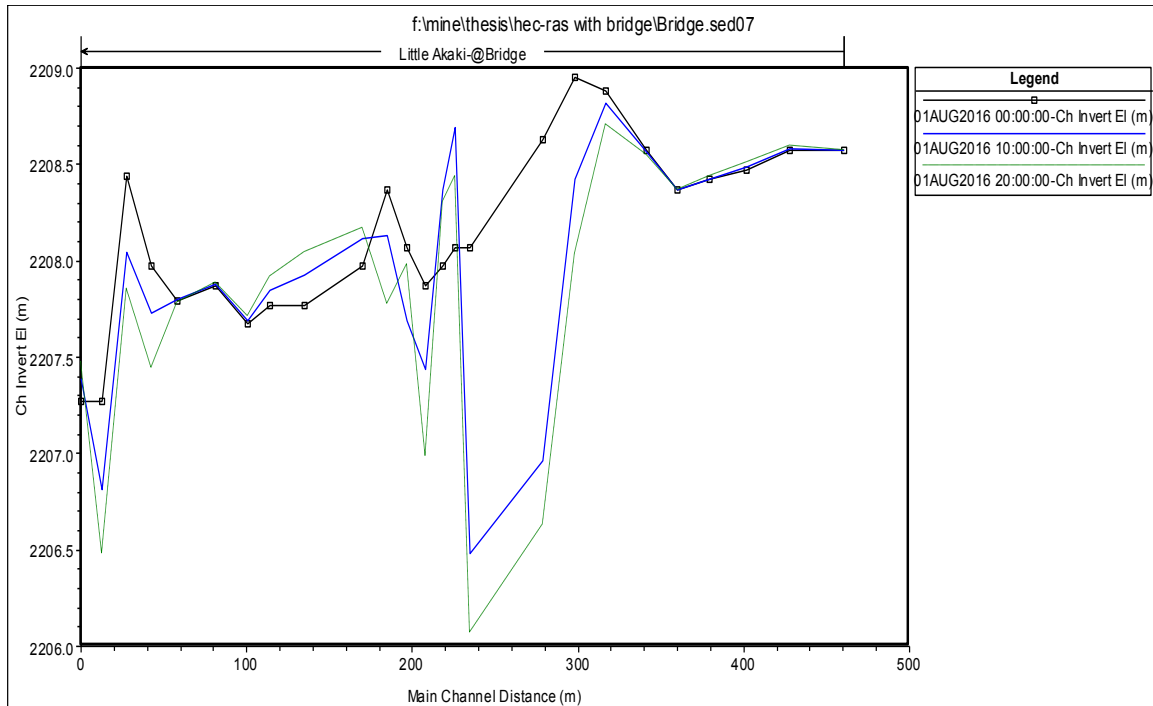


Figure 45. HEC_RAS river bed profile plot along the river (Q50).

From Figure 45 we can conclude that there exists a series of sediment deposition and scouring both at the upstream and downstream side of the Bridge. Scouring of bed observed at the immediate upstream side of the Bridge whereas deposition observed at the downstream side of the Bridge. The bed elevation change outputs are compiled in Table 10 below.

Table 10. Bed elevation change output of HEC-RAS (Q50).

River	Reach	RS	Ch Dist (m)	(01Aug2016 00:00:00) Ch Invert El (m)	(01AUG2016 10:00:00) Ch Invert El (m)	(01AUG2016 20:00:00) Ch Invert El (m)	Final bed elevation change (m)
Little Akaki	@Bridge	25	32.28	2208.57	2208.57	2208.57	0.00
Little Akaki	@Bridge	24	26.16	2208.57	2208.59	2208.60	0.03
Little Akaki	@Bridge	23	22.87	2208.47	2208.48	2208.51	0.04
Little Akaki	@Bridge	22	19.41	2208.42	2208.43	2208.44	0.02
Little Akaki	@Bridge	21	18.08	2208.37	2208.37	2208.37	0.00
Little Akaki	@Bridge	20	24.80	2208.57	2208.56	2208.55	-0.02
Little Akaki	@Bridge	19	18.38	2208.88	2208.82	2208.71	-0.17
Little Akaki	@Bridge	18	19.36	2208.95	2208.43	2208.04	-0.91
Little Akaki	@Bridge	17	44.24	2208.63	2206.97	2206.63	-2.00
Little Akaki	@Bridge	16	9.00	2208.07	2206.48	2206.07	-2.00
Little Akaki	@Bridge	15	7.06	2208.07	2208.69	2208.44	0.37
Little Akaki	@Bridge	14	11.07	2207.97	2208.37	2208.31	0.34
Little Akaki	@Bridge	13	11.20	2207.87	2207.44	2206.99	-0.88
Little Akaki	@Bridge	12	11.89	2208.07	2207.69	2207.98	-0.09
Little Akaki	@Bridge	11	14.91	2208.37	2208.13	2207.78	-0.59
Little Akaki	@Bridge	10	35.06	2207.97	2208.12	2208.17	0.20
Little Akaki	@Bridge	9	20.65	2207.77	2207.93	2208.05	0.28
Little Akaki	@Bridge	8	13.05	2207.77	2207.84	2207.92	0.15
Little Akaki	@Bridge	7	19.62	2207.67	2207.69	2207.71	0.04
Little Akaki	@Bridge	6	23.17	2207.87	2207.88	2207.88	0.01
Little Akaki	@Bridge	5	15.48	2207.79	2207.80	2207.78	-0.01
Little Akaki	@Bridge	4	15.19	2207.97	2207.73	2207.44	-0.53
Little Akaki	@Bridge	3	15.01	2208.44	2208.05	2207.86	-0.58
Little Akaki	@Bridge	2	12.40	2207.27	2206.82	2206.48	-0.79
Little Akaki	@Bridge	1	0.00	2207.27	2207.39	2207.48	0.21

In order to investigate the short term effects of the river flow on the river bed profile, more frequent flood must be used in the model. For this purpose the 2 year return period river flow was used. Based on the 2 year peak flood, the following bed elevation change results were determined.

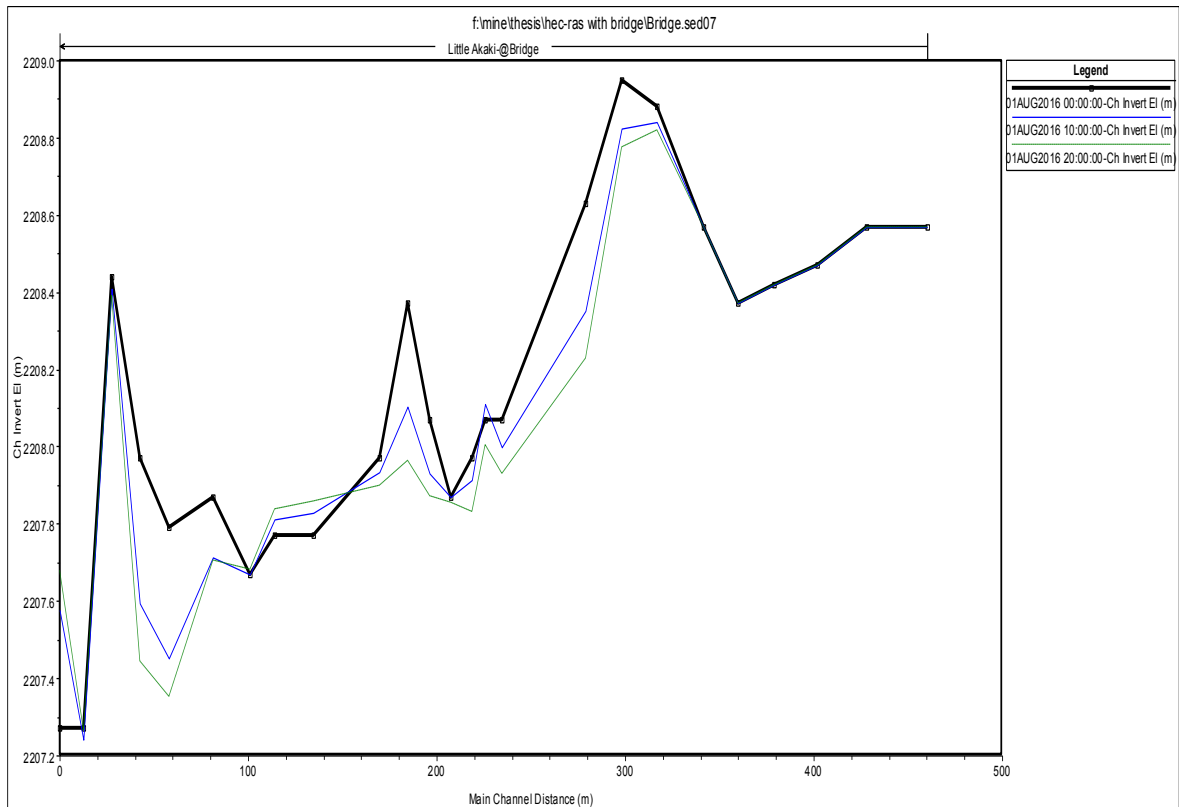


Figure 46. HEC_RAS river bed profile plot along the river (Q2).

Figure 46 also showed the same pattern of sediment aggradation and degradation as in Figure 52. The major difference here is the magnitude of bed elevation change both due to aggradation and degradation reduced, which is directly connected to the reduction in flow input. The outputs of bed elevation are summarized in Table 11 below.

Table 11. Bed elevation change output based of HEC-RAS (Q2).

River	Reach	RS	Ch Dist (m)	(01Aug2016 00:00:00) Ch Invert El (m)	(01AUG2016 10:00:00) Ch Invert El (m)	(01AUG2016 20:00:00)- Ch Invert El (m)	Final bed elevation change (m)
Little Akaki	@Bridge	25	32.28	2208.57	2208.57	2208.57	0.00
Little Akaki	@Bridge	24	26.16	2208.57	2208.57	2208.57	0.00
Little Akaki	@Bridge	23	22.87	2208.47	2208.47	2208.47	0.00
Little Akaki	@Bridge	22	19.41	2208.42	2208.42	2208.42	0.00
Little Akaki	@Bridge	21	18.08	2208.37	2208.37	2208.37	0.00
Little Akaki	@Bridge	20	24.80	2208.57	2208.57	2208.57	0.00
Little Akaki	@Bridge	19	18.38	2208.88	2208.84	2208.82	-0.06
Little Akaki	@Bridge	18	19.36	2208.95	2208.82	2208.78	-0.17
Little Akaki	@Bridge	17	44.24	2208.63	2208.35	2208.23	-0.40
Little Akaki	@Bridge	16	9.00	2208.07	2208.00	2207.93	-0.14
Little Akaki	@Bridge	15	7.06	2208.07	2208.11	2208.00	-0.07
Little Akaki	@Bridge	14	11.07	2207.97	2207.91	2207.83	-0.14
Little Akaki	@Bridge	13	11.20	2207.87	2207.87	2207.86	-0.01
Little Akaki	@Bridge	12	11.89	2208.07	2207.93	2207.87	-0.20
Little Akaki	@Bridge	11	14.91	2208.37	2208.10	2207.96	-0.41
Little Akaki	@Bridge	10	35.06	2207.97	2207.93	2207.90	-0.07
Little Akaki	@Bridge	9	20.65	2207.77	2207.83	2207.86	0.09
Little Akaki	@Bridge	8	13.05	2207.77	2207.81	2207.84	0.07
Little Akaki	@Bridge	7	19.62	2207.67	2207.67	2207.68	0.01
Little Akaki	@Bridge	6	23.17	2207.87	2207.71	2207.71	-0.16
Little Akaki	@Bridge	5	15.48	2207.79	2207.45	2207.35	-0.44
Little Akaki	@Bridge	4	15.19	2207.97	2207.59	2207.45	-0.52
Little Akaki	@Bridge	3	15.01	2208.44	2208.41	2208.39	-0.05
Little Akaki	@Bridge	2	12.40	2207.27	2207.24	2207.27	0.00
Little Akaki	@Bridge	1	0.00	2207.27	2207.58	2207.68	0.41

On both cases the HEC-RAS model results showed that river bank and bed erosion exists on the place where the Bridge is located. On the other hand no bed change were observed on the over bank side of the river as showed in *Figure.47 (a)*.

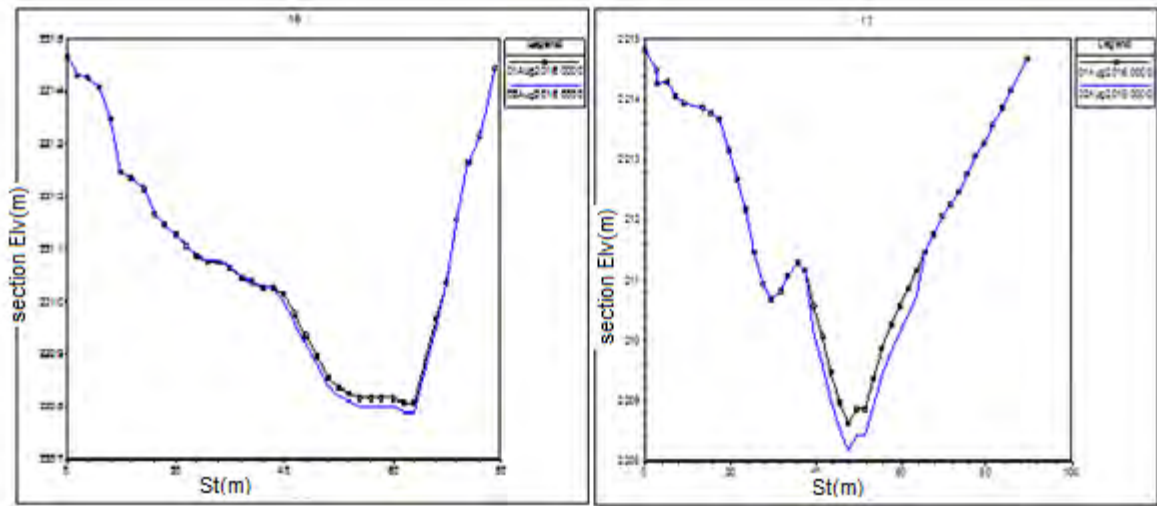


Figure 47(a).HEC_RAS sediment profile at cross section 16 (downstream) and 17 (upstream) of the Bridge before and after simulation (Q2).

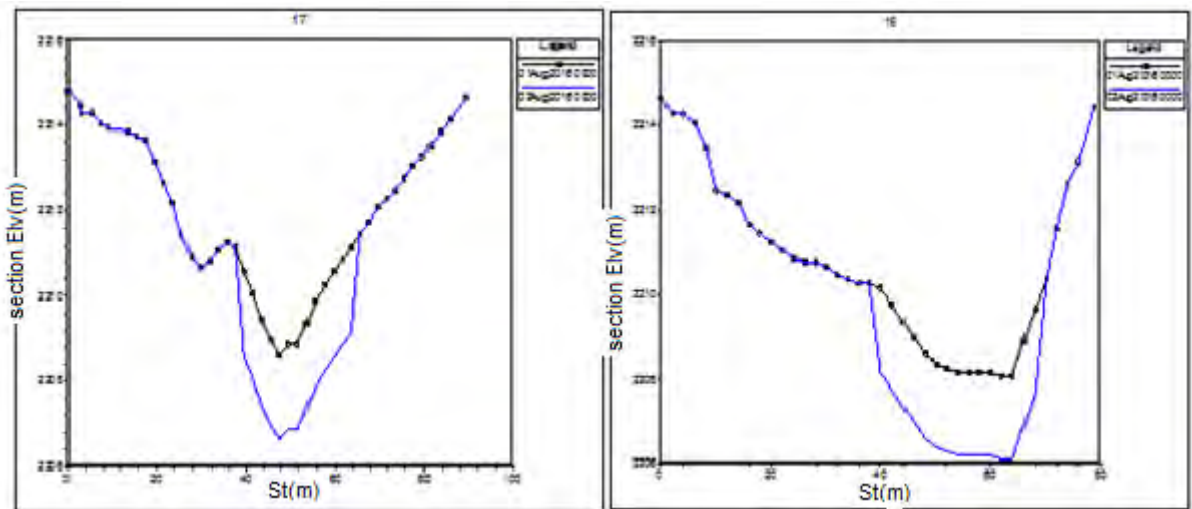


Figure 47(b).HEC_RAS sediment profile at cross section 16 (downstream) and 17 (upstream) of the Bridge before and after simulation (Q50).

The possible explanation for the bed and bank scour of the river channel would be the increase in velocity and consequently the shear force due to the reduction in the opening size of the bridge. From field observation bed and bank erosion is not a problem only at the bridge location. As the model predicts erosion and channel widening is also a problem at up and down stream locations.

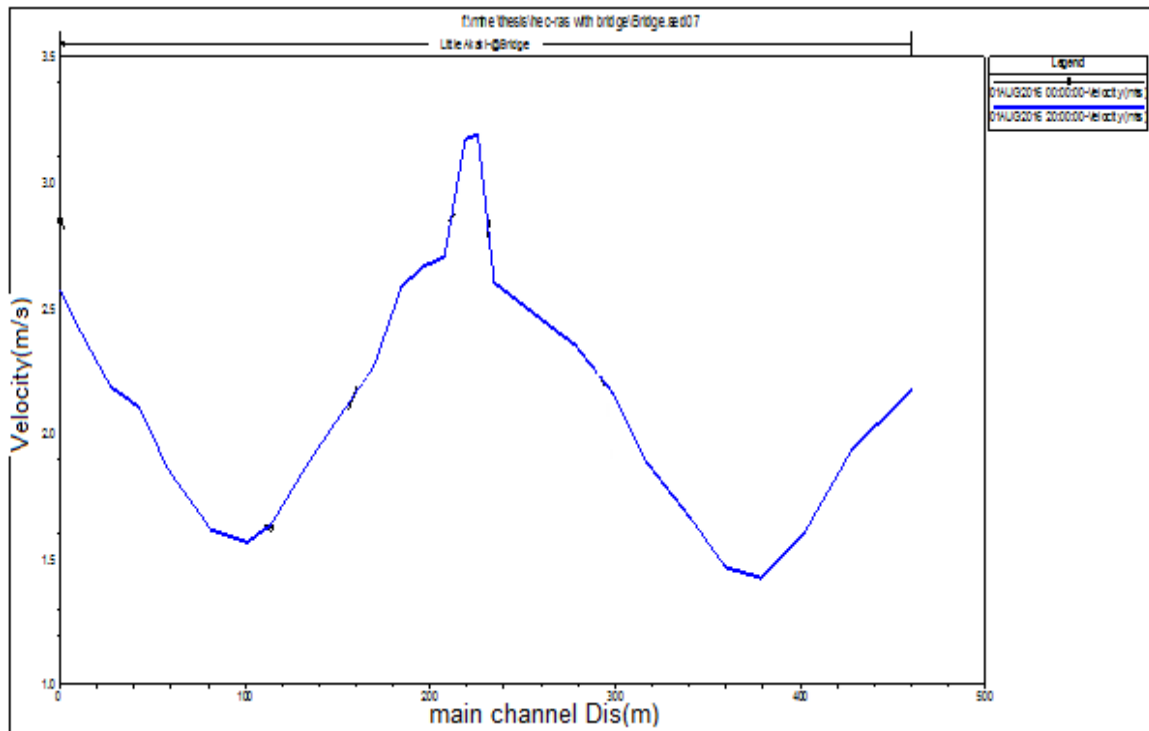


Figure 48. HEC_RAS Velocity output of the flow along the profile of the river at the end of simulation (Q50).

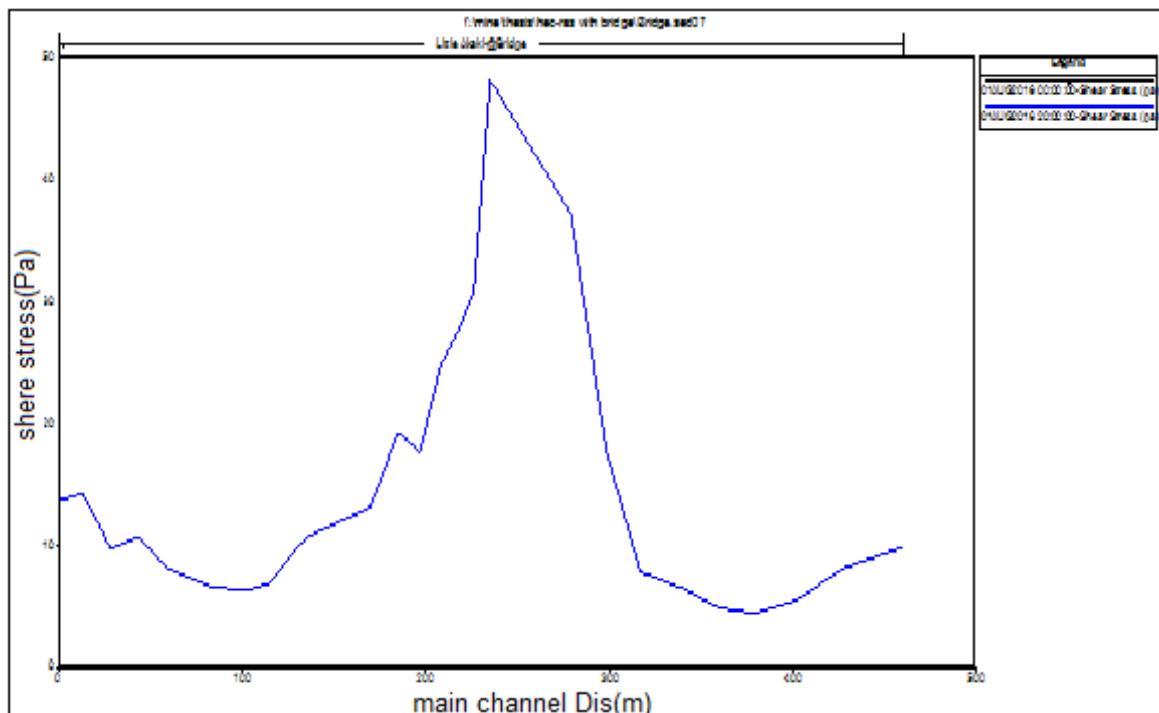


Figure 49. HEC_RAS shear force output of the flow along the profile of the river at the end of simulation (Q50).

Based on field visit and photo materials taken at the site, sedimentation occurs both at the left and right side of the river bank specifically between the piers and the abutment of the Bridge.

The bridge piers were located on the river banks making about 40° skew angle with the river flow direction and this facilitates debris and sediment accumulation between the piers and the abutment of the Bridge.



Figure 50. Skew angle and Bridge alignment with respect to the flow direction.

In addition different studies have showed that as the number of piers having a direct contact with the flowing water increases, the drag force also increases which initiates head lose. In order to compensate the head lose the river needs to rise up and create back water and flood inundation just upstream of the Bridge. This creates excess time for sediment particles to settle down on the bed and overbank of the river. When this process repeated through time sedimentation around the piers of a Bridge develops, and this is what actually happened on Mekenisa Bridge.

5. Conclusion and Recommendation

5.1 Conclusion

This thesis work tries to cover the basic hydrologic and hydraulic aspects of bridge design in order to evaluate the current hydraulic performance of a bridge. As described in detail in analysis part, sediment aggradation at bridge location plays a significant role in the reduction of the hydraulic performance of the Bridge. The effect of reduction in the opening size of the Bridge is already being observed on the area including flooding and bank over topping which puts pressure on the society living along the river side. From surveying documents, both from field survey and design document clearly showed that the Bridge location is totally on the flood plain. Therefore during the hydrological analysis phase this should have been considered.

Based on the hydrologic analysis result the maximum 50 year design flood which is used for the actual design of the bridge was **497m³/sec** and the maximum design flood simulated in HEC-HMS was **405.5me/sec**. The difference is not much significant to cause such a problem and we can conclude error in the hydrologic computation is not the direct problem.

When we come to the hydraulic modelling results the maximum 50 year design flood water surface elevation which was used for the actual bridge design was **2211.04m** amsl. When we come to the HEC-RAS model results, the maximum 50 year design flood water surface elevation computed was **2213.95m amsl** before bridge inserted into the model and **2214.6m amsl** just after bridge is inserted in to the model which implies the back water effect of the bridge. From the results we can conclude that the bridge will be overtopped by the 50year design flood water surface elevation.

Based on the above results and field observation we can conclude that river bed elevation change due to sediment aggradation is a significant cause for the reduction of the hydraulic performance of the Bridge. The Bridge and pier layout with respect to the flow direction which is skewness of the Bridge, location of the bridge layout, agricultural activity along the river reach and the soil type plays important role in the sediment deposition at the Bridge location.

5.2 Recommendation

Until now the problems and their end results were discussed in detail. From the analysis result the major causes for the reduction of the hydraulic performance of the Bridge was the sediment accumulation and river bed elevation change in the vicinity of the Bridge. Therefore the main concern should be how to reduce sediment transport on the channel.

From field visit number of river cross sections were identified which shows a significant bank erosion. In addition there are number of river cross sections which are located on bends and curves. This type of cross sections have a potential to supply sediment materials to the downstream. Therefore retaining wall must be provided at these locations in order to reduce further bank erosion.

Dredging river bed could also be considered after its impact on the environment and the cost considered. Dredging may not bring permanent solution to the problem but it will provide temporary solution based on the severity of the problem. River training work just at the downstream side of the bridge is also recommended. This is mainly because the river alignment bends just after it pass through the Bridge and returns back to the original alignment after it follows a half circular river alignment. During high flood season the flow tops the original bank just at the bend in order to get a straight river alignment. This facilitates flooding just downstream of the Bridge and also creates jam to flow just before the Bridge.

Finally irrigation practice on the over bank of the river should be carried out in a controlled way. Agricultural activity generally looseness the soil surface and facilitate surface erosion during high flood seasons. If possible create means by which the soil is covered with plants or grass throughout the year. This will protect the top most layer of the soil from erosion during peak flood seasons of the year.

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Appendix

Appendix A.1 SCS Curve Number Table

Table.A.1 CN for Urban Area

Table 2-2a Runoff curve numbers for urban areas ^{1/}		Curve numbers for hydrologic soil group			
Cover description	Average percent impervious area ^{2/}	A	B	C	D
Cover type and hydrologic condition					
<i>Fully developed urban areas (vegetation established)</i>					
Open space (lawns, parks, golf courses, cemeteries, etc.) ^{3/} :					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)					
		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)					
		98	98	98	98
Paved; open ditches (including right-of-way)					
		83	89	92	93
Gravel (including right-of-way)					
		76	85	89	91
Dirt (including right-of-way)					
		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) ^{4/}					
		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)					
		96	96	96	96
Urban districts:					
Commercial and business					
	85	89	92	94	95
Industrial					
	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)					
	65	77	85	90	92
1/4 acre					
	38	61	75	83	87
1/3 acre					
	30	57	72	81	86
1/2 acre					
	25	54	70	80	85
1 acre					
	20	51	68	79	84
2 acres					
	12	46	65	77	82
<i>Developing urban areas</i>					
Newly graded areas (pervious areas only, no vegetation) ^{5/}					
		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

Table.B.1 CN for Agricultural Land

Table 2-2b Runoff curve numbers for cultivated agricultural lands ^{1/}

Cover description			Curve numbers for hydrologic soil group			
Cover type	Treatment ^{2/}	Hydrologic condition ^{3/}	A	B	C	D
Fallow	Bare soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
C&T + CR	Poor	65	73	79	81	
	Good	61	70	77	80	
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
C&T + CR	Poor	60	71	78	81	
	Good	58	69	77	80	
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

^{1/} Average runoff condition, and $I_p - 0.2S$

^{2/} Crop residue cover applies only if residue is on at least 5% of the surface throughout the year.

^{3/} Hydraulic condition is based on combination factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes, (d) percent of residue cover on the land surface (good $\geq 20\%$), and (e) degree of surface roughness.

Poor: Factors impair infiltration and tend to increase runoff.

Good: Factors encourage average and better than average infiltration and tend to decrease runoff.

Table.C.1 CN for Other Agricultural land

Table 2-2c Runoff curve numbers for other agricultural lands ^{1/}

Cover description	Hydrologic condition	Curve numbers for hydrologic soil group			
		A	B	C	D
Pasture, grassland, or range—continuous forage for grazing. ^{2/}	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element. ^{3/}	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30 ^{4/}	48	65	73
Woods—grass combination (orchard or tree farm). ^{5/}	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods. ^{6/}	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30 ^{4/}	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

^{1/} Average runoff condition, and $I_a = 0.2S$.

^{2/} *Poor*: <50% ground cover or heavily grazed with no mulch.

Fair: 50 to 75% ground cover and not heavily grazed.

Good: > 75% ground cover and lightly or only occasionally grazed.

^{3/} *Poor*: <50% ground cover.

Fair: 50 to 75% ground cover.

Good: >75% ground cover.

^{4/} Actual curve number is less than 30; use CN = 30 for runoff computations.

^{5/} CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

^{6/} *Poor*: Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.

Fair: Woods are grazed but not burned, and some forest litter covers the soil.

Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

Appendix B.1 Frequency analysis results

Table.B.1 Log normal method

Year	Qmax (m ³ /sec)	logQ	(logQ- logQavg)	(logQ- logQavg) ²		
1981	693.10	2.841	0.4837276	0.2339924		
1982	615.76	2.789	0.4323426	0.1869202		
1983	573.57	2.759	0.4015161	0.1612152		
1984	435.34	2.639	0.2817570	0.0793870		
1985	421.52	2.625	0.2677466	0.0716882		
1986	420.06	2.623	0.2662407	0.0708841		
1987	277.22	2.443	0.0857534	0.0073537		
1988	276.32	2.441	0.0843475	0.0071145		
1989	257.98	2.412	0.0545098	0.0029713		
1990	255.78	2.408	0.0507902	0.0025796		
1991	250.47	2.399	0.0416827	0.0017374		
1992	233.77	2.369	0.0117174	0.0001373		
1993	219.87	2.342	-0.0149055	0.0002222		
1994	215.22	2.333	-0.0241788	0.0005846		
1995	201.31	2.304	-0.0531999	0.0028302		
1996	189.38	2.277	-0.0797286	0.0063566		
1997	172.77	2.237	-0.1195962	0.0143032		
1998	165.65	2.219	-0.1378781	0.0190104		
1999	162.58	2.211	-0.1460024	0.0213167		
2000	153.07	2.185	-0.1721681	0.0296419		
2001	148.35	2.171	-0.1857732	0.0345117		
2002	138.72	2.142	-0.2149399	0.0461991		
2003	68.78	1.837	-0.5196263	0.2700115		
2004	36.55	1.563	-0.7941346	0.6306498		
		LogQavg		(logQ-logQavg) ²		
		2.35707		1.90161901		
n=	24					
σ =	0.2875					
K2 =	-0.0000001	logQ2 =	2.357	Q2 =	227.55	m3/s
K5 =	0.8414567	logQ5 =	2.599	Q5 =	397.21	m3/s
K10 =	1.2817288	logQ10 =	2.726	Q10 =	531.64	m3/s
K25 =	1.7510765	logQ25 =	2.861	Q25 =	725.39	m3/s
K50 =	2.0541886	logQ50 =	2.948	Q50 =	886.61	m3/s
K100 =	2.3267853	logQ100 =	3.026	Q100 =	1061.97	m3/s

Table.B.2 EVT I

Year	Qmax (m3/sec)	Q-Qavg	(Q-Qavg) ²	
1981	693.10	418.80	175397.10	
1982	615.76	341.46	116597.24	
1983	573.57	299.27	89563.36	
1984	435.34	161.04	25934.00	
1985	421.52	147.22	21673.84	
1986	420.06	145.76	21246.38	
1987	277.22	2.92	8.53	
1988	276.32	2.03	4.10	
1989	257.98	-16.32	266.40	
1990	255.78	-18.52	343.05	
1991	250.47	-23.83	567.85	
1992	233.77	-40.53	1642.57	
1993	219.87	-54.43	2962.48	
1994	215.22	-59.07	3489.69	
1995	201.31	-72.99	5326.90	
1996	189.38	-84.91	7210.49	
1997	172.77	-101.53	10307.45	
1998	165.65	-108.65	11804.31	
1999	162.58	-111.72	12480.83	
2000	153.07	-121.22	14695.17	
2001	148.35	-125.94	15862.05	
2002	138.72	-135.58	18382.11	
2003	68.78	-205.52	42238.73	
2004	36.55	-237.74	56522.03	
			$\Sigma(Q-Qavg)^2=$	
Qavg=	274.30		654526.65	
n=	24			
$\pi=$	3.141593			
$\sigma =$	168.694			
$\alpha =$	131.5302			
$u=$	198.3784			
Y2=	0.366513	Q2 =	246.59	m3/s
Y5=	1.49994	Q5 =	395.67	m3/s
Y10=	2.250367	Q10 =	494.37	m3/s
Y25=	3.198534	Q25 =	619.08	m3/s
Y50=	3.901939	Q50 =	711.60	m3/s
Y100=	4.600149	Q100 =	803.44	m3/s

Table.B.3 Log person III

Year	Qmax (m3/sec)	logQ	(logQ-logQavg)	(logQ-logQavg) ²	(logQ-logQavg) ³
1981	693.1020	2.84079715	0.48372760	0.23399239	0.11318858
1982	615.7610	2.78941218	0.43234263	0.18692015	0.08081355
1983	573.5690	2.75858567	0.40151612	0.16121520	0.06473050
1984	435.3380	2.63882658	0.28175703	0.07938702	0.02236785
1985	421.5180	2.62481612	0.26774658	0.07168823	0.01919428
1986	420.0590	2.62331029	0.26624075	0.07088413	0.01887224
1987	277.2190	2.44282299	0.08575344	0.00735365	0.00063060
1988	276.3230	2.44141704	0.08434749	0.00711450	0.00060009
1989	257.9760	2.4115793	0.05450976	0.00297131	0.00016197
1990	255.7760	2.40785979	0.05079024	0.00257965	0.00013102
1991	250.4680	2.39875225	0.04168270	0.00173745	0.00007242
1992	233.7690	2.36878692	0.01171737	0.00013730	0.00000161
1993	219.8690	2.342164	-0.01490555	0.00022218	-0.00000331
1994	215.2240	2.3328907	-0.02417885	0.00058462	-0.00001414
1995	201.3120	2.30386966	-0.05319988	0.00283023	-0.00015057
1996	189.3830	2.27734099	-0.07972856	0.00635664	-0.00050681
1997	172.7720	2.23747336	-0.11959619	0.01430325	-0.00171061
1998	165.6500	2.21919144	-0.13787811	0.01901037	-0.00262111
1999	162.5800	2.21106712	-0.14600243	0.02131671	-0.00311229
2000	153.0740	2.18490143	-0.17216812	0.02964186	-0.00510338
2001	148.3530	2.17129633	-0.18577321	0.03451169	-0.00641135
2002	138.7170	2.14212969	-0.21493986	0.04619914	-0.00993004
2003	68.7770	1.83744323	-0.51962632	0.27001151	-0.14030509
2004	36.5540	1.56293491	-0.79413464	0.63064983	-0.50082087
		2.35706955		1.90161901	-0.349924856
n=	24				
σ =	0.288				
Cs =	-0.640				
K2 =	0.106	logQ2 =	2.387	Q2 =	244.06 m3/s
K5 =	0.857	logQ5 =	2.603	Q5 =	401.32 m3/s
K10 =	1.1932	logQ10 =	2.700	Q10 =	501.37 m3/s
K25 =	1.512	logQ25 =	2.792	Q25 =	619.20 m3/s
K50 =	1.6972	logQ50 =	2.845	Q50 =	699.97 m3/s
K100 =	1.8504	logQ100 =	2.889	Q100 =	774.70 m3/s

Appendix C.1 River Hydrology

Table.C.1 The daily peak discharge at Akaki Gauging station from 1981 to 2004.

1981	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1.02	0.92	0.92	2.93	1.13	0.65	0.83	31.70	100.63	4.92	1.58	1.34
2	1.13	0.92	0.92	2.63	1.46	0.65	0.83	29.55	25.11	4.22	1.34	1.34
3	0.92	0.92	1.34	2.93	1.23	0.65	1.23	26.11	10.19	4.74	1.70	1.34
4	0.92	0.92	2.35	2.08	0.92	0.65	2.35	26.45	44.85	4.22	1.46	1.34
5	0.92	0.92	5.67	3.39	0.83	0.73	1.58	14.26	36.15	3.88	1.46	1.34
6	0.92	0.92	3.08	4.22	0.83	0.73	1.95	11.66	25.44	4.22	1.46	1.34
7	0.92	0.92	2.63	1.95	0.73	0.73	1.46	90.31	16.19	5.86	1.46	1.34
8	0.92	0.92	1.34	1.34	0.73	0.73	5.48	21.87	87.14	3.88	1.46	1.34
9	0.92	0.92	1.13	1.13	0.73	0.65	2.35	22.82	118.34	3.23	1.46	1.34
10	0.92	0.92	1.02	1.13	0.73	0.65	3.39	14.53	88.19	2.63	1.46	1.34
11	1.02	0.92	0.92	1.02	0.65	0.73	3.39	11.91	52.47	2.78	1.34	1.34
12	1.02	2.49	0.92	0.92	0.65	0.73	3.39	28.85	44.03	2.49	1.34	1.34
13	0.92	1.13	0.92	1.34	0.56	0.73	5.48	30.26	15.91	2.35	1.34	1.34
14	0.92	1.13	1.34	1.23	0.73	0.73	5.29	22.18	24.77	2.21	1.46	1.34
15	0.92	1.02	1.34	2.35	0.65	0.73	3.55	69.96	65.18	2.08	1.34	1.34
16	1.13	0.92	1.82	2.93	0.65	0.73	13.99	92.45	72.89	1.95	1.34	1.34
17	1.02	1.23	2.08	2.35	0.73	0.83	3.39	201.31	42.81	1.82	1.34	1.34
18	1.13	1.02	1.46	3.55	0.65	0.83	9.96	16.76	146.51	1.82	1.34	1.34
19	0.92	1.23	2.35	1.70	0.73	0.73	8.58	34.64	88.19	1.95	1.34	1.46
20	0.92	0.92	1.58	1.82	0.65	0.83	11.91	19.40	17.91	1.70	1.34	1.34
21	0.92	1.02	1.13	6.46	0.65	2.93	8.14	8.36	10.92	1.70	1.34	1.23
22	0.92	0.92	1.46	4.05	0.65	1.02	18.50	22.18	8.14	1.82	1.34	1.23
23	0.92	0.92	2.21	4.22	0.65	0.83	14.53	29.91	31.70	1.82	1.34	1.23
24	0.92	0.92	7.07	2.35	0.65	0.73	16.76	8.36	24.77	1.70	1.34	1.23
25	0.92	0.73	1.82	3.71	0.65	1.13	26.45	12.42	25.11	1.70	1.34	1.34
26	1.13	0.92	5.67	3.23	0.65	0.83	55.11	35.77	19.10	1.58	1.34	1.23
27	0.92	0.92	4.22	1.70	0.56	0.92	17.91	27.81	9.49	1.58	1.34	1.23
28	0.73	0.92	4.05	1.58	0.65	0.73	36.91	45.26	6.46	1.58	1.34	1.23
29	0.92		5.67	1.34	0.65	0.92	25.44	58.24	5.29	1.58	1.34	1.23
30	0.92		9.03	1.13	0.65	1.02	176.17	152.93	4.92	1.58	1.34	1.34
31	0.92		4.92		0.65		17.33	33.89		1.58		1.58
1982	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1.13	1.23	2.08	2.93	0.92	0.73	2.08	8.36	5.11	1.63	0.93	0.93
2	1.46	1.23	1.34	1.58	0.92	0.73	3.88	15.63	32.42	2.22	0.93	0.93
3	1.34	1.13	1.58	1.34	0.83	0.73	3.23	9.49	39.62	1.74	0.93	0.93
4	1.46	1.13	1.34	1.34	0.73	0.83	3.88	9.03	6.26	3.16	0.93	0.93
5	1.46	1.13	1.13	1.34	0.92	0.73	2.35	7.70	3.88	3.76	0.93	0.93
6	1.34	1.13	1.13	1.34	0.73	0.83	10.67	5.11	22.82	3.76	1.21	0.93
7	1.34	1.23	0.92	7.28	2.93	0.92	5.86	4.57	44.85	2.22	1.31	0.93
8	1.34	1.23	0.92	1.46	1.58	0.92	3.88	37.68	10.19	3.02	1.11	0.84
9	1.34	1.23	0.73	1.13	1.58	0.83	2.08	12.67	4.92	2.61	1.31	0.93
10	1.13	1.23	0.73	0.92	2.93	0.92	2.21	6.46	4.57	2.47	1.74	0.93

11	1.23	1.23	0.73	0.92	2.49	0.83	3.39	12.67	40.81	1.74	1.21	0.84
12	1.34	5.29	0.73	1.13	9.03	0.73	2.08	9.26	32.42	1.74	1.11	0.93
13	1.34	2.63	0.73	6.46	2.93	0.73	1.70	29.55	15.07	1.52	1.11	0.93
14	3.23	2.49	0.73	1.82	3.39	0.92	2.63	11.16	25.77	1.63	1.11	1.11
15	2.93	2.63	0.73	1.58	3.23	0.92	5.48	11.66	17.91	1.52	0.93	0.93
16	1.82	2.35	0.73	1.34	4.74	1.13	7.28	16.76	10.53	1.41	0.93	0.93
17	7.92	1.58	0.73	1.34	3.55	1.13	9.72	28.85	6.71	1.31	0.93	1.11
18	3.23	1.58	0.73	1.13	2.35	1.13	7.49	11.91	4.89	1.31	0.93	0.93
19	1.82	1.46	0.73	1.02	1.82	1.95	4.74	9.26	4.89	1.31	1.02	0.93
20	1.58	1.13	0.92	1.34	1.46	4.05	2.93	27.47	4.55	1.31	0.93	0.93
21	1.46	1.02	0.92	1.02	1.23	2.78	3.23	110.78	2.74	1.11	0.93	0.93
22	1.46	0.92	0.92	0.92	1.13	1.95	8.80	172.77	2.22	1.02	0.93	0.76
23	1.34	0.92	0.92	1.34	1.13	1.23	33.89	92.99	5.24	1.11	0.93	0.84
24	1.34	0.92	0.92	3.23	1.02	1.02	9.03	44.03	16.06	1.02	0.93	0.84
25	1.34	1.13	0.92	1.34	1.13	1.02	41.60	20.31	3.76	1.02	0.93	0.84
26	1.23	1.34	0.92	0.92	1.02	0.92	9.72	36.15	2.61	0.93	0.93	0.76
27	1.23	1.34	0.92	1.34	1.13	1.82	12.16	19.70	2.10	0.93	0.93	0.76
28	1.34	2.49	0.92	1.58	1.02	1.70	13.46	17.91	1.97	0.93	0.93	0.76
29	1.02		1.13	0.92	0.92	2.35	76.36	24.77	1.97	0.93	0.93	0.76
30	1.23		2.35	0.92	0.92	1.95	22.82	12.16	1.63	0.93	0.93	0.76
31	1.23		4.92		0.92		32.42	15.63		0.93		0.76
1983	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.76	0.93	0.76	0.46	0.60	0.84	2.10	28.32	33.96	5.96	0.93	0.68
2	0.76	0.93	0.68	0.46	0.60	1.31	1.31	15.79	30.74	3.31	0.93	0.76
3	0.76	0.84	0.53	0.46	0.68	3.16	0.93	16.33	22.78	2.74	0.93	0.68
4	0.76	1.02	0.60	0.33	0.68	3.91	0.76	16.61	14.20	2.35	0.93	0.68
5	0.76	0.84	0.76	0.27	0.76	3.76	0.68	16.61	9.85	2.35	0.93	0.60
6	0.76	0.68	0.60	0.27	0.86	3.91	0.60	23.09	12.19	2.88	0.93	0.53
7	0.76	0.68	0.46	0.33	0.84	3.16	0.60	21.24	14.46	2.35	0.93	0.53
8	0.76	0.76	0.46	0.39	0.84	1.97	1.31	53.63	9.18	2.35	0.93	0.53
9	0.76	0.84	0.39	0.39	0.84	0.93	4.23	29.01	16.33	1.63	0.93	0.53
10	0.76	0.76	0.46	0.39	0.93	2.22	0.93	25.01	42.76	1.63	0.93	0.53
11	0.76	0.84	0.46	0.39	0.93	2.74	0.84	83.28	99.41	1.41	0.84	0.53
12	0.76	0.93	0.46	0.33	0.93	2.22	1.41	127.49	39.61	1.41	0.84	0.53
13	0.68	0.76	0.46	0.39	1.02	2.22	2.10	127.49	33.96	1.41	0.76	0.53
14	0.68	0.76	0.53	0.46	1.86	2.22	3.16	111.94	35.81	1.41	0.76	0.46
15	0.68	0.76	0.60	0.53	1.31	2.61	5.06	106.18	19.45	1.52	0.76	0.53
16	0.68	0.68	0.60	0.68	3.91	0.60	6.33	133.68	15.52	1.52	0.76	0.53
17	0.68	0.68	0.68	0.68	5.77	1.97	3.91	111.94	26.31	2.35	0.84	0.53
18	0.76	0.76	0.60	0.68	14.20	3.31	5.41	111.94	40.39	3.31	0.76	0.53
19	0.68	0.76	0.46	0.68	1.02	1.31	9.85	18.87	26.98	1.74	0.76	0.46
20	0.68	0.76	0.39	0.68	0.22	1.31	8.75	14.72	23.09	1.31	0.76	0.46
21	0.68	0.84	0.33	0.68	2.35	0.93	9.18	10.99	17.16	1.21	0.76	0.53
22	0.76	0.84	0.33	0.60	1.74	0.76	8.32	8.11	6.14	1.11	0.76	0.53
23	0.76	0.68	0.39	0.60	0.17	1.02	10.53	19.16	4.89	1.02	0.76	0.60

24	0.84	0.68	0.46	0.60	6.52	0.84	18.87	50.60	6.14	0.93	0.60	0.53
25	0.84	0.93	0.53	0.60	0.27	0.68	12.43	37.31	11.95	0.93	0.60	0.60
26	0.84	1.02	0.27	0.60	1.21	1.52	16.06	47.65	7.30	0.93	0.68	0.60
27	0.84	1.02	0.27	0.60	0.27	1.52	21.85	56.27	5.06	1.02	0.68	0.53
28	0.76	0.84	0.22	0.60	2.47	3.16	38.07	41.56	11.47	1.02	0.68	0.53
29	0.76		0.22	0.60	3.91	3.02	19.45	127.49	9.18	1.11	0.76	0.46
30	0.76		0.27	0.60	2.88	3.76	20.64	45.18	11.23	1.02	0.68	0.46
31	0.76		0.39		2.47		22.78	138.72		0.93		0.46
1984	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.53	0.93	0.76	0.46	0.60	0.84	5.96	31.80	43.96	1.86	1.02	0.68
2	0.53	0.93	0.68	0.46	0.60	1.31	4.89	162.94	20.04	1.74	1.02	0.68
3	0.53	0.84	0.53	0.46	0.68	3.16	3.16	65.91	11.95	1.74	1.02	0.68
4	0.53	1.02	0.60	0.33	0.68	3.91	6.71	70.71	11.95	1.63	1.02	0.68
5	0.60	0.84	0.76	0.27	0.76	3.76	4.72	11.47	31.45	1.63	1.02	0.60
6	0.60	0.68	0.60	0.27	0.76	3.91	5.77	35.43	19.45	1.63	1.02	0.60
7	0.53	0.68	0.46	0.33	0.84	3.16	4.55	33.24	13.94	1.74	1.02	0.60
8	0.53	0.76	0.46	0.39	0.84	1.97	4.39	9.62	107.89	1.41	0.84	0.53
9	0.53	0.84	0.39	0.39	0.93	0.93	6.33	6.14	51.46	1.41	0.93	0.46
10	0.60	0.76	0.46	0.39	0.93	2.22	5.96	6.52	29.70	1.31	0.93	0.53
11	0.53	0.76	0.46	0.33	0.93	2.74	10.99	4.55	29.70	1.31	0.84	0.60
12	0.60	0.93	0.46	0.39	0.93	2.22	7.10	10.76	33.96	1.21	0.93	0.60
13	0.60	0.76	0.46	0.46	1.02	2.22	15.79	9.18	8.75	1.11	0.93	0.68
14	0.60	0.76	0.53	0.53	1.86	2.22	34.70	32.87	6.33	1.31	0.93	0.68
15	0.76	0.76	0.60	0.68	1.11	2.61	20.64	9.62	4.89	1.52	0.93	0.60
16	0.84	0.68	0.60	0.68	0.60	4.55	61.25	52.76	4.55	0.93	0.84	0.60
17	0.76	0.68	0.68	0.68	0.53	3.16	26.98	23.73	3.60	0.84	0.76	0.68
18	0.60	0.76	0.60	0.68	0.53	2.47	84.85	61.71	3.16	0.93	0.76	0.60
19	0.53	0.76	0.46	0.68	2.74	2.10	33.96	8.11	2.74	0.84	0.76	0.53
20	0.53	0.76	0.39	0.68	1.52	2.61	16.61	25.01	3.16	0.84	0.76	0.53
21	0.53	0.84	0.33	0.68	0.93	5.41	10.99	11.47	5.96	0.84	0.68	0.53
22	0.60	0.84	0.33	0.60	0.60	2.47	6.90	7.91	2.47	0.84	0.68	0.60
23	0.68	0.68	0.39	0.60	0.60	7.10	36.93	5.59	2.61	0.84	0.68	0.76
24	0.68	0.68	0.46	0.60	0.93	3.91	23.73	5.24	2.88	0.84	0.68	0.84
25	0.68	0.93	0.53	0.60	0.76	18.87	23.73	14.46	2.35	0.84	0.76	0.84
26	0.60	1.02	0.27	0.60	3.02	26.98	32.52	9.62	2.22	0.84	0.84	0.68
27	0.68	1.02	0.33	0.60	1.31	18.01	189.38	13.18	2.61	0.84	0.76	0.60
28	0.84	0.84	0.22	0.60	2.47	12.93	125.66	7.70	2.61	0.93	0.76	0.60
29	0.84	0.76	0.22	0.60	3.91	9.85	52.32	7.91	2.22	0.93	0.68	0.53
30	0.76		0.60	0.60	2.88	7.70	111.36	26.31	2.74	0.84	0.68	0.46
31	0.76		0.39		2.47		20.04	20.04		0.93		0.46
1985	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.60	0.84	0.68	-	0.93	1.52	2.10	49.33	36.93	6.71	1.41	1.31
2	0.60	0.84	0.60	-	0.76	1.52	2.61	28.32	27.98	6.52	1.31	1.21
3	0.60	0.84	0.60	-	0.76	1.41	4.39	41.17	16.61	5.77	1.31	1.31
4	0.60	0.84	0.60	-	0.68	1.52	4.89	93.37	12.68	4.89	1.31	1.41

5	0.68	0.84	0.60	-	0.84	1.52	3.76	157.57	26.98	4.39	1.21	1.52
6	0.76	0.84	0.60	-	2.22	1.52	2.10	19.45	25.01	3.76	1.21	1.52
7	0.76	0.84	0.60	-	7.30	1.63	3.31	23.09	30.04	3.60	1.11	1.63
8	0.76	0.84	0.53	-	9.40	1.63	3.31	113.11	53.19	3.60	1.02	1.63
9	0.76	0.84	0.53	-	27.31	1.74	3.31	64.50	44.77	3.91	1.02	1.52
10	0.68	0.93	0.53	-	6.33	1.74	3.16	105.61	40.39	3.91	1.02	1.52
11	0.68	1.11	0.53	-	3.60	1.74	3.60	65.91	44.36	3.91	1.02	1.63
12	0.76	1.11	-	-	2.74	1.63	5.24	94.46	29.35	4.07	1.02	1.63
13	0.84	1.11	-	-	1.97	1.63	5.96	114.87	5.77	3.91	1.02	1.63
14	1.02	1.11	-	-	1.52	1.63	5.59	165.65	4.23	3.76	1.11	1.63
15	1.02	1.11	-	-	1.21	1.63	5.24	91.75	8.11	3.60	1.11	1.63
16	1.02	0.93	-	-	1.11	1.63	5.77	39.22	10.07	3.45	1.11	1.52
17	0.93	0.93	-	-	1.02	1.63	8.54	26.31	8.11	3.31	1.11	1.52
18	0.84	0.93	-	-	1.11	1.74	8.75	48.91	17.44	3.16	1.21	1.63
19	0.93	0.84	-	-	1.21	1.74	8.75	44.77	20.34	2.88	1.21	1.63
20	1.02	0.76	-	-	1.11	2.35	9.18	43.96	16.61	2.61	1.11	1.63
21	0.93	0.76	-	-	1.31	1.86	10.76	32.87	21.85	2.35	1.11	1.52
22	0.84	0.84	-	-	1.31	2.22	10.53	64.03	21.24	2.10	1.21	1.63
23	0.93	0.84	-	-	1.31	2.22	13.94	105.61	17.73	1.97	1.31	1.52
24	0.84	0.76	-	-	1.21	1.86	13.69	54.06	12.93	1.86	1.31	1.52
25	0.84	0.76	-	-	1.21	1.86	18.29	101.09	10.30	1.74	1.11	1.52
26	0.84	0.76	-	-	1.21	1.86	29.01	48.07	9.62	1.63	1.11	1.41
27	0.84	0.76	-	-	1.21	2.22	21.85	20.04	8.54	1.63	1.21	1.41
28	0.84	0.76	-	2.10	1.21	2.35	16.61	27.65	8.11	1.52	1.21	1.41
29	0.84		-	1.74	1.21	2.22	101.09	12.93	7.50	1.41	1.31	1.41
30	0.84		-	1.11	1.41	2.10	55.83	16.88	7.10	1.52	1.21	1.41
31	0.84		-		1.52		73.16	25.66		1.52		1.41
1986	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1.41	1.21	1.21	1.86	2.10	0.84	3.91	18.29	29.01	3.91	3.16	0.68
2	1.31	1.21	1.86	2.35	1.31	0.76	4.55	13.18	11.47	4.89	3.16	0.68
3	1.31	1.31	2.74	5.77	2.35	0.93	9.62	16.88	9.40	4.23	3.16	0.68
4	1.31	1.21	5.06	7.50	2.10	0.84	10.53	26.64	8.11	4.23	3.02	0.68
5	1.21	1.21	2.88	6.71	1.97	0.84	9.18	16.61	9.62	4.39	3.02	0.68
6	1.21	1.21	2.22	5.06	1.21	0.84	10.30	19.45	23.73	4.72	2.88	0.68
7	1.21	1.31	2.10	4.89	1.11	1.02	10.07	13.69	17.16	4.89	2.74	0.68
8	1.31	1.21	1.74	6.90	1.11	0.84	11.47	38.45	68.78	4.89	2.61	0.68
9	1.41	1.21	1.74	2.47	1.02	1.31	10.76	59.42	33.24	4.89	2.61	0.68
10	1.31	1.11	1.74	2.47	1.31	1.74	10.07	22.47	25.66	4.89	2.35	0.68
11	1.31	1.11	1.74	2.61	5.96	2.10	10.99	17.73	24.04	4.89	2.22	0.68
12	1.31	1.11	1.63	2.61	1.74	2.10	9.85	15.25	12.68	4.89	2.10	0.68
13	1.21	1.11	1.52	2.88	1.31	1.74	4.89	16.88	23.73	4.89	2.10	0.60
14	1.21	1.11	1.52	7.91	1.86	2.74	4.39	19.75	13.18	4.89	1.97	0.60
15	1.21	1.11	1.52	1.74	1.97	1.63	3.76	22.16	27.65	4.89	1.86	0.60
16	1.21	1.02	1.63	1.41	1.31	2.10	3.16	27.31	30.39	5.59	1.74	0.60
17	1.21	1.86	1.74	1.11	1.31	1.86	3.02	39.22	10.76	3.91	1.63	0.60

18	1.21	1.74	1.86	1.11	1.31	2.47	3.02	31.45	10.30	3.91	1.52	0.60
19	1.21	1.41	3.76	3.76	1.41	6.33	3.31	29.01	8.54	4.07	1.41	0.68
20	1.11	1.41	2.47	2.47	1.31	10.30	6.14	19.16	7.10	4.23	1.41	0.68
21	1.02	1.31	3.31	1.74	1.52	6.14	9.18	23.73	9.18	4.39	1.31	0.68
22	1.02	1.21	2.61	1.63	1.74	4.89	5.96	22.16	12.68	4.72	1.21	0.68
23	1.11	1.21	2.47	1.02	1.21	4.07	9.18	18.29	5.59	4.39	1.21	0.68
24	1.02	2.88	1.97	1.21	1.21	5.06	16.88	55.83	11.70	4.07	1.11	0.68
25	1.02	1.31	1.86	4.55	1.02	3.91	12.68	38.45	11.95	3.91	1.02	0.68
26	1.02	1.86	2.10	1.74	0.93	3.45	11.23	17.16	4.55	3.91	0.93	0.68
27	1.02	1.21	1.97	1.63	0.93	4.23	9.40	27.98	3.91	3.76	0.93	0.68
28	1.11	1.11	1.86	1.74	0.93	11.47	10.76	11.47	3.60	3.60	0.84	0.68
29	1.11		1.74	5.77	0.93	10.53	10.76	29.70	3.91	3.60	0.84	0.68
30	1.11		1.74	1.63	0.93	6.14	67.82	48.49	4.07	3.45	0.76	0.68
31	1.11		1.86		0.93		25.01	41.17		3.31		0.68
1987	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.68	0.76	1.41	1.74	0.93	6.52	2.10	16.06	4.07	2.10	0.93	0.93
2	0.68	0.76	1.63	2.88	0.93	5.41	1.97	12.43	3.60	1.11	0.93	0.93
3	0.76	0.76	1.02	2.47	0.84	3.91	2.10	9.85	3.76	1.02	0.93	0.93
4	0.84	0.76	1.02	4.55	0.53	3.91	2.74	7.91	4.72	1.41	1.02	1.11
5	0.76	0.76	1.41	4.89	0.53	4.72	2.61	6.90	4.55	1.41	1.02	1.11
6	0.76	0.76	1.21	4.23	0.53	4.07	6.90	17.73	8.75	1.21	1.02	1.11
7	0.76	0.76	7.10	11.23	0.68	3.45	4.23	11.95	5.06	0.93	1.02	1.02
8	0.68	0.76	3.16	3.60	0.84	3.02	3.31	15.79	3.91	0.84	1.02	1.02
9	0.76	0.76	2.10	4.72	1.52	3.91	24.36	14.99	3.60	0.84	1.02	1.02
10	0.68	0.76	3.91	6.90	1.31	4.23	11.70	16.06	2.74	0.84	1.02	1.02
11	0.68	0.76	3.76	3.02	0.93	7.91	9.18	33.96	6.14	0.93	1.11	1.02
12	0.68	2.35	1.63	23.41	0.76	3.91	6.52	12.43	4.89	0.93	1.11	1.21
13	0.68	1.11	2.74	11.70	0.68	3.31	12.93	10.30	5.06	0.93	1.11	1.11
14	0.68	0.84	5.96	7.50	0.68	4.55	7.70	35.06	5.06	0.84	1.11	1.02
15	0.68	0.76	5.24	4.89	0.76	2.74	9.40	11.23	3.91	0.76	1.11	1.02
16	0.68	0.68	4.07	3.45	0.76	2.22	7.70	15.25	3.31	0.76	1.11	1.02
17	0.68	0.68	2.22	3.60	0.76	2.10	9.85	10.30	2.88	0.76	1.11	1.02
18	0.68	0.60	2.35	3.02	0.76	1.74	12.93	8.32	2.35	0.76	1.11	1.02
19	0.68	0.84	1.11	2.74	0.76	1.63	12.19	12.93	2.10	0.84	1.21	1.02
20	0.68	1.41	1.52	2.47	1.21	1.52	9.62	12.43	2.10	0.84	1.21	1.02
21	0.68	0.93	1.41	2.47	4.07	2.10	8.32	10.53	2.35	0.84	1.11	1.02
22	0.68	0.93	1.97	2.22	4.55	1.63	9.85	9.62	2.10	0.76	1.02	1.02
23	0.84	0.93	1.31	1.31	7.50	1.63	12.19	7.30	2.74	0.76	0.93	1.02
24	0.76	1.02	0.84	1.11	14.99	2.61	12.68	9.18	2.22	0.76	0.93	1.02
25	0.76	0.84	0.84	1.21	36.55	2.35	11.47	12.43	2.22	0.84	0.93	1.02
26	0.76	0.84	1.21	1.31	8.32	2.61	21.24	7.30	1.74	0.84	0.93	1.11
27	0.76	0.84	1.21	1.21	4.23	1.86	8.96	6.71	1.74	0.93	0.93	1.11
28	0.76	1.21	2.47	1.31	7.50	1.74	8.75	7.30	1.86	0.93	0.93	1.11
29	0.84		9.85	1.21	4.23	1.74	11.47	6.33	1.86	0.93	0.93	1.11
30	0.87		2.10	1.21	3.60	2.22	12.68	15.52	1.97	0.93	0.93	1.21

31 0.76 2.88 7.91 13.94 4.89 0.93 1.21

1988	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1.2	1.1	1.2	0.9	2.7	0.9	2.5	24.0	8.7	4.8	3.1	1.7
2	1.3	1.3	1.1	0.9	2.0	1.4	2.5	17.4	13.9	7.1	3.0	1.6
3	1.3	1.1	1.6	0.9	1.5	2.1	3.9	33.2	19.5	5.0	2.9	1.6
4	1.3	1.1	1.3	0.9	1.3	2.1	3.6	18.3	14.5	3.7	2.9	1.6
5	1.3	1.1	1.3	0.9	1.3	2.0	6.5	26.0	13.2	3.2	2.8	1.6
6	1.3	1.1	1.3	1.2	1.1	2.5	4.7	12.7	9.6	2.9	2.8	1.5
7	1.3	1.1	1.3	1.1	1.0	2.0	3.9	8.7	10.1	2.5	2.7	1.5
8	1.3	1.1	1.1	1.0	0.9	1.5	9.0	10.1	8.5	2.4	2.6	1.5
9	1.3	1.3	1.1	1.3	0.9	1.2	7.9	28.7	9.0	2.2	2.6	1.5
10	1.3	1.3	1.1	1.1	0.8	1.2	10.1	63.1	70.2	2.2	2.5	1.4
11	1.3	2.5	1.1	1.1	0.8	1.1	9.2	63.1	47.7	2.0	2.5	1.4
12	1.3	1.5	1.0	1.3	0.9	1.3	19.2	13.2	13.7	2.0	2.4	1.4
13	1.3	1.5	1.0	1.3	2.0	1.4	10.1	148.4	12.9	2.0	2.4	1.4
14	1.3	3.2	0.9	3.9	1.6	1.7	7.1	12.9	97.8	5.4	2.3	1.4
15	1.3	2.1	0.9	2.3	1.3	1.4	8.1	46.8	62.6	3.5	2.3	1.3
16	1.3	1.7	0.9	7.1	1.2	1.3	9.0	96.1	11.2	2.5	2.2	1.3
17	1.3	1.4	0.9	2.0	1.1	1.1	15.5	12.7	124.3	2.7	2.2	1.3
18	7.9	1.4	1.0	1.3	1.0	1.7	8.5	13.4	26.5	4.3	2.2	1.3
19	1.3	1.4	1.1	5.6	1.0	1.3	7.7	12.9	12.2	4.2	2.1	1.3
20	1.3	1.2	1.0	2.0	0.9	1.3	9.6	13.9	27.2	4.1	2.0	1.3
21	1.5	1.2	1.0	4.6	0.9	1.3	8.3	11.5	25.5	4.0	2.0	1.2
22	1.2	1.2	1.0	2.1	0.9	1.1	6.1	47.2	11.4	3.9	2.0	1.2
23	1.2	1.2	1.0	1.5	0.9	1.5	4.9	13.4	10.9	3.8	1.9	1.2
24	1.2	1.7	1.0	1.9	0.9	1.5	20.6	13.4	10.9	3.7	1.9	1.2
25	1.2	1.4	1.0	1.3	0.8	1.1	10.8	28.7	6.9	3.6	1.9	1.2
26	1.2	1.4	1.1	3.0	0.9	2.2	15.0	12.9	5.2	3.5	1.8	1.2
27	1.2	1.4	1.0	1.9	0.9	2.2	15.0	13.9	4.2	3.5	1.8	1.2
28	1.1	1.2	0.9	1.7	0.9	2.9	17.2	12.9	7.1	3.4	1.8	1.1
29	1.1	1.2	0.9	1.3	0.9	3.0	11.5	28.3	9.4	3.3	1.7	1.1
30	1.1		0.9	1.7	0.9	2.9	7.9	28.3	8.0	3.2	1.7	1.1
31	1.1		0.9		0.8		16.9	47.2		3.1		1.1
1989	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1.10	0.87	0.64	1.68	1.95	1.55	3.53	13.59	133.43	5.00	1.42	1.68
2	1.08	0.87	0.38	1.30	1.95	1.55	10.40	14.14	37.35	4.24	1.55	1.42
3	1.03	0.86	0.38	1.18	1.81	1.55	5.00	78.43	40.56	3.88	1.42	1.55
4	1.06	0.86	0.23	1.18	1.68	1.55	4.62	32.71	22.09	3.53	1.42	1.55
5	1.05	0.86	0.23	1.18	1.68	1.55	3.19	57.03	14.71	3.19	1.42	1.55
6	1.04	4.62	0.23	1.18	1.68	1.55	5.40	11.96	8.69	2.86	1.42	1.42
7	1.03	2.39	0.23	1.06	1.68	1.68	7.99	18.89	8.93	2.70	1.42	1.42
8	1.02	1.55	0.46	0.95	1.68	1.68	5.80	10.91	30.47	2.70	1.42	1.42

9	1.01	2.70	0.38	1.18	1.68	2.10	8.22	23.76	32.71	2.54	1.42	1.55
10	1.01	1.55	0.38	1.30	1.68	5.80	13.03	13.59	13.59	2.54	1.42	1.42
11	1.00	1.42	0.23	1.55	1.55	2.54	5.80	63.10	9.90	2.24	1.42	1.42
12	0.99	1.06	0.23	1.18	1.68	2.10	38.14	13.59	8.45	2.10	1.42	1.42
13	0.98	1.06	0.38	1.18	1.68	3.19	10.40	38.14	6.43	2.10	1.42	1.55
14	0.98	1.18	0.38	1.18	1.68	2.86	39.34	73.86	47.68	2.24	1.30	1.42
15	0.97	1.06	0.74	1.18	1.68	2.10	9.90	15.87	26.16	1.95	1.42	1.42
16	0.96	0.95	0.95	1.18	1.68	1.95	19.52	54.30	18.27	1.81	1.55	1.42
17	0.95	1.06	3.70	0.95	1.68	1.68	7.76	65.98	34.62	1.81	1.42	1.95
18	0.95	1.06	1.68	1.18	1.68	1.68	35.78	48.12	85.20	2.10	1.68	1.68
19	0.94	0.95	1.68	1.06	1.68	1.68	10.91	62.63	19.52	1.95	1.42	1.68
20	0.93	0.95	1.18	1.95	1.55	1.68	7.08	21.11	13.03	3.53	1.55	1.68
21	0.93	0.95	0.84	2.10	1.68	1.68	13.31	39.75	10.15	2.24	1.55	1.68
22	0.92	0.95	0.84	2.24	1.55	1.81	80.49	233.77	8.93	1.95	1.68	1.68
23	0.92	0.95	0.74	1.95	1.68	2.39	11.43	77.41	9.65	0.84	1.42	1.68
24	0.91	0.95	1.18	9.41	1.68	2.10	19.52	37.35	7.99	1.68	1.68	1.68
25	0.91	0.95	1.18	7.99	1.55	1.95	11.43	48.12	8.22	1.68	1.55	2.39
26	0.90	0.95	0.55	2.24	1.55	1.95	30.47	206.52	8.93	1.55	1.55	1.81
27	0.90	0.74	0.95	22.76	1.55	2.24	13.03	108.95	9.41	1.68	1.68	1.81
28	0.89	0.55	0.74	4.06	1.55	10.91	11.69	93.25	11.69	1.55	1.42	1.81
29	0.89		4.62	2.70	1.55	3.29	20.15	73.36	7.99	1.68	1.68	1.95
30	0.88		2.54	2.24	1.55	2.39	57.95	50.29	5.80	1.55	1.55	1.68
31	0.88		2.54		1.55		34.23	36.95		1.42		1.81
1990	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1.4	1.4	15.0	3.0	2.2	3.7	2.9	15.3	18.3	12.8	1.8	1.7
2	1.4	2.0	4.2	3.9	2.1	2.7	2.9	59.3	16.5	29.0	1.8	1.7
3	1.4	1.5	3.9	3.9	2.0	3.7	8.9	91.1	15.3	12.5	2.0	1.5
4	1.4	1.7	3.9	5.4	1.8	2.5	8.5	62.6	13.0	6.6	1.8	1.4
5	1.4	1.7	10.4	10.4	1.7	2.1	2.5	38.9	18.3	5.8	1.7	1.7
6	1.4	3.5	5.8	9.9	1.7	2.2	6.4	18.6	30.5	5.0	1.8	1.5
7	1.4	2.2	4.6	76.4	1.7	2.1	2.5	96.0	26.9	4.6	1.7	1.7
8	1.4	3.7	3.5	12.0	1.7	2.2	5.0	92.7	20.2	4.6	1.7	2.0
9	1.4	5.4	2.9	10.4	1.4	2.2	4.2	19.5	13.6	3.9	1.7	1.2
10	1.4	2.2	2.5	5.2	1.7	2.2	3.7	20.8	30.8	3.7	1.7	1.4
11	1.4	2.5	2.4	4.1	1.4	2.1	5.8	36.6	24.4	3.2	1.7	1.5
12	1.4	1.7	2.2	3.2	2.2	2.2	5.6	44.7	8.5	3.0	1.7	1.7
13	1.4	1.4	2.2	2.5	1.5	2.0	3.9	142.8	13.0	3.4	1.7	1.7
14	1.4	1.4	2.2	2.2	2.0	2.0	11.4	99.3	38.9	2.7	1.7	1.7
15	1.4	1.4	2.1	2.2	1.8	2.0	17.1	118.9	19.5	2.9	1.7	1.5
16	1.4	1.8	2.1	2.2	1.7	2.0	29.4	39.7	27.6	2.7	1.7	1.4
17	1.4	4.2	2.0	2.1	1.7	2.5	10.4	63.6	24.8	2.5	1.4	1.7
18	1.5	5.0	2.0	1.8	1.7	2.4	13.6	173.6	17.7	2.2	1.7	1.5
19	1.5	3.5	2.0	1.8	1.7	2.7	43.4	74.9	43.0	2.9	1.7	1.5
20	1.5	3.9	2.0	2.0	1.7	2.7	9.7	42.2	32.0	2.5	1.3	1.7
21	1.5	2.9	2.9	2.0	2.0	4.6	52.5	29.0	16.5	2.2	1.5	1.5

22	1.4	4.6	2.9	2.0	1.8	3.9	10.2	15.3	12.8	2.0	1.5	1.2
23	1.4	5.4	2.5	2.0	1.7	2.4	9.9	88.9	25.5	2.1	1.5	1.2
24	1.4	4.6	2.0	3.5	1.8	2.0	11.4	277.2	61.2	2.1	1.7	1.5
25	1.4	4.8	2.0	2.0	1.8	1.7	22.8	88.9	18.3	2.2	1.7	1.5
26	1.4	8.5	2.0	2.0	1.8	1.7	19.8	30.1	13.6	2.0	1.7	1.5
27	1.4	5.4	1.8	2.5	1.7	1.2	8.7	28.3	10.4	2.0	1.5	1.5
28	1.4	10.4	1.8	2.1	1.8	2.0	6.0	17.1	17.1	2.0	1.7	1.5
29	1.4		1.8	8.9	2.1	2.0	6.6	17.7	9.4	2.0	1.7	1.5
30	1.4		1.2	3.5	3.9	2.1	19.5	33.5	6.6	1.7	1.7	1.5
31	1.4		5.0		2.9		94.9	27.6		1.4		1.5
1991	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1.55	1.42	1.42	2.70	0.95	0.95	24.78	83.10	97.65	5.80	3.53	3.35
2	1.42	1.42	1.42	4.24	0.74	1.18	15.29	14.43	77.41	5.80	2.70	3.35
3	1.68	1.18	1.18	9.90	0.95	0.95	7.99	11.43	105.51	5.40	3.35	3.35
4	1.30	1.42	1.30	3.70	0.95	0.95	11.43	7.08	31.21	5.40	3.19	3.35
5	1.55	1.42	1.18	2.24	0.95	1.18	9.41	81.01	215.22	5.60	3.53	3.53
6	1.42	1.42	1.30	1.42	4.43	0.95	10.40	114.17	67.43	5.60	3.35	3.88
7	1.55	1.18	4.43	1.55	1.68	0.95	25.12	20.47	135.92	5.20	3.29	3.88
8	1.55	1.42	1.68	1.18	1.18	0.95	35.00	20.47	36.56	5.00	3.19	3.35
9	1.68	1.42	1.81	1.18	1.18	1.06	17.66	12.49	27.57	4.62	2.86	3.35
10	1.55	2.10	4.62	0.74	0.95	9.41	9.65	119.48	181.84	4.62	3.19	3.19
11	1.42	2.24	2.39	0.95	0.95	2.86	11.69	36.95	18.27	4.62	3.19	3.35
12	1.30	1.55	2.54	0.84	0.95	2.54	9.90	43.03	91.08	4.62	3.19	3.35
13	1.55	2.54	5.60	0.95	0.95	1.42	52.51	35.78	41.79	4.62	3.19	3.19
14	1.55	1.68	4.24	0.95	0.95	1.68	13.59	19.52	16.46	4.24	3.19	2.86
15	1.42	1.42	1.95	0.95	0.95	1.18	12.76	100.43	14.14	3.88	3.19	3.35
16	1.42	1.81	1.55	0.95	0.95	1.30	2.54	30.47	11.96	4.06	3.19	3.19
17	1.42	1.42	1.68	1.18	0.95	0.95	23.09	65.98	10.40	3.88	3.19	3.19
18	1.42	1.68	1.68	0.95	0.95	1.06	27.57	35.39	9.90	3.88	3.19	3.35
19	1.42	1.55	0.95	0.95	0.95	2.54	21.44	33.85	10.40	3.88	3.35	3.53
20	1.18	1.42	1.06	0.84	1.06	1.42	15.87	58.41	9.41	3.88	3.35	3.35
21	1.18	1.42	0.95	0.84	1.06	2.86	13.03	113.01	8.69	3.70	3.19	2.86
22	1.30	1.42	0.95	0.95	1.42	6.22	24.10	73.86	17.66	3.70	3.53	9.90
23	1.18	1.42	0.74	1.06	1.18	1.95	102.68	107.80	11.96	3.53	3.53	5.40
24	1.30	1.95	1.06	1.18	1.18	3.53	15.87	51.62	9.41	3.70	3.19	4.62
25	1.42	2.24	3.19	0.95	1.18	18.89	21.44	29.37	8.69	3.53	3.35	2.24
26	1.30	4.43	1.42	0.95	0.74	8.45	10.91	47.68	7.08	3.53	3.19	1.81
27	1.68	2.10	1.42	0.95	0.95	3.53	20.47	117.71	7.76	3.53	2.86	2.24
28	1.42	1.55	1.18	0.95	0.95	14.71	56.11	63.58	7.08	3.70	3.35	1.95
29	1.55		1.55	1.06	0.95	7.99	15.29	20.79	6.22	3.53	3.35	1.95
30	1.18		1.68	0.95	0.95	6.65	10.40	22.09	5.40	3.53	3.35	2.10
31	1.55		1.42		0.95		9.41	124.28		2.86		1.95
1992	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	2.24	2.70	2.10	2.54	1.95	1.68	9.41	36.56	16.16	4.81	2.39	2.24
2	1.95	3.88	2.54	2.70	2.10	2.24	6.01	13.03	16.46	4.81	2.24	2.10

3	2.10	3.35	1.95	2.39	2.10	1.95	5.60	12.49	19.83	4.43	2.24	2.10
4	2.10	8.69	2.10	2.39	2.24	1.68	8.22	84.15	34.62	3.88	2.24	2.10
5	2.70	7.31	1.95	2.10	1.68	1.68	28.29	60.27	106.65	3.88	2.24	2.10
6	2.24	6.65	1.95	1.95	1.68	2.24	13.86	57.03	30.84	3.88	2.24	2.10
7	2.24	7.08	1.95	1.95	1.68	2.54	10.15	36.95	51.18	3.70	2.24	2.10
8	2.24	3.53	1.68	1.68	3.88	3.19	13.31	17.96	53.40	5.80	2.24	2.10
9	2.24	3.88	1.81	1.95	2.86	2.54	13.86	65.02	98.20	3.88	2.24	2.24
10	1.95	3.35	1.68	1.81	2.70	3.19	12.76	70.37	22.09	5.60	2.24	2.24
11	2.24	4.24	1.68	1.68	2.10	2.24	5.60	30.84	40.56	12.76	2.10	2.10
12	1.68	3.19	1.68	1.68	2.24	2.54	7.76	33.47	20.15	7.08	2.10	2.10
13	1.95	2.54	1.68	1.55	2.24	3.35	6.86	17.05	52.51	4.43	2.10	2.10
14	2.24	2.39	1.68	1.55	2.10	2.70	13.59	43.03	87.86	3.53	2.10	2.10
15	1.95	2.24	1.55	1.68	1.55	2.24	13.86	21.77	34.23	3.19	2.10	2.10
16	1.81	2.10	1.68	2.24	1.55	1.55	7.53	20.15	15.00	3.19	2.10	2.10
17	1.81	2.10	1.68	2.70	1.55	1.95	8.93	24.10	13.86	3.70	1.81	2.24
18	1.81	1.95	1.68	1.81	1.55	2.10	6.22	80.49	10.91	3.35	1.81	2.24
19	2.10	2.10	1.68	1.68	2.10	1.55	13.59	33.85	17.66	3.35	1.81	2.24
20	2.54	1.95	1.55	1.68	2.54	1.68	13.03	18.89	153.07	3.35	1.81	2.24
21	3.70	1.95	1.68	1.95	2.10	1.55	9.90	17.05	24.78	3.35	1.81	2.24
22	3.70	2.10	1.68	1.68	1.81	1.55	13.31	16.46	13.03	3.35	1.81	2.10
23	3.70	1.95	1.68	1.68	1.68	1.68	14.14	83.62	9.41	2.86	1.95	2.10
24	3.70	1.95	1.68	2.10	1.68	1.95	11.43	20.15	7.76	2.86	1.95	1.95
25	1.95	1.95	1.68	2.39	2.24	1.81	13.03	17.66	6.65	2.86	1.95	1.95
26	6.01	1.95	1.68	3.19	3.88	4.62	12.49	15.87	6.01	2.86	1.95	2.10
27	4.62	2.10	1.68	2.39	3.53	4.24	11.43	112.42	5.20	2.70	1.95	2.10
28	2.70	1.95	1.95	2.86	2.24	5.00	52.06	68.41	5.40	2.54	1.95	2.10
29	2.86	1.95	2.70	2.10	1.95	3.53	12.49	73.86	5.00	2.54	1.95	2.24
30	3.88		2.39	2.10	1.81	4.24	14.43	37.74	4.81	2.54	1.95	2.24
31	3.19		2.10		1.81		42.20	16.46		2.54		2.24
1993	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	2.24	1.81	1.68	1.42	3.53	2.24	14.71	43.44	573.57	83.73	15.48	13.58
2	2.24	1.68	1.68	1.42	2.86	7.53	16.76	75.88	280.66	39.69	15.20	13.07
3	2.24	1.68	1.55	1.42	3.19	4.43	21.11	31.21	205.95	29.52	14.93	13.58
4	2.24	2.86	1.42	1.95	3.19	2.24	12.49	26.16	213.34	27.14	15.20	13.58
5	2.10	1.81	1.42	2.10	2.24	7.53	18.89	31.21	218.34	25.62	14.93	13.32
6	1.81	6.01	1.55	2.54	2.10	22.42	19.20	57.03	283.57	23.79	14.93	13.32
7	1.55	4.81	1.68	1.95	2.10	28.29	10.91	175.00	139.12	23.43	14.65	13.32
8	1.55	2.54	1.68	2.54	3.02	7.99	8.45	34.23	49.39	22.38	14.65	13.32
9	1.55	2.54	1.68	1.95	2.24	24.10	15.29	21.44	47.25	21.35	14.38	13.32
10	1.95	1.95	1.42	1.68	1.81	4.62	14.43	17.66	41.14	20.69	14.38	13.32
11	1.81	4.81	1.42	1.68	1.81	22.09	13.59	16.46	53.84	18.44	14.65	13.07
12	1.81	10.15	1.42	1.68	1.68	4.81	21.11	41.38	46.19	18.44	14.38	13.32
13	1.55	3.19	1.42	2.86	2.54	2.86	17.36	46.83	47.25	17.82	14.11	13.32
14	1.68	2.24	1.42	2.86	3.19	2.54	16.46	104.38	77.99	17.82	14.11	13.07
15	1.55	1.95	1.55	7.31	3.02	3.02	15.00	142.82	59.71	17.52	14.11	13.32

16	1.68	1.81	1.42	9.90	1.95	2.70	9.90	29.01	241.67	16.92	13.85	13.32
17	1.68	1.68	1.42	5.40	1.81	2.54	33.47	31.21	69.82	16.34	13.58	13.32
18	1.68	1.68	1.55	5.40	1.68	2.54	10.66	81.01	45.16	16.34	14.11	13.32
19	1.68	1.55	1.68	3.19	1.68	3.70	33.47	107.23	51.59	16.34	14.11	13.32
20	1.68	1.55	1.42	10.91	1.81	3.88	33.09	84.67	37.33	16.34	14.11	13.07
21	1.68	1.55	1.42	7.53	1.68	15.58	30.47	51.62	34.17	21.35	13.85	13.07
22	1.68	1.55	1.42	5.60	9.90	3.88	54.30	178.41	33.29	18.13	13.85	13.07
23	1.68	1.68	1.42	4.24	21.11	2.70	62.63	253.62	47.78	22.73	13.85	13.07
24	1.68	1.55	1.55	2.86	3.88	2.70	80.49	151.10	32.01	31.58	14.11	13.07
25	1.68	1.55	1.42	2.24	15.58	6.65	51.62	92.77	57.32	28.71	13.58	14.11
26	2.10	1.68	1.42	4.62	8.31	10.91	52.06	239.01	38.73	20.03	13.58	13.58
27	1.95	1.95	1.42	8.69	3.19	5.60	41.38	50.48	103.99	17.52	13.58	13.32
28	1.68	1.68	1.42	13.03	2.54	7.53	118.30	52.70	41.14	16.92	13.58	13.07
29	1.68		1.42	34.23	3.19	4.62	189.48	69.16	40.17	16.34	13.85	13.07
30	1.42		1.55	10.15	2.39	37.35	34.23	166.87	31.16	15.76	13.32	13.07
31	1.68		1.42		2.39		31.21	403.47		15.48		13.07

1994	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	12.81	12.07	12.07	11.83	13.85	16.34	19.71	55.56	113.31	11.11	8.51	8.12
2	12.81	12.31	12.07	11.83	14.38	14.11	35.06	31.58	41.14	10.65	8.51	8.12
3	12.81	12.07	12.07	12.07	12.56	12.81	21.35	32.43	82.27	10.65	8.51	8.12
4	12.81	12.31	12.07	12.07	12.56	13.58	41.14	99.09	114.18	10.43	8.32	8.12
5	12.81	12.07	12.07	11.83	12.07	16.34	19.38	44.13	43.62	10.43	8.32	8.12
6	13.07	12.07	12.07	11.83	11.83	14.11	36.41	28.71	48.31	9.98	8.32	8.12
7	12.81	12.31	12.07	12.31	12.31	13.85	24.15	32.01	55.56	9.77	8.32	8.12
8	13.07	12.56	12.07	12.07	12.07	13.07	21.35	30.75	35.50	9.77	8.51	8.12
9	13.07	12.31	12.07	12.07	12.14	15.48	61.53	97.49	24.51	9.55	8.32	8.12
10	13.07	12.07	14.93	11.83	32.86	15.76	49.93	51.03	18.44	9.55	8.51	8.12
11	12.81	12.07	12.31	11.83	25.62	15.20	24.15	82.27	16.63	9.55	8.92	8.12
12	12.81	12.31	13.58	11.59	17.22	14.65	21.69	43.12	15.76	9.34	8.51	8.12
13	12.81	12.07	20.69	11.59	14.93	21.02	21.35	28.71	14.11	9.13	8.51	8.12
14	12.81	12.07	13.07	11.59	13.07	16.63	16.92	52.70	13.07	9.13	8.51	8.12
15	12.81	12.07	12.81	11.59	12.31	14.65	30.34	162.58	12.56	8.92	8.32	8.12
16	12.56	12.07	12.31	11.59	12.07	23.43	29.52	69.16	12.56	8.92	8.32	8.12
17	12.56	12.07	12.07	20.69	13.07	19.07	19.38	34.61	13.07	9.13	8.32	8.12
18	12.56	12.07	12.31	24.88	12.56	15.76	24.15	33.73	12.31	8.92	8.32	7.93
19	12.56	12.07	12.07	15.76	12.56	14.38	34.17	26.38	11.83	8.72	8.32	7.93
20	13.07	12.07	12.07	13.58	12.07	14.11	83.73	45.67	31.58	8.72	8.12	7.93
21	12.56	12.07	12.07	15.20	12.07	14.38	27.14	35.50	14.93	8.72	8.32	8.12
22	12.56	12.07	12.07	13.85	11.83	13.07	30.34	49.93	18.44	8.72	8.32	7.93
23	12.56	12.07	12.07	13.07	12.07	12.56	41.14	39.21	139.12	8.72	8.32	7.93
24	12.56	12.07	12.81	13.58	12.07	14.65	43.12	28.71	68.50	8.51	8.32	7.93
25	12.56	12.07	19.38	12.56	12.07	31.58	27.92	26.00	24.15	8.51	8.32	7.93
26	12.56	12.07	15.20	14.11	11.83	21.02	42.12	139.12	17.52	8.32	8.32	7.93
27	12.56	12.07	13.32	14.65	12.07	17.52	121.28	39.69	15.20	8.32	8.32	8.12
28	12.56	12.07	12.81	14.38	11.83	15.20	83.00	29.93	13.58	8.51	8.32	7.93

29	12.56		12.07	12.81	11.83	15.20	49.93	35.50	12.56	8.51	8.32	8.12
30	12.56		12.07	12.56	11.83	18.44	49.93	48.31	12.07	8.51	8.12	7.93
31	12.56		12.07		11.59		41.14	115.93		9.34		7.93
1995	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	7.93	7.93	8.32	7.73	8.92	8.12	27.92	42.62	124.92	10.20	7.73	7.55
2	7.93	7.93	8.12	7.73	8.51	8.12	10.65	45.16	46.72	9.55	7.93	7.55
3	8.12	8.12	8.12	8.12	7.36	7.93	12.07	52.14	20.69	9.34	7.93	7.55
4	8.12	8.12	7.73	8.12	8.12	7.73	22.38	67.20	32.43	9.34	7.55	7.55
5	8.12	8.12	8.12	10.20	8.51	7.73	9.77	65.28	33.73	9.13	7.73	7.55
6	7.93	8.12	7.73	9.77	9.13	7.73	10.65	26.38	37.33	8.92	7.55	7.73
7	7.93	8.12	7.73	12.07	9.13	7.73	19.07	57.32	32.86	8.92	7.73	7.73
8	7.93	24.88	8.12	11.83	8.51	7.55	10.88	193.98	34.61	8.72	7.55	7.55
9	8.12	11.11	8.12	10.43	8.12	7.73	9.77	210.86	17.22	8.72	7.73	7.55
10	8.12	9.55	8.92	8.72	8.12	7.73	18.13	162.58	15.48	8.51	7.73	7.73
11	8.12	8.92	11.11	8.51	8.32	7.73	21.69	43.12	14.11	8.51	7.55	7.73
12	7.93	8.32	11.59	14.38	8.12	8.12	12.81	92.77	13.32	8.51	7.73	7.73
13	7.93	8.92	8.51	8.92	40.17	7.73	11.59	33.29	12.56	8.32	7.55	7.73
14	7.93	16.63	8.12	8.32	8.92	7.73	12.07	115.93	12.07	8.51	7.73	7.73
15	7.93	8.72	8.12	18.75	8.51	7.73	53.84	88.18	11.59	8.51	7.73	7.73
16	7.93	18.75	7.73	10.20	8.12	7.73	15.20	105.65	11.83	8.32	7.36	7.73
17	7.93	8.72	7.73	11.11	8.12	8.12	24.15	32.01	17.82	8.12	7.36	7.73
18	7.93	8.12	7.73	14.65	10.43	8.12	28.71	257.98	77.99	8.12	7.36	7.73
19	7.73	8.12	7.73	9.98	8.32	8.32	27.14	44.13	41.14	8.12	7.73	7.73
20	7.93	8.12	7.73	9.34	9.34	8.12	21.35	32.01	20.36	8.12	7.55	7.73
21	7.73	7.73	13.32	8.92	8.32	8.51	13.32	26.76	24.15	8.12	7.73	7.73
22	7.73	7.73	15.76	8.51	7.93	8.51	16.92	26.38	16.34	8.12	7.73	7.73
23	8.12	7.73	9.13	8.51	7.73	8.12	27.92	32.86	19.07	7.73	7.36	7.73
24	8.12	7.73	8.51	40.17	7.73	9.98	20.69	37.33	16.34	7.73	7.55	7.73
25	8.12	7.73	8.12	12.07	7.73	8.92	17.22	67.85	13.07	7.93	7.55	7.73
26	7.93	7.73	7.73	12.56	7.73	24.15	42.12	42.12	12.07	7.73	7.55	7.36
27	7.93	7.73	7.73	11.59	7.73	9.77	21.02	79.40	11.59	7.73	7.55	7.36
28	7.93	7.73	7.73	16.63	7.73	9.77	38.26	138.14	11.11	7.93	7.55	7.36
29	7.12		7.73	9.13	8.32	33.29	35.96	41.63	10.65	7.73	7.55	7.36
30	7.93		7.93	8.51	9.34	14.93	30.34	23.43	10.20	7.73	7.55	7.36
31	7.93		7.73		8.51		27.14	23.43		7.73		7.36
1996	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	7.36	7.36	7.00	7.73	7.36	8.51	11.11	121.28	77.99	30.34	19.38	18.75
2	8.92	7.36	7.00	7.36	7.18	12.56	10.65	196.34	67.20	29.11	19.38	18.75
3	8.12	7.00	7.36	7.36	7.00	8.12	8.92	37.33	103.16	27.92	19.38	18.75
4	8.92	7.00	7.00	7.36	7.00	7.93	28.71	34.61	47.78	27.14	19.38	18.75
5	8.51	7.00	7.00	7.00	7.00	18.44	24.88	31.16	63.39	26.00	19.38	18.75
6	7.73	7.00	7.00	7.36	6.82	37.33	10.65	365.32	95.90	25.62	19.38	18.44
7	7.36	7.00	7.00	8.51	6.64	14.11	11.59	310.54	53.27	24.88	19.07	18.75
8	8.12	7.00	8.51	14.11	7.93	10.20	28.71	358.61	44.64	24.88	19.38	18.75
9	7.73	7.00	8.92	9.98	15.48	13.85	26.00	115.05	129.56	24.51	18.75	19.07

10	7.73	7.00	8.12	7.93	8.12	39.21	80.12	490.24	161.52	24.15	18.75	18.44
11	7.73	7.00	8.92	7.55	8.12	71.81	26.38	392.85	85.94	23.43	18.75	18.13
12	7.36	7.00	13.07	7.36	8.12	13.07	65.28	392.85	56.14	23.08	18.75	18.44
13	7.36	7.00	8.51	7.55	26.00	48.31	181.27	283.57	46.19	22.73	18.75	18.13
14	7.36	7.00	8.12	7.55	31.16	30.34	196.34	160.46	49.39	22.38	19.07	18.13
15	7.36	7.00	8.51	8.12	12.31	130.49	59.10	220.86	40.65	22.04	18.75	18.13
16	7.36	7.00	9.34	13.58	8.92	36.41	41.14	134.29	71.14	21.69	19.07	18.44
17	7.55	7.00	8.51	8.32	9.55	18.75	277.76	77.99	160.46	21.69	19.07	18.44
18	7.36	7.00	10.65	8.32	18.13	22.73	66.56	85.20	59.10	21.35	19.38	18.13
19	8.12	7.00	7.73	7.93	9.34	32.86	82.27	615.76	53.84	21.69	19.38	18.13
20	7.73	7.00	9.34	9.77	10.20	71.81	202.32	554.17	60.92	21.35	19.38	18.13
21	7.73	7.00	7.36	7.73	7.73	13.58	42.12	235.06	53.84	21.02	19.38	18.13
22	7.73	7.00	7.36	7.36	7.55	34.61	56.14	201.11	40.65	20.69	19.07	17.82
23	7.36	7.00	7.36	7.36	8.12	18.44	298.38	130.49	89.70	20.69	19.38	17.82
24	7.55	7.00	7.36	7.36	7.36	47.25	150.08	173.43	71.14	20.69	19.38	17.82
25	7.55	7.36	7.36	7.00	7.73	16.92	33.73	63.39	69.16	20.69	19.71	18.13
26	7.55	7.00	9.34	7.00	7.36	31.16	343.78	59.10	36.41	20.36	19.71	17.82
27	7.36	7.36	15.76	23.43	7.36	32.86	103.99	51.03	33.73	20.36	19.38	18.13
28	7.36	7.00	8.92	9.77	7.36	12.07	33.73	69.82	31.58	20.03	19.38	17.82
29	7.36	7.00	8.12	8.51	7.36	10.20	309.01	45.67	31.16	19.71	18.75	18.44
30	7.36		8.12	7.36	20.36	32.01	45.16	214.58	30.34	20.03	18.75	18.13
31	7.36		7.73		8.72		41.14	63.39		19.38		17.82
1997	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	17.82	17.22	16.34	16.92	14.38	17.52	26.76	25.25	22.04	13.07	13.07	12.07
2	17.52	17.52	16.34	16.63	14.65	16.63	17.22	42.62	20.69	12.81	12.81	11.59
3	17.82	17.52	16.05	16.34	14.11	14.93	21.35	54.41	33.29	12.81	12.81	11.59
4	17.82	16.92	16.05	16.92	13.58	14.11	17.52	42.12	35.96	12.31	12.07	11.59
5	17.82	16.92	16.34	16.34	14.38	14.11	16.92	61.53	33.29	12.56	12.07	11.59
6	17.82	16.92	16.34	15.20	14.11	14.65	47.78	75.90	32.86	12.56	12.07	11.83
7	17.82	16.92	16.34	16.05	14.11	14.11	55.56	57.91	32.86	12.81	11.83	11.59
8	18.13	16.34	16.34	16.92	14.11	14.11	23.43	53.27	59.10	12.31	11.83	11.59
9	18.13	16.34	16.34	16.34	13.85	14.11	67.20	33.73	26.76	12.31	11.83	11.59
10	17.82	16.34	16.34	15.48	14.11	13.85	24.88	43.62	21.69	12.31	11.83	11.59
11	17.52	16.34	16.34	15.20	13.85	13.58	30.75	67.20	19.38	12.31	11.83	11.59
12	17.52	16.63	16.34	14.65	13.85	14.11	23.43	44.64	18.75	12.07	11.59	11.59
13	17.52	16.34	16.05	14.65	13.85	14.11	22.04	62.15	18.75	11.83	15.76	11.59
14	17.52	16.34	16.34	14.65	14.11	14.11	20.03	38.26	18.75	11.83	13.07	11.59
15	17.52	16.34	16.34	14.11	13.58	17.52	23.43	112.44	48.85	11.83	13.07	11.59
16	17.82	16.34	15.76	14.11	13.58	15.76	83.73	79.40	25.25	12.07	12.81	11.59
17	17.82	16.34	16.05	14.11	14.65	14.65	30.34	276.32	39.69	12.07	13.07	11.59
18	17.52	16.34	15.76	14.11	14.65	16.05	26.38	129.56	22.04	24.88	12.81	11.59
19	18.13	16.05	15.76	14.11	14.38	14.65	23.43	92.00	19.38	30.34	13.07	11.59
20	18.44	16.05	15.76	14.11	14.38	17.52	32.86	36.87	18.75	17.82	12.31	11.59
21	19.07	16.34	16.05	17.52	14.11	24.88	52.70	36.41	18.75	14.93	12.07	11.59
22	19.07	16.34	15.76	22.04	14.11	23.79	45.16	34.61	18.44	14.93	17.82	11.59

23	26.38	16.34	15.76	17.52	13.85	14.93	33.73	35.50	16.92	13.85	15.48	11.59
24	20.36	16.34	16.92	16.92	13.58	15.20	78.70	33.73	15.76	13.07	12.81	11.59
25	18.13	16.34	16.34	15.48	14.11	17.52	29.93	52.70	14.65	13.07	12.56	11.59
26	18.13	16.34	19.38	15.48	13.58	18.75	36.87	49.39	14.38	13.07	12.07	11.35
27	19.71	16.05	17.52	16.92	13.85	16.92	54.98	152.12	14.65	14.11	12.07	11.59
28	18.13	16.34	16.92	16.34	13.85	23.43	47.25	39.21	14.11	14.38	12.81	11.59
29	17.52		16.63	15.20	13.58	36.41	64.02	29.11	13.85	14.38	12.56	11.59
30	17.22		17.52	14.65	13.58	31.16	83.00	24.88	13.32	14.65	12.07	11.59
31	17.52		16.92		25.25		32.86	24.15		14.11		11.35

1998	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	11.59	11.35	11.59	10.88	12.56	17.52	20.69	166.87	99.09	20.03	18.75	15.76
2	11.59	11.35	11.83	11.11	11.11	16.34	18.75	114.18	79.40	20.03	18.75	15.76
3	11.59	11.11	11.59	11.11	52.70	13.32	16.92	208.40	99.09	33.73	18.75	15.76
4	11.83	11.59	16.34	11.11	37.79	35.06	17.52	95.90	94.33	21.69	18.75	15.76
5	11.59	11.11	16.63	11.11	17.82	14.93	15.48	62.77	213.34	21.35	17.52	15.76
6	11.35	11.35	13.85	11.11	13.58	13.07	15.48	62.77	269.18	20.36	17.52	15.76
7	11.59	11.35	13.85	11.11	13.58	12.31	18.44	57.32	316.73	22.38	17.22	15.76
8	11.59	11.11	13.07	11.11	13.85	15.20	40.17	228.54	78.70	21.35	17.22	15.76
9	11.35	11.35	15.20	11.11	13.58	16.92	39.21	361.96	46.72	37.33	17.22	15.76
10	11.59	11.11	12.56	11.11	12.07	14.65	18.75	330.89	36.41	134.29	16.92	15.48
11	23.43	11.11	12.07	16.92	12.07	12.07	37.33	160.46	203.52	82.27	16.92	15.76
12	15.20	11.35	11.83	15.20	11.59	16.05	67.20	152.12	59.71	48.85	16.92	15.48
13	17.52	13.32	11.59	12.56	20.69	12.81	27.14	143.05	47.25	31.16	16.92	15.76
14	15.20	11.83	11.59	11.35	54.98	13.32	101.52	201.11	123.09	24.88	16.63	15.76
15	13.58	11.59	11.35	12.81	71.81	12.81	28.71	136.21	95.90	28.71	16.92	15.76
16	12.56	16.63	11.59	11.59	26.38	13.07	25.62	39.69	48.31	26.00	16.34	15.76
17	12.31	11.59	11.11	12.56	18.13	12.56	277.76	76.59	46.19	30.75	16.34	15.76
18	12.07	27.53	11.35	12.56	14.38	17.22	48.31	210.86	35.50	22.73	16.63	15.76
19	12.07	11.35	11.35	12.31	13.32	13.07	158.35	138.14	28.71	20.69	16.34	15.76
20	12.07	14.11	11.35	12.56	12.56	12.81	214.58	46.19	27.14	20.03	16.34	15.76
21	11.83	13.07	11.35	12.56	12.56	13.32	94.33	52.14	26.76	20.03	16.34	15.76
22	11.83	11.83	11.35	19.07	12.81	16.34	91.23	47.25	77.29	20.03	16.34	16.05
23	11.59	11.59	11.35	13.58	13.32	17.52	49.39	183.54	31.16	29.11	16.34	15.76
24	11.59	11.59	11.59	12.07	12.56	45.16	46.19	114.18	31.16	20.69	16.34	16.05
25	11.35	11.35	11.11	12.31	14.93	33.29	39.21	421.52	24.15	19.38	16.34	16.05
26	11.35	11.11	10.65	14.93	11.83	17.22	35.50	65.92	24.15	19.07	15.76	16.05
27	11.11	11.35	10.88	13.58	11.83	21.35	29.93	164.72	22.04	18.75	14.65	16.34
28	11.35	12.56	11.11	12.56	12.07	18.13	88.18	88.18	22.38	18.75	15.20	16.05
29	11.35		10.88	11.59	11.59	21.35	43.12	150.08	24.88	18.44	15.76	16.05
30	11.35		10.88	11.35	11.59	22.38	57.32	97.49	21.35	18.75	16.05	16.05
31	11.35		10.88		13.58		183.54	137.17		18.75		16.34
1999	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	16.05	15.20	14.93	15.76	15.76	18.13	17.82	52.70	31.98	2.77	5.38	3.56

2	16.34	15.20	15.20	15.20	15.48	40.17	132.38	33.73	11.73	2.99	5.22	3.44
3	16.34	14.93	17.22	14.93	15.20	19.38	26.38	309.01	14.02	5.38	4.62	3.32
4	16.34	14.65	15.48	14.65	14.93	18.13	64.65	232.44	20.98	4.48	4.34	3.44
5	16.34	14.65	17.52	14.65	15.20	15.76	25.62	157.30	14.02	3.32	4.20	3.56
6	16.34	15.20	15.76	14.65	14.65	15.76	48.85	93.55	14.02	2.57	3.93	3.32
7	16.34	15.20	18.13	14.65	14.65	15.20	46.19	138.14	16.58	2.20	3.81	3.21
8	16.34	15.20	18.75	14.65	14.38	15.20	41.63	54.98	15.26	5.07	3.68	3.21
9	16.05	15.20	20.36	15.20	14.65	15.20	89.70	102.34	14.02	8.15	3.68	3.21
10	16.34	15.20	16.34	15.20	14.65	14.65	83.73	518.57	12.28	14.63	5.70	3.09
11	16.34	15.20	16.34	14.65	14.65	15.76	48.85	584.51	11.73	10.19	6.04	3.09
12	16.34	15.20	15.20	14.65	14.65	15.76	129.56	693.10	10.69	8.80	5.54	3.09
13	16.34	15.20	15.20	15.20	14.93	16.63	30.75	266.40	10.19	5.38	5.07	3.09
14	18.13	14.93	15.48	14.65	14.65	22.73	25.62	453.51	9.48	5.07	4.62	1.43
15	16.34	14.93	16.34	14.65	14.65	20.69	80.12	99.31	9.02	7.14	4.48	4.20
16	16.63	14.65	16.34	14.65	14.65	16.92	62.77	524.48	8.58	7.94	4.20	3.68
17	16.34	14.65	15.48	14.38	14.65	15.76	26.38	44.96	8.15	6.22	4.07	3.32
18	16.05	15.20	15.20	15.48	14.65	15.20	138.14	31.46	7.94	5.07	3.93	3.09
19	15.76	15.20	15.20	18.13	14.38	15.76	43.12	26.10	19.44	7.53	7.14	2.99
20	16.05	14.93	15.20	15.20	14.65	18.75	65.28	11.20	50.43	5.70	7.94	2.99
21	15.76	14.93	15.20	14.65	14.93	19.38	129.56	11.73	14.32	4.76	6.76	2.99
22	15.76	14.93	14.93	14.65	15.48	20.03	122.18	12.00	20.98	4.20	6.04	2.99
23	15.76	14.65	14.65	14.65	15.20	20.03	35.50	83.50	5.07	3.93	5.54	2.99
24	15.76	14.93	15.20	14.65	15.20	18.44	92.77	35.23	3.93	3.68	5.07	2.99
25	15.20	14.93	14.65	14.65	15.76	40.17	52.14	57.09	3.32	3.68	4.62	2.99
26	15.20	14.65	14.65	14.65	16.92	18.75	80.83	11.20	2.77	3.44	4.20	2.99
27	15.20	14.93	14.93	14.65	16.92	26.00	48.31	25.19	2.20	3.44	3.93	2.88
28	15.20	15.20	14.93	14.65	16.63	43.12	55.56	39.90	1.79	3.81	3.93	4.48
29	15.20		16.63	14.65	16.05	37.33	111.58	44.96	1.57	4.20	3.81	6.76
30	15.20		15.76	17.52	15.76	20.03	80.83	235.38	1.57	3.93	3.68	3.09
31	15.20		15.48		16.34		60.92	114.54		3.93		2.67
2000	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	2.38	2.29	1.57	3.21	4.20	2.29	6.40	21.78	10.69	6.76	2.38	1.87
2	2.20	2.20	1.57	3.21	3.68	2.29	6.04	6.95	11.20	5.07	2.38	1.87
3	1.95	2.12	1.50	3.21	3.68	2.38	4.20	6.76	9.71	13.42	2.38	1.87
4	1.79	2.03	1.50	3.21	3.68	5.07	3.44	6.22	7.94	12.84	2.38	1.87
5	1.64	1.95	1.43	3.21	7.53	3.21	3.21	7.53	7.14	5.07	2.29	1.87
6	1.50	1.87	1.43	3.21	15.26	3.81	5.07	65.16	7.14	3.93	2.29	1.79
7	1.43	1.87	1.43	3.21	5.70	2.99	40.51	82.51	5.54	3.68	2.29	1.87
8	1.37	1.87	1.43	3.21	0.82	2.77	3.93	7.14	5.70	3.32	2.29	1.87
9	1.31	1.87	1.43	3.21	20.20	4.20	3.56	13.42	6.04	3.21	6.04	1.87
10	1.31	1.79	1.43	3.09	8.36	3.44	9.48	15.26	6.40	3.44	3.21	1.87
11	1.31	1.72	1.43	3.09	5.07	2.99	4.20	53.32	6.40	3.32	2.57	1.87
12	1.24	1.72	2.67	3.09	3.68	4.48	10.69	7.53	4.20	3.21	2.38	1.87
13	1.24	1.64	2.67	2.99	3.09	2.77	33.04	150.96	5.54	2.88	2.38	1.87
14	1.72	1.64	2.57	2.99	2.77	2.67	15.91	120.78	5.38	2.77	2.29	1.79

15	2.20	1.57	2.57	2.99	2.67	2.77	4.20	12.28	5.54	2.77	2.20	1.87
16	2.77	1.57	2.57	3.21	2.57	2.77	3.93	27.02	36.94	2.77	2.20	1.87
17	4.62	1.57	2.57	3.21	2.48	3.44	14.63	12.84	7.94	2.77	2.20	1.79
18	6.40	1.57	2.57	3.21	2.38	2.77	12.00	99.31	6.95	2.67	2.20	1.79
19	5.38	1.50	2.48	6.58	2.29	5.70	8.80	161.52	30.95	2.77	2.20	1.79
20	4.76	1.57	2.48	17.97	2.29	2.88	6.40	106.16	17.26	3.09	2.20	1.72
21	4.20	1.87	2.48	9.25	2.20	5.87	4.20	24.31	19.44	2.77	2.12	1.72
22	3.81	1.79	2.48	5.38	2.20	3.21	35.23	75.80	44.96	2.57	2.03	1.79
23	3.56	1.79	2.48	4.34	2.20	3.21	24.31	216.10	11.73	2.57	2.03	1.72
24	3.32	1.72	2.38	3.93	2.12	3.56	21.78	255.78	4.76	2.57	1.95	1.72
25	2.99	1.72	2.77	3.39	2.12	6.40	15.26	128.57	4.91	2.57	2.03	1.79
26	2.77	1.64	2.77	3.21	2.12	5.70	12.84	180.76	5.54	2.57	1.95	1.72
27	2.77	1.64	2.77	2.99	2.38	9.71	6.04	30.95	7.33	2.57	1.95	1.95
28	2.77	1.57	2.77	3.68	2.20	6.58	5.07	57.09	30.95	3.81	1.87	1.79
29	2.67	1.57	2.77	3.68	2.12	5.54	51.14	49.02	46.29	2.57	1.87	1.87
30	2.38		2.77	5.38	2.12	2.99	21.78	118.26	16.58	2.57	1.95	1.87
31	2.29		2.77		2.12		6.95	82.51		2.38		2.03
2001	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1.6	1.6	1.5	2.0	2.6	3.2	2.5	403.3	8.4	3.1	1.9	1.8
2	1.7	1.6	1.6	2.0	2.2	2.3	10.0	435.3	135.3	3.1	1.9	1.7
3	1.8	1.6	1.6	1.9	2.4	2.0	5.4	142.3	12.0	3.0	1.9	1.9
4	1.7	1.6	1.6	1.8	2.0	1.9	51.9	61.0	43.7	2.8	1.9	1.8
5	1.7	1.6	1.6	1.7	3.1	2.0	99.3	28.9	18.3	2.8	1.9	1.7
6	1.7	1.6	1.7	1.6	3.4	4.5	5.7	21.0	11.7	2.8	1.9	1.9
7	1.7	1.6	2.6	1.6	2.3	2.6	5.7	11.7	114.5	2.7	1.9	1.7
8	1.7	1.6	2.2	1.6	2.0	2.3	3.9	13.7	18.3	2.7	1.9	1.7
9	1.7	2.4	2.0	1.6	2.0	2.8	5.4	21.8	9.2	2.4	1.9	1.8
10	1.8	1.9	9.5	1.6	2.8	2.6	5.4	172.6	7.5	2.4	1.9	1.8
11	1.8	1.9	5.7	1.5	3.9	4.5	10.7	106.2	5.9	2.4	1.9	1.8
12	1.7	1.7	3.7	1.5	21.0	6.8	10.2	96.0	4.6	2.3	1.8	1.9
13	1.9	1.6	4.6	1.4	3.7	32.0	27.0	194.4	5.1	2.2	1.8	1.9
14	1.7	1.6	2.7	1.4	3.3	6.4	26.1	216.1	5.4	2.2	1.9	1.8
15	1.7	1.6	2.4	1.6	5.5	9.2	43.7	42.4	5.2	2.1	1.9	1.8
16	1.7	1.6	2.1	1.6	4.2	2.6	7.5	41.1	18.3	2.1	1.9	1.8
17	1.7	1.6	2.0	1.4	2.6	3.7	14.0	76.7	18.3	2.1	1.9	1.8
18	1.7	1.6	2.0	1.4	2.1	12.0	118.3	107.3	3.4	2.2	1.8	1.8
19	1.7	1.6	5.1	1.4	2.0	6.6	237.4	27.5	3.9	2.1	1.9	1.8
20	1.7	1.6	2.2	1.4	1.9	19.8	383.7	51.9	3.7	2.0	1.9	1.7
21	1.7	1.6	1.9	1.6	1.9	5.7	113.3	67.7	3.4	2.0	1.9	1.8
22	1.7	1.6	1.9	1.8	1.7	4.2	30.9	9.5	3.3	2.0	1.9	1.8
23	1.7	1.6	1.7	14.9	1.7	3.8	11.5	9.2	3.3	2.0	1.9	1.8
24	1.7	1.6	2.2	1.7	1.7	9.2	229.5	9.7	3.2	2.0	1.9	1.8
25	1.6	1.6	2.0	1.6	1.6	12.0	15.3	7.9	3.2	2.4	2.1	1.8
26	1.6	1.6	3.7	1.4	2.0	6.9	136.7	16.6	3.0	2.0	1.8	1.9
27	1.6	1.6	2.6	1.4	3.2	4.3	47.6	7.1	3.0	2.0	1.9	1.7

28	1.7	1.6	2.5	1.5	1.9	3.4	196.1	13.7	3.0	2.0	1.8	1.9
29	1.7		4.1	2.7	2.8	4.1	33.6	45.6	2.8	1.9	2.0	1.8
30	1.7		6.4	5.7	2.8	5.5	18.7	29.4	3.0	1.9	1.7	1.9
31	1.7		2.9		7.5		42.4	8.4		1.9		1.9
2002	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1.87	1.57	1.43	1.72	1.43	1.50	3.81	9.71	11.73	2.12	1.43	1.50
2	1.87	2.48	1.43	1.72	1.43	1.64	2.99	105.00	6.76	1.95	1.43	1.43
3	2.99	1.64	2.38	1.43	1.43	1.72	3.81	8.36	10.69	1.87	1.43	1.43
4	2.77	1.57	2.38	1.50	1.50	1.57	2.67	9.25	37.52	1.87	1.43	1.43
5	2.48	1.50	8.15	15.58	1.50	2.03	2.57	6.22	52.59	1.79	1.43	1.43
6	2.03	1.57	2.67	4.20	4.20	1.72	5.38	21.38	6.58	1.87	1.43	1.50
7	2.20	1.57	2.29	2.20	2.57	1.72	2.77	76.74	10.95	1.87	1.43	1.50
8	2.03	1.57	1.87	1.87	2.38	1.72	2.38	11.47	9.71	1.72	1.43	1.57
9	1.87	1.57	1.79	1.79	1.72	1.79	3.68	6.95	6.58	1.72	1.43	1.50
10	1.87	1.57	1.72	2.12	2.03	1.72	7.53	9.71	4.48	1.72	1.43	1.50
11	1.87	1.57	1.72	2.12	1.64	5.54	4.91	14.94	3.68	1.72	1.43	1.50
12	2.20	1.50	1.79	1.87	1.57	3.44	12.56	7.53	5.07	1.64	1.43	1.57
13	2.38	1.50	1.64	1.72	1.57	1.95	12.56	14.32	6.76	1.64	1.43	1.50
14	2.03	1.50	1.57	1.87	1.43	6.22	4.48	9.71	10.95	1.57	1.43	1.50
15	1.95	1.43	1.57	2.03	1.43	4.48	5.38	53.32	14.02	1.57	1.43	1.50
16	1.87	1.57	3.68	1.87	1.57	3.44	3.44	9.95	10.69	1.57	1.43	1.57
17	1.87	1.72	2.77	1.72	1.79	8.80	2.67	12.28	6.04	1.50	1.43	1.57
18	1.87	1.72	2.20	6.58	1.57	8.15	10.44	15.91	5.54	1.50	1.43	1.57
19	1.79	2.03	1.87	2.38	1.72	3.21	17.97	25.19	4.48	1.57	1.43	1.57
20	1.79	2.38	1.72	1.87	1.87	2.77	14.02	22.60	3.68	1.50	1.43	1.57
21	1.72	2.29	1.72	1.79	1.79	4.20	6.04	13.13	3.44	1.50	1.43	1.95
22	1.72	2.57	1.72	1.72	2.03	10.44	4.48	29.93	2.99	1.50	1.43	1.72
23	1.72	2.03	1.64	1.57	2.12	2.57	9.25	27.97	2.77	1.50	1.43	1.72
24	1.72	1.43	1.72	3.93	1.87	6.58	7.94	8.36	3.09	1.43	1.43	2.57
25	1.72	1.50	1.64	1.50	2.67	2.03	12.28	71.24	2.77	1.50	1.43	1.79
26	1.64	1.50	1.57	1.43	1.79	2.03	91.71	8.80	2.57	1.43	1.43	1.57
27	1.72	1.43	1.72	1.57	1.72	1.87	18.69	5.54	2.48	1.43	1.43	1.57
28	1.72	1.43	1.79	1.50	1.57	2.03	11.73	24.31	2.38	1.50	1.43	1.50
29	1.64		1.87	1.43	1.50	2.99	30.95	10.69	2.38	1.50	1.43	1.57
30	1.64		1.64	1.43	1.57	2.03	219.87	5.70	2.29	1.57	1.43	1.57
31	1.57		1.57		1.50		8.15	17.61		1.57		1.43
2003	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1.49	1.37	1.55	4.27	1.82	1.37	6.65	7.48	104.22	8.76	3.69	3.48
2	1.49	1.37	1.55	1.89	1.75	1.37	2.69	30.13	24.20	6.81	3.58	3.48
3	1.49	1.37	1.43	1.55	1.62	1.43	8.20	28.47	26.86	6.18	3.69	3.48
4	1.49	1.31	1.37	1.49	1.62	1.49	27.26	11.26	15.24	5.88	3.69	3.48
5	1.43	1.37	1.37	1.37	1.62	1.37	4.90	8.76	68.61	5.44	3.58	3.48
6	1.49	1.37	1.37	1.37	1.55	5.73	5.44	8.76	43.56	5.44	3.69	3.48
7	1.43	1.37	1.37	1.49	1.49	2.19	6.98	5.17	28.88	5.03	3.58	7.48
8	1.37	1.37	1.37	1.37	1.55	1.62	5.30	103.29	73.02	4.90	3.58	5.03

9	1.37	1.37	1.31	1.31	1.62	1.49	4.39	41.97	55.17	4.77	3.48	3.80
10	1.43	1.37	1.37	1.37	1.55	1.62	10.38	295.88	32.30	4.64	3.48	3.69
11	1.37	1.31	1.37	1.37	3.27	1.55	52.10	130.59	10.38	4.51	3.69	3.48
12	1.37	1.37	1.37	1.75	1.75	1.62	6.03	46.30	24.94	4.51	3.58	3.48
13	1.37	1.31	1.37	2.97	1.62	2.11	13.66	22.75	11.71	4.39	3.48	3.48
14	1.37	1.37	1.37	2.27	1.55	1.75	19.07	53.32	11.03	4.39	3.48	3.48
15	1.37	1.31	1.31	3.07	1.55	2.35	10.17	14.70	24.20	4.39	3.48	3.48
16	1.37	1.26	1.37	2.27	1.68	2.52	46.30	11.71	30.56	4.15	3.48	3.48
17	1.43	1.26	1.37	2.69	1.55	2.35	10.17	12.66	17.83	4.15	3.48	3.37
18	1.37	1.26	1.49	2.69	1.49	1.89	21.36	10.17	9.96	4.03	3.48	3.48
19	1.49	1.26	1.31	2.52	1.37	1.89	13.40	14.70	8.38	3.92	3.48	3.48
20	1.37	1.37	1.75	2.04	1.31	2.52	11.71	33.19	7.14	4.03	3.48	3.48
21	1.37	1.37	1.62	3.27	1.26	2.69	11.48	95.08	21.36	3.80	3.48	3.37
22	1.37	1.26	1.89	2.11	1.37	3.58	50.32	420.06	10.38	3.92	3.48	3.48
23	1.37	1.26	2.19	1.82	1.37	3.92	11.03	74.53	7.48	3.92	3.48	3.48
24	1.37	1.26	1.75	4.64	1.26	2.88	12.18	55.80	8.20	3.80	3.37	3.48
25	1.49	1.89	1.55	5.44	1.37	3.58	65.77	43.56	8.20	3.92	3.48	3.48
26	1.49	8.20	1.49	4.27	1.31	8.02	110.95	44.10	6.65	3.69	3.48	3.27
27	2.04	2.35	1.37	2.35	1.37	3.07	24.20	243.91	6.03	3.69	3.48	3.27
28	1.49	1.75	1.37	2.19	1.26	2.88	52.10	274.32	6.03	3.69	3.48	3.27
29	1.43		1.37	2.19	1.37	4.51	9.96	209.80	9.96	3.69	3.58	3.27
30	1.37		1.37	1.89	1.37	4.90	21.36	44.10	19.39	3.69	3.48	3.27
31	1.37		1.49		1.31		8.38	79.96		3.69		3.27
2004	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	3.268	3.268	2.878	3.268	4.389	2.972	15.794	16.36	17.531	5.167	3.802	3.582
2	3.268	4.389	2.878	4.148	3.371	2.878	12.42	35.029	18.755	5.032	3.691	3.582
3	3.268	3.915	2.878	3.268	3.371	2.878	6.491	14.435	11.258	7.658	3.691	3.476
4	3.268	3.476	2.785	3.268	4.148	3.069	9.959	140.62	10.38	5.167	3.691	3.476
5	3.268	3.268	2.785	15.241	3.168	3.069	7.835	64.383	111.93	5.167	3.691	3.691
6	3.268	3.268	2.878	5.444	3.691	2.878	11.946	26.469	250.47	8.382	3.691	3.582
7	3.268	3.268	2.878	4.389	3.168	2.878	11.714	16.939	46.859	8.76	3.691	3.691
8	3.268	3.268	2.878	7.312	2.878	3.168	9.752	20.032	14.172	6.976	3.691	3.691
9	3.168	3.268	2.878	3.802	2.878	3.371	6.65	38.396	14.7	8.382	3.691	3.691
10	3.069	3.069	2.878	4.148	2.878	3.371	5.032	34.564	9.959	6.491	3.582	3.691
11	3.069	3.069	2.878	3.691	2.878	3.476	5.167	148.75	16.939	5.587	3.582	3.691
12	3.268	2.972	2.878	4.639	2.878	3.915	9.347	43.558	81.556	5.032	3.582	3.691
13	3.268	3.069	2.878	8.197	2.878	4.148	6.491	99.586	182.95	4.899	3.476	3.691
14	3.268	3.069	2.878	8.76	2.878	3.691	9.149	21.364	132.77	4.899	3.582	3.691
15	3.582	3.069	2.878	7.484	2.878	3.268	11.714	22.399	21.364	4.639	3.582	3.691
16	3.268	2.972	3.691	6.028	2.878	3.168	28.876	72.271	14.7	4.639	3.476	3.691
17	3.371	2.972	3.069	3.802	2.878	3.691	11.484	29.709	13.153	4.389	3.476	3.691
18	3.268	2.972	4.639	3.691	2.878	6.18	8.015	37.903	19.708	4.267	3.476	3.691
19	3.268	2.878	3.476	4.03	2.878	3.268	9.959	49.146	11.946	4.148	3.476	3.691
20	3.268	2.972	3.476	3.915	2.878	10.168	6.334	17.234	9.347	4.148	3.476	3.691
21	3.268	2.878	3.069	6.491	2.785	3.476	8.015	163.39	24.565	4.03	3.476	3.691

22	3.268	2.972	2.972	3.691	2.878	3.582	20.032	128.42	9.347	3.915	3.582	3.691
23	5.587	2.878	2.878	3.268	2.878	3.802	157.18	169.75	7.312	3.915	3.476	3.691
24	3.476	2.878	2.878	3.069	2.878	3.691	11.484	40.925	6.491	4.148	3.691	3.691
25	3.915	2.878	2.878	3.069	2.878	3.691	21.364	38.894	6.334	4.148	3.691	3.691
26	3.268	2.878	2.878	3.069	2.878	7.143	107.07	12.42	11.714	4.03	3.582	3.691
27	3.268	2.878	3.069	3.069	2.878	10.38	12.181	154.74	55.802	4.03	3.582	3.691
28	3.168	2.878	3.168	2.972	3.069	7.658	8.953	49.146	8.015	4.03	3.582	3.582
29	3.168	2.972	3.371	2.972	3.069	4.768	27.256	47.424	5.731	3.915	3.582	3.582
30	3.268		3.069	3.069	2.878	7.484	12.181	15.516	5.444	3.915	3.476	3.691
31	3.268		10.813		3.069		11.484	35.971		3.915		3.582

Appendix.D.1 Soil sample gradation data

Table.D.1 Soil sample gradation data

Sieve size (mm)	Sieve weight (gm)	sieve + sample1 (gm)	sieve + sample2 (gm)	sample1 (gm)	sample2 (gm)	% retain (sample1)	Σ% retain (Sample1)	% retain (sample2)	Σ% retain (Sample2)	% Pass (sample1)	% Pass (sample2)
9.5	446.00	449.6	452.6	3.60	6.60	0.76	0.76	1.32	1.32	99.24	98.68
4.75	567.40	579.3	634.6	11.90	67.20	2.52	3.28	13.48	14.81	96.72	85.19
2	378.00	396.1	469.4	18.10	91.40	3.83	7.11	18.34	33.15	92.89	66.85
1	526.10	564.6	612.1	38.50	86.00	8.15	15.27	17.26	50.40	84.73	49.60
0.5	483.70	632.7	583.5	149.00	99.80	31.55	46.81	20.02	70.43	53.19	29.57
0.25	461.70	610.4	549.7	148.70	88.00	31.48	78.30	17.66	88.08	21.70	11.92
0.15	271.70	343.9	306.7	72.20	35.00	15.29	93.58	7.02	95.10	6.42	4.90
0.075	273.20	291.1	274	17.90	0.80	3.79	97.37	0.16	95.26	2.63	4.74
pan	396.80	409.2	420.4	12.40	23.60	2.63	100.00	4.74	100.00	0.00	0.00

**Note sample 1 is soil sample under Bridge*

**Note sample 2 is soil sample downstream of the Bridge*

Appendix.E.1 Manning's n values

Table.E.1 Manning's n values

Type of Channel and Description	Minimum	Normal	Maximum
<i>A. Natural Streams</i>			
1. Main Channels			
a. Clean, straight, full, no rifts or deep pools			
b. Same as above, but more stones and weeds	0.025	0.030	0.033
c. Clean, winding, some pools and shoals	0.030	0.035	0.040
d. Same as above, but some weeds and stones	0.033	0.040	0.045
e. Same as above, lower stages, more ineffective slopes and sections	0.035	0.045	0.050
f. Same as "d" but more stones	0.040	0.048	0.055
g. Sluggish reaches, weedy, deep pools	0.045	0.050	0.060
h. Very weedy reaches, deep pools, or floodways with heavy stands of timber and brush	0.050	0.070	0.080
	0.070	0.100	0.150
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
b. Cultivated areas			
1. No crop	0.020	0.030	0.040
2. Mature row crops	0.025	0.035	0.045
3. Mature field crops	0.030	0.040	0.050
c. Brush			
1. Scattered brush, heavy weeds	0.035	0.050	0.070
2. Light brush and trees, in winter	0.035	0.050	0.060
3. Light brush and trees, in summer	0.040	0.060	0.080
4. Medium to dense brush, in winter	0.045	0.070	0.110
5. Medium to dense brush, in summer	0.070	0.100	0.160
d. Trees			
1. Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
2. Same as above, but heavy sprouts	0.050	0.060	0.080
3. Heavy stand of timber, few down trees, little undergrowth, flow below branches	0.080	0.100	0.120
4. Same as above, but with flow into branches	0.100	0.120	0.160
5. Dense willows, summer, straight	0.110	0.150	0.200
3. Mountain Streams, no vegetation in channel, banks usually steep, with trees and brush on banks submerged			
a. Bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
b. Bottom: cobbles with large boulders	0.040	0.050	0.070

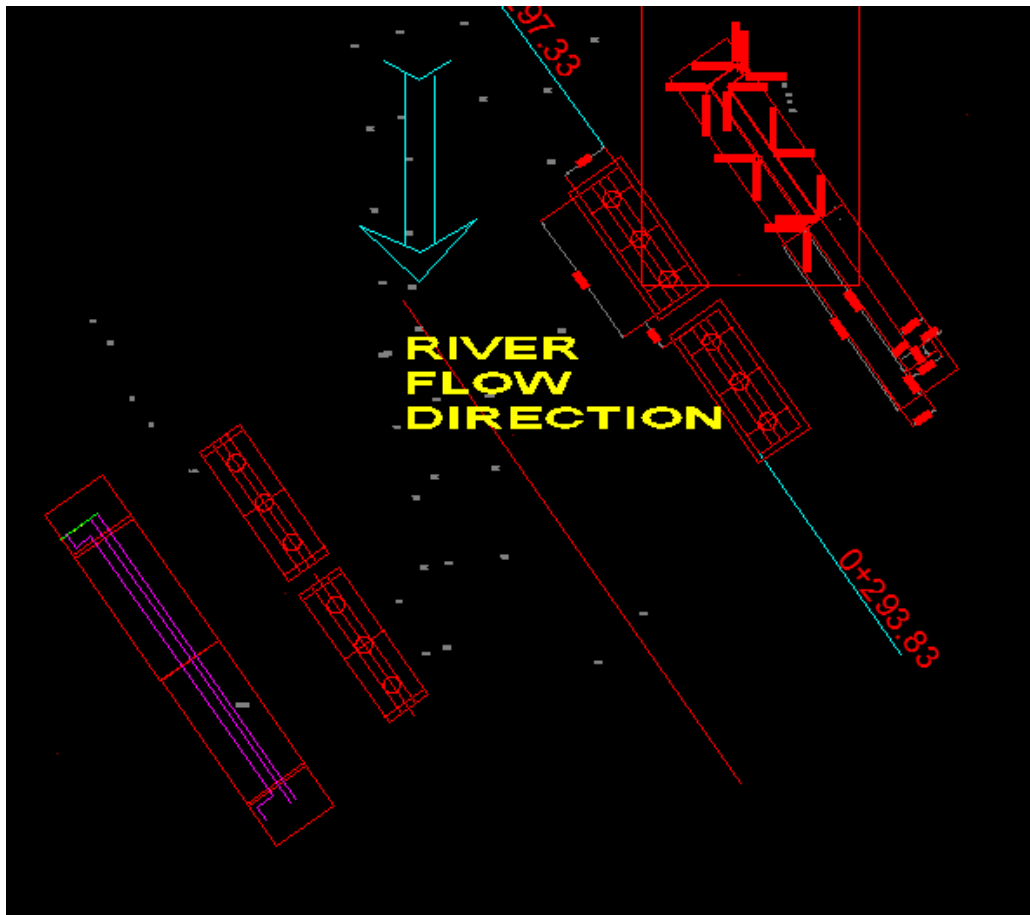


Figure.F.2 Bridge Pier layout

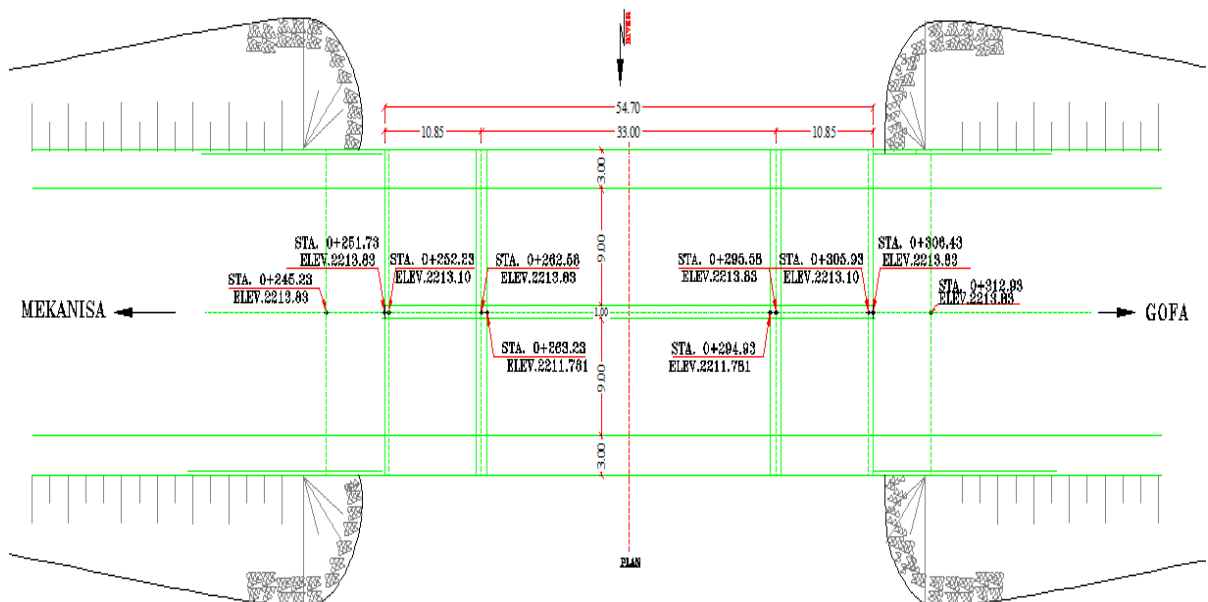


Figure.F.3 Bridge Plan layout

