IMPACT OF THE SMART TUNNEL OUTFLOW ON THE HYDRAULICS OF THE KERAYONG RIVER, MALAYSIA

Technical Report

Prepared by:

Kennard Xun Onn Lai

Department of Civil & Environmental Engineering

In partial fulfillment of the requirements

For the Degree of Master of Science – Plan B

Colorado State University

Fort Collins, Colorado

Advisor: Dr. Pierre Julien

Spring 2016

ABSTRACT

Kuala Lumpur, the capital of Malaysia has been dealing with flooding problems since historical times and flood incidents have increased in the past decades due to rapid urbanization. The SMART tunnel was built in 2007 to divert water away from the city and into the Kerayong River. The site of interest is the downstream reach of the Kerayong River which naturally experiences 184 m^3/s with a 500 year return period. The river experiences an increased discharge by 300 m^3/s during extreme events from the SMART Tunnel. The new Google Street View technology is used to aid estimation of river geometry. River modeling was carried out using HEC-RAS under different flows on the river under two conditions: before river improvement works and after river improvement works. It is found that the increased peak discharge up to 484 m^3/s has caused up to 3.74 m of flooding on the river banks before improvement works was completed. The Kerayong River improvement works lowered the stage of the 484 m^3/s discharge up to 3.51 m. It is also determined that the bed lining and revetment at the confluence on Kerayong and Klang Rivers were sized appropriately for erosion during peak discharge. Finally, the model was used to predict a future increase in flow of 10% from the Kerayong Watershed due to increased urbanization. The simulation results suggest that a flow of 502 m^3/s will cause 9 of 12 river stations on the downstream reach of Kerayong River to overtop their banks by up to 0.71 m.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my advisor, Dr. Pierre Julien for his guidance, support, and encouragement throughout my time at CSU. I would also like to extend my gratitude to my Master's program committee members Dr. Jorge Ramirez and Dr. Stephanie Kampf for their guidance in this study.

I would also like to thank my fellow friends and Stars of Dr. Julien's Dream Team: Dr. Jazuri Abdullah (UITM), Atikah Shafie(DID), Patrick Ndolo Goy, Hwa Young Kim, Marcos Palu, Dr. Jose Anderson, Dr. Jai Hong Lee, and Neil Andika for sharing their knowledge and peer mentorship to help me through this process.

Special acknowledgements to the Department of Irrigation and Drainage of Malaysia and MARA University of Technology, Malaysia for granting me access to data for this study.

Last but not least, I'd like to express my deepest gratitude to my family. My parents: Oi Mei Chooi and Thomas Lai, not forgetting my siblings Nicholas and Nicole for their unconditional love, support, and encouragement; for without them I would not be here today.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION

Kuala Lumpur or more affectionately known as KL is the capital and largest city in Malaysia. Literally the translation of “Muddy Confluence” from the Malay language, KL was aptly named due to its location in the muddy confluence of the Klang River and the Gombak River. Founded in the late 1900’s, what was initially a tin mining settlement transformed into an ultra-modern metropolis today and serves as the center of business and commerce for the country.

Kuala Lumpur is situated in the middle upper region of the Klang Watershed that has an area of about 1288 km^2. The Greater Kuala Lumpur region is mostly situated in the Klang Watershed, where locals refer to the region as Klang Valley. Klang Valley is the most densely populated region in Malaysia; home to more than 7.5 million people.

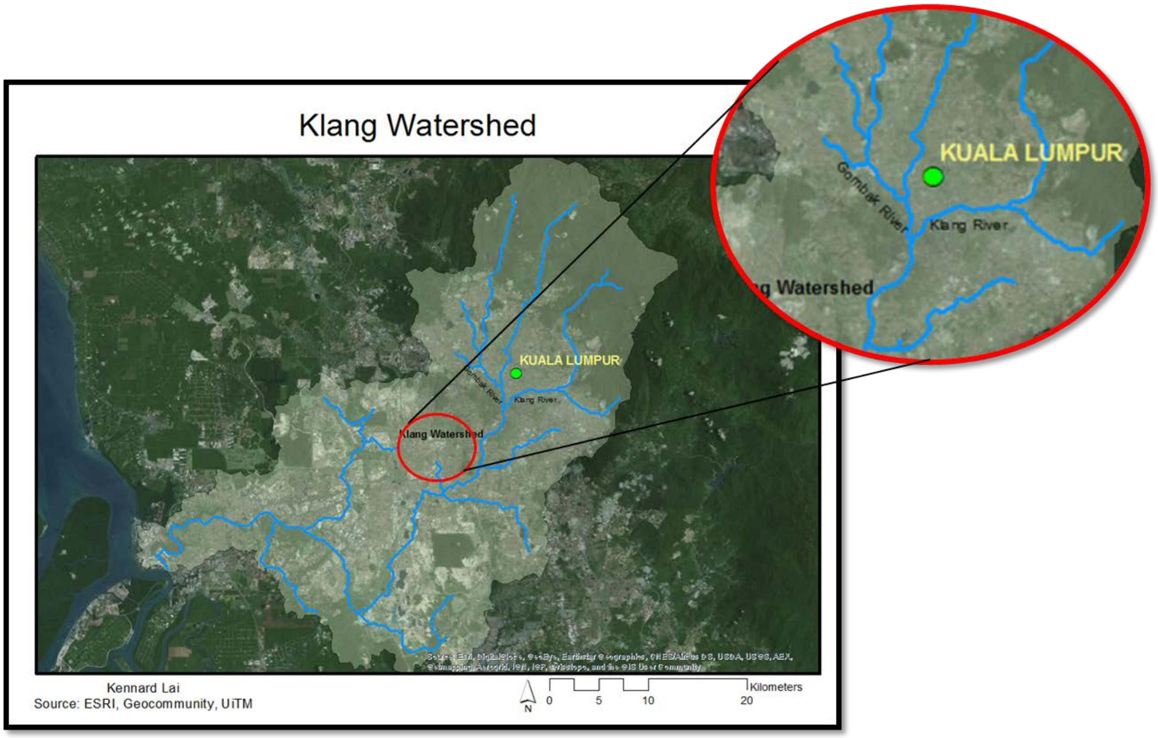


Figure 1-1 Location of Kuala Lumpur in the Klang Watershed

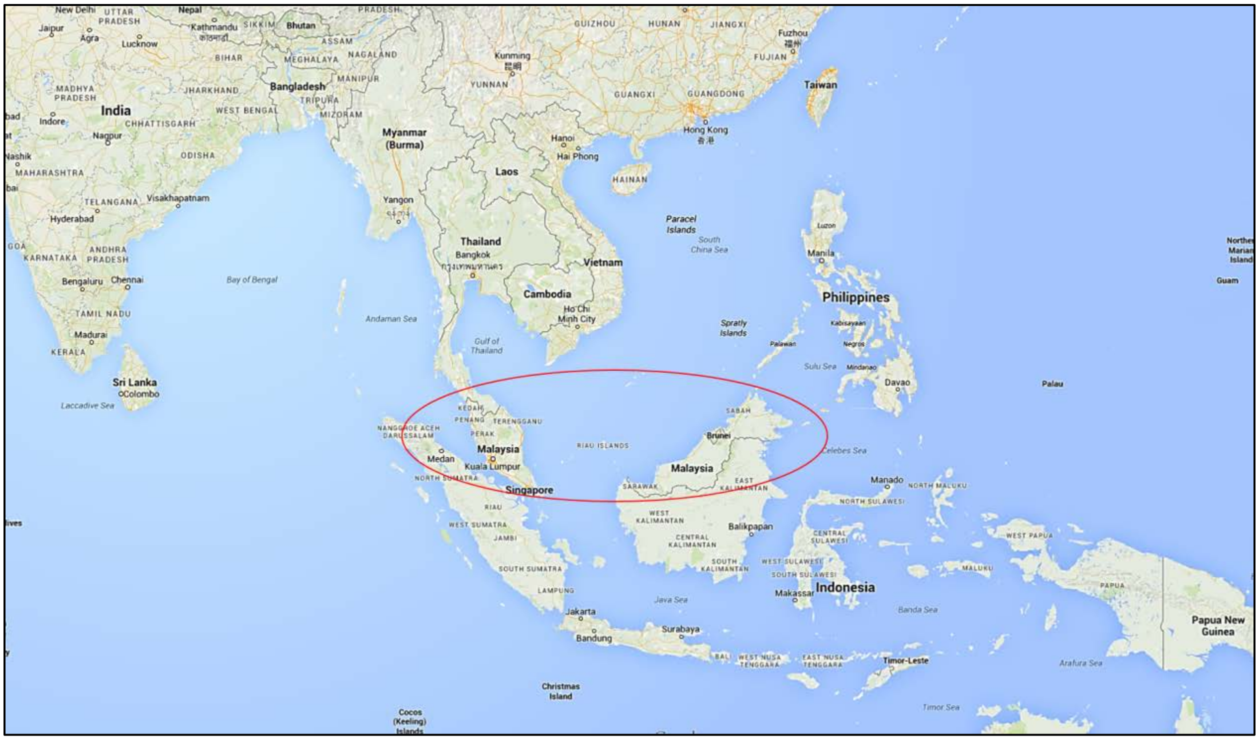


Figure 1-2 - Location of Malaysia in Southeast Asia

1.1 Background

Malaysia consists of two landforms situated in Southeast Asia along the equator. West Malaysia – where Kuala Lumpur is located, is a peninsula surrounded by the sea. The climate of Malaysia is classified as tropical rainforest (Köppen climate classification *Af*) (Arnfield 2016). Average temperatures range from 23°C to 30°C and relative humidity is about 80% year round. Weather in Malaysia is highly influenced by monsoons. The main monsoon season from the east runs from November to February that brings the most intense rainfalls (Muhammad and Julien 2014). Annually, Malaysia receives between 2000 and 4000 mm of total rainfall with 150-200 rainy days (Jamaludin and Jemain 2007).

The abundance of rainfall in Malaysia has created problems that have plagued the country since historical times. During major rainstorm events, flooding is a common occurrence at low lying regions. Kuala Lumpur was susceptible to flooding because of its location on the floodplain of Klang and Gombak Rivers. Flooding in Kuala Lumpur was recorded as early as 1881

(Williamson 2015). The next few decades saw an increase in population, development, urbanization. Rapid uncontrolled development in the Klang Watershed exacerbated the flooding problem by affecting watershed hydrology and geomorphology. Decreased infiltration led to increase runoff that in turn increased peak flow and magnitude. Development on floodplains and encroaching river banks decreased river capacity (DID 2012). The increased discharge and decreased river capacity caused overtopping of banks leading to bank-overtopping flood. Inadequately designed drainage system and poor management led to clogged drainage and made flash flooding a common occurrence in the city.

Table 1-1 Flooding Incidences in KL until 2004 (Abdullah, 2004a)

Period	**No. of Times**	**Year**
1900 - 1949	1	1926
1950 - 1975	1	1971
1976 - 1985	1	1982
1986 - 1995	4	1986, 1988, 1994, 1995
1996 - 2004	7	1996, 1997, 2001, 2002, 2003

Major flooding incidences in Kuala Lumpur have increased throughout the years (see Table 1-1). Short-duration flash flooding events has also seen an increase during the rainstorms. The combined bank overtopping flood and flash flooding problems often times bring the city to a grinding halt, causing property damages, affecting the livelihood of its citizens, and damaging the economy. In the year 2015 itself, flood damages for Malaysia were estimated to be close to a quarter of a million dollars USD(DID 2009a). The flooding problem and rapid urbanization has brought upon tremendous challenges for the government, developers, engineers and inhabitants of Kuala Lumpur.

1.2 SMART Tunnel

Since 1971, the Department of Irrigation and Drainage (DID), the flood management sector of the government, has established the Kuala Lumpur Flood Mitigation Project (KLFMP) (ADB 2007). The objective is to mitigate the effects of flooding in Kuala Lumpur. Multiple public works project has been carried out such as channel improvement, dam height raising, dam construction, building detention ponds, installing pumps, and building floodwater diversion systems.

These flood mitigation measures however, could not keep up with the rapid development in the river basin. Between 1986 and 2000, Kuala Lumpur was hit by a slew of floods, increasing in frequency and magnitude. This prompted studies to review the KLFMP.

In 2000, a review on the KLFMP has shown that:

i) Flood magnitudes in the city had increased drastically largely due to intense land development.

ii) The computed 100-year flood peak has increased from 353 m^3/s to 460 m^3/s at Tun Perak Bridge - a bridge near the confluence that would choke the flow if overtopped.

iii) New points of constriction had emerged in the river upstream of the confluence due to development that encroached the river banks.

Figure 1-3 Confluence of Gombak and Klang Rivers

The government sought proposals that would solve the flooding issue. The winning proposal was developed by a group led by Gamuda Bhd, a Malaysian engineering consulting firm and Mott MacDonald UK which is known as the SMART Tunnel project.

The Stormwater Management and Road Tunnel or SMART Tunnel is designed to be a dual-purpose tunnel that serves both as a stormwater tunnel and also a roadway tunnel. It would not only solve the flooding problem in the city center, but also alleviate traffic problems in the large city. During a storm event, the SMART Tunnel would divert water upstream of the Klang River into a holding pond and into the tunnel that would divert the water downstream and away from the city center. The lowered discharge would prevent a choke at Tun Perak Bridge therefore prevent bank-overtopping flood in the city center.

There are a few reasons that the SMART Tunnel proposal was chosen by the government. First being that it is an effective method to prevent flooding in the city center. It also has the roadway component which is an innovative solution. When compared to other alternatives, the SMART was also chosen because there was no room in the city center for more river improvement such as widening and deepening. There was also no space in the city for more rain water detention ponds (Abdullah 2004b). The tunnel design was selected over an open channel floodwater diversion because the terrain between the points of inlet and outlet were rolling hills (Abdullah, 2004a)

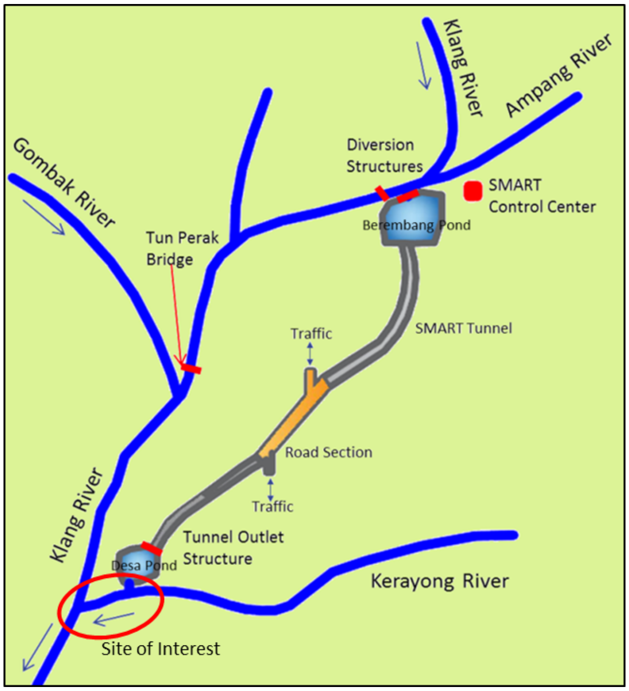


Figure 1-4 Components of SMART Tunnel

One of the design considerations for SMART Tunnel is such that the peak flow at Tun Perak Bridge to not exceed 180 m^3/s. For the 100-year flood flow of 460 m^3/s on the Klang River before Tun Perak Bridge, 280 m^3/s needs to be diverted by the tunnel. To meet the requirements, the tunnel was designed to be 13 m in diameter and 9.7 km in length. 3 km of the tunnel has a roadway incorporated in the tunnel; with three levels in total: two dual-purpose road decks and bottom most deck used for conveying stormwater (Klados et al. 2007).

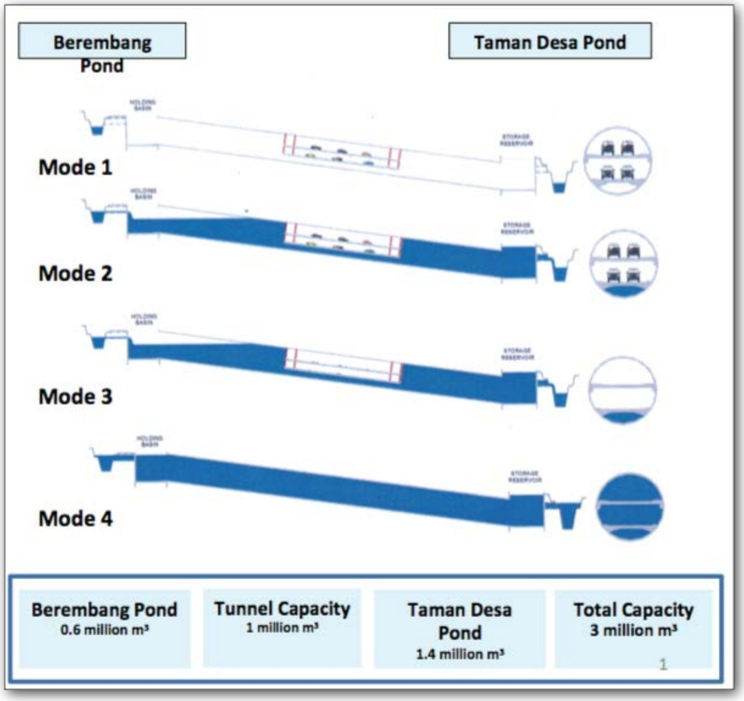


Figure 1-5 Operational Modes of SMART Tunnel (SMART 2016)

The SMART system has a total capacity of 3 million m^3 in its 3 components:

i) Berembang inlet storage pond: 0.6 million m^3

ii) Tunnel: 1 million m^3

iii) Desa outlet storage pond: 1.4 million m^3

The operations of SMART Tunnel are controlled by the SMART Tunnel Control Center using Supervisory Control and Data Acquisition (SCADA). The control center monitors real-time river and precipitation gages around the area. Four modes are developed for the operation of the SMART Tunnel which is described by DID as follows:

i) Mode 1: When the weather is fair with little or no rain and traffic is allowed.

ii) Mode 2:
  - Activated when moderate rainfalls and the flow rate recorded at the confluence at Klang River and Ampang River (L4) is 70 – 150 m^3/s. Only 50 m^3/s is allowed to flow downstream.
  - Excess flood water will be diverted to SMART storages and only the lower drains of the tunnel will be used to convey flood flow to the Desa attenuation pond.
  - Road tunnel will still be opened to traffic.

iii) Mode 3:
  - Activated when major storm event occurs and flood model forecasts a flow rate of 150 m^3/s or more at L4.
  - Traffic will be evacuated from the road tunnel. This normally takes about one hour. Only 10 m^3/s is allowed to flow downstream.
  - Road tunnel will be re-opened to traffic within 2-8 hours if not used.

iv) Mode 4:
  - Activated if heavy rain storm prolongs, usually within 1-2 hours after Mode 3.
  - Road tunnel will be used for floodwater conveyance. Only 10 m^3/s is allowed to flow downstream.
  - Road tunnel will be re-opened within 4 days of closure.

Construction for the SMART Tunnel began in 2003 and was completed in 2007. Since it was operational, up until 2013, the SMART Tunnel has been utilized a total of 268 times: 182 times at Mode 2, 81 times at Mode 3, and five times in Mode 4 (DID 2015).

1.3 Site Description

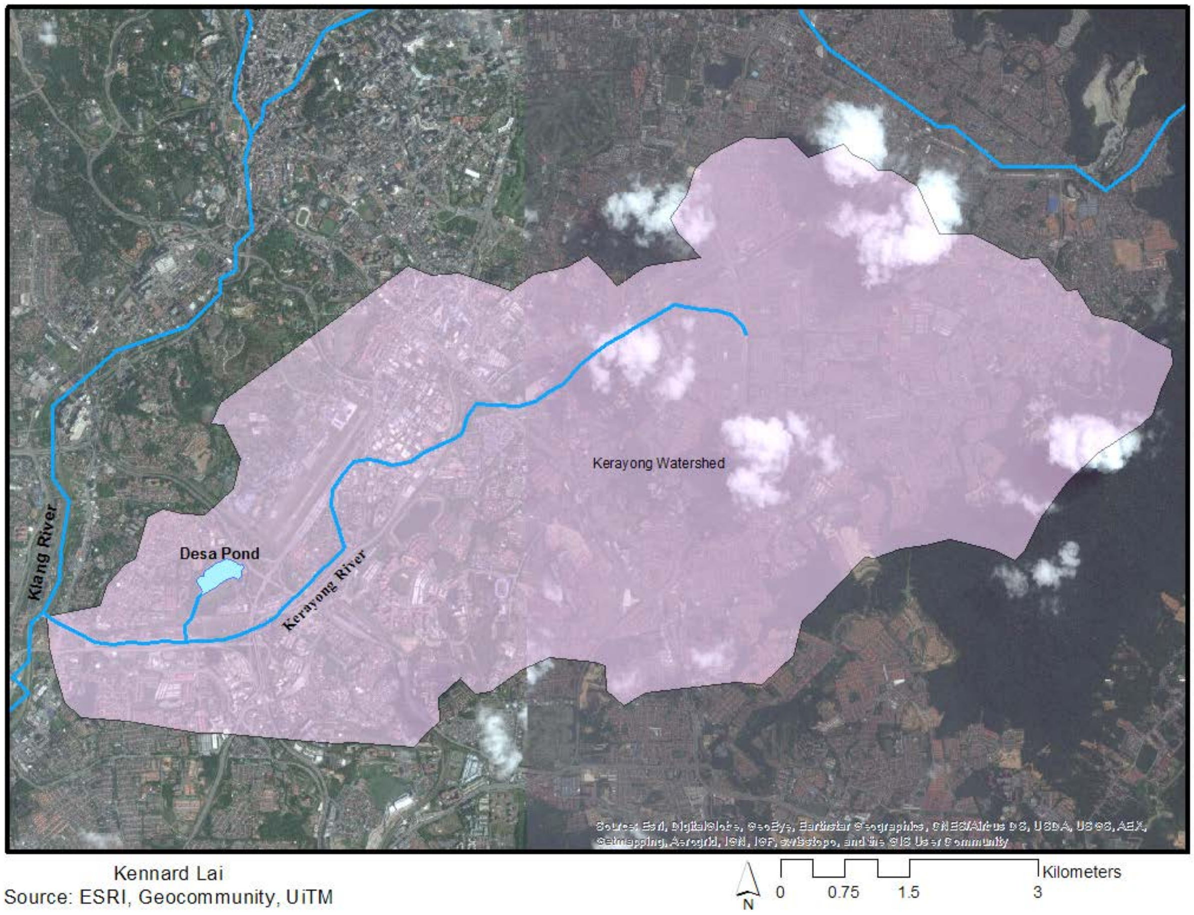


Figure 1-6 Kerayong River and Watershed

The SMART Tunnel flows into the Desa attenuation pond which discharges into the Kerayong River. A tributary of the Klang River, the Kerayong River is the main stream of the Kerayong

Watershed about 10 km long and drains the about 48 km^2. The Desa attenuation pond discharges into the downstream reach of the Kerayong River which is about 1.8 km long. The topography of the Kerayong Watershed is similar to Klang Watershed; with rolling hills along the north edge and steeper hills to the east. According to Abustan et. al (2008), the Kerayong Watershed is highly urbanized with 77.5% imperviousness.

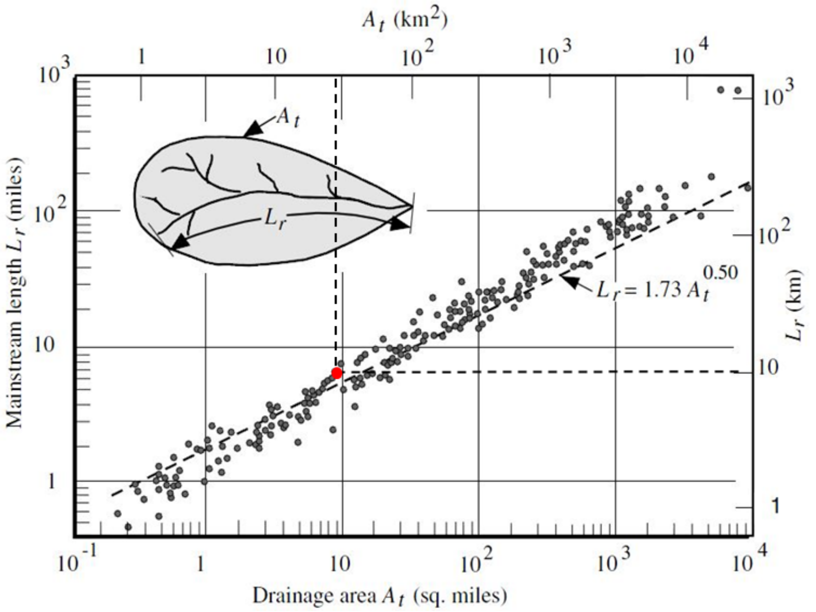


Figure 1-7 - Kerayong River in comparison with mainstream lengths (Julien 2002)

The reach of interest is the downstream reach starting from the point where Desa pond discharges into the Kerayong River until the confluence of the Kerayong and Klang River. The reach length is about 1.8 km (see Figure 8). River geometry data was provided by UITM (2015) and mapped in ArcGIS.

Figure 1-8 Reach of interest highlighted in red

1.4 Problem Statement

At Mode 4 of SMART Tunnel operation, the design flow into the SMART Tunnel system is 280 m^3/s. The Berembang Pond with capacity of 0.6 million m^3 will take 36 mins to fill. When the Berembang Pond is at capacity, the floodwater will start to enter the SMART Tunnel and discharge on the other end, Desa Pond. Desa Pond with capacity of 1.4 million m^3 will fill to capacity in 1 hour and 23 mins. Taking into account the flow control structure at the outlet of the Tunnel, 1 million m^3 can be stored in the Tunnel itself; the time taken to fill the tunnel will be 1 hour. During a major storm where SMART Tunnel is in full operational mode, the SMART Tunnel system and the holding ponds up and downstream will take 3 hours to reach full capacity before it has to discharge into the Kerayong. For a major rainstorm that has high intensity and lasts for more than 3 hours, the discharge will significantly increase the flow in the Kerayong River.

During a major storm event in the Klang Watershed, the Kerayong River draining its watershed will be at flood flow as well. Over the course of a prolonged and intense storm, the downstream reach of the Kerayong River will be carrying its flood flow and have an increase of 280 m^3/s contributed by the SMART Tunnel.

The sudden artificial increase in flow in the Kerayong River is expected to impact the open channel hydraulics and geomorphology of the river. It is important to understand the impacts of the increase of flow and potential problems that may arise in order to be able to address them.

An online literature search has shown no studies available pertaining to the hydraulic impacts of the SMART Tunnel on the Kerayong. The available hydrologic data for the Kerayong River are:

i) Cross section geometry of 54 river stations on Kerayong River for a year prior to 2008, provided by UITM (2015).

ii) Stage and discharge data on Kerayong River from 2008-2009, gage station is upstream of the outlet of Desa Pond (UITM 2015).

Based on Google Earth Satellite images, there has been channel improvement works on the downstream reach of the Kerayong River that was carried out after April 2008 and was completed in 2010.

Figure 1-9 Pre-2009 before construction (Google Earth 2016)

Figure 1-10 Post-2010 after construction (Google Earth 2016)

1.5 Objectives

This report presents methods to a preliminary examination on the case based on available data and information. The objectives of this study are:

i) GIS Analysis: Utilize GIS tools and datasets such as digital elevation mapping (DEM) to delineate the watersheds of the study area and utilizing Google Earth and Street view to prepare river geometry for hydraulic analysis.
ii) Hydraulic Analysis: Utilizing HEC-RAS to model different river flows before and after channel improvement works at the downstream reach of Kerayong River to understand the hydraulics of the river under different conditions.
iii) Investigate the stability of the downstream reach of the Kerayong River after river improvement works.
iv) Predict future extreme event water level using developed HEC-RAS model.

CHAPTER 2: LITERATURE REVIEW

This chapter aims to provide a brief explanation of a few concepts that is used in the study. The concepts used are urban stormwater processes, one-dimensional (1-D) hydraulic modeling, governing equations in hydraulic modeling, the standard step method, and shear stress calculation.

2.1 Flood Hydrology Overview

The European Union Directive (2007) defines flood as “the temporary covering by water of land not normally covered by water. This shall include floods from rivers, mountain torrents, Mediterranean ephemeral water courses, and floods from the sea in coastal areas, and may exclude flood from sewage systems”. The same directive defines flood risk as the combination of probability of a flood event and its potential adverse consequences for human health, the environment, cultural heritage and economic activity. According to Department of Irrigation and Drainage (2009a), Malaysia is impacted by a few types of flooding which have both natural and anthropogenic causes which are: river floods, regional floods, localized floods, coastal floods, urban floods, rural and agriculture floods, and flash floods. The floods that affect Klang Watershed are river floods, urban floods, and flash floods. River floods occur when rivers carrying capacity is exceeded and the discharge overtops the river banks, flowing downstream through the flood plain. River floods can be natural caused or influenced by human activity such as channel narrowing or sedimentation on river beds. Urban floods and flash floods in Klang Watershed have a complex combination of causes (DID 2009a). One of which is the rapid development without consideration for flooding that led to more impervious surfaces and higher surface runoff rates, therefore increasing the magnitude of flooding (Jha et al. 2012).

Frequency Analysis

The magnitude of a flood is inversely related to its frequency of occurrence (Chow et al. 1988). Frequency analysis is the statistical process where the probability of occurrence of a given event is estimated. The recurrence interval or return period is the time between the occurrences of a given event will be equaled or exceeded in any given year (Robinson et al. 1998). Chow et al. (1988) described recurrence interval as: “Suppose an extreme event is defined to have occurred if a random variable X is greater than or equal to some level x_T. The recurrence interval, τ is the time between occurrences of $X \geq x_T$”. Once recurrence intervals are determined based on historical hydrological data, the flood frequency distribution can be assumed. Flood probability is used to predict the likelihood of future occurrence. The probability of occurrence is the inverse of the return period (Jha et al. 2012):

$$P\ (X \geq x_T) = \frac{1}{T} \qquad (1)$$

For example if the recurrence interval, τ of 50,000 cfs annual maximum discharge on the Guadalupe River is 5.1, the probability that the maximum discharge in the river will equal or exceed 50,000 cfs in any year is approximately 1/5.1 = 0.195 (Chow et al. 1988).

Damage causing floods or flood hazard is the event that may cause loss of life, injury, property damage, social and economic disruption or adverse impacts on the environment (UNISDR 2004). Flood hazard events have a certain probability of occurrence and given intensity, usually the intensity is high and probability of occurrence is low. Flood management is the course of action taken after identifying the effects of flood hazards, such as probability of occurrence, magnitude and duration, and expected recurrence interval for the next event. Assessment is aided through flood risk maps like the 100-year flood plain map for management schemes such as the FEMA National Flood Insurance Program (FEMA 2015). Flood hazard can be better understood by using flood models; one of the methods used in this study is described in section 2.2.

2.2 One-dimensional (1-D) Hydraulic Modeling

1-D hydraulic modeling is method used by many to calculate water surface profiles and energy grade line under steady-state conditions in gradually varied flow analyses. The most used model, which is also utilized in this study, is the Hydrologic Engineering Center – River Analysis System also known as HEC-RAS that was developed by the US Army Corp of Engineers (USACE 2010c). 1-D hydraulic modeling with HEC-RAS has many advantages; for example: its ease of use, simplification of a problem, requires less parameter inputs than 2-D modeling, and is available to the public free of charge. In 1-D, steady-state gradually varied flow modeling, it is assumed that:

1) The dominant velocity is the flow direction
2) Hydraulic characteristics such as channel geometry and resistance factors remain constant
3) Streamlines are parallel and hydraulic pressure distribution prevails over channel section.

The governing equations used in HEC-RAS are discussed as in the next few sections.

2.3 HEC-RAS Governing Equations

In USACE (2010b) HEC-RAS 1-D steady state gradually varied flow calculations are calculated based on the concepts of continuity, energy, channel geometry, and resistance to flow.

Continuity

The continuity equation describes the conservation of mass in fluid dynamics where the discharge is constant in a control volume under steady state (Munson et al. 2002). It implies that inflow equal outflow as described in the continuity equation:

$$Q_1 = Q_2 \tag{2}$$

Where:
Q_1 = discharge at downstream of cross section (m^3/s)
Q_2 = discharge at upstream of cross section (m^3/s)
Discharge is described as the velocity multiplied by the area of flow:

$$Q = VA \tag{3}$$

Where:
A = area of cross section (m^2)
V = average velocity (m/s)

Energy Equation

Chow (1959) describes the total energy is the sum of the elevation head, depth of flow, and velocity head. Also known as the energy grade line, the energy equation is described as:

$$z_2 + y_2 + \alpha_2 \frac{V_2^2}{2g} = z_1 + y_1 + \alpha_1 \frac{V_1^2}{2g} + h_l \tag{4}$$

Where:
z = elevation head
y = flow depth
α = velocity weighing coefficient
V = velocity
g = gravitational acceleration = 9.81 m/s^s

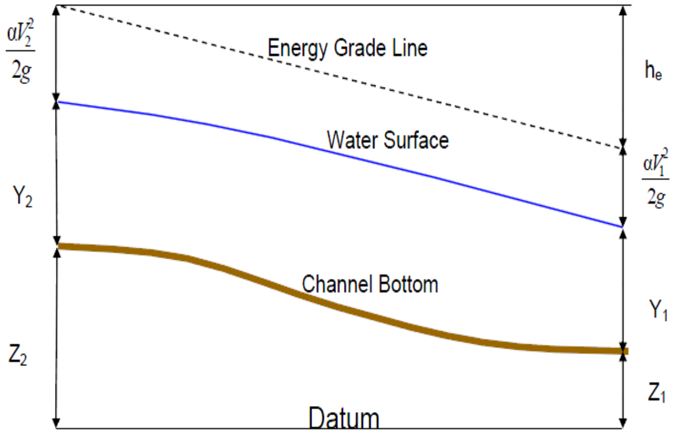


Figure 2 - 1 Illustration of the terms in energy equation

Flow Resistance

Resistance to flow can be commonly described by the Manning's equation (Cruise et al. 2007).

HEC-RAS calculates conveyance based on the form of Manning's equation:

$$Q = KS_f^{1/2} \qquad (5)$$

$$K = \frac{1}{n} A R^{2/3} \qquad (6)$$

Where:

K = channel conveyance
Q = discharge
S_f = friction Slope
n = Manning's roughness coefficient
A = flow area
R = hydraulic radius = A/P
P = wetted perimeter

2.4 Standard Step Method

The technique most commonly used in computing steady flow water surface profile is the standard step method; this method is also employed by HEC-RAS (USACE 2010a). At known cross sections along the channel, the energy equation is solved section from section starting from the control section. In subcritical flow, the control section will be downstream whereas in supercritical flow, the control section will be upstream. Consecutive sections used for this method should be as close enough as possible because the calculations are based on the linearization of the energy grade line (see Figure 2-1). In addition, additional sections should be included if there is a drastic change in channel geometry, slope, or roughness. The method is incorporated in HEC-RAS with an algorithm which is described as follows: The water surface (WS) elevation at the control section is assumed, K and V is determined, S_f and h_e is computed by calculating conveyance, the energy equation is solved for the WS elevation on the next cross section. The WS elevation is then compared with the calculated/assumed WS elevation and iterated until the values agree.

2.5 Riverbank Protection

Shear stress is the measure of fluid force acting on the channel boundary. It is related to sediment mobilization hence effecting erosion and sedimentation in a channel. It is important to understand the mechanisms and basis of shear stress to design a stable channel. An increase in discharge on the river can cause a perturbation the equilibrium of a channel and change the dynamics of a river. The DID (2009c) River Management Manual requires channels to be designed to allowable shear stress and velocity.

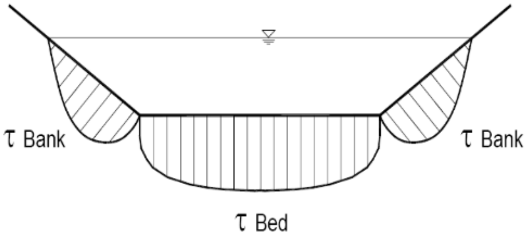


Figure 2 - 2 Lane's diagram on shear stress distribution on streambed and bank (DID 2009c)

Shear stress, τ is defined by the equation

$$\tau = \gamma R S \qquad (7)$$

Where: τ = shear stress
R = hydraulic radius = A/P
S = energy slope
A = cross sectional area
P = wetted perimeter

There are several river stabilization methods that can be used to protect banks from erosion. Methods like riprap, vegetation, gabions, windrows and trenches, sacks and blocks, and retaining walls will be briefly described in the Table 2.

Table 1-1 - Bank Stabilization Methods (Julien 2002, DID 2009c, Garanik and Sholtes 2013)

Method	Description	Advantages	Disadvantages
Riprap	Blanket of rocks to protecting bank from erosion	Low cost, ease of construction	Not suitable for tight spaces, steep slopes may need to be battered
Vegetation	Using grass or woody plants to line streambanks	Most natural, low cost, improves habitat, aesthetically pleasing	May be hard to grow, subject to undercut, may increase channel roughness
Gabions	Wire baskets filled with small stones used where velocity is too high for riprap of small stones	Can be stacked on steep slopes, effective for high velocities	Labor intensive, Expensive, Wires may rust and break
Windrows and Trenches	Piling of erosion resistant material on banks. Trenches are same as windrows but buried. Allows bank to erode until materials slide to protect bank.	Easy to install on high banks, little design work needed	Allows erosion before banks are protected, inconsistent results, side slope influenced by river velocity
Sacks	Burlap sacks filled with soil or sand-cement mixtures. Usually used for emergency work.	Possible placement on steep slopes, smooth boundary for conveyance	Labor intensive, costly, less effective against erosion, unsightly
Blocks	Precast cellular blocks lined on streambank	Allows for vegetation growth, pedestrian access to river, smooth, flexible	Labor intensive, not suitable for steep slopes
Retaining Walls	Built from materials like reinforced concrete, steel, vinyl, concrete. Designed to hold back soil and provides a vertical side slope.	Highly effective erosion protection, suitable for tight spaces	Most expensive, most design work requires, not natural-counteracts river rehabilitation efforts

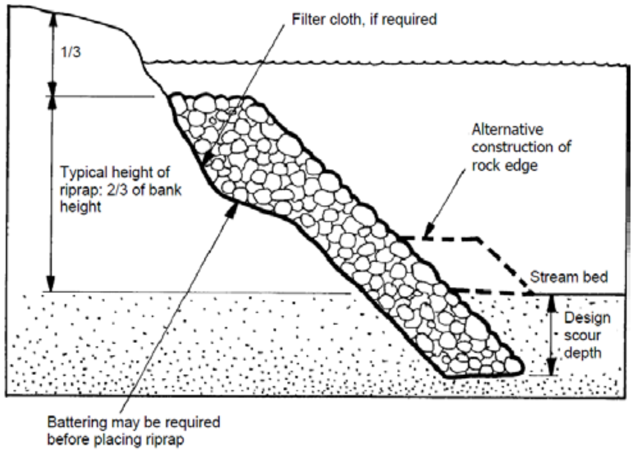


Figure 2 - 3 Riprap

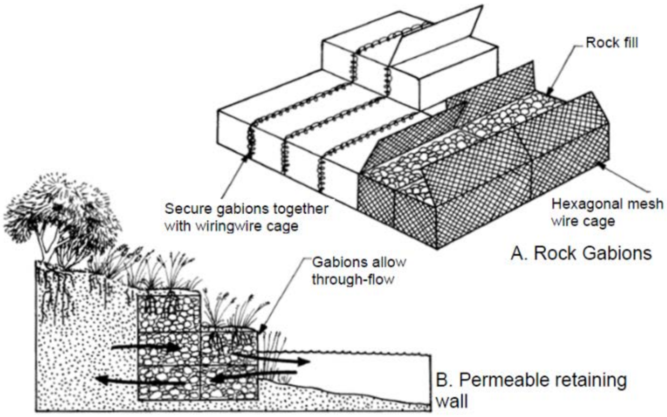


Figure 2 - 4 Gabions

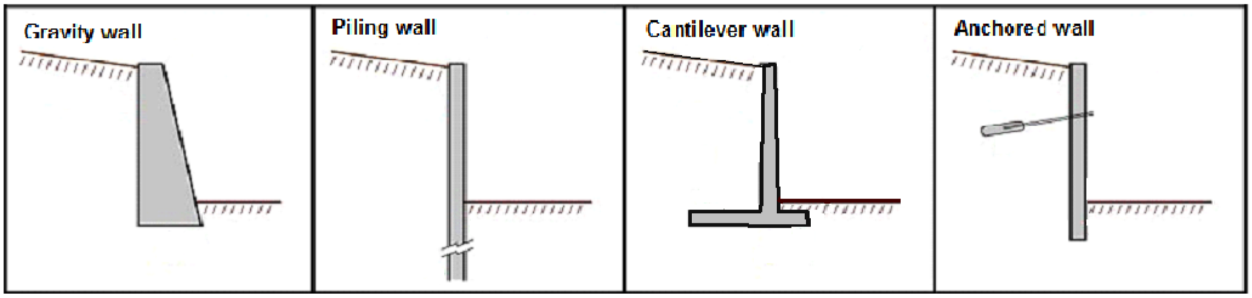


Figure 2 - 5 Types of Retaining Walls

Figure 2-6 Gabions being filled (Gabion1 2016)

CHAPTER 3: METHODS

This chapter will explain the methods that were used in this study. Stage and discharge data was used for flow duration analysis. The site and watershed was mapped using geographic information systems (GIS). Visual inspection was done through site visit photos, Google aerial photos, and Google Street View photos. The HEC-RAS model preparation is also described in this chapter.

3.1 GIS Site Mapping

It is important to obtain site information about watershed area, drainage characteristics, land use, etc. Traditionally, this is done by using contour and topographic maps. 90 meter resolution Digital Elevation Mapping (DEM) data was obtained from Mara University of Technology (UITM). Using ArcGIS 10.1, The DEM raster file was clipped with the polygon shape file of geographical Malaysia to locate the site of interest, Klang Watershed and Kerayong Watershed.

The Hydrology tools in Spatial Analyst tool box are used to delineate both the Klang and Kerayong Watersheds. First, the sinks of the DEM file are filled to remove small imperfections in the data using the Fill tool. Secondly, the flow direction is determined using the Flow Direction tool. The Flow Direction tool creates a raster from the DEM file that determines the flow direction from each cell to its steepest downslope neighbor. Then, the flow direction raster used to create a raster of accumulated flow using the Flow Accumulation tool. After that, the pour points of the Klang and Kerayong River are designated on the flow accumulation raster using the Snap Pour Point tool. The Watershed tool is then used to determine the contributing area of the flow accumulation up until the pour point to delineate the watershed. These steps were done in both delineating the Klang Watershed and Kerayong Watershed. Final adjustments had to be made; the delineated watershed is compared carefully with the base map obtained from Google Earth. The watershed shapefiles are adjusted to align with the terrain of the base map. Figure 3-1 illustrates the sequence of the process.

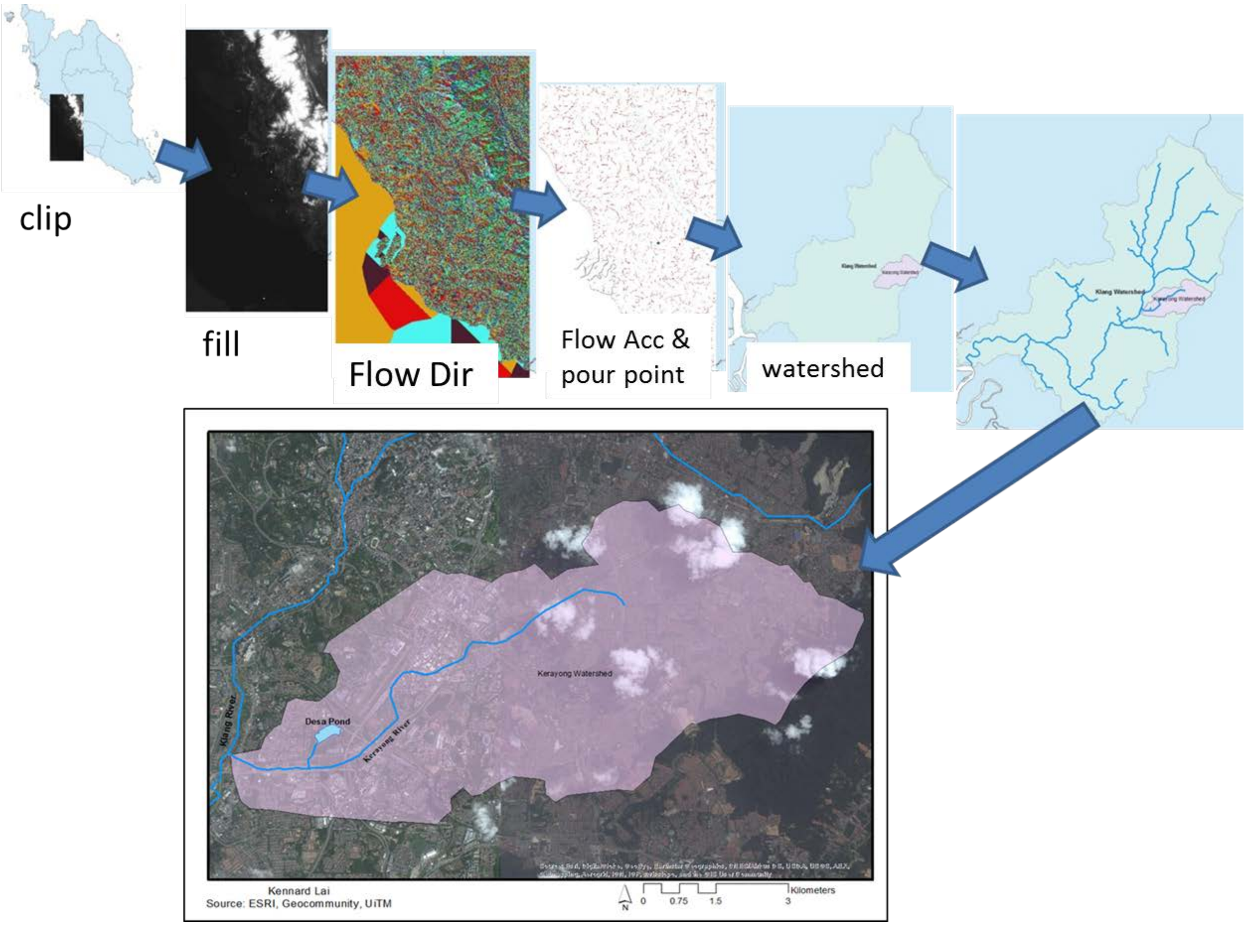


Figure 3 - 1 Watershed Delineation in ArcGIS

3.2 Updating River Geometry using Site visit photos, Google Earth, and Google Street View

To prepare river geometry data for hydraulic analysis, site visit photos, Google Earth imagery, and Google Street View imagery was used to update and verify obtained river geometry data. River geometry data was obtained from UITM. Data was obtained in the format of Excel spreadsheet with River Station, X, Y, and Z. It is then found that X and Y are coordinates of the Universal Transverse Mercator (UTM) Kertau coordinate system and Z is the elevation from mean sea level in meters. There are a total of 54 cross sections stations spanning the length of about 10 km of the Kerayong River. Starting from downstream to upstream, river station 1 is located at the confluence of Klang and Kerayong Rivers whereas the upstream most available cross section data is river station 54. In HEC-RAS, cross sections are divided into Left of Bank (LOB), main channel, and Right of Bank (ROB) but the river banks were not included in the river geometry data. The river banks are defined using the site visit photos, Google Earth imagery, and Google Street View imagery. The average distances between cross sections are 195.57 meters. It can be observed from Figure 16 that the outlet of Desa Pond from SMART Tunnel is between river stations 9 and 10. Since river stations 1 to 9 are receiving the increased flow from the SMART Tunnel, the reach from said stations is defined in this study as the Downstream Reach of the Kerayong River. The coordinates X and Y of the river stations were plotted in ArcGIS and georeferenced with the aerial photo obtained from Google Earth to create a map of the river.

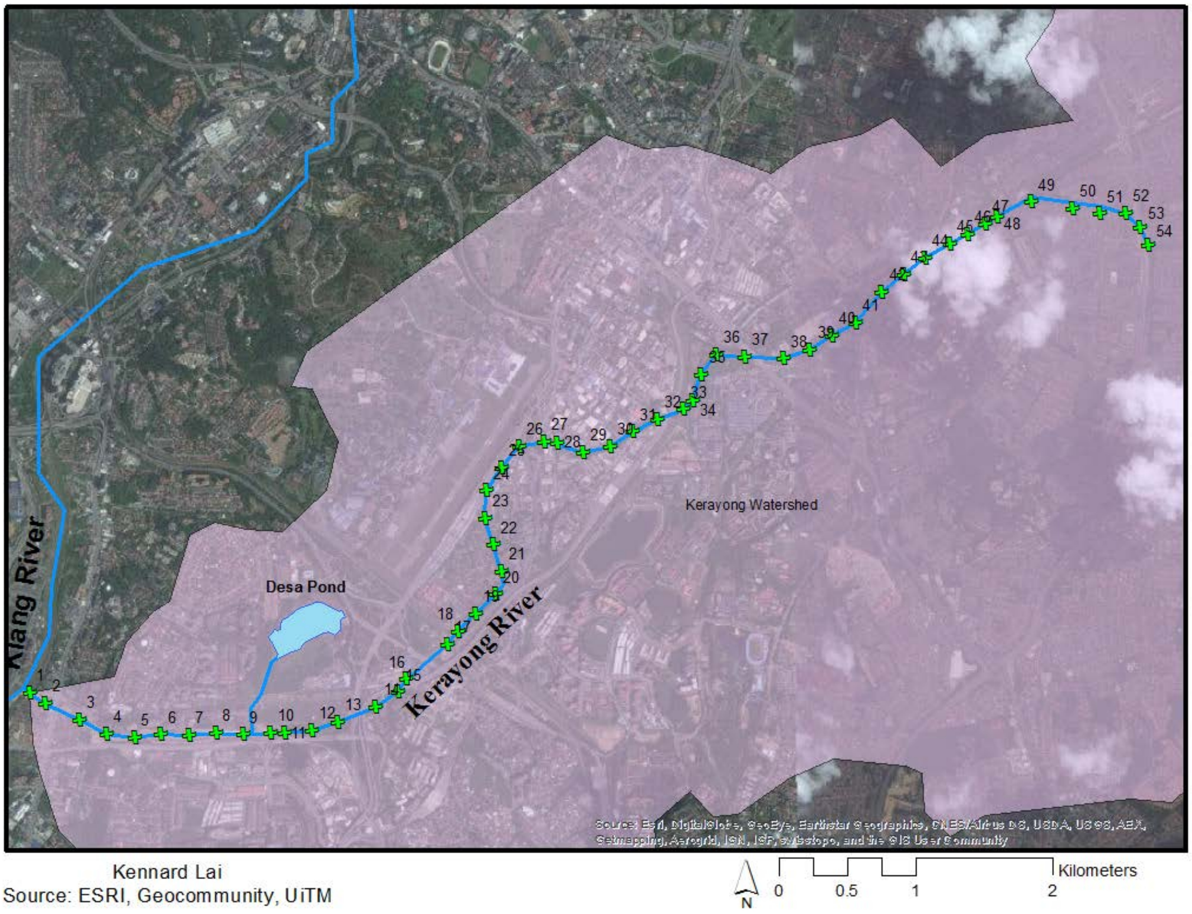


Figure 3 - 2 Map of River Stations on the Kerayong River

With the river stations plotted on the map, the locations of the river stations can be pinpointed. The cross-section geometry data is then compared with site photos, Google aerial images, and Google street view photos to determine if there were any changes since the river cross section was surveyed.

Through Google Earth's Historical Imagery function, satellite images since 2001 can be accessed. The year of satellite images for the site that can be accessed from Google Earth are: 2001, 2004, 2008, 2009, 2010, 2011, 2014, and 2015. A comparison of the Kerayong River and

SMART components found that river engineering works has been started sometime around January 2008 and completed after April 2010.

Figure 3 - 3 River Station 1 at Confluence of Kerayong and Klang in Jan 2008

Figure 3 - 4 River Station 1 at Confluence of Kerayong and Klang in April 2010

Figure 3 - 5 River Stations 3, 4, 5 in Jan 2008

Figure 3 - 6 River Stations 3, 4, 5 in April 2010

Figure 3 - 7 River Stations 6, 7, 8 in Jan 2008

Figure 3 - 8 River Stations 6, 7, 8 in April 2010

Figure 3 - 9 River Stations 9, 10 and outlet of Desa Pond in 2008, 2010, 2011, respectively (notice ongoing construction in April 2010)

Site visit photos were used alongside Google imagery to determine the changes on river geometry (Figure 24 and 25). River geometry such as channel wall height, channel width as well as bed material was measured and recorded during the site visit. Based on the comparisons, it could then be determined that channel improvement works include widening, deepening, and straightening. Bed material prior to improvement works were assumed to be natural (gravel) and was replaced with concrete lining. It can be observed the presence of small boulders at the confluence of the Kerayong and Klang Rivers.

Figure 3 - 10 Site visit photos and the location they were taken on the Klang and Kerayong confluence (RS1)

Figure 3 - 11 Site visit photos looking upstream and downstream between River Stations 4 and 5

Besides site visit photos and Google satellite images, Google Street View imagery was useful in determining channel geometry. Although there were not site visits throughout the entire length of the river, information could be gathered for the river through Google Street View. Street View is a function of Google Maps and Google Earth where 360 degree panoramic photos are taken by Google Maps Camera Cars and stitched together, creating a continuous first person virtual world. As its name suggests, Street View mostly provides viewpoints from streets in many parts of the world. While most photography is done with a car, other methods like tricycles, boats, and underwater equipment are used as well.

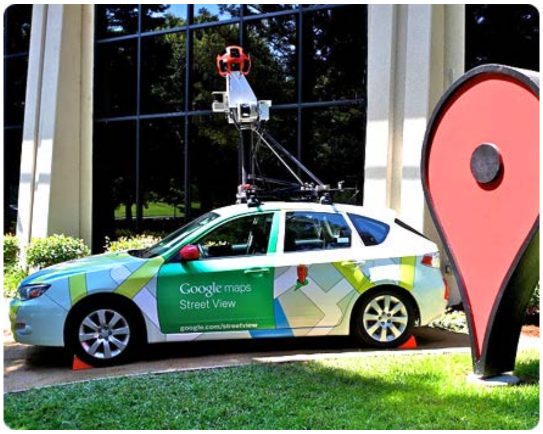


Figure 3 - 12 The specially equipped Google Maps Camera Car (Google 2016)

For the Kerayong River, Street View images were taken from as many vantage points as possible where the river is visible from the street. Common vantage points are bridges which intersect the Kerayong River. Many vantage points on bridges allow both upstream and downstream views thanks to Street View's 360 degree panoramic technology. A total of 27 Street View images were obtained for the Kerayong River. Paired with the location of the river stations plotted on the map in ArcGIS, it is possible to identify the river station through Street View. From there, the cross section geometry data can be verified or modified. Together with site visit photos and Google Earth satellite images, Information that is obtained from Street View is use to aid estimation of channel width, height, bank slope, Manning's roughness coefficient, bed material, and flow pattern of the Kerayong River.

HEC-RAS requires cross sections to be divided into three sub-sections, namely Left of Bank (LOB), main channel, and Right of Bank (ROB). HEC-RAS also requires Manning's roughness for analysis. The channel banks and Manning's roughness were not included in the original cross section geometry data so they were estimated based on Street View images and modified. Bed and bank lining such as vegetation in the images enables estimation of Manning's n values when referenced with the HEC-RAS Hydraulic Reference Manual (USACE 2010). River stations that were not accessible through Street View or site visit photos were examined through Google Earth satellite images to estimate and update channel geometry.

The implementation of information gathered from Google Street View enables the updating and improvement of the hydraulic model when site visits and surveys are not possible. Many times, the river geometry such as channel, banks in the HEC-RAS model were updated by visually estimating a combination of Google Earth and Street View images.

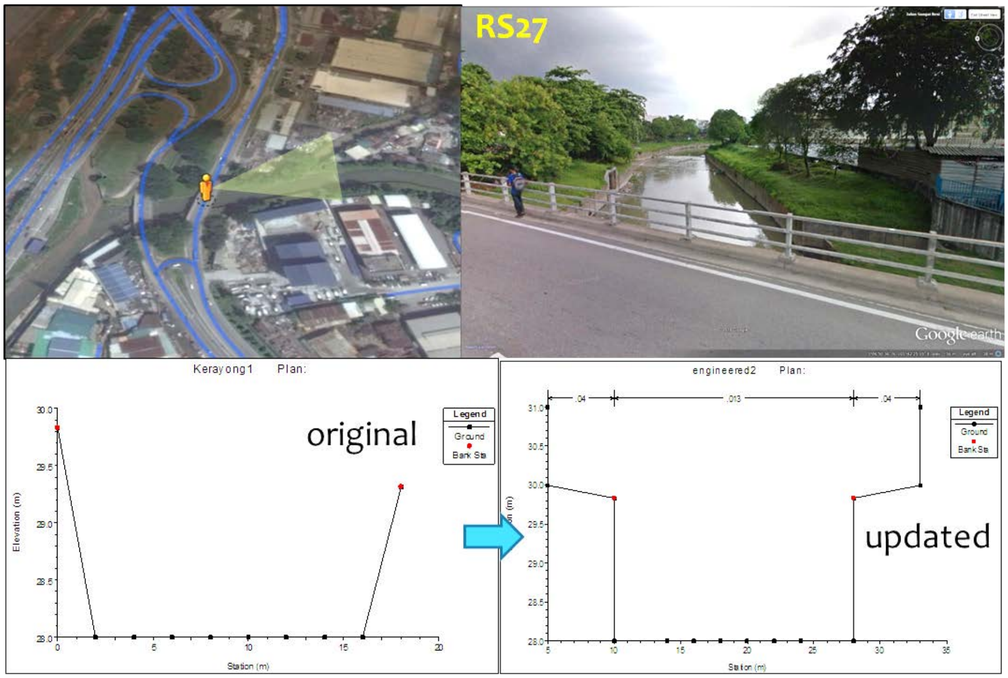


Figure 3 - 13 Google Street View provided up-to-date river geometry information for RS27

Figure 3 - 14 A combination of site visit photos and Google satellite image was used to estimate channel geometry of RS6

3.3 Preparing the HEC-RAS Model

River Geometry

River geometry was prepared as described in sections 3.1 and 3.2. The HEC-RAS model was simulated for two different river geometries – “Pre-2009” and “Engineered”.

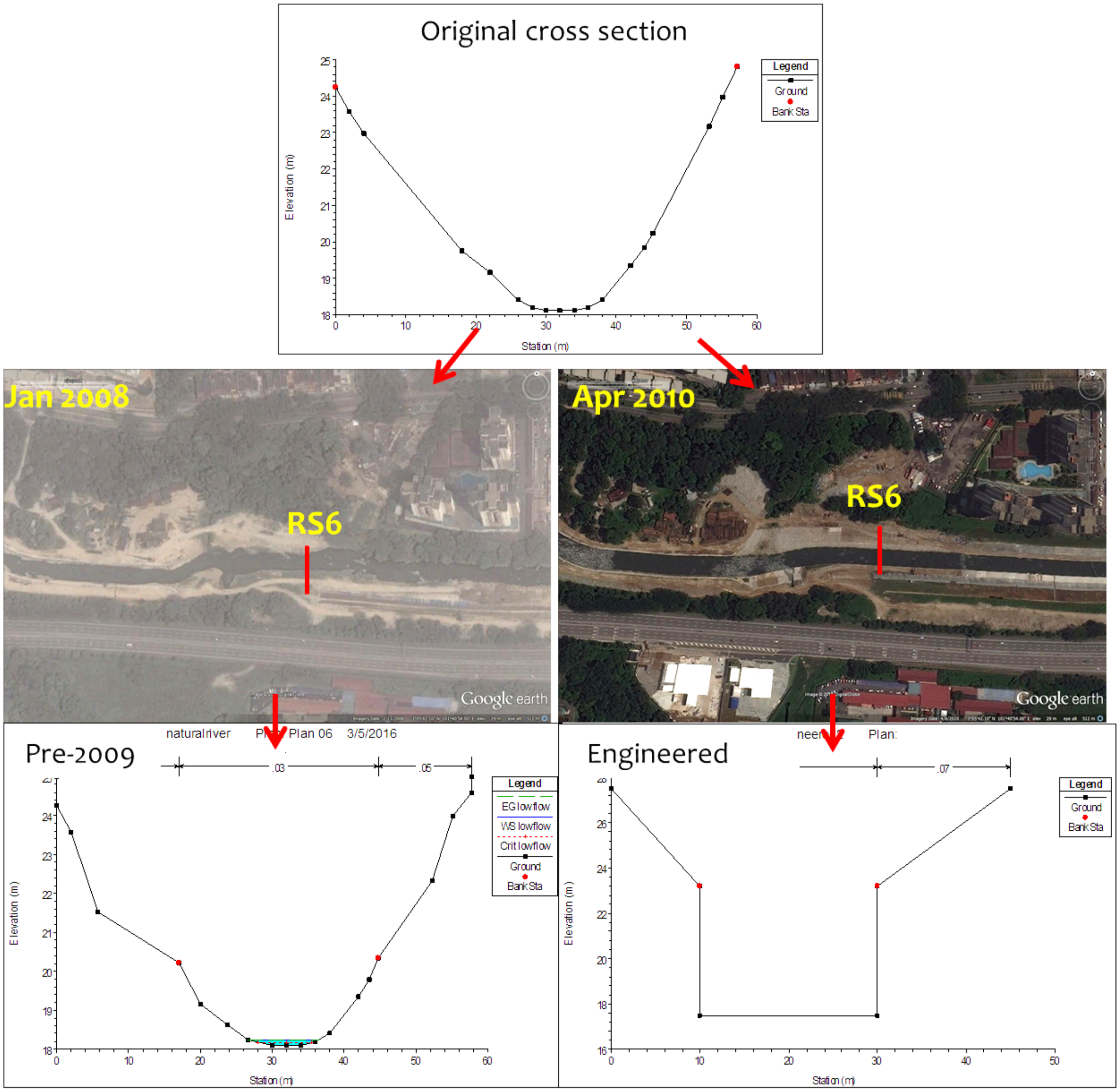


Figure 3 - 15 The Downstream reach of Kerayong River was modified to "Pre-2009" and "Engineered" conditions

Notice from Figure 3-15 that both the Pre-2009 and Engineered cross sections are different that the original cross section. The river banks for the pre-2009 are defined and the floodplain is modified to fit with the Google satellite image. In order to contain the flow, some channel floodplains are artificially extended in HEC-RAS using assumptions and best judgement. Most of the 54 river stations are modified based on the methods described in section 3.2.

Channel Conveyance

As described in Chapter 2, conveyance in HEC-RAS is described by Manning’s equation. Using the methods described in section 3.2, the surface roughness or vegetation of channel bed and banks can be estimated. The corresponding Manning’s n that is used in the conveyance calculation is obtained from the HEC-RAS Reference Manual (USACE 2010b). On main channels Manning’s n range from 0.017 for float finished concrete to 0.03 for clean, straight, natural channels. On Floodplains, Manning’s n range from 0.03 for short grass to 0.05 for scattered brush and heavy weeds.

Slope

The slope is plotted for both Pre-2009 and Engineered channels and was found to be similar with slope of 0.0022. The slope is used to approximate normal depth.

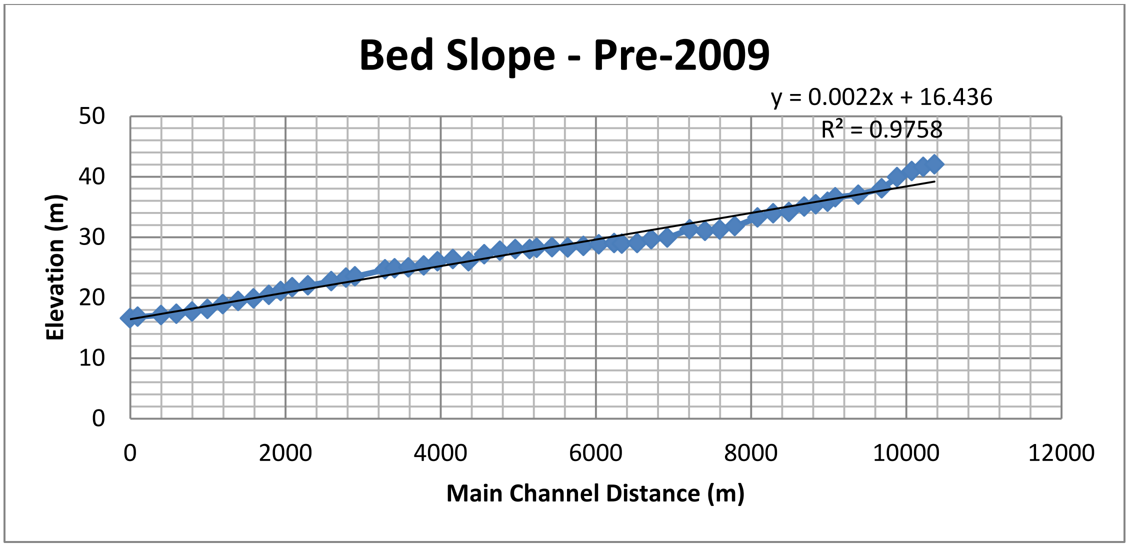


Figure 3 - 16 Pre-2009 bed slope

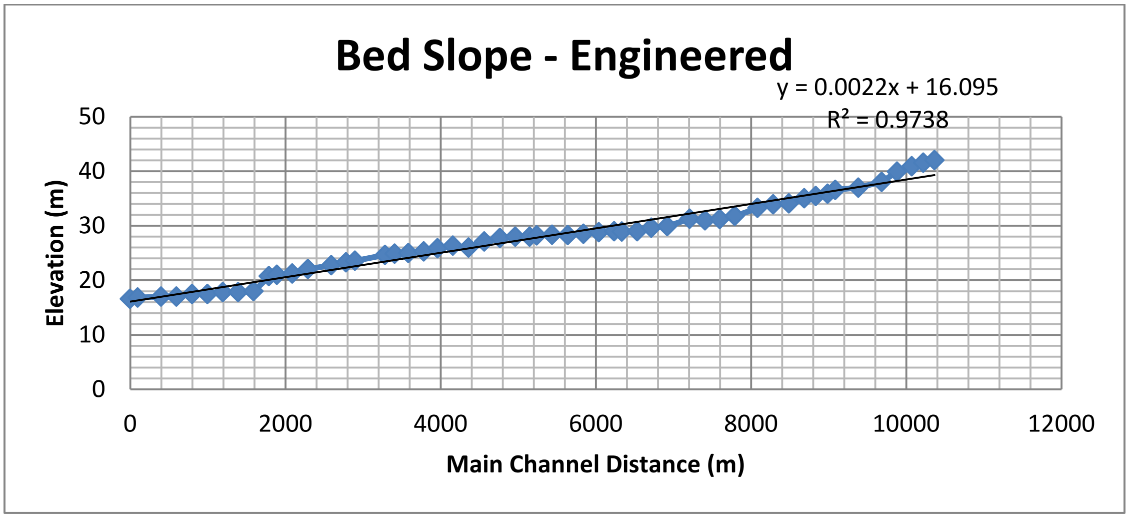


Figure 3 - 17 Engineered bed slope

Flow Data

Using HEC-RAS, flow is simulated as steady non-uniform for this study. Two years – 2008 and 2009, of hourly flow data at the weir just upstream of the Desa Pond junction to the Kerayong River (about River Station 10) was obtained from UITM (2009). Because the gage station is just upstream of the Desa Pond outlet, the flow does not include the increased flow from the SMART

Tunnel. A flow duration analysis is performed to obtain the average recurrence interval of flows on the Kerayong before the increased discharge from the SMART Tunnel.

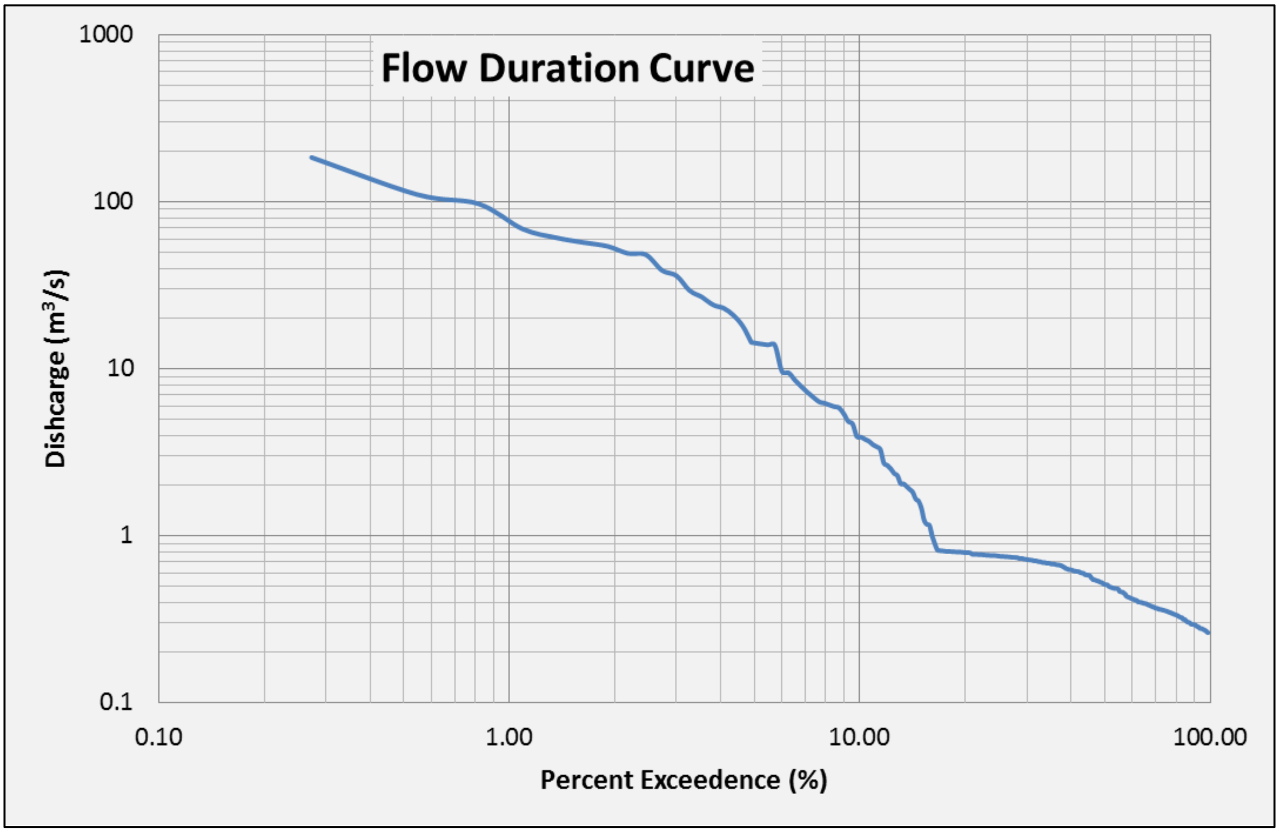


Figure 3 - 18 Flow duration curve

Different flows profiles were initially selected for simulation based on the flow duration curve. Based on percent exceedance, flow profiles and corresponding flows in were defined:

1) Low Flow : 75% exceedance = 0.3 m^3/s
2) Median Flow: 50% exceedance (2-year flood) = 0.54 m^3/s
3) Flood Flow: 1% exceedance (100-year flood) = 67 m^3/s
4) Max Flow: Maximum recorded discharge (~500-year flood) = 184 m^3/s

In this study, only the discharges from Flood Flow and Max Flow were presented in the results section for both Pre-2009 and Engineered Rivers because the objective is to determine the impact on the downstream reach of the Kerayong River due to the increased flow from the SMART Tunnel. Low Flow and Median Flow were still modeled to identify the flow patterns during "normal" conditions in the Kerayong River.

The design flow of the SMART Tunnel is 280 m^3/s (Abdullah 2004). The Flood Flow and Max Flow profiles are modeled in HEC-RAS based on the assumption of a prolonged intense rainstorm (>3 hours) where the SMART Tunnel and its two holding ponds, Berembang and Desa, are at full capacity. During this event, the flow of 280 m^3/s from the SMART Tunnel will flow through the Desa outlet structure where it is combined with the flow from upstream of the Kerayong River. An additional 20 m^3/s is assumed to be contributed by the Desa Pond watershed (DID 2014). This increase in flow is added at River Station (RS) 9 in the HEC-RAS model. For Flood Flow profile, the increase in flow of 300 m^3/s leads to a flow of 367 m^3/s in the downstream reach of the Kerayong River. For Max Flow Profile, the increased in flow of 300 m^3/s leads to a flow of 484 m^3/s in the downstream reach of the Kerayong River (Figure 3-19).

In HEC-RAS, the flows profiles were obtained from a gage closest to RS10, hence the flow profiles are set as such at RS10 and the flow is increased by 300 m^3/s at RS9 for Flood Flow and Max Flow. Because the flow at RS10 is a function of the watershed area of the river station, the flows were staggered in decreasing order upstream for flow profiles Flood Flow and Max Flow (Table 3-1). For example, RS40 will have less flow than RS10 for the same flow profile because the contributing watershed is smaller. Flow profiles for Low Flow and Median flow were assumed to be constant throughout because they are too low to have any significant effect. The boundary conditions are set as shown in Figures 3-20 and 3-21. Because the upper boundary

(RS54) conditions are not known, it is assumed to be at normal depth. The Slope 0.0022 that was obtained from Figures 3-16 and 3-17 were used in HEC-RAS to calculate the normal depth. The downstream boundary conditions are estimated based on site visit photos, the drop structures at the downstream end (RS1) of the Kerayong River are used as the control section. At the downstream end, the existence of the drop structure allows for the downstream conditions for Low Flow and Median Flow to be set at critical depth. However, the flow conditions for Flood Flow and Max Flow cannot be set at critical depth because it is expected that the water level after the drop structure will be higher than the drop structure elevation, resulting in a submerged weir effect. Ng (2004) has found that the water level on the Klang River slightly downstream of the confluence of Kerayong and Klang at maximum flow to be 21.8 m. As such, the Flood Flow lower boundary condition is set slightly lower as known water surface level at 21 m and for Max Flow at 21.8 m.

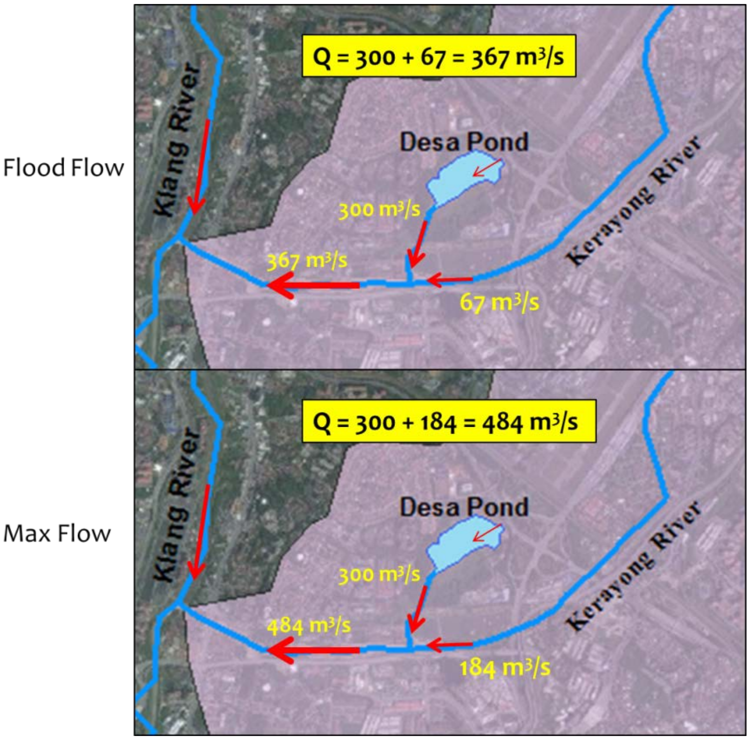
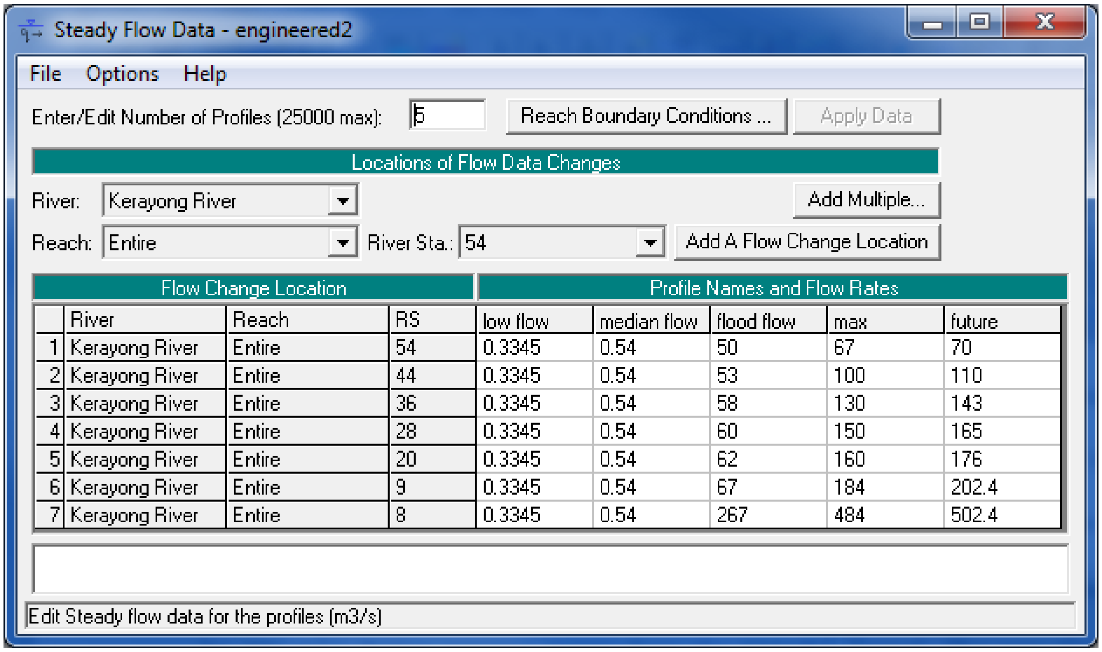


Figure 3 - 19 Modeled flow profiles in HEC-RAS



Enter/Edit Number of Profiles (25000 max): 5

River: Kerayong River

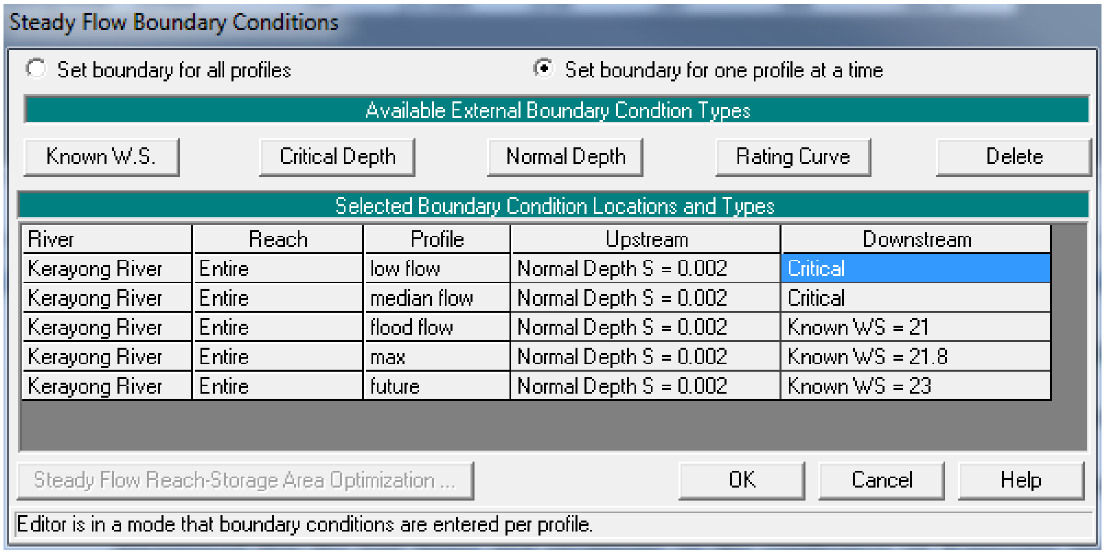
Reach: Entire

River Sta.: 54

	Flow Change Location			Profile Names and Flow Rates				
	River	Reach	RS	low flow	median flow	flood flow	max	future
1	Kerayong River	Entire	54	0.3345	0.54	50	67	70
2	Kerayong River	Entire	44	0.3345	0.54	53	100	110
3	Kerayong River	Entire	36	0.3345	0.54	58	130	143
4	Kerayong River	Entire	28	0.3345	0.54	60	150	165
5	Kerayong River	Entire	20	0.3345	0.54	62	160	176
6	Kerayong River	Entire	9	0.3345	0.54	67	184	202.4
7	Kerayong River	Entire	8	0.3345	0.54	267	484	502.4

Edit Steady flow data for the profiles (m3/s)

Figure 3 - 20 Steady flow data for the different profiles



○ Set boundary for all profiles
● Set boundary for one profile at a time

River	Reach	Profile	Upstream	Downstream
Kerayong River	Entire	low flow	Normal Depth S = 0.002	Critical
Kerayong River	Entire	median flow	Normal Depth S = 0.002	Critical
Kerayong River	Entire	flood flow	Normal Depth S = 0.002	Known WS = 21
Kerayong River	Entire	max	Normal Depth S = 0.002	Known WS = 21.8
Kerayong River	Entire	future	Normal Depth S = 0.002	Known WS = 23

Editor is in a mode that boundary conditions are entered per profile.

Figure 3 - 21 Boundary conditions

An additional flow profile named Future Flow was modeled using HEC-RAS on the Engineered channel to simulate possible increased flow for future extreme events. This is discussed more in section 5.2.

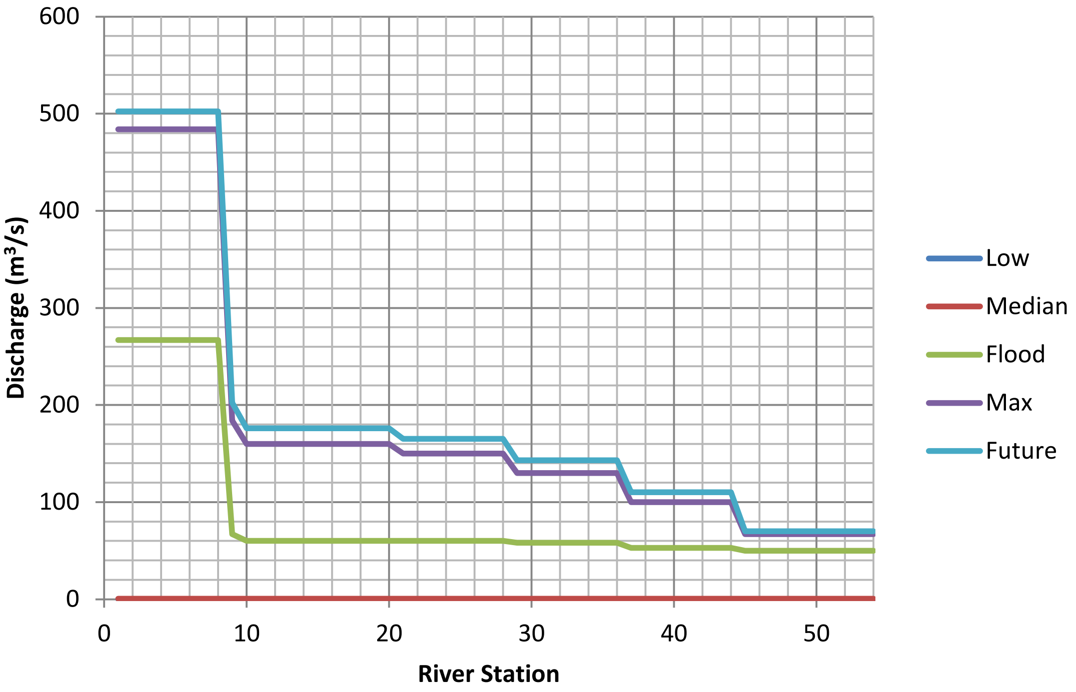


Figure 3 - 22 Flow Profiles used in simulations

CHAPTER 4: RESULTS

This chapter presents the modeling results from HEC-RAS including water surface profiles, cross sections. Sections on the validation of HEC-RAS results and channel stability are also included.

4.1 Water Surface Profiles

Water Surface Profiles for Flood Flow and Max Flow are presented in this section for Pre-2009 and Engineered River geometries. To determine bank overtopping, the lower of each channel banks (LOB and ROB) are recorded manually into Excel and labeled as “Top of Bank”. While water surface elevation at some sections may be higher than the Top of Bank, actual damage-causing-flooding may or may not be happening. One of the reasons that actual damaging flood may not happen is because the Top of Bank only represents the elevation of the main channel banks but the overbank region is a designated flood plain (see Figure 4-1). On the other hand, damaging floods may happen if there are properties on the floodplain or that that overbank regions are artificially raised in HEC-RAS to contain the flow. To determine if an actual damaging flood is happening, a closer look at each cross section may be required (Section 4.2).

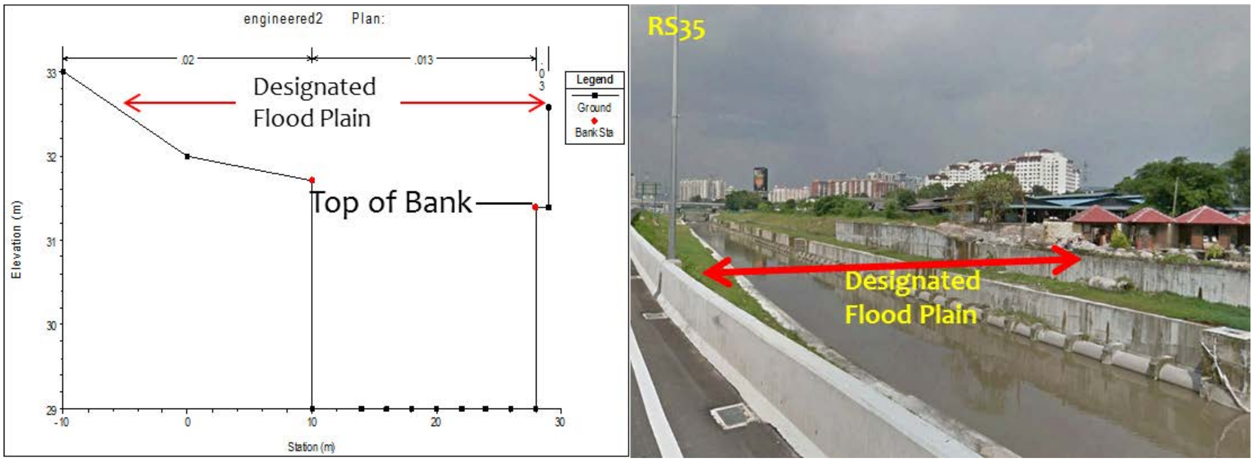


Figure 4 - 1 Designated floodplain on RS 35

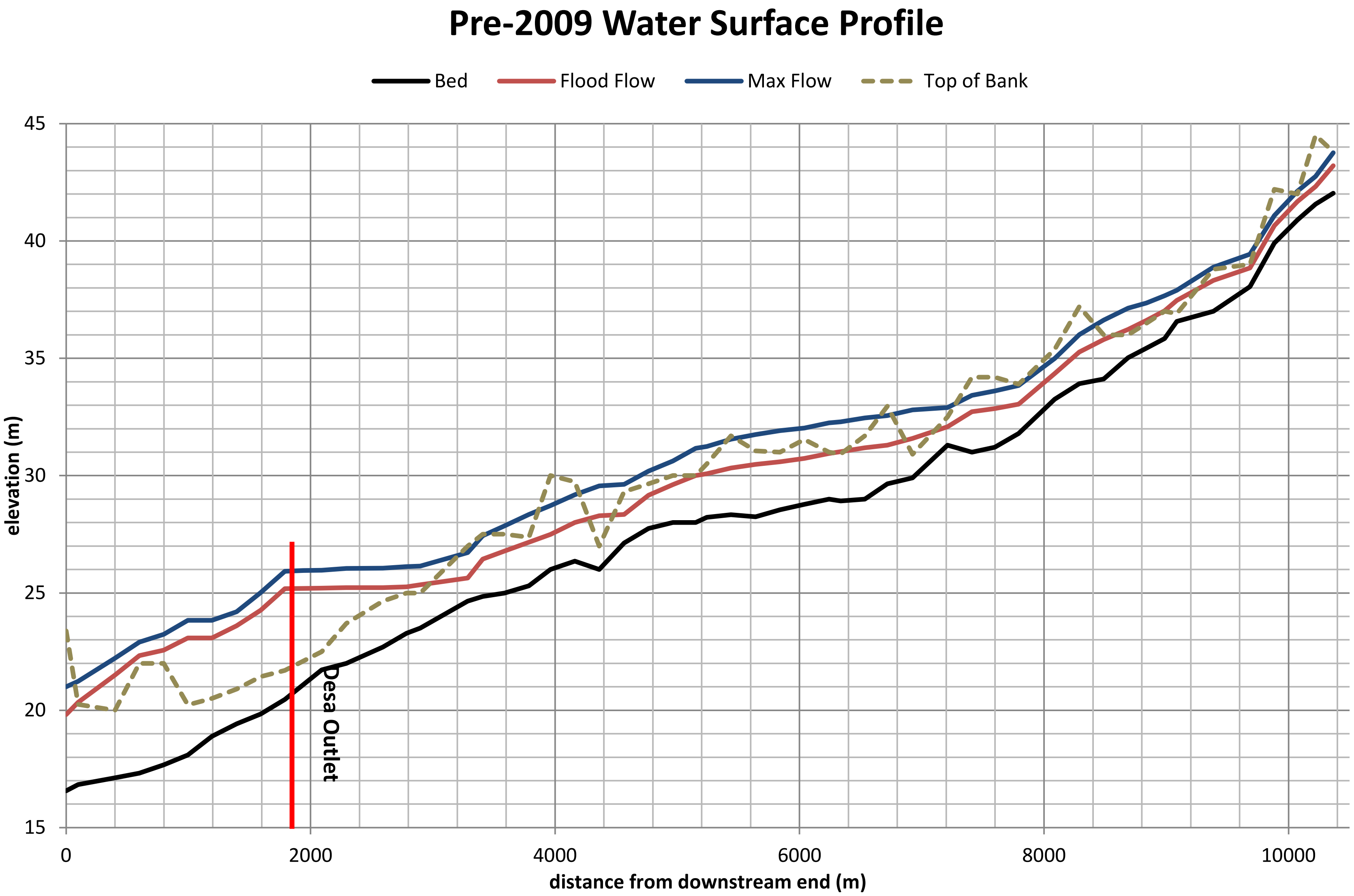


Figure 4 - 2 Pre-2009 water surface profile

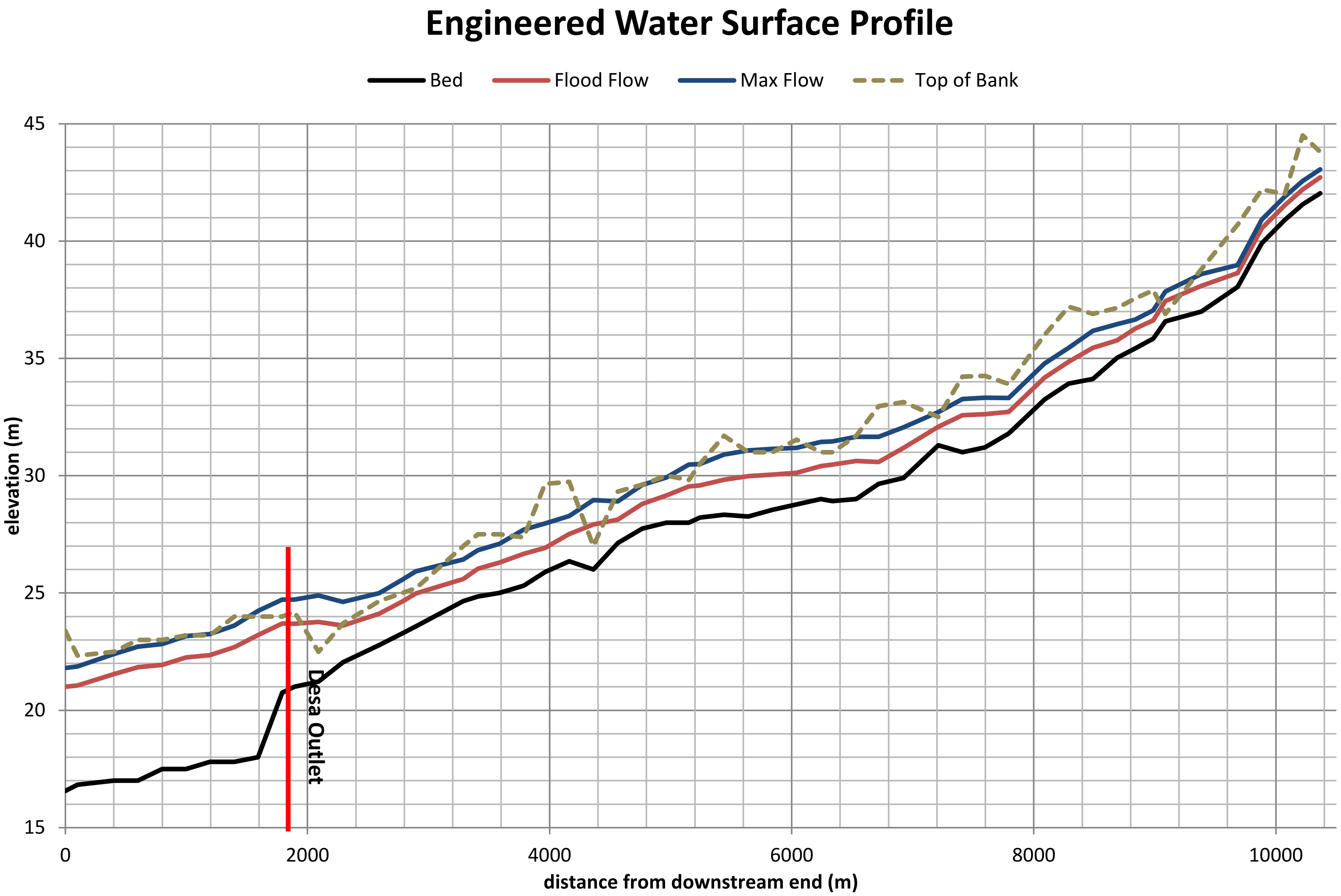


Figure 4 - 3 Engineered water surface profile

4.2 Cross Sections

Because the site of interest is the downstream reach of the Kerayong River, only the cross sections from river stations (RS) 1 to 16 (Desa Outlet is between RS 9 and 10) are presented in this section. All of the results will be available in the Appendix section. Table 4-1 shows the water surface elevation of each river station. Figures 4-4 to 4-11 shows the cross section plots from HEC-RAS. It can be observed that downstream of SMART Tunnel Desa Pond outlet, the Pre-2009 River overflow its banks at 7 out of 9 cross sections (from RS 3 to RS 9) for Flood Flow (100-year flood) and 8out of 9 cross sections (RS 2 to RS 9) for Max Flow (484 m^3/s). The maximum overbank flow depth increase (floodplain flow depth) on the Pre-2009 River for Flood Flow and Max Flow are 2.98 m and 3.74 m, respectively. Both of the depths occurred at RS 6. Although HEC-RAS results showed up to 3.74 m of flooding, in reality the flood depth may be lower than the model because the floodplains around RS 6 were artificially raised in the model to contain the flow. In reality, the overbank flow may have been able to spread over a larger area.

On the other hand, between RS 1 and RS 9, the Engineered River managed to contain Flood Flow without bank overtopping. Max flow in the Engineered River saw a 23 cm bank overtopping at RS 9.

In all four simulations, upstream of the Desa outlet (RS 10 to RS 16) resulted in overbank flow of up to 4.22 m at RS 10 for Pre-2009 River at Max Flow. This could be due to backwater effects caused by a sudden increase in flow downstream, choking the flow. Again, for the Pre-2009 River, many of the cross sections overbank edges were raised artificially in the model to contain flow so the real flooding (if occurred) may be lower.

Table 4- 1 River Stage and Stage Difference

	River Stage (m)						
	Pre-2009		Engineered			Stage Difference	
River Station	Flood Flow	Max Flow	Flood Flow	Max Flow	Future Flow	$\text{Flood}_{\text{Pre-2009}}$ - $\text{Flood}_{\text{Engineered}}$	$\text{Max}_{\text{Pre-2009}}$ - $\text{Max}_{\text{Engineered}}$
1	19.82	21.00	21.00	21.80	23.00	-1.18	-0.80
2	20.34	21.23	21.06	21.87	22.99	-0.71	-0.63
3	21.50	22.22	21.54	22.39	23.11	-0.04	-0.17
4	22.33	22.90	21.84	22.72	23.24	0.49	0.19
5	22.56	23.23	21.94	22.83	23.23	0.63	0.41
6	23.08	23.84	22.26	23.16	23.40	0.82	0.67
7	23.08	23.83	22.35	23.25	23.36	0.73	0.58
8	23.60	24.20	22.70	23.62	23.60	0.91	0.58
9	24.26	25.02	23.21	24.23	24.71	1.05	0.78
10	25.19	25.92	23.71	24.72	24.67	1.48	1.20
11	25.19	25.95	23.69	24.72	24.59	1.50	1.23
12	25.20	25.96	23.77	24.90	24.85	1.43	1.07
13	25.22	26.04	23.62	24.62	24.38	1.61	1.43
14	25.23	26.06	24.12	24.99	25.28	1.11	1.07
15	25.26	26.12	24.64	25.58	25.72	0.62	0.54
16	25.35	26.15	24.98	25.93	26.30	0.37	0.22
17	25.64	26.72	25.60	26.43	27.21	0.04	0.29
18	26.44	27.44	26.04	26.82	27.23	0.41	0.62
19	26.79	27.86	26.30	27.09	27.59	0.49	0.77
20	27.16	28.34	26.67	27.70	27.71	0.50	0.64
21	27.49	28.73	26.92	27.96	28.04	0.57	0.77
22	28.00	29.19	27.51	28.28	28.50	0.49	0.91
23	28.29	29.57	27.92	28.96	29.40	0.37	0.60
24	28.34	29.63	28.13	28.90	29.25	0.21	0.73
25	29.17	30.19	28.80	29.60	29.65	0.37	0.59
26	29.62	30.63	29.15	29.92	30.11	0.46	0.71
27	30.01	31.17	29.55	30.48	30.74	0.46	0.69
28	30.08	31.24	29.59	30.50	30.69	0.49	0.74
29	30.32	31.56	29.83	30.90	31.08	0.50	0.66
30	30.48	31.76	29.98	31.07	31.32	0.50	0.68
31	30.59	31.91	30.05	31.14	31.36	0.54	0.77
32	30.73	32.03	30.13	31.18	31.31	0.61	0.84
33	30.95	32.24	30.41	31.44	31.69	0.54	0.81
34	31.03	32.30	30.47	31.46	31.68	0.56	0.83

35	31.19	32.45	30.63	31.66	31.93	0.56	0.79
36	31.30	32.55	30.59	31.65	31.79	0.71	0.90
37	31.59	32.81	31.19	32.07	32.42	0.40	0.74
38	32.08	32.90	32.09	32.71	33.02	0.00	0.19
39	32.73	33.42	32.58	33.27	33.56	0.15	0.16
40	32.86	33.61	32.63	33.32	33.58	0.23	0.29
41	33.05	33.84	32.73	33.31	33.73	0.32	0.53
42	34.35	34.99	34.18	34.78	35.21	0.16	0.20
43	35.27	36.01	34.86	35.45	35.88	0.42	0.55
44	35.80	36.62	35.45	36.17	36.43	0.35	0.45
45	36.23	37.14	35.76	36.46	36.86	0.47	0.68
46	36.61	37.36	36.27	36.65	36.88	0.34	0.71
47	37.03	37.67	36.62	37.05	37.29	0.40	0.62
48	37.47	37.90	37.44	37.85	38.11	0.02	0.05
49	38.32	38.88	38.09	38.60	38.76	0.23	0.29
50	38.85	39.44	38.64	38.98	39.38	0.22	0.46
51	40.66	41.08	40.55	40.92	41.37	0.11	0.16
52	41.68	42.13	41.52	41.90	42.15	0.16	0.23
53	42.32	42.75	42.20	42.57	43.04	0.12	0.18
54	43.20	43.76	42.71	43.05	43.48	0.49	0.70

Table 4-1 shows that the engineered channel prevented overtopping of bank for Max Flow from RS2 to RS8. It also shows reduced bank overtopping for RS9 to RS15. However, it does show that bank overtopping increased by 18 cm at RS16. This could be due to misrepresentation of river geometry between RS11 and RS16 because there was no available Google Street View images for said river stations therefore the estimation of the cross section geometry may not be accurate.

Table 4- 2 Bank overtopped depth (if any)

	Bank overtopping depth (m)				
River Station	Flood$_{\text{pre-2009}}$	Max$_{\text{pre-2009}}$	Flood$_{\text{engineered}}$	Max$_{\text{engineered}}$	Future$_{\text{engineered}}$
1					0.80
2	0.09	0.98			0.66
3	1.50	2.22			0.61
4	0.33	0.90			0.24
5	0.56	1.23			0.23
6	2.85	3.61			0.20
7	2.57	3.32		0.05	0.16
8	2.74	3.34			
9	2.98	3.74		0.23	0.71
DESA OUTLET					
10	3.49	4.22		0.72	0.67
11	3.09	3.85		0.52	0.39
12	2.70	3.46	1.27	2.40	2.35
13	1.52	2.34		0.92	0.68
14	0.58	1.41		0.34	0.63
15	0.26	1.12		0.58	0.72
16	0.01	0.81		0.93	1.30
17					0.21
18					
19		0.36			0.09
20		0.97		0.33	0.34
21					
22					

23	1.29	2.57	0.92	1.96	2.40
24	1.21	2.50			
25		0.54			0.02
26		0.63			0.11
27	0.01	1.17		0.48	0.74
28		0.74			0.19
29					
30		0.76		0.07	0.32
31		0.91		0.14	0.36
32		0.49		0.18	0.31
33		1.24		0.44	0.69
34	0.11	1.38		0.54	0.76
35		0.75			0.23
36		0.33			
37					
38		0.40		0.21	0.52
39					
40					
41					
42					
43					
44					
45					
46					
47					
48					
49					
50					
51					
52		0.13			0.15
53					
54					

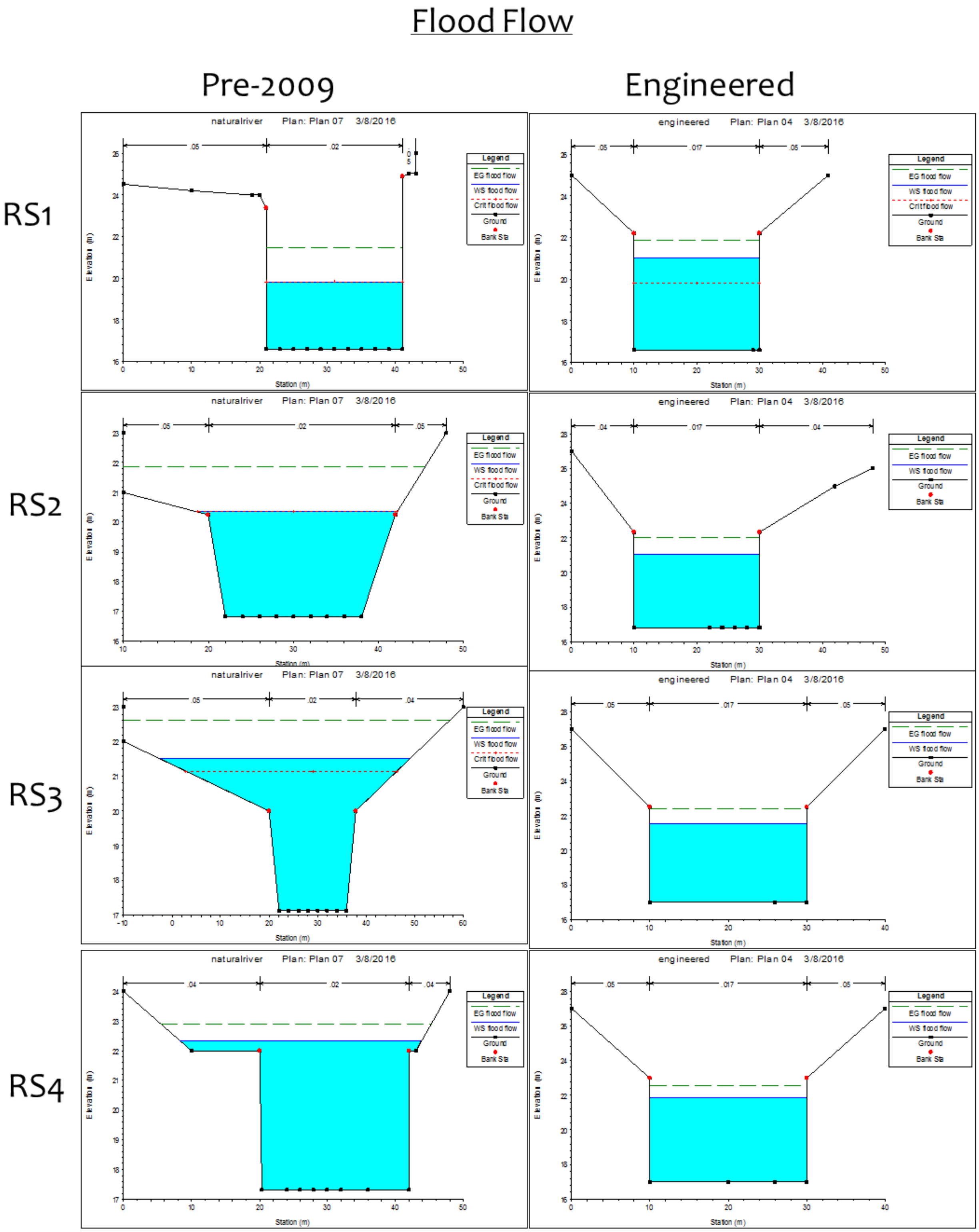


Figure 4 - 4 RS 1-4 at Flood Flow

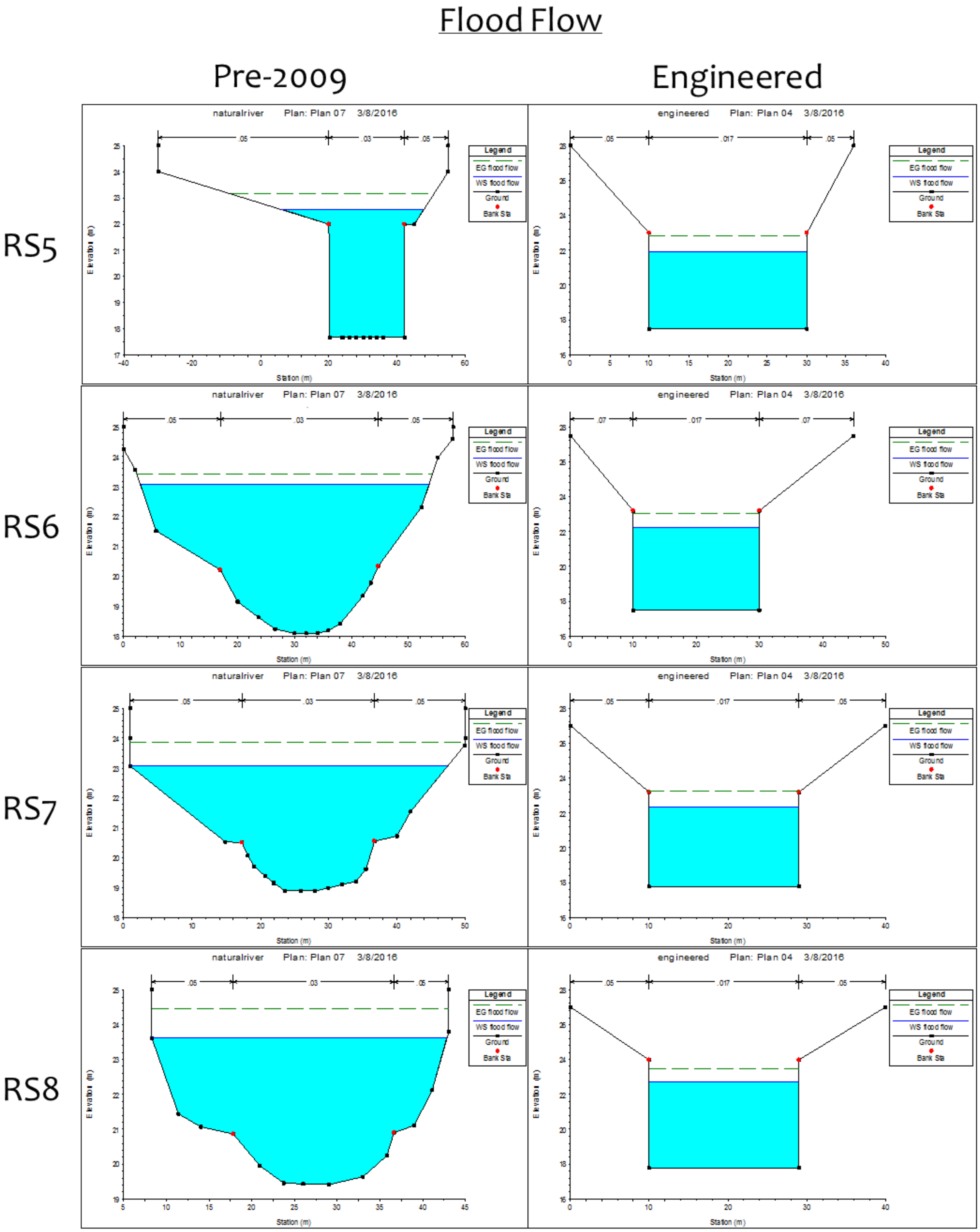


Figure 4 - 5 RS 5-8 at Flood Flow

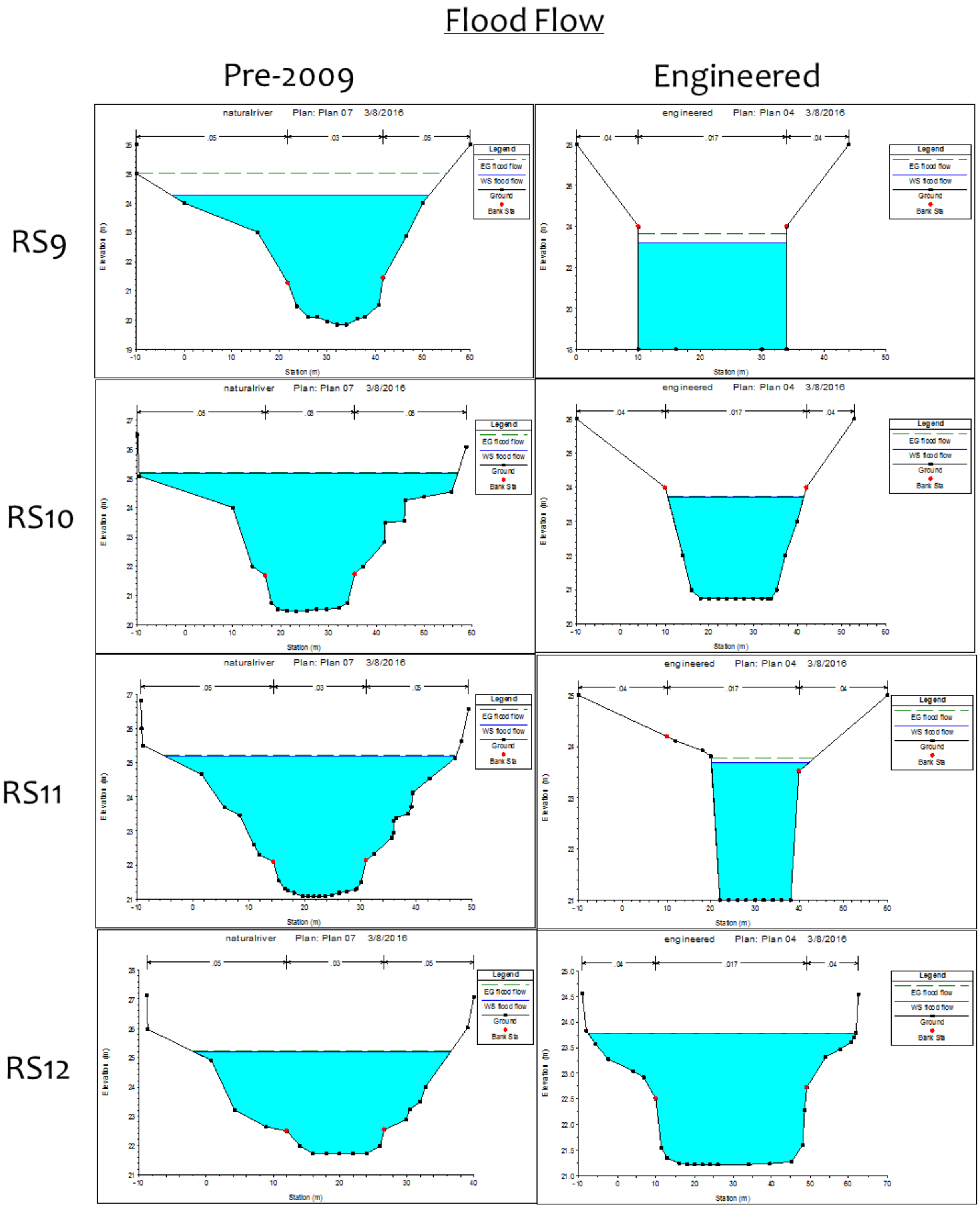


Figure 4 - 6 RS 9-12 at Flood Flow

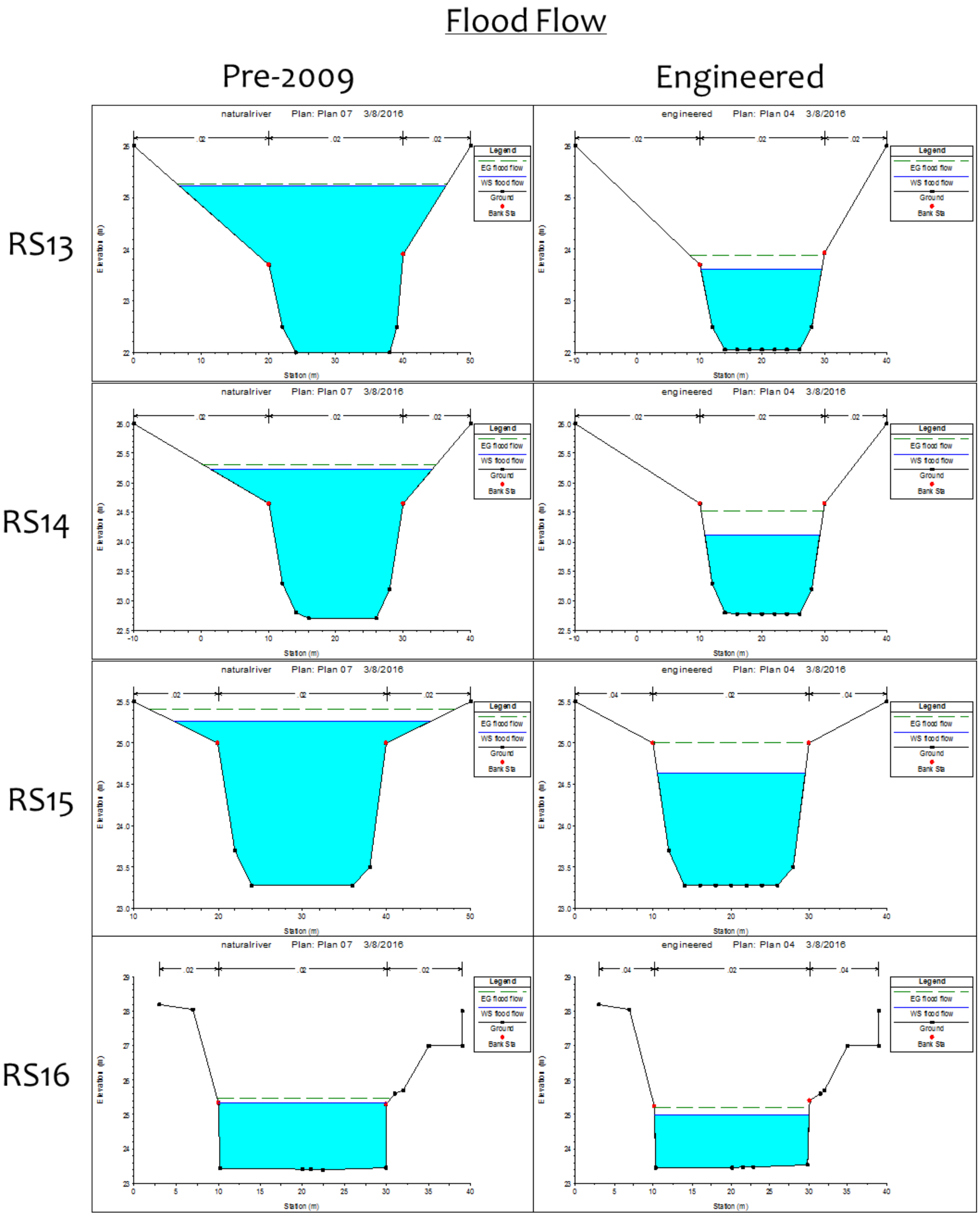


Figure 4 - 7 RS 13-16 at Flood Flow

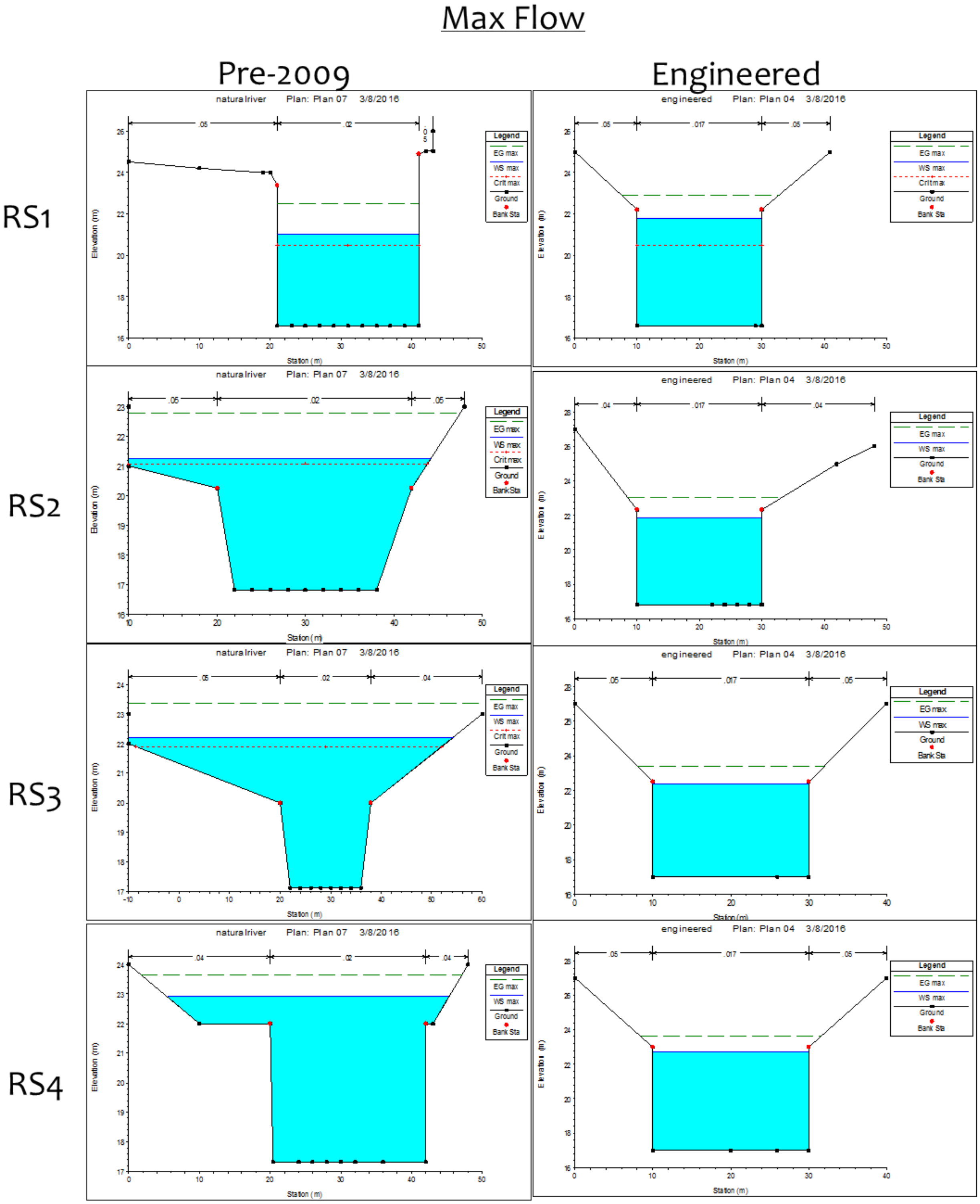


Figure 4 - 8 RS 1-4 at Max Flow

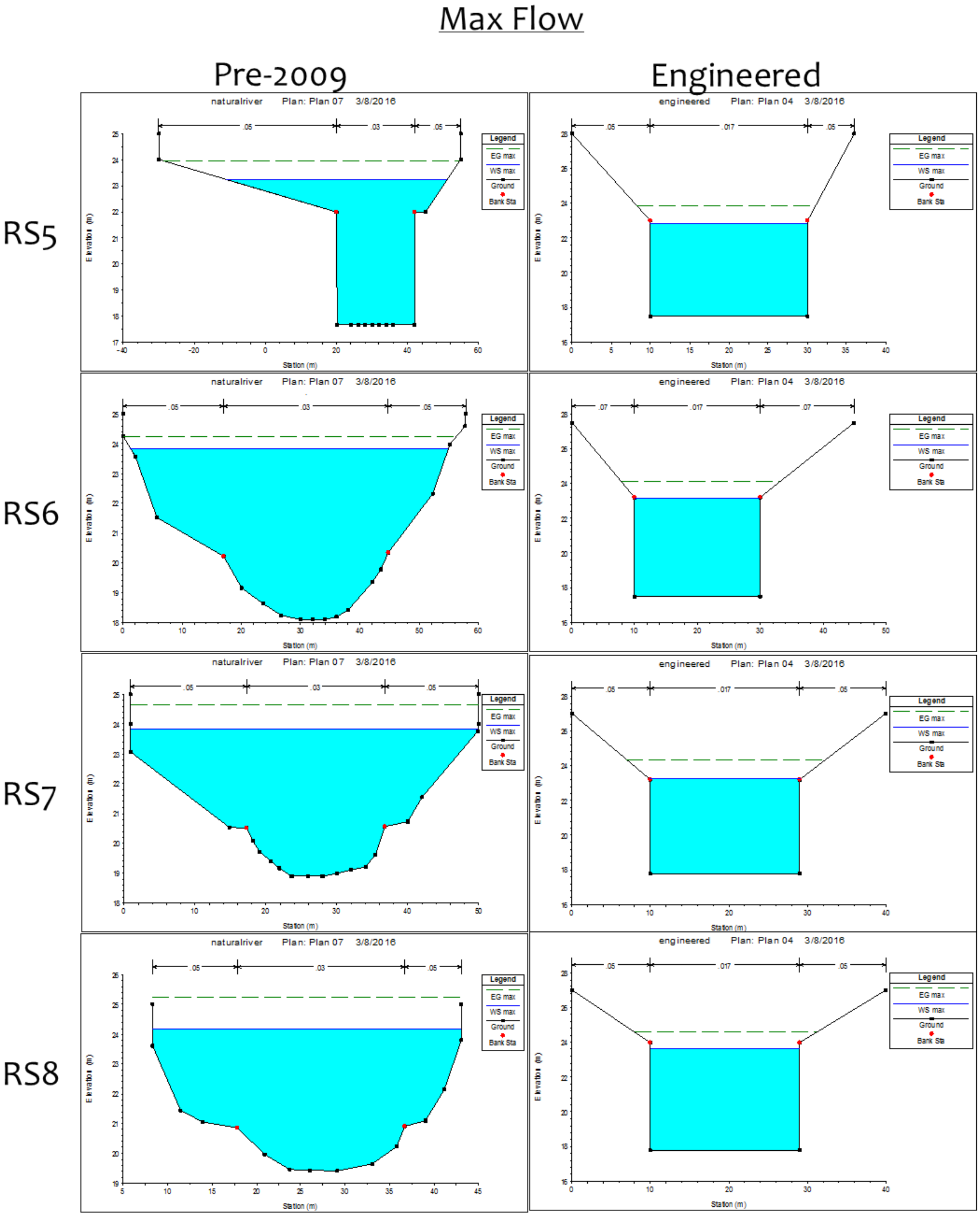


Figure 4 - 9 RS 5-8 at Max Flow

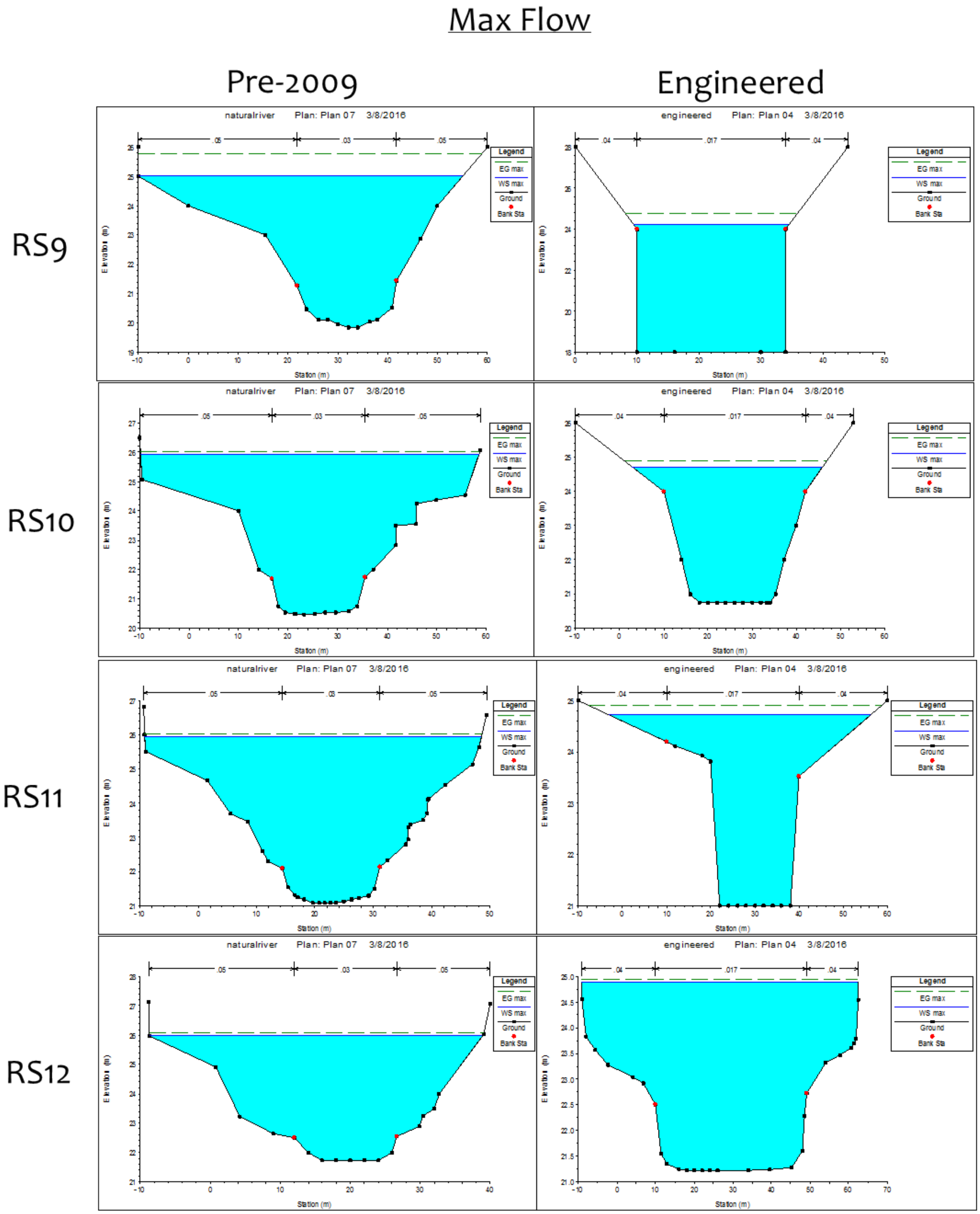


Figure 4 - 10 RS 9-12 at Max Flow

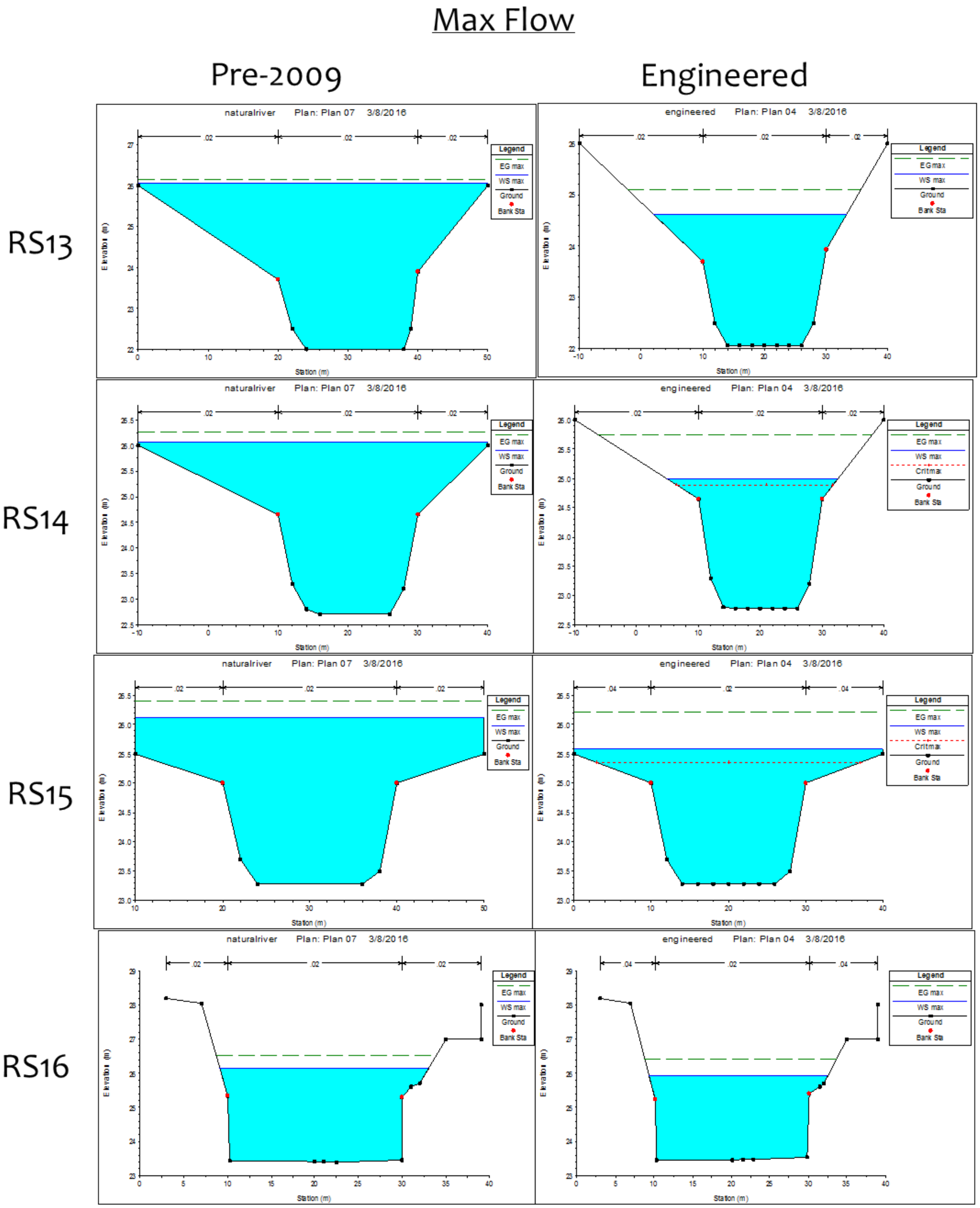


Figure 4 - 11 RS 13-16 at Max Flow

4.3 Validation of Simulation Results

While there are no water level gaging stations in the downstream reach of the Kerayong River, the Max Flow on the Pre-2009 can be supported by a flood report produced by the DID (2008) (See appendix). The date of the maximum flow of 184 m^3/s from the flow data matches with the date of the flood incident - April 2nd of 2008. The report states that the Kerayong River's flood wall breached and about 100 homes in a residential area in the vicinity of the downstream reach experienced up to 0.5 m of flooding. No other flood report was produced by DID for the Kerayong river in 2008 and 2009.

4.4 Channel Stability

One of the objectives of this study is to investigate channel stability of the downstream reach after river improvement works has been completed. Based on the allowable shear stress and velocity conditions of a channel, the velocity and shear stress of Max Flow of the Engineered River from the HEC-RAS simulation are presented in this section (Figures 4-12 and 4-13). The maximum velocity at the downstream reach is identified to be 4.81 m/s at RS 2. At RS 2 as well, the maximum shear stress is identified to be 43.76 Pa.

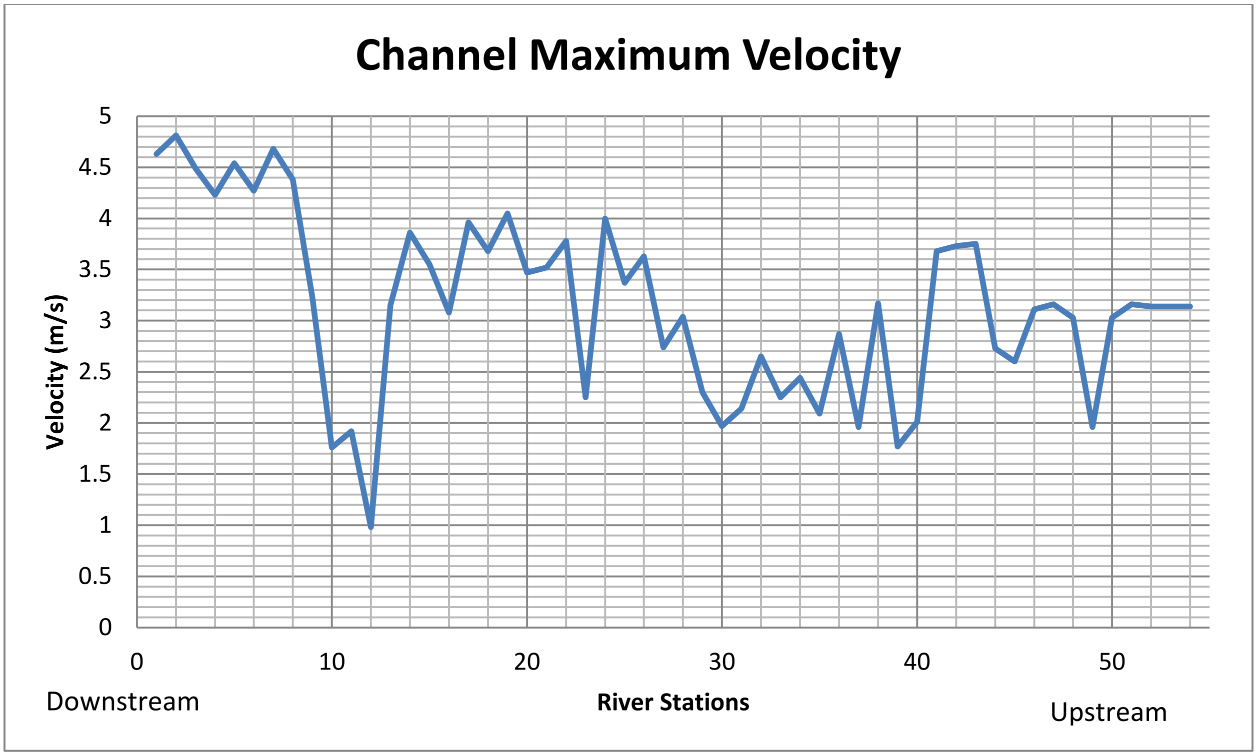


Figure 4 - 12 Channel maximum velocity

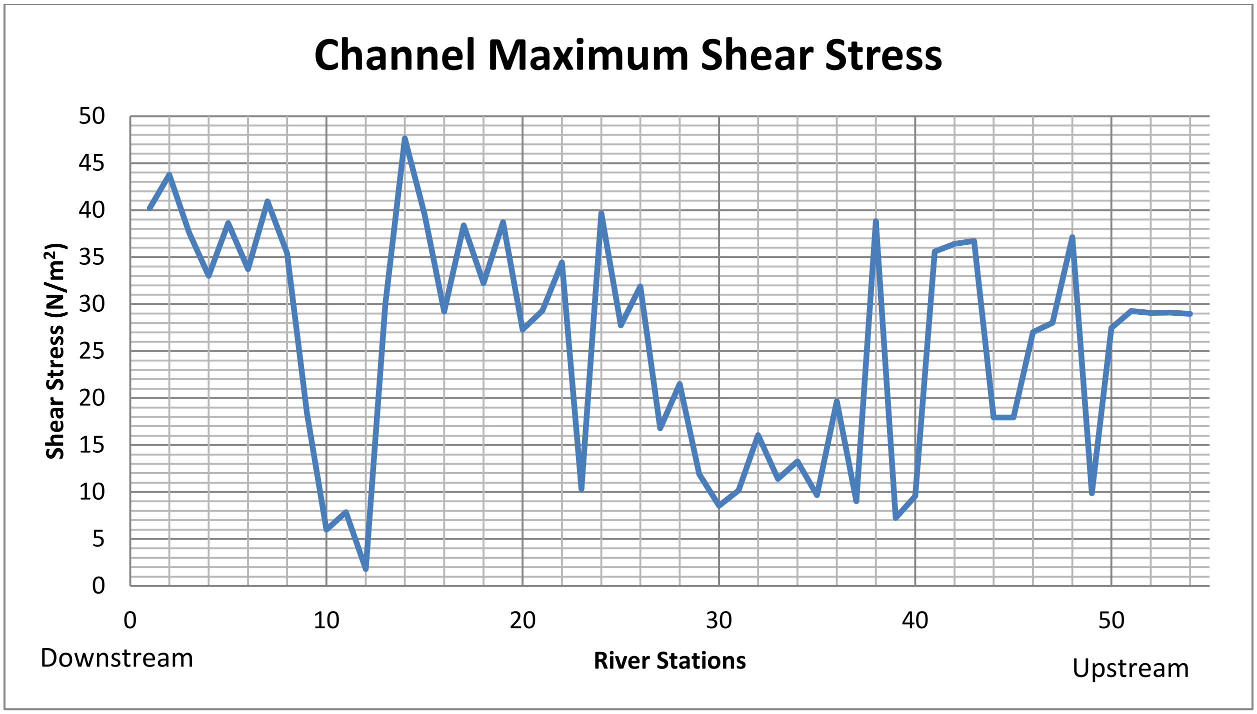


Figure 4 - 13 Channel maximum shear stress

4.5 Uncertainty of Results

The accuracy of the modeled results are based on the uncertainty propagated from the variables involved in the overall process such as input data, parameter values, and modeling approaches. There are uncertainties that arise from variables such as discharge, Manning's n, channel geometry, and particle size. The flow data of up to 502.4 m^3/s is used with a boundary condition at the downstream end of water surface of up to 23 m. Channel geometry is measured based on Google Earth Distance measurement tool and ArcGIS measurement tool which gives accuracy of up to 0.01. The highest uncertainty is contributed by the Manning's n roughness estimation. While magnitudes of 0.001 are used in the HEC-RAS simulation, the roughness is estimated from photographs which are prone to errors so it should be accurate to 0.01. While water level from HEC-RAS of up to 2 decimal places were reported, the propagation of uncertainty should bring the accuracy to 1 decimal place. Based on the data used for the analysis, the accuracy to the order of magnitude of the priority variables is presented in Table 4-3.

Table 4- 3 Order of magnitude of variables

Variables	Order of Magnitude
Discharge	1 m^3/s
Channel Geometry	0.01 m
Manning's n	0.01
Water Level	0.1 m

CHAPTER 5: DISCUSSION

This chapter discusses the findings from Chapter 4 and relevant flood and river management concepts.

5.1 Channel Stability

In section 4.1, it is found that the maximum velocity in the channel is 4.81 m/s and maximum shear stress is 43.7 Pa. An effective channel design is more than just being capable of carrying a designated flow; the concept of river dynamics such as erosion and sedimentation should be understood by the design engineer so that the channel does not fail within its design life. The most conventional way in designing a channel is by using the allowable velocity and allowable shear stress method, usually provided in manual published by authorities. In this case, the most suitable manual is the Malaysian River Management Manual published by the DID (2009c). After river improvement works were completed, the downstream reach of the Kerayong River is lined with concrete whereby the allowable velocity is more than 5.5 m/s and allowable shear stress is 598 Pa (DID 2009). It can be determined then, that the channel is stable from the extreme event.

It would be interesting to look at the stability of the confluence of the Kerayong River and Klang River as well. The bed and the outside bend of the confluence are expected to experience more erosive forces from the increase in discharge from the Kerayong. Based on site visit photos and Google satellite images, it can be determined that the outside bend of the confluence is lined with small boulder riprap (particle size about 300 mm) and downstream of the drop structures are lined with small cobbles (particle size about 100 mm). Using the shear stress method presented in *River Mechanics* (Julien 2002), the effective riprap size required to for stabilizing the bank is estimated to be 91 mm. The riprap size of 300 mm is sized appropriately for bank stabilization. The erosion control measures were assumed to be made as part of the river improvement works in April 2010. Although there is vegetation in the riprap, the riprap seems intact and doesn't show signs of failure. The boulders are still present after six years and the confluence does not show signs of scour. Both the riprap and small boulders are good indicators that the erosion control measures are effective in stabilizing the channel.

Figure 5 - 1 River stabilization measures at the confluence

5.2 Flood Management in Malaysia

A Culture of Flood

Malaysia has been plagued with floods annually since historical times. The country declared independence from the British in 1957 but is not expected to gain independence from floods in the foreseeable future. Yet despite facing multiple floods annually, the country has been growing, taking floods as part of the culture, and managing floods with ingenuity and technology (Shafie 2009, DID 2009b). Traditionally, flooding happened because people were living on the flood plains and coastal regions. Today, while the symptoms are the same, the causes are different than it was 50 years ago. Rapid urbanization, deforestation, uncontrolled development, and ineffective drainage systems add pressure to the already flood-stricken country. While the SMART Tunnel is able to alleviate some of the symptoms in the city center, there needs to be effective management at a large scale to address the contributing factors.

Integrated River Basin Management

Malaysia’s flooding and water resources management has been disorganized and fractured. In the late 1990’s, Malaysians began to have environmental awareness, realizing that healthy water bodies are important to sustaining a healthy community. The government started to develop the idea of Integrated Water Resources Management (IWRM) and Integrated River Basin Management (IRBM) and implemented the concept around 2006. IRBM is a concept where water is treated as a finite and valuable resource that is essential to the economic and social health of the nation (Elfithri 2011). It is a style of management that involves all levels of stakeholders from the government, private sector, and the public. This concept enables the system to be managed as a whole. For example, flooding downstream is a problem that is caused by ineffective management upstream; without IRBM, a control measure would be to raise levees or floodwalls that alleviates the symptom but does not solve the problem; with IRBM, the problems can be addressed at the system level. The holistic approach involves policies and laws, planning, enforcing of policies, preventive measures, public participation, and finance (Abdullah 2011).

Urban Stormwater Management

As part of policy making and master planning approach of IRBM, understanding urban stormwater hydrology is imperative in dealing with floodwaters at its source. Through urbanization, there are less pervious surfaces for infiltration of rainwater leading to more runoff. Existing drainage systems provides a fast track for stormwater to be drained into rivers, leading to faster and higher peak flows (Figure 5-2). The River Engineering and Urban Drainage Research Center (REDAC) and DID developed and implemented a new Urban Drainage Manual named Stormwater Management Manual for Malaysia (MSMA) (Zakaria et al. 2004). The manual provides guidelines for new developments and best management practices to control stormwater runoff quantity and quality at the source. As such, floodplain development should be controlled and planned properly so that it does not cause restriction of flow and that it should improve the quality of the water way.

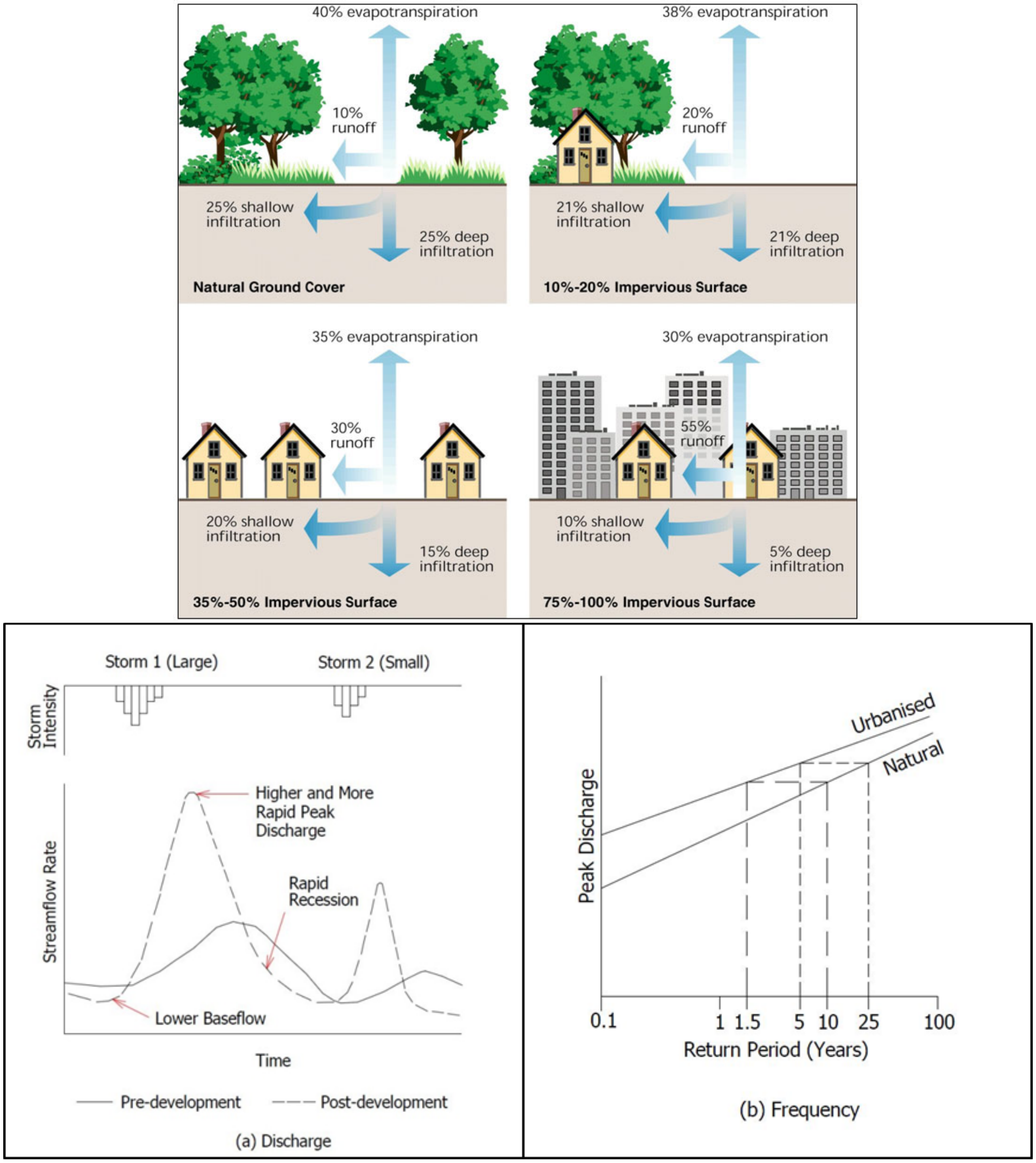


Figure 5 - 2 Changes in hydrologic characteristics from urbanization

Planning for the Future

Advances in science and technology enable us to make certain predictions about future conditions. While it may or may not manifest itself to varying degrees of certainty, projections on population growth and climate change will be the most pressing issues that will affect the water resources in Malaysia. The effects of such issues should be studied and addressed. A DID study in 2009(a) found that the maximum monthly flows on the Klang river will increase by 46%. As seen in chapter 4, the simulation of an extreme event has brought the Engineered Kerayong River to its capacity with minimal overtopping. Now facing the risk of increased extreme flows, action should be taken to prevent devastating floods from happening in the future.

It is expected that there will be more development in the future on the Kerayong Watershed. Abustan et al. (2008) estimated that the current imperviousness of the watershed is 77.5% and will increase in the future. The increase in imperviousness is expected to lead to more runoff and contribute to a higher flood hydrograph peak. It will be interesting to see the impact of the increased future flow on the downstream reach of the Kerayong River. The HEC-RAS model was used to simulate an event where the possibility of the event to exceed the maximum flow of 484 m^3/s. In this scenario, it is expected that the outflow from the SMART Tunnel outlet and the Desa Pond watershed remains the same at 300 m^3/s whereby the new flow contributed by the Kerayong Watershed at an increased imperviousness is assumed to give an increase of 10% to the max flow of 184 m^3/s which gives $Q = 1.1 \times 184\ m^3/s = 202.4\ m^3/s$. Added to the design flow of the SMART outlet gives an expected future flow, Q_{Future} of 502.4 m^3/s. The increased flow is simulated in HEC-RAS on the “Engineered” channel geometry and the boundary conditions downstream which is the known water surface is assumed to increase by 5% which is 1.2 m. The results are shown in Figures 5-3 to 5-5. It can be observed that for Q_{Future} the model simulated an increase in water level and bank overtopping at 9 of 12 river stations as compared to 4 of 12 for $Q_{max.}$ Between the outlet of Desa Pond to the confluence of Kerayong and Klang River, the results suggests that bank overtopping of up to 0.71 m is expected.

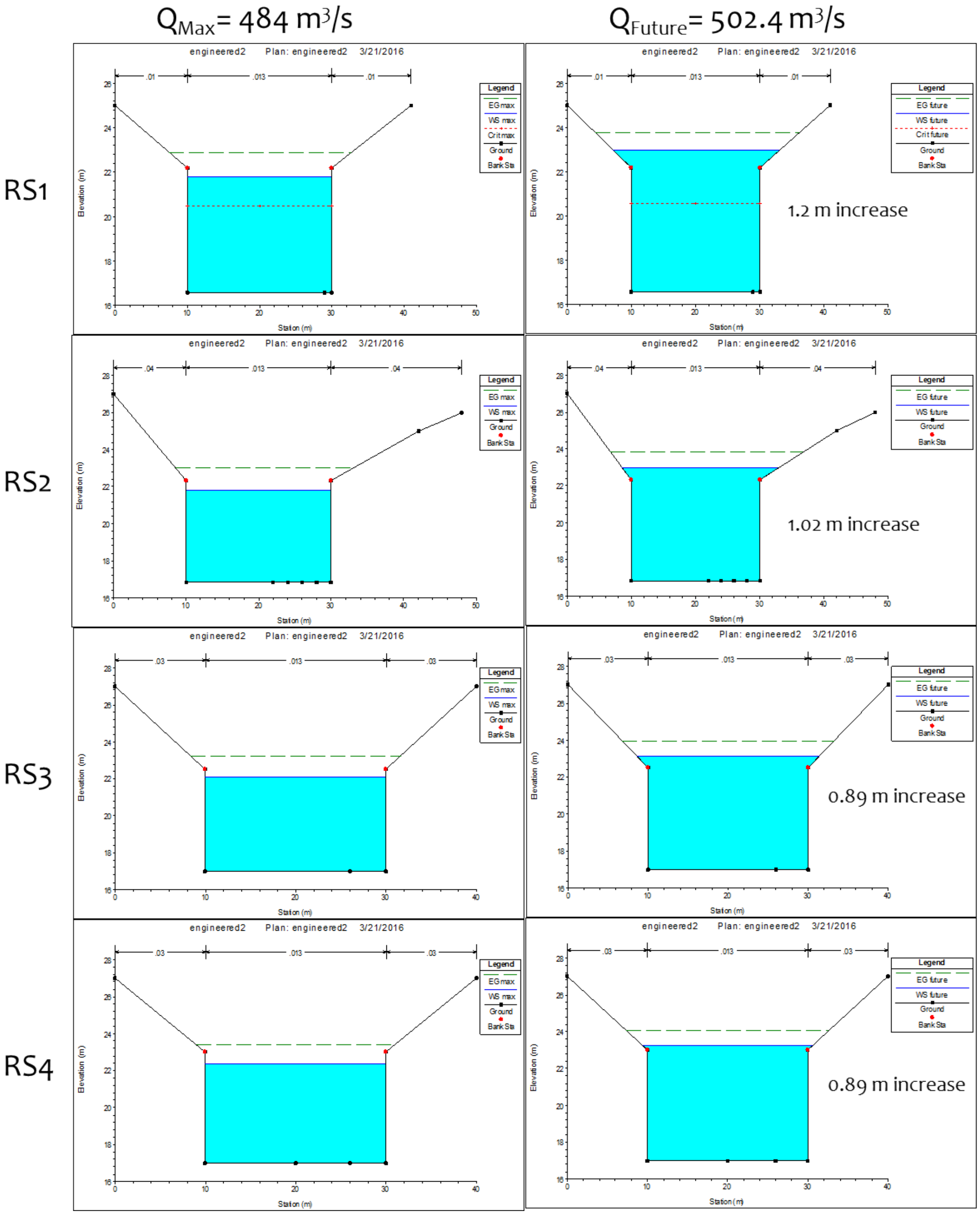


Figure 5 - 3 Comparison of Max Flow and Future Flow RS1 to RS4

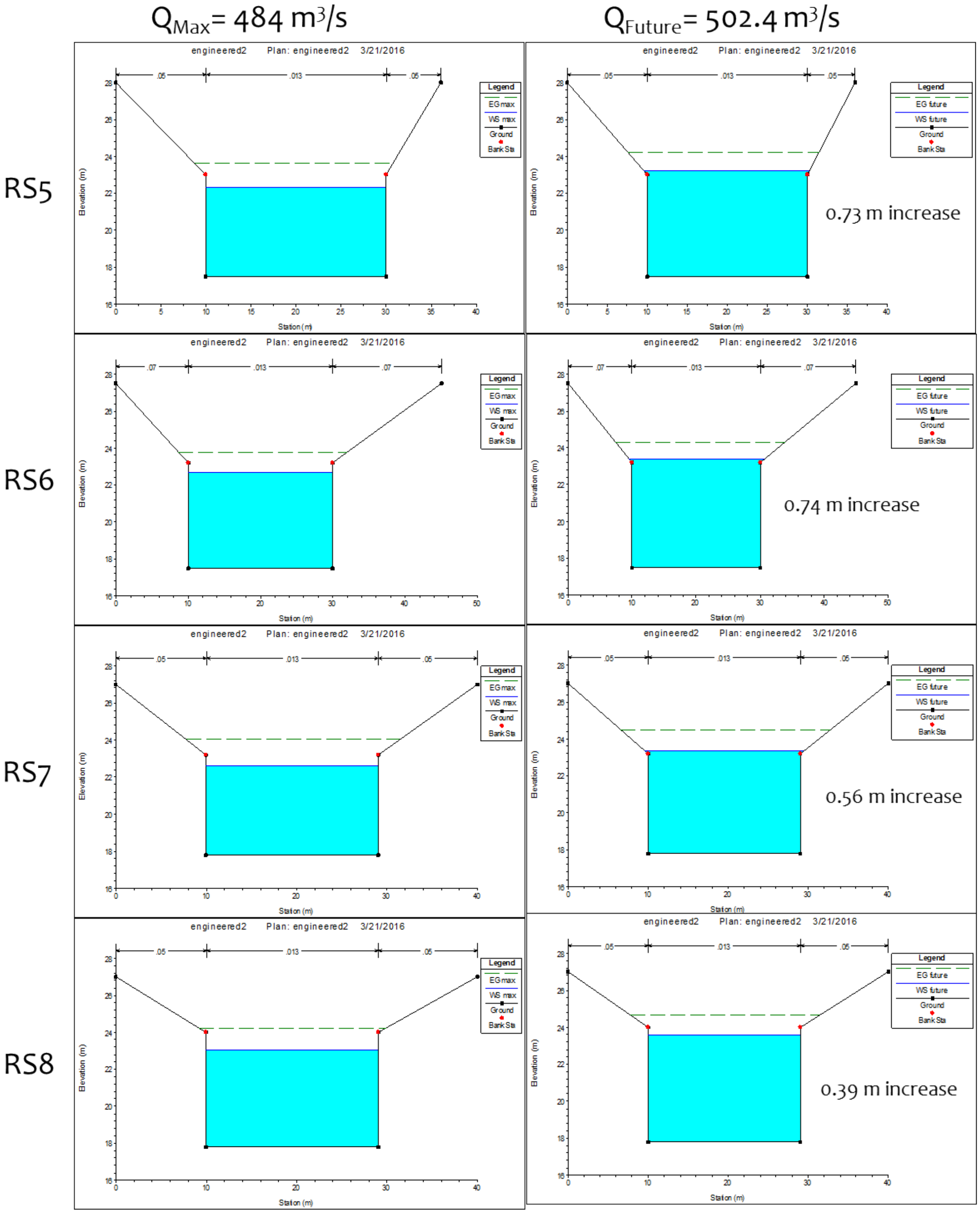


Figure 5 - 4 Comparison of Max Flow and Future Flow RS5 to RS8

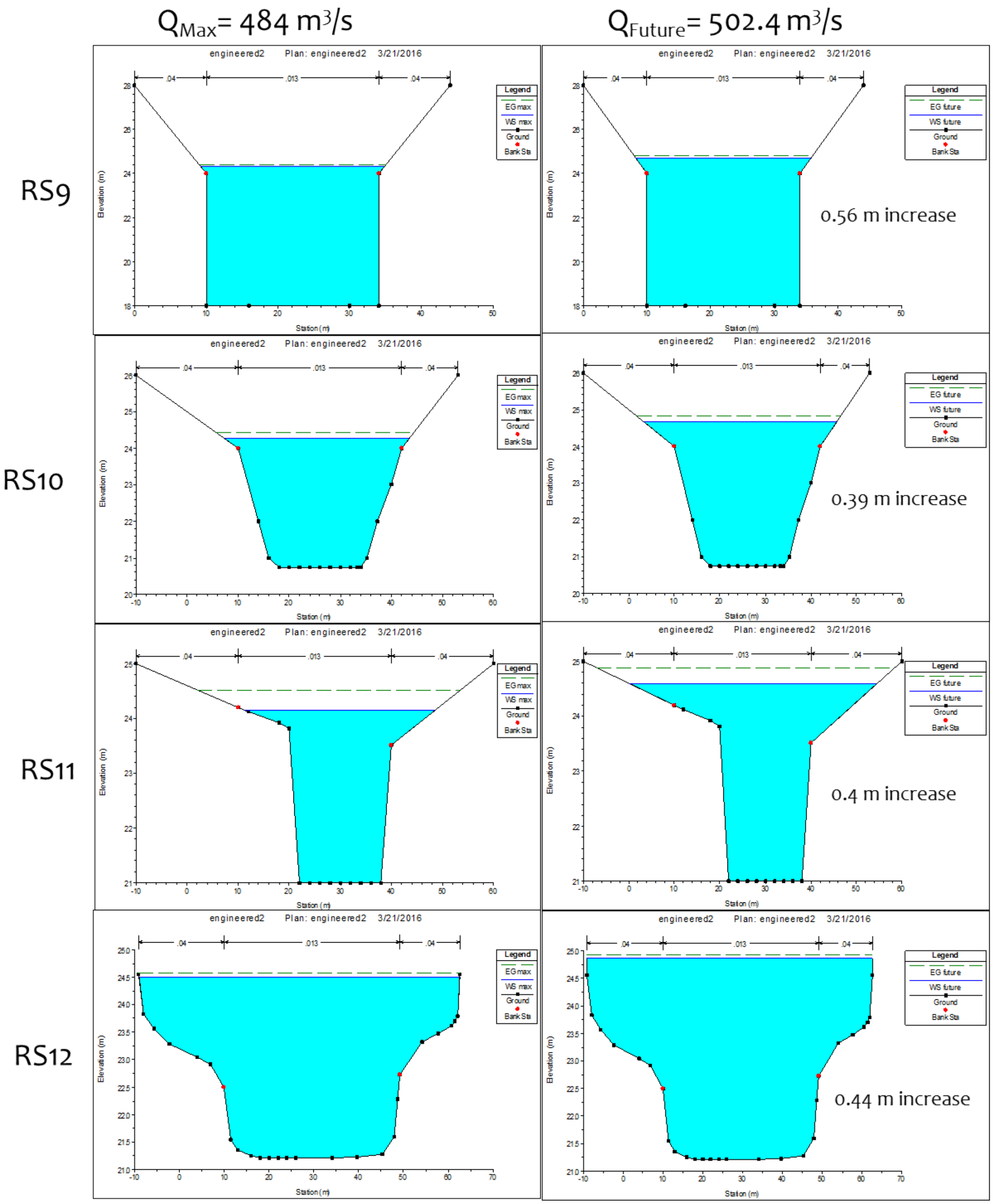


Figure 5 - 5 Comparison of Max Flow and Future Flow RS9 to RS 12

CHAPTER 6: CONCLUSIONS

The site of interest is the downstream reach of the Kerayong River in Malaysia because it experiences increased discharge during extreme events from the diversion of the Klang River through the SMART Tunnel. The objectives of the study are to utilize GIS to prepare the site for hydraulic analysis, conduct hydraulic analysis to investigate the effects of increased flow on the reach, investigate the stability of the downstream reach of the Kerayong River after river improvement works, and predict future river response from increased flow.

The watershed of the Klang River and the Kerayong River were both delineated using the spatial analyst tools in ArcGIS. Both river geometry conditions (Pre-2009 and Engineered) were prepared using a combination of the map produced from ArcGIS, Site Visit Photos, Google Earth satellite imagery, and Google Street View imagery.

The hydraulic analysis was conducted using a flow duration analysis and HEC-RAS model. A total of four scenarios were presented from HEC-RAS based on two different geometries (Pre-2009 and Engineered) and two flow conditions (Flood Flow and Max Flow), the combinations of the geometry and flow are: (1) Pre-2009 – Flood Flow; (2) Pre-2009 – Max Flow (3) Engineered – Flood Flow; (4) Engineered – Max Flow. The water surface results were used to determine if flooding occurred.

The velocity and shear stress results from HEC-RAS are used to investigate the stability of the reach and the confluence based on Site Visit Photos, Google Earth satellite imagery, and Google Street View imagery.

The model was used to predict a future 10% increase flow from the Kerayong Watershed due to increased urbanization. The downstream flow is subsequently increased from 484 m^3/s to 502.4 m^3/s and simulated.

The following conclusions can be made:

i) ArcGIS was used to remotely delineate the watershed characteristics for the study area and it is determined that by exercising judgement, Google Earth satellite imagery and Google Street View imagery are new tools that can be used to estimate channel geometry and roughness.

ii) The engineered channel has the capacity to convey an increased flow of up to 484 m^3/s from the SMART Tunnel with a reduction of up to 3.51 m of bank overtopping depth.

iii) The effects of increased velocity and shear stress due to the increased discharge are 4.81 m/s and 43.7 Pa, respectively. The increased velocity would scour the Pre-2009 sand-bed channel but the channel was appropriately designed with a concrete bed and revetment wall. The 300 mm particle size riprap on the outside bend near the confluence are also considered to be stable

iv) In anticipation for increased intensity of future extreme events, the model predicted that the engineered channel will have 9 of its 12 banks that will be overtopped up to 0.7 m when flow is increased from 484 m^3/s to 502.4 m^3/s at the downstream reach of the Kerayong River.

REFERENCES

(ADB) Asian Development Bank. (2007). *Malaysia: Klang River Basin Environmental Improvement and Flood Mitigation Project.* ADB.

Abdullah, Jazuri. (2013). Distributed Runoff Simulation of Extreme Monsson rainstorms in Malaysia using TREX.

Abdullah, K. (2004a). Kuala Lumpur: Re-engineering a Flooded Confluence. *14th Professor Chin Fung Kee Memorial Lecture.* Kuala Lumpur.

Abdullah, K. (2004b). Stormwater Management and Road Tunnel (SMART): a Lateral Approach to Flood Mitigation Works. *International Conference on Bridge Engineering & Hydraulic Structures*, (pp. 59-79). Selangor, Malaysia.

Abdullah, K. (2011). *Integrated River Basin Management Report.* Kuala Lumpur, Malaysia: Department of Irrigation and Drainage Malaysia. Retrieved March 9, 2016, from http://www.water.gov.my/home/20

Abustan, I., Sulaiman, A. H., Wahid, N. A., & Baharudin, F. (2008). Determination of Rainfall-Runoff Characteristics in an Urban Area: Sungai Kerayong Catchment, Kuala Lumpur. *11th International Conference on Urban Drainage*, (pp. 1-9). Edinburgh.

Arnfield, J. A. (2016). Köppen Climate Classification. In *Encyclopaedia Brittannica Online.* Retrieved March 15, 2016, from http://www.britannica.com/science/Koppen-climate-classification

Chow, V. T. (1959). *Open Channel Hydraulics.* New York: McGraw Hill.

Chow, V. T., Maidment, D. R., & Mays, L. (1988). *Applied Hydrology.* McGraw Hill.

Cruise, J., Sherif, M., & Singh, V. (2007). *Elementary Hydraulics.* Thomson Nelson.

DID, Department of Irrigation and Drainage. (2008). *Laporan Banjir 0204081 (translated: Flood Report 0204081).* Kuala Lumpur: DID.

DID, Department of Irrigation and Drainage. (2009a). Chapter 13 - Future Concerns. In *DID manual - Volume 1 - Flood Management* (pp. 13-1 - 13-17). DID.

DID, Department of Irrigation and Drainage. (2009b). *Volume 1: Flood Management.* Department of Irrigation and Drainage.

DID, Department of Irrigation and Drainage. (2009c, January 2). Vol 2 - River Management. In D. o. Malaysia, *DID Manual.* Kuala Lumpur. Retrieved March 2, 2016, from http://www.themalaymailonline.com/malaysia/article/flood-damage-estimate-tops-rm1b

DID, Department of Irrigation and Drainage. (2012). Malaysia Perspective. In *Urban Stormwater Management Manual for Malaysia (MSMA).* Department of Irrigation and Drainage (DID).

DID, Department of Irrigation and Drainage. (2014). *SMART: A Unique Flood Management Solution in the 21st Century*. DID.

DID, Department of Irrigation and Drainage. (2015, November 6). *Statistics of SMART Tunnel*. Retrieved March 3, 2016, from http://state.water.gov.my/scc/index.php/en/services/statistics

Elfithri, R., Toriman, M., Mokhtar, M., & Juahir, H. (2011). Perspectives and Initiatives on Integrated River Basin Management in Malaysia: A Review. *The Social Sciences*, 167-176.

England, J., Velleux, M., & Julien, P. (2007). Two Dimensional simulations of extreme floods on a large watershed. *Journal of Hydrology 347(1-2)*, 229-241.

EU, E. U. (2007). *Directive 2007/60/EC of the European Parliament and of the council on the assessment and management of flood risks.* Official Journal of the European Union.

FEMA, Federal Emergency Management Agency. (2015). *The National Flood Insurance Program*. Retrieved March 21, 2016, from https://www.fema.gov/national-flood-insurance-program

Gabion1. (2016). *Gabion Erosion Control.* Retrieved March 21, 2016, from Gabion1: http://www.gabion1.co.uk/gabion_erosion_control.htm

Garanik, A., & Sholtes, J. (2013). *River Bank Protection.* Powerpoint Presentation for CIVE 717 River Mechanics .

Google. (2016). *Google Street View: Use Street View in Maps*. Retrieved from Google: https://support.google.com/maps/answer/3093484?hl=en

Google Earth. (2016). *Google Earth User Guide.* Google. Retrieved March 22, 2016, from http://static.googleusercontent.com/media/earth.google.com/en//userguide/v4/google_earth_user_guide.pdf

Jamaludin, S., & Jemain, A. A. (2007). Fitting the Statistical Distributions to the Daily Rainfall Amounth in Peninsular Malaysia. *Techology Journal*, 33-48. Retrieved from eprints.utm.my/5702/4/277

Jha, A. K., Bloch, R., & Lamond, J. (2012). *Cities and Flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century.* Washington DC: The World Bank.

Julien, P. (2002). *River Mechanics.* Cambridge University Press.

Julien, P. (2010). *Erosion and Sedimentation.* Cambridge University Press.

Klados, G., Kok, Y. H., Parks, D. R., & Tavender, D. T. (2007). Stormwater Management and Road Tunnel (SMART). *Underground Space - the 4th Dimension of Metropolises*, 1183-1189.

Leopold, L. B. (1994). *Flood Hydrology and the Floodplain.* University of California.

Muhammad, N. S., & Julien, P. Y. (2014). Multiday Rainfall Simulations for Malaysian Monsoons. In S. T. Abu Bakar (Ed.), *International Symposium on Flood Research and Management* (pp. 111-120). Singapore: Springer Science+ Business. doi:10.1007/978-981-287-365-1_10

Munson, B., Young, D., & Oikiishi, T. (2002). *Fundamentals of Fluid Mechanics.* New York: Wiley.

Ng, K. H. (2004). *Effects of "SMART" Tunnel on Flood Flow with "MIKE11" Application.* University of Technology Malaysia.

NRCS, Natural Resources Conservation Service, USDA. (2007). *Stream Restoration Design.* USDA.

Robinson, J. B., Hazell, W. F., & Young, W. S. (1998). *Effects of August 1995 and July 1997 Storms in the city of Charlotte and Mecklenburg County, North Carolina.* USGS.

Shafie, A. (2009). *Extreme Flood Event: A Case Study on Floods of 2006 and 2007 in Johor, Malaysia.* Fort Collins, CO.

SMART. (2016). *Stormwater and Road Tunnel (SMART).* Retrieved March 2, 2016, from http://smarttunnel.com.my/operational-modes/

Teng, Y. Y. (2014, May 28). Don't Blame SMART Tunnel. *The Star Online*. Retrieved March 9th, 2016, from http://www.thestar.com.my/news/community/2014/05/28/dont-blame-smart-tunnel-did-flash-floods-in-the-city-caused-by-clogged-drains-and-heavy-rainfall-not/

UITM, Mara University of Technology. (2009). Flow at Sg. Kerayong at US Weir. DID.

UITM, Mara University of Technology. (2015). Kerayong River Cross Section.

UNISDR, The United Nations Office for Disaster Risk Reduction. (2004). *Living with Risk: A Global Review of Disaster Reduction Initiative.* UNISDR.

USACE, U. A. (2010a). *HEC-RAS Applications Guide.* USACE HEC.

USACE, U. A. (2010b). *HEC-RAS Hydraulic Reference Manual.* USACE HEC.

USACE, U. A. (2010c). *HEC-RAS User Manual.* Manual.

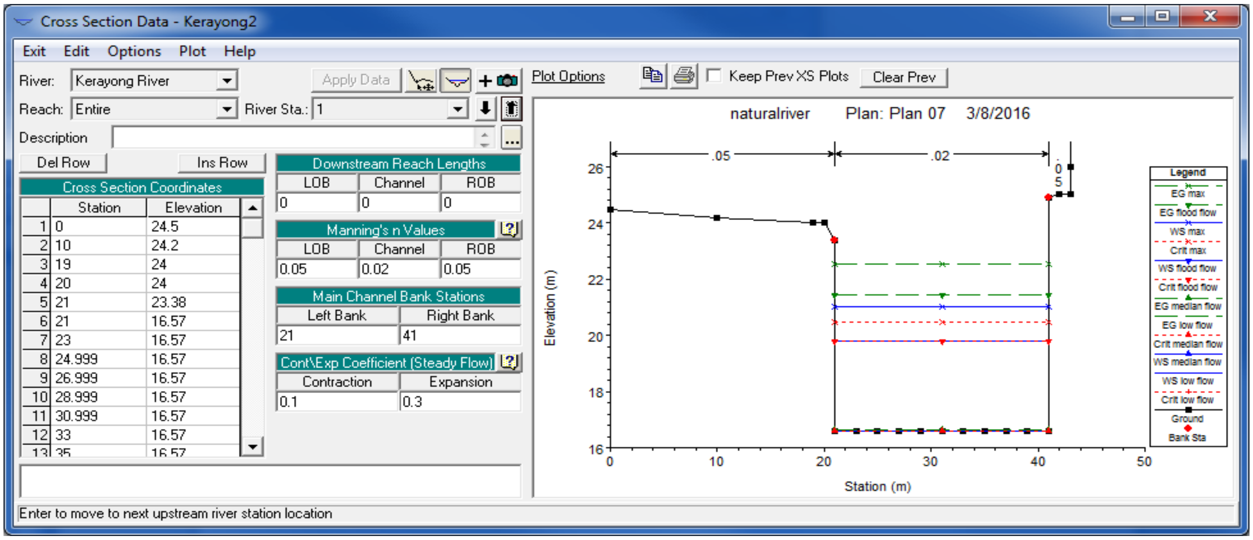
Williamson, F. (2015). Historic Flood Records in Colonial Malaysia: Sources and Context. Kuala Lumpur. Retrieved March 9, 2016, from https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=6&ved=0ahUKEwihxOCawrTLAhXCsIMKHfVSCwIQFgg-MAU&url=https%3A%2F%2Fblog.nus.edu.sg%2Fenvironmentcluster%2Ffiles%2F2015%2F03%2FFUTURE-FLOODS-1tp9vk9.pptx&usg=AFQjCNHY8MYQW4zeC-rjahJu8_POcNFISg&sig

Zakaria, N. A., Ghani, A., Abdullah, R., L, S., Kassim, A., & Ainan, A. (2004). MSMA - A New Urban Stormwater Management Manual for Malaysia. *Advances in Hydro-Science and -Engineering*.

APPENDIX A-I

CROSS SECTION

Pre-2009



River: Kerayong River

Reach: Entire

River Sta.: 1

Description:

Cross Section Coordinates

	Station	Elevation
1	0	24.5
2	10	24.2
3	19	24
4	20	24
5	21	23.38
6	21	16.57
7	23	16.57
8	24.999	16.57
9	26.999	16.57
10	28.999	16.57
11	30.999	16.57
12	33	16.57
13	35	16.57

Downstream Reach Lengths

LOB	Channel	ROB
0	0	0

Manning's n Values

LOB	Channel	ROB
0.05	0.02	0.05

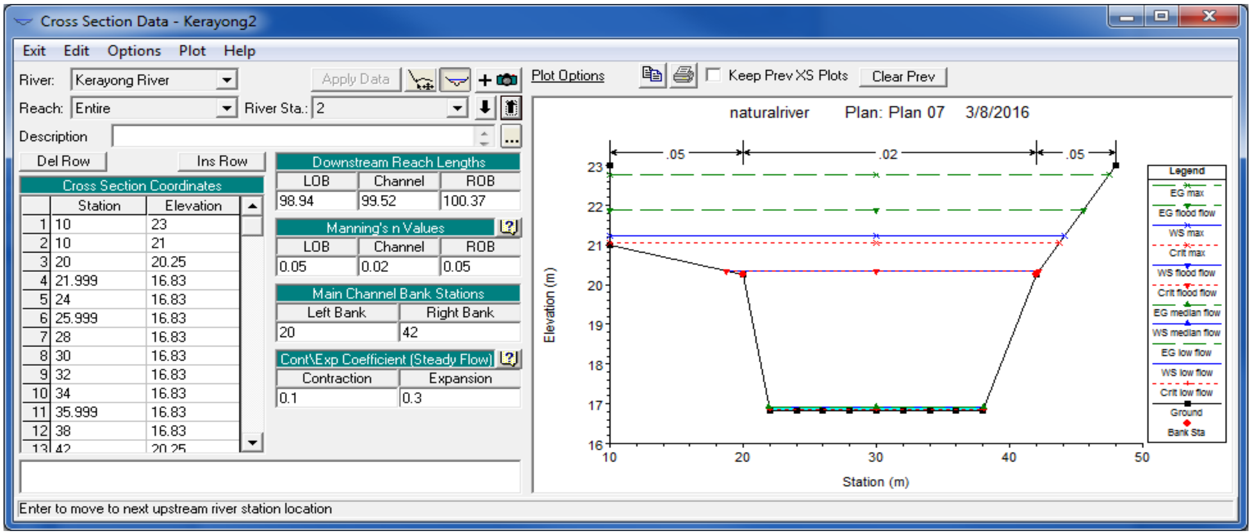
Main Channel Bank Stations

Left Bank	Right Bank
21	41

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 2

Description:

Cross Section Coordinates

	Station	Elevation
1	10	23
2	10	21
3	20	20.25
4	21.999	16.83
5	24	16.83
6	25.999	16.83
7	28	16.83
8	30	16.83
9	32	16.83
10	34	16.83
11	35.999	16.83
12	38	16.83
13	42	20.25

Downstream Reach Lengths

LOB	Channel	ROB
98.94	99.52	100.37

Manning's n Values

LOB	Channel	ROB
0.05	0.02	0.05

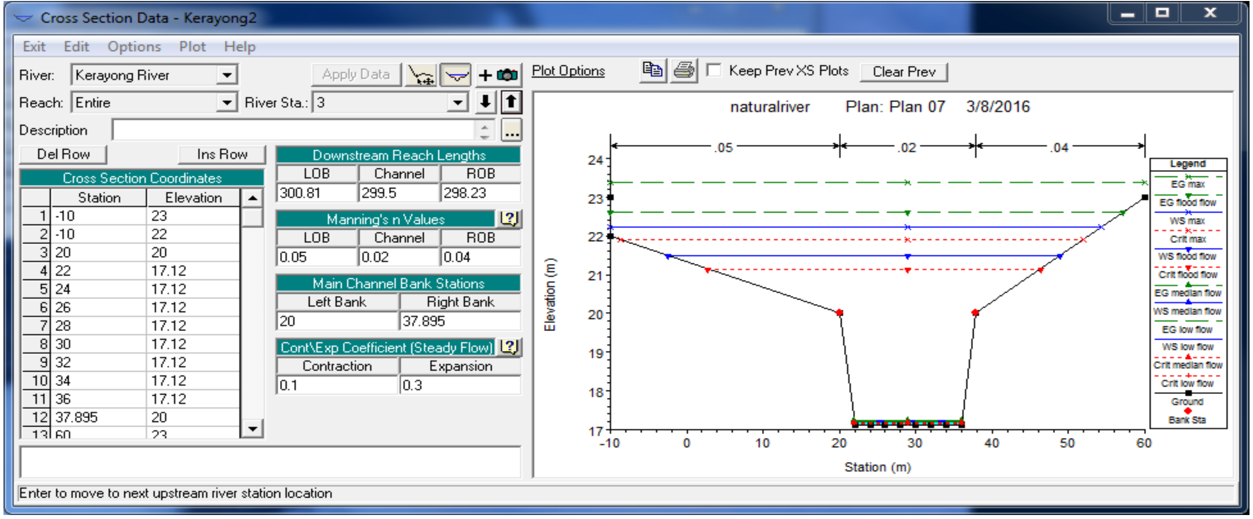
Main Channel Bank Stations

Left Bank	Right Bank
20	42

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 3

Description:

Cross Section Coordinates

	Station	Elevation
1	-10	23
2	-10	22
3	20	20
4	22	17.12
5	24	17.12
6	26	17.12
7	28	17.12
8	30	17.12
9	32	17.12
10	34	17.12
11	36	17.12
12	37.895	20
13	60	23

Downstream Reach Lengths

LOB	Channel	ROB
300.81	299.5	298.23

Manning's n Values

LOB	Channel	ROB
0.05	0.02	0.04

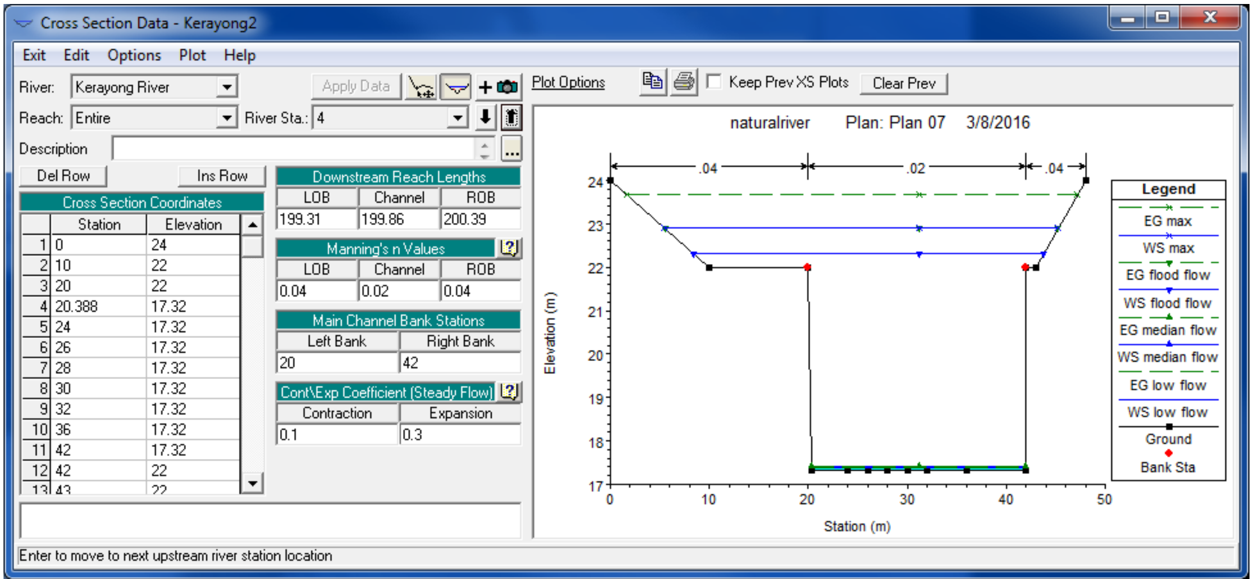
Main Channel Bank Stations

Left Bank	Right Bank
20	37.895

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 4

Description:

Cross Section Coordinates

	Station	Elevation
1	0	24
2	10	22
3	20	22
4	20.388	17.32
5	24	17.32
6	26	17.32
7	28	17.32
8	30	17.32
9	32	17.32
10	36	17.32
11	42	17.32
12	42	22
13	43	22

Downstream Reach Lengths

LOB	Channel	ROB
199.31	199.86	200.39

Manning's n Values

LOB	Channel	ROB
0.04	0.02	0.04

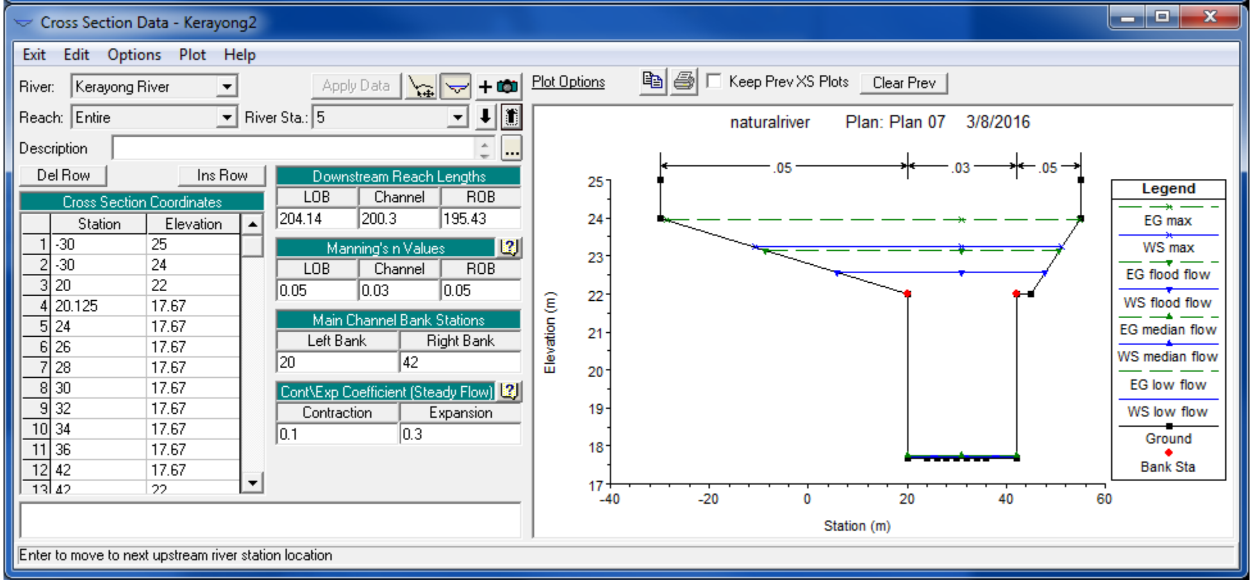
Main Channel Bank Stations

Left Bank	Right Bank
20	42

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 5

Description:

Cross Section Coordinates

	Station	Elevation
1	-30	25
2	-30	24
3	20	22
4	20.125	17.67
5	24	17.67
6	26	17.67
7	28	17.67
8	30	17.67
9	32	17.67
10	34	17.67
11	36	17.67
12	42	17.67
13	42	22

Downstream Reach Lengths

LOB	Channel	ROB
204.14	200.3	195.43

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

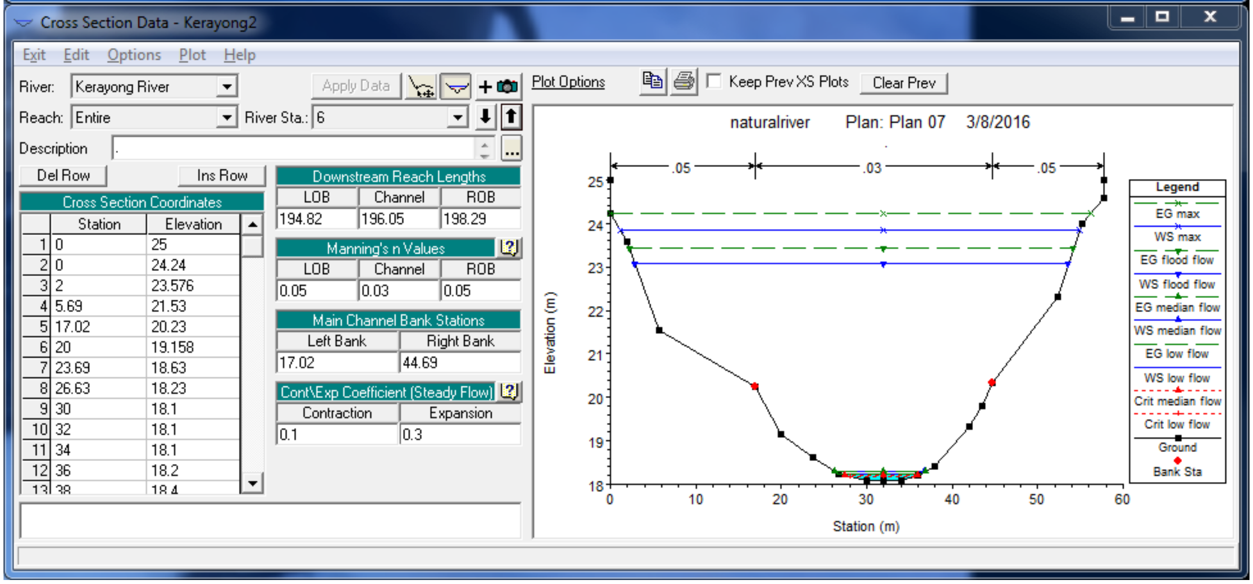
Main Channel Bank Stations

Left Bank	Right Bank
20	42

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 6

Description: .

Cross Section Coordinates

	Station	Elevation
1	0	25
2	0	24.24
3	2	23.576
4	5.69	21.53
5	17.02	20.23
6	20	19.158
7	23.69	18.63
8	26.63	18.23
9	30	18.1
10	32	18.1
11	34	18.1
12	36	18.2
13	38	18.4

Downstream Reach Lengths

LOB	Channel	ROB
194.82	196.05	198.29

Manning's n Values

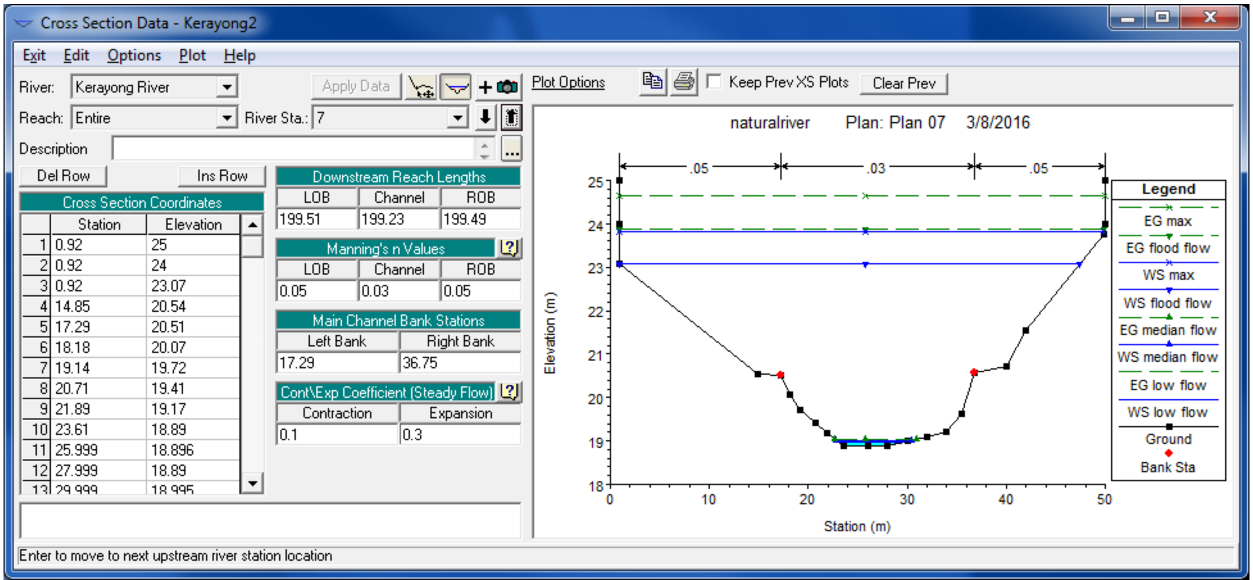
LOB	Channel	ROB
0.05	0.03	0.05

Main Channel Bank Stations

Left Bank	Right Bank
17.02	44.69

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3



River: Keravong River

Reach: Entire

River Sta.: 7

Description

Cross Section Coordinates

	Station	Elevation
1	0.92	25
2	0.92	24
3	0.92	23.07
4	14.85	20.54
5	17.29	20.51
6	18.18	20.07
7	19.14	19.72
8	20.71	19.41
9	21.89	19.17
10	23.61	18.89
11	25.999	18.896
12	27.999	18.89
13	29.999	18.995

Downstream Reach Lengths

LOB	Channel	ROB
199.51	199.23	199.49

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

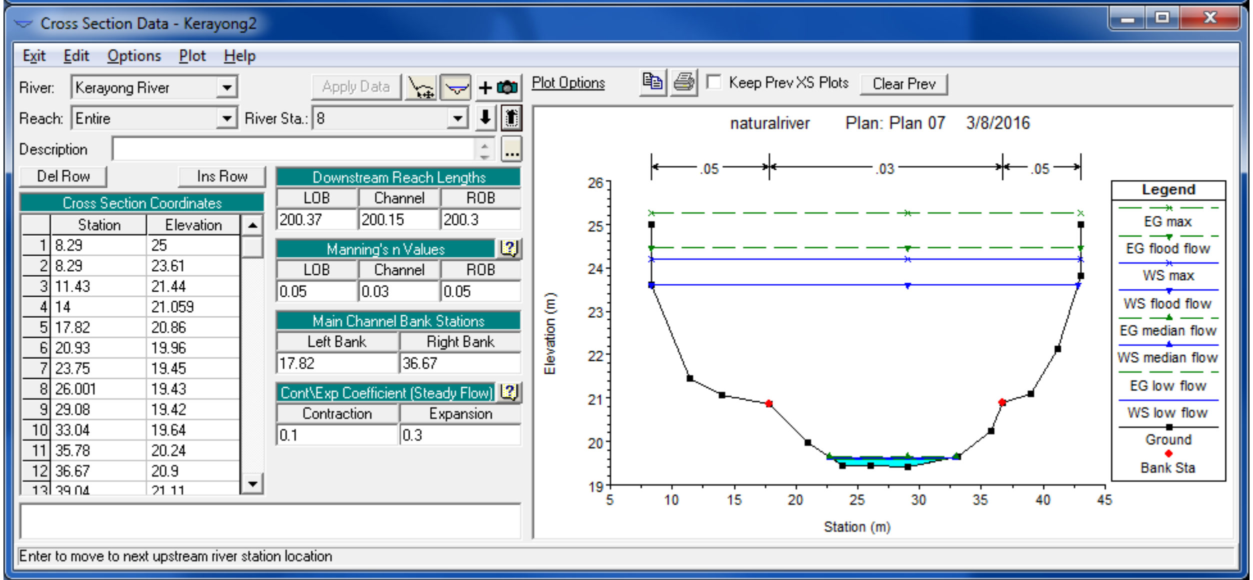
Main Channel Bank Stations

Left Bank	Right Bank
17.29	36.75

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 8

Description

Cross Section Coordinates

	Station	Elevation
1	8.29	25
2	8.29	23.61
3	11.43	21.44
4	14	21.059
5	17.82	20.86
6	20.93	19.96
7	23.75	19.45
8	26.001	19.43
9	29.08	19.42
10	33.04	19.64
11	35.78	20.24
12	36.67	20.9
13	39.04	21.11

Downstream Reach Lengths

LOB	Channel	ROB
200.37	200.15	200.3

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

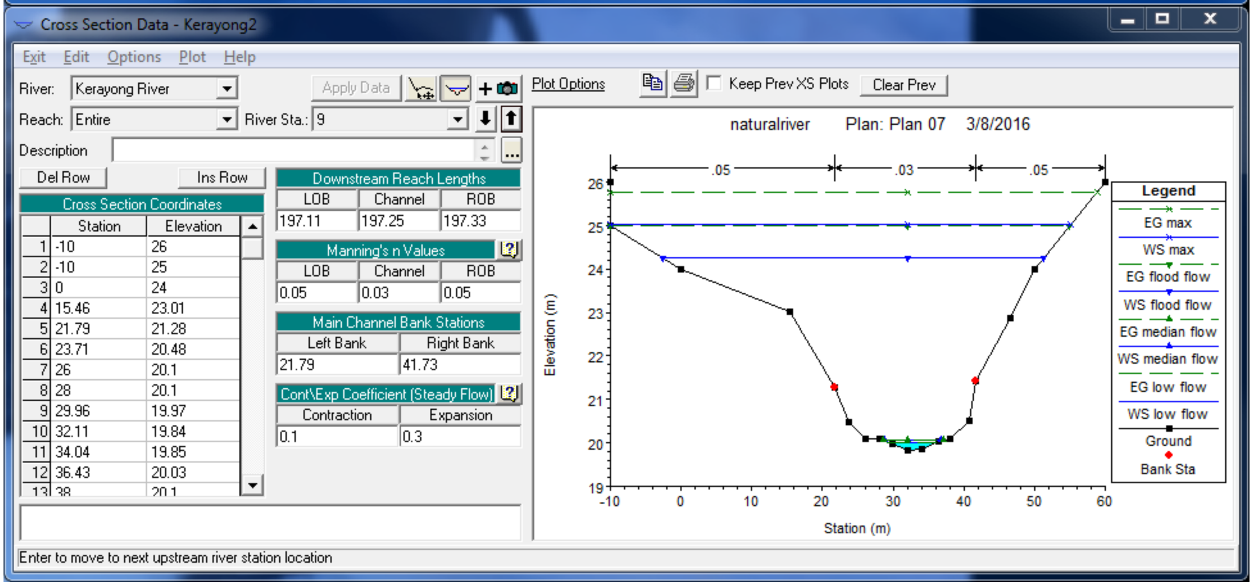
Main Channel Bank Stations

Left Bank	Right Bank
17.82	36.67

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 9

Description

Cross Section Coordinates

	Station	Elevation
1	-10	26
2	-10	25
3	0	24
4	15.46	23.01
5	21.79	21.28
6	23.71	20.48
7	26	20.1
8	28	20.1
9	29.96	19.97
10	32.11	19.84
11	34.04	19.85
12	36.43	20.03
13	38	20.1

Downstream Reach Lengths

LOB	Channel	ROB
197.11	197.25	197.33

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

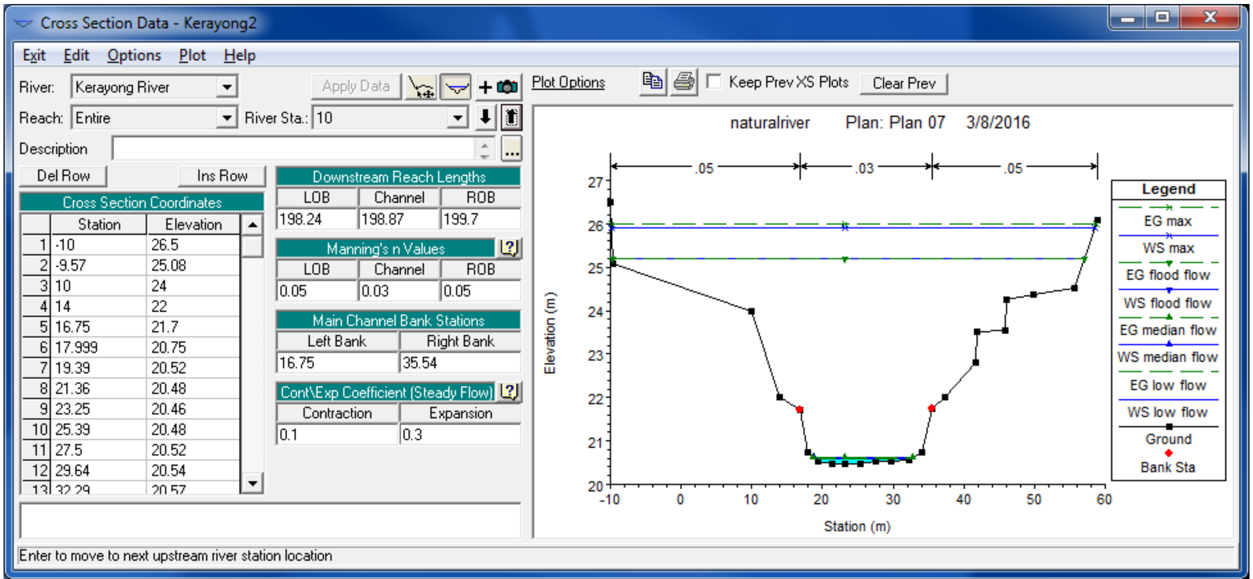
Main Channel Bank Stations

Left Bank	Right Bank
21.79	41.73

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 10

Description:

Cross Section Coordinates

	Station	Elevation
1	-10	26.5
2	-9.57	25.08
3	10	24
4	14	22
5	16.75	21.7
6	17.999	20.75
7	19.39	20.52
8	21.36	20.48
9	23.25	20.46
10	25.39	20.48
11	27.5	20.52
12	29.64	20.54
13	32.29	20.57

Downstream Reach Lengths

LOB	Channel	ROB
198.24	198.87	199.7

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

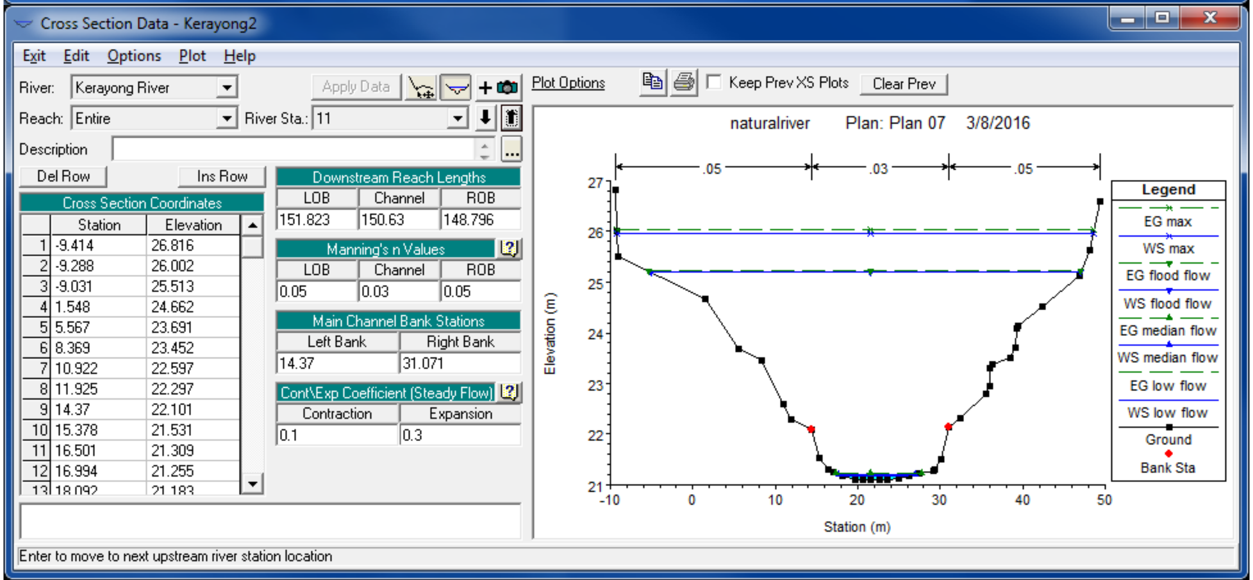
Main Channel Bank Stations

Left Bank	Right Bank
16.75	35.54

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 11

Description:

Cross Section Coordinates

	Station	Elevation
1	-9.414	26.816
2	-9.288	26.002
3	-9.031	25.513
4	1.548	24.662
5	5.567	23.691
6	8.369	23.452
7	10.922	22.597
8	11.925	22.297
9	14.37	22.101
10	15.378	21.531
11	16.501	21.309
12	16.994	21.255
13	18.092	21.183

Downstream Reach Lengths

LOB	Channel	ROB
151.823	150.63	148.796

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

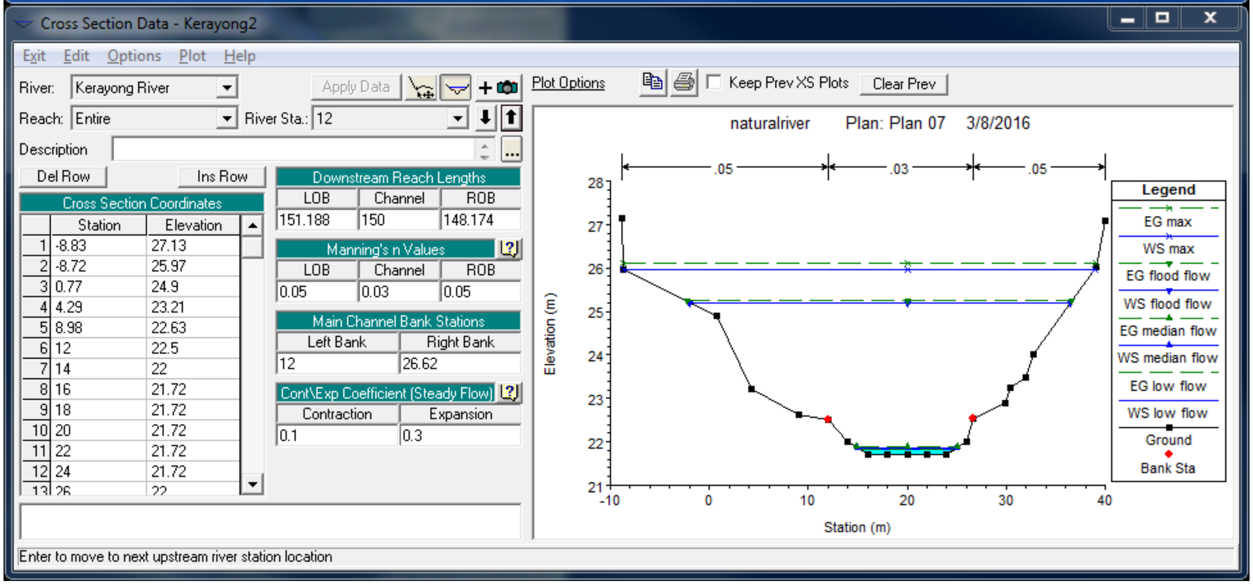
Main Channel Bank Stations

Left Bank	Right Bank
14.37	31.071

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 12

Description:

Cross Section Coordinates

	Station	Elevation
1	-8.83	27.13
2	-8.72	25.97
3	0.77	24.9
4	4.29	23.21
5	8.98	22.63
6	12	22.5
7	14	22
8	16	21.72
9	18	21.72
10	20	21.72
11	22	21.72
12	24	21.72
13	26	22

Downstream Reach Lengths

LOB	Channel	ROB
151.188	150	148.174

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

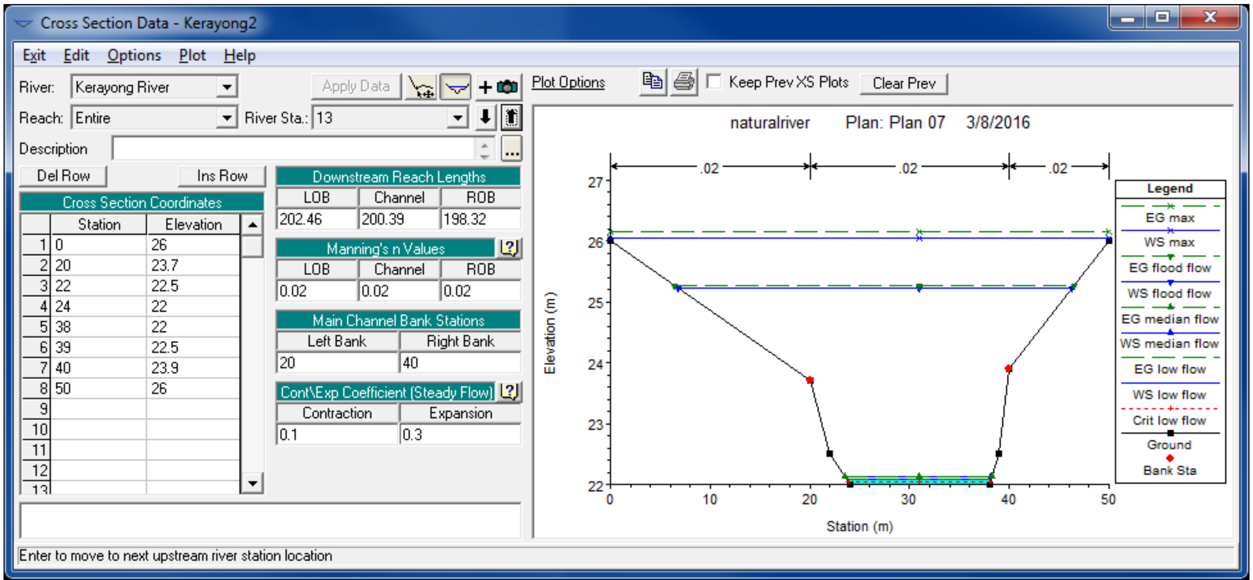
Main Channel Bank Stations

Left Bank	Right Bank
12	26.62

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 13

Description:

Cross Section Coordinates

	Station	Elevation
1	0	26
2	20	23.7
3	22	22.5
4	24	22
5	38	22
6	39	22.5
7	40	23.9
8	50	26
9		
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
202.46	200.39	198.32

Manning's n Values

LOB	Channel	ROB
0.02	0.02	0.02

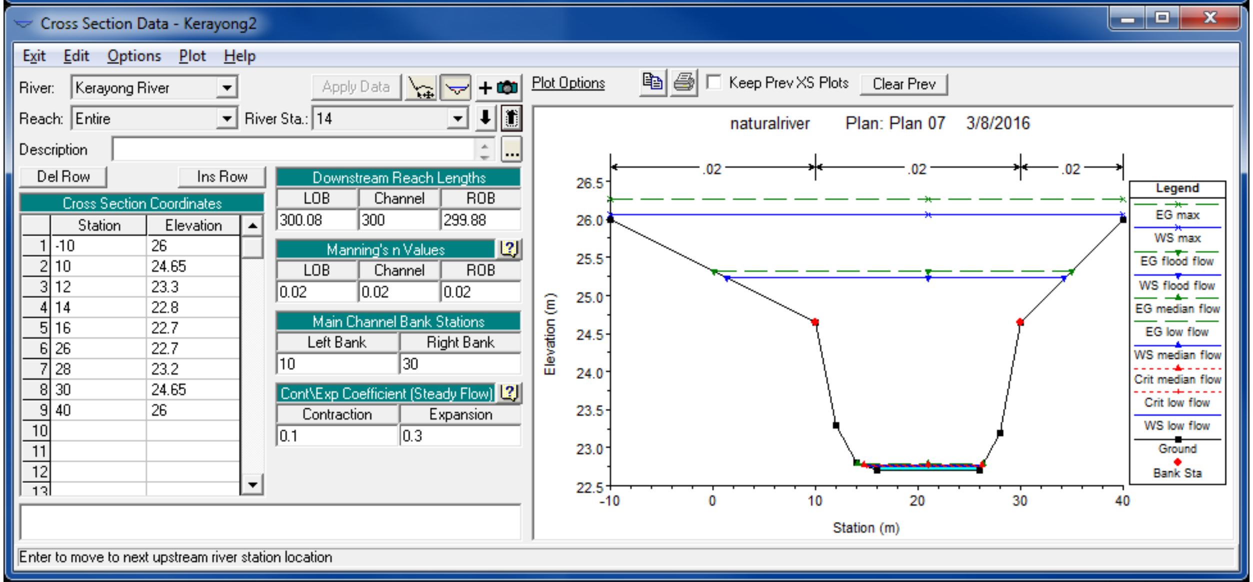
Main Channel Bank Stations

Left Bank	Right Bank
20	40

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 14

Description:

Cross Section Coordinates

	Station	Elevation
1	-10	26
2	10	24.65
3	12	23.3
4	14	22.8
5	16	22.7
6	26	22.7
7	28	23.2
8	30	24.65
9	40	26
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
300.08	300	299.88

Manning's n Values

LOB	Channel	ROB
0.02	0.02	0.02

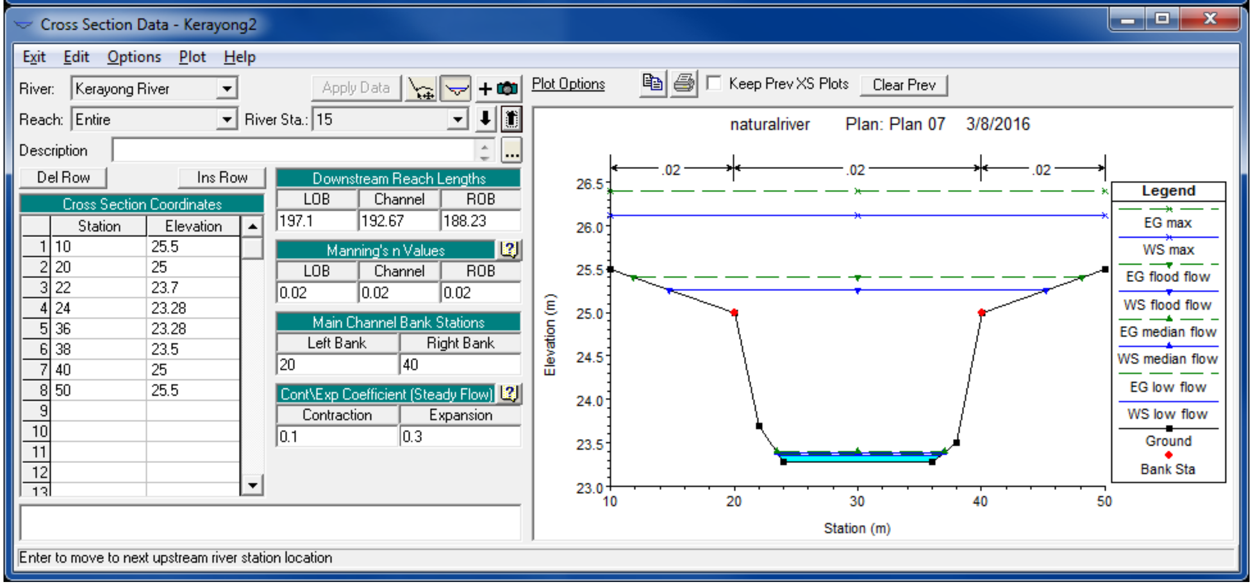
Main Channel Bank Stations

Left Bank	Right Bank
10	30

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 15

Description:

Cross Section Coordinates

	Station	Elevation
1	10	25.5
2	20	25
3	22	23.7
4	24	23.28
5	36	23.28
6	38	23.5
7	40	25
8	50	25.5
9		
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
197.1	192.67	188.23

Manning's n Values

LOB	Channel	ROB
0.02	0.02	0.02

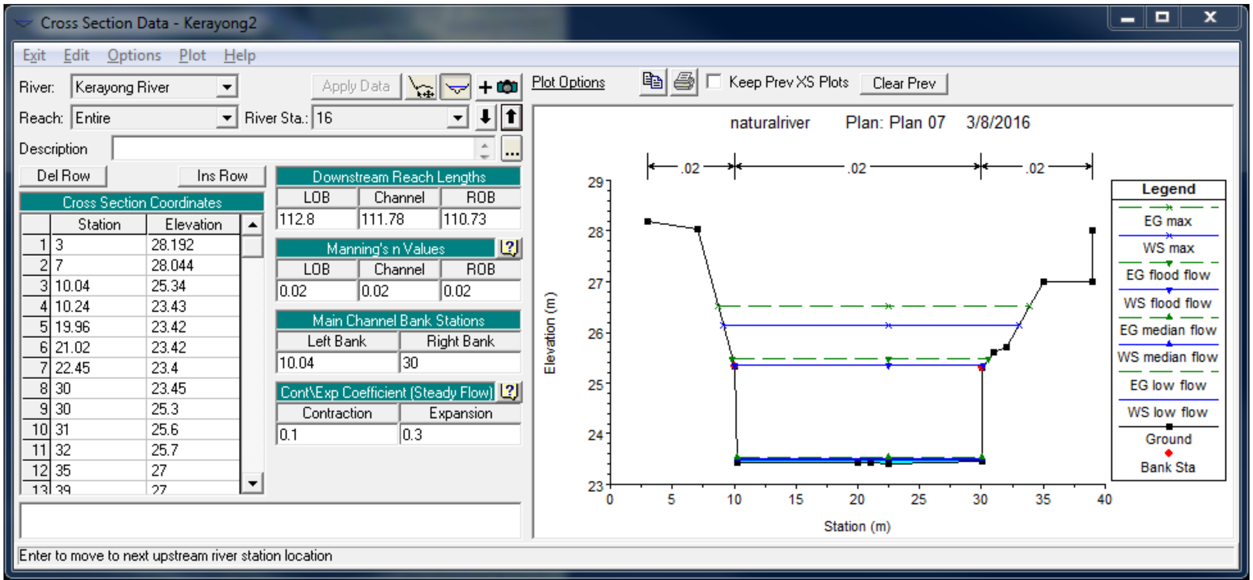
Main Channel Bank Stations

Left Bank	Right Bank
20	40

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 16

Description

Cross Section Coordinates

	Station	Elevation
1	3	28.192
2	7	28.044
3	10.04	25.34
4	10.24	23.43
5	19.96	23.42
6	21.02	23.42
7	22.45	23.4
8	30	23.45
9	30	25.3
10	31	25.6
11	32	25.7
12	35	27
13	39	27

Downstream Reach Lengths

LOB	Channel	ROB
112.8	111.78	110.73

Manning's n Values

LOB	Channel	ROB
0.02	0.02	0.02

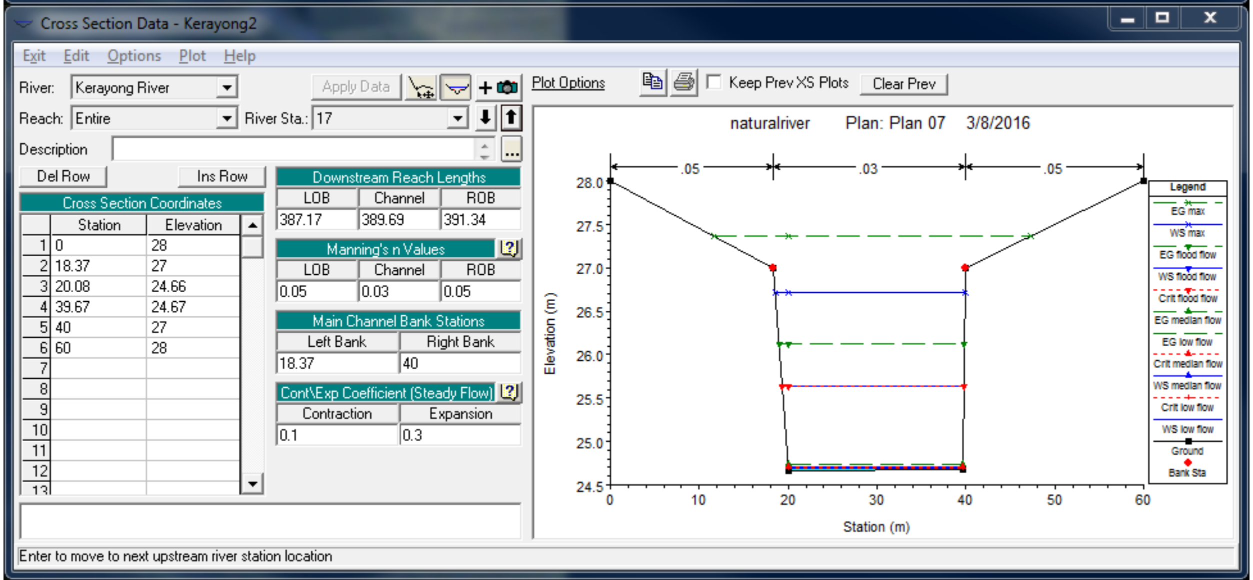
Main Channel Bank Stations

Left Bank	Right Bank
10.04	30

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 17

Description

Cross Section Coordinates

	Station	Elevation
1	0	28
2	18.37	27
3	20.08	24.66
4	39.67	24.67
5	40	27
6	60	28
7		
8		
9		
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
387.17	389.69	391.34

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

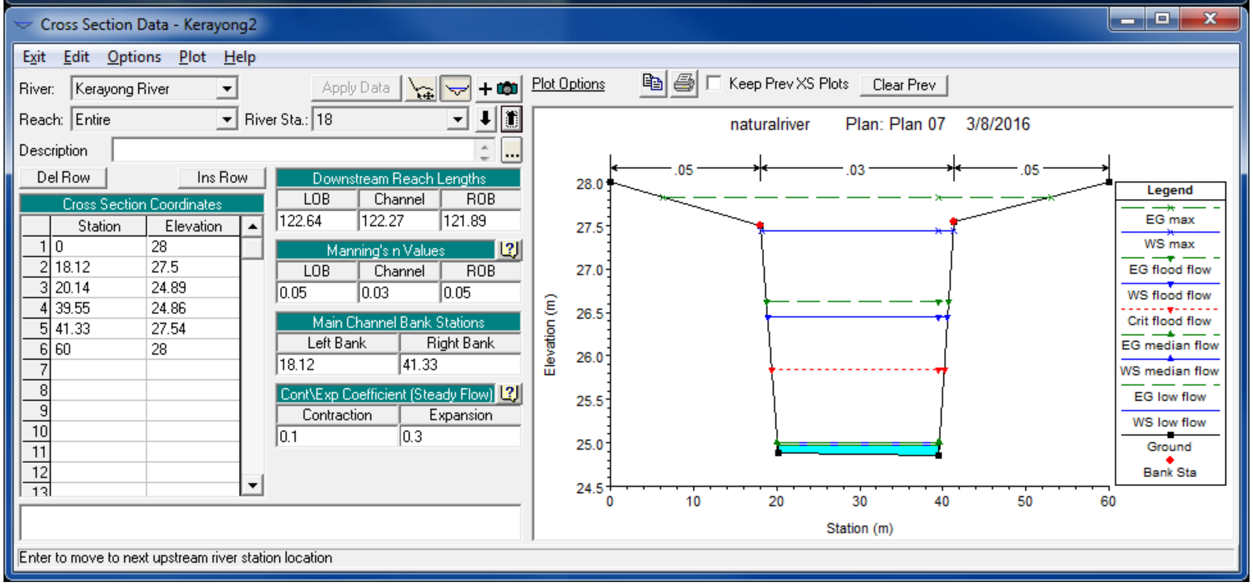
Main Channel Bank Stations

Left Bank	Right Bank
18.37	40

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 18

Description

Cross Section Coordinates

	Station	Elevation
1	0	28
2	18.12	27.5
3	20.14	24.89
4	39.55	24.86
5	41.33	27.54
6	60	28
7		
8		
9		
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
122.64	122.27	121.89

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

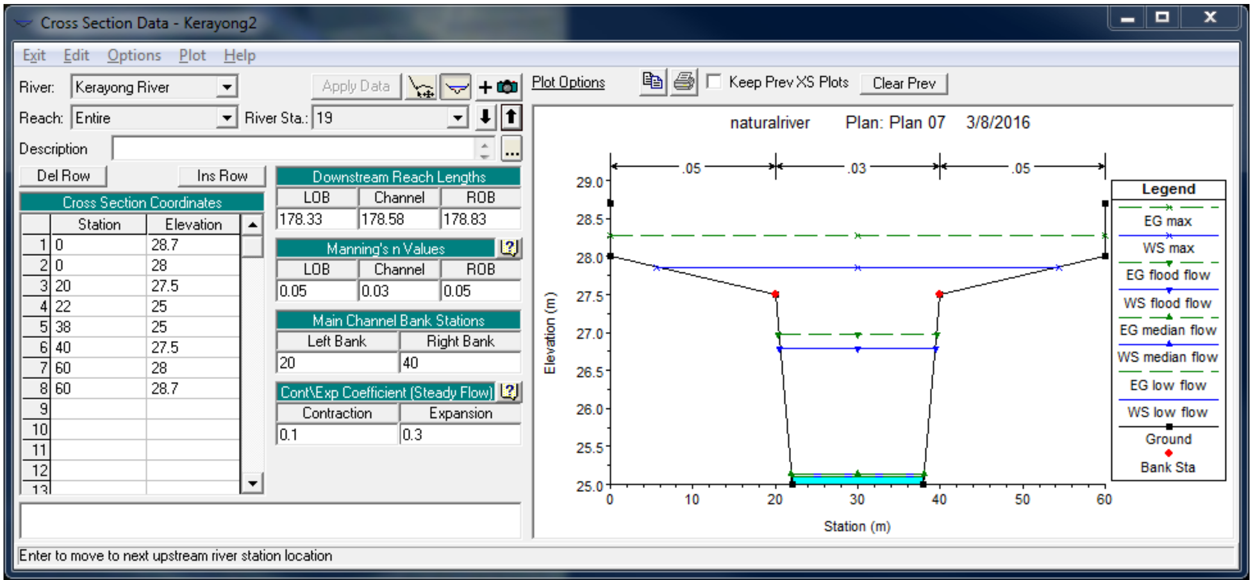
Main Channel Bank Stations

Left Bank	Right Bank
18.12	41.33

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire River Sta.: 19

Description

Cross Section Coordinates

	Station	Elevation
1	0	28.7
2	0	28
3	20	27.5
4	22	25
5	38	25
6	40	27.5
7	60	28
8	60	28.7
9		
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
178.33	178.58	178.83

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

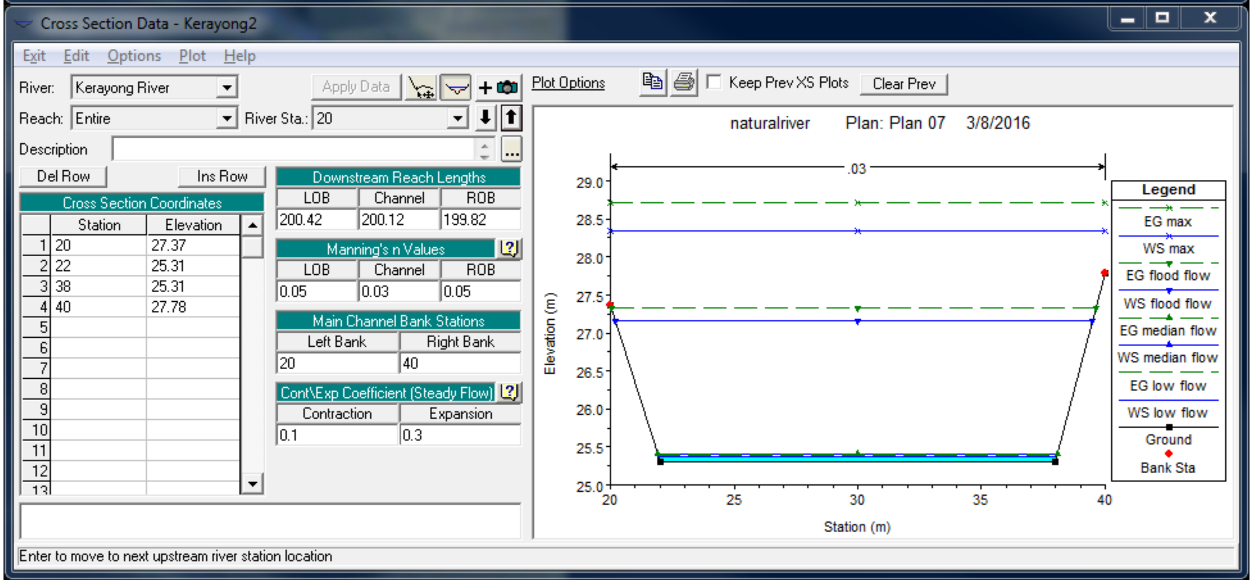
Main Channel Bank Stations

Left Bank	Right Bank
20	40

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire River Sta.: 20

Description

Cross Section Coordinates

	Station	Elevation
1	20	27.37
2	22	25.31
3	38	25.31
4	40	27.78
5		
6		
7		
8		
9		
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
200.42	200.12	199.82

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

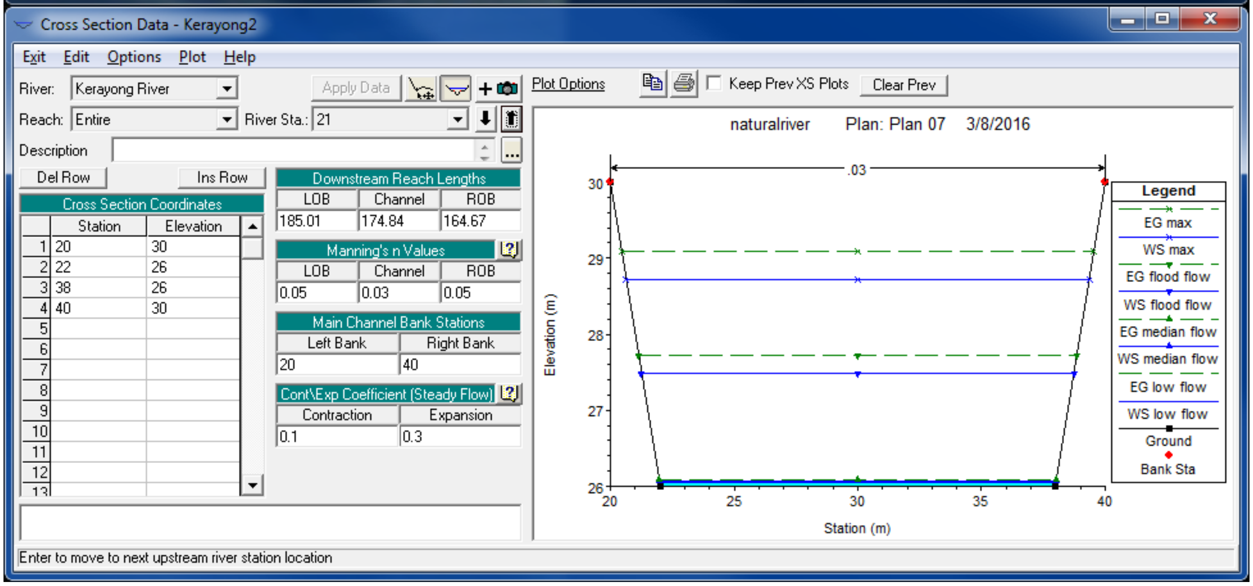
Main Channel Bank Stations

Left Bank	Right Bank
20	40

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire River Sta.: 21

Description

Cross Section Coordinates

	Station	Elevation
1	20	30
2	22	26
3	38	26
4	40	30
5		
6		
7		
8		
9		
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
185.01	174.84	164.67

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

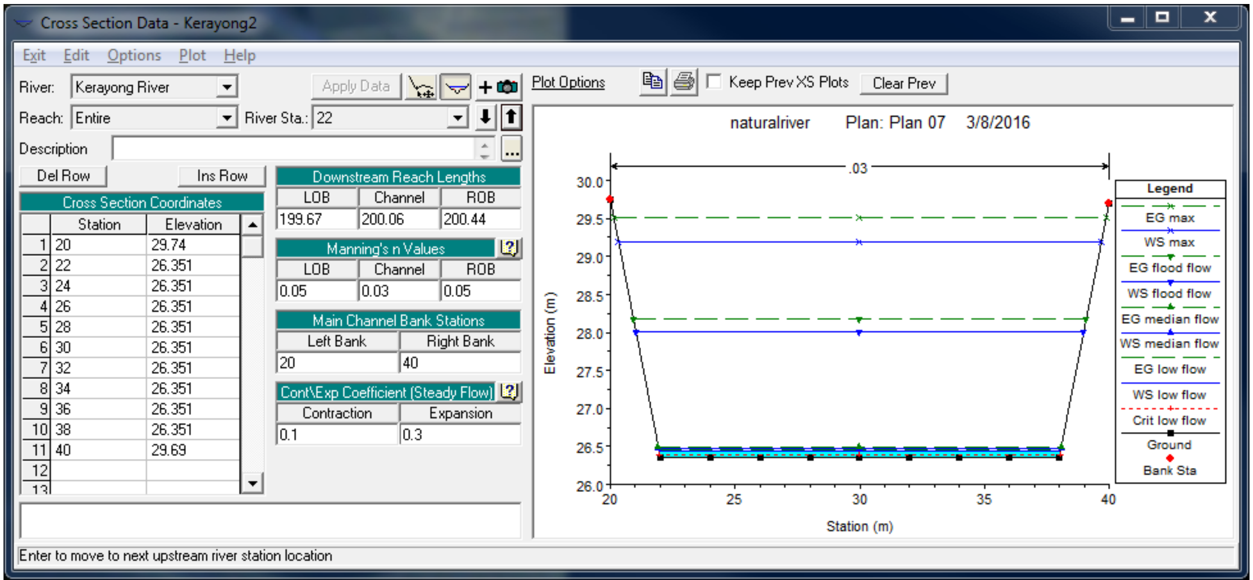
Main Channel Bank Stations

Left Bank	Right Bank
20	40

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 22

Description

Cross Section Coordinates

	Station	Elevation
1	20	29.74
2	22	26.351
3	24	26.351
4	26	26.351
5	28	26.351
6	30	26.351
7	32	26.351
8	34	26.351
9	36	26.351
10	38	26.351
11	40	29.69
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
199.67	200.06	200.44

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

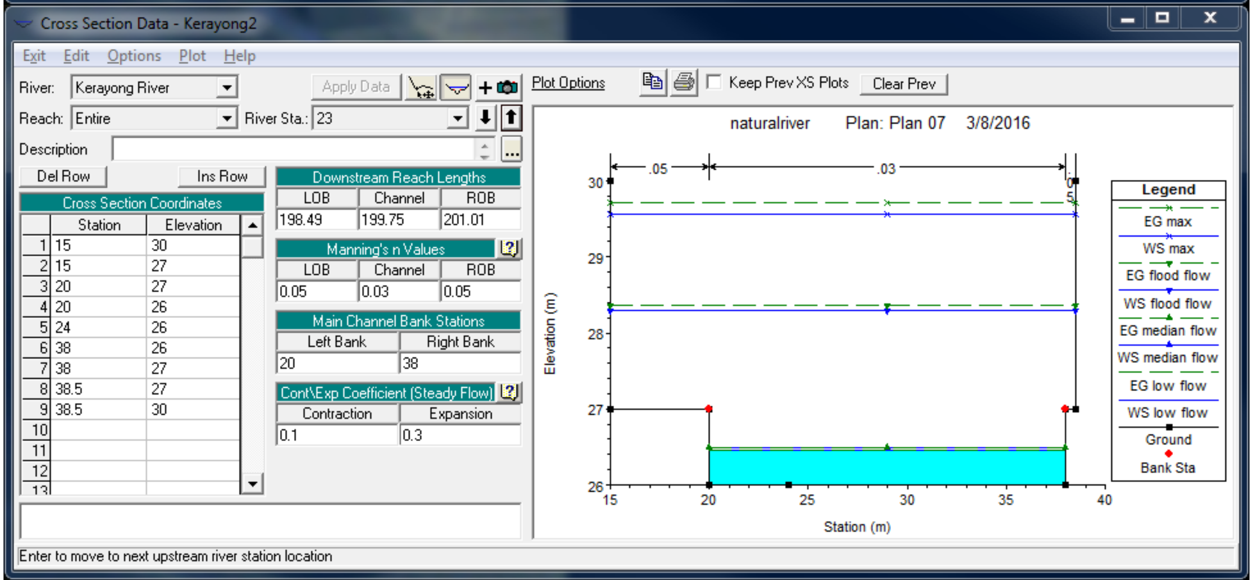
Main Channel Bank Stations

Left Bank	Right Bank
20	40

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 23

Description

Cross Section Coordinates

	Station	Elevation
1	15	30
2	15	27
3	20	27
4	20	26
5	24	26
6	38	26
7	38	27
8	38.5	27
9	38.5	30
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
198.49	199.75	201.01

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

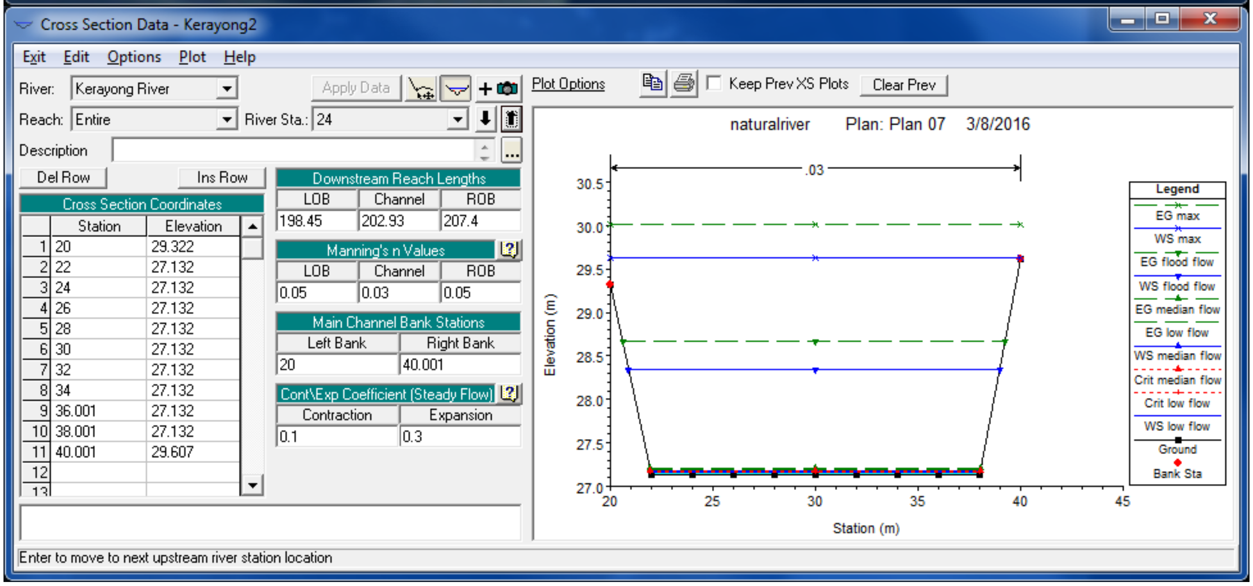
Main Channel Bank Stations

Left Bank	Right Bank
20	38

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 24

Description

Cross Section Coordinates

	Station	Elevation
1	20	29.322
2	22	27.132
3	24	27.132
4	26	27.132
5	28	27.132
6	30	27.132
7	32	27.132
8	34	27.132
9	36.001	27.132
10	38.001	27.132
11	40.001	29.607
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
198.45	202.93	207.4

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

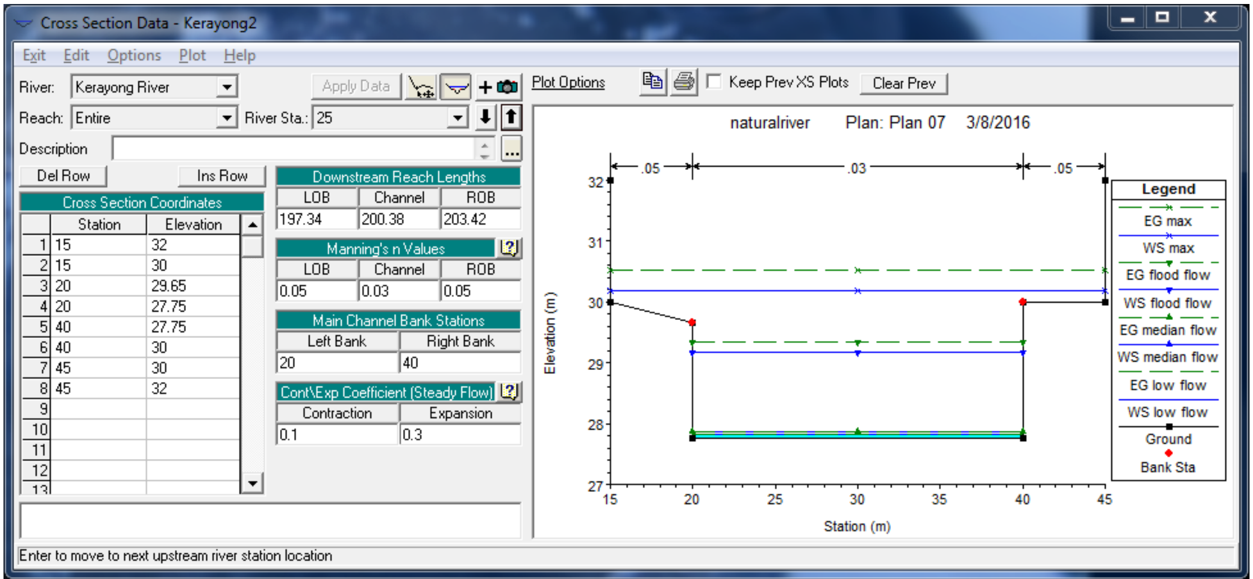
Main Channel Bank Stations

Left Bank	Right Bank
20	40.001

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire   River Sta.: 25

Description

Cross Section Coordinates

	Station	Elevation
1	15	32
2	15	30
3	20	29.65
4	20	27.75
5	40	27.75
6	40	30
7	45	30
8	45	32
9		
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
197.34	200.38	203.42

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

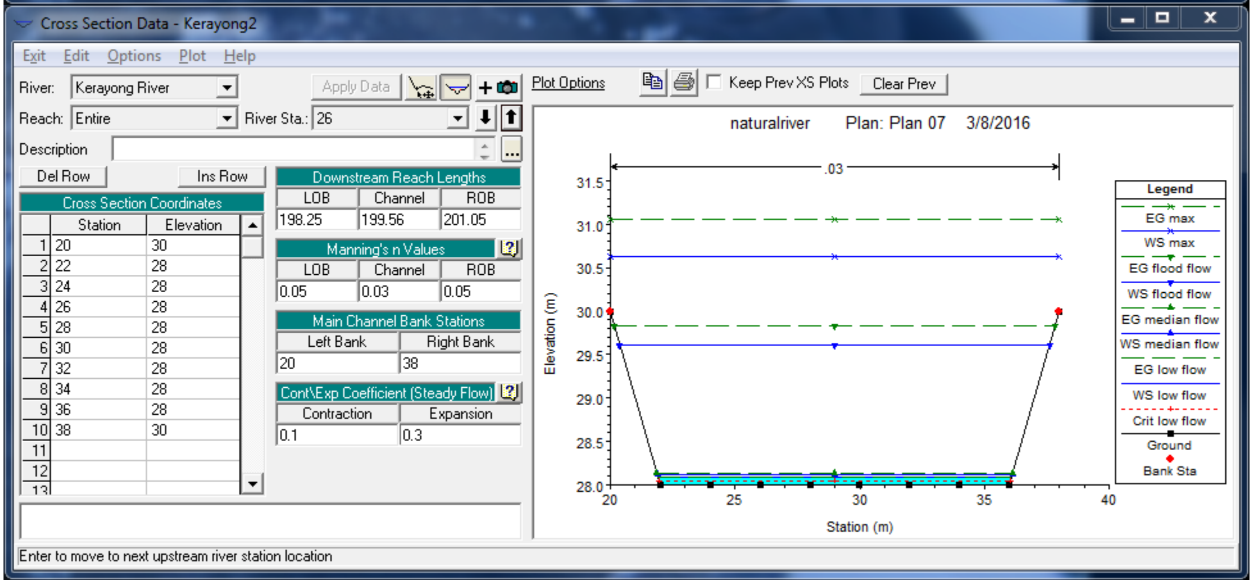
Main Channel Bank Stations

Left Bank	Right Bank
20	40

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire   River Sta.: 26

Description

Cross Section Coordinates

	Station	Elevation
1	20	30
2	22	28
3	24	28
4	26	28
5	28	28
6	30	28
7	32	28
8	34	28
9	36	28
10	38	30
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
198.25	199.56	201.05

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

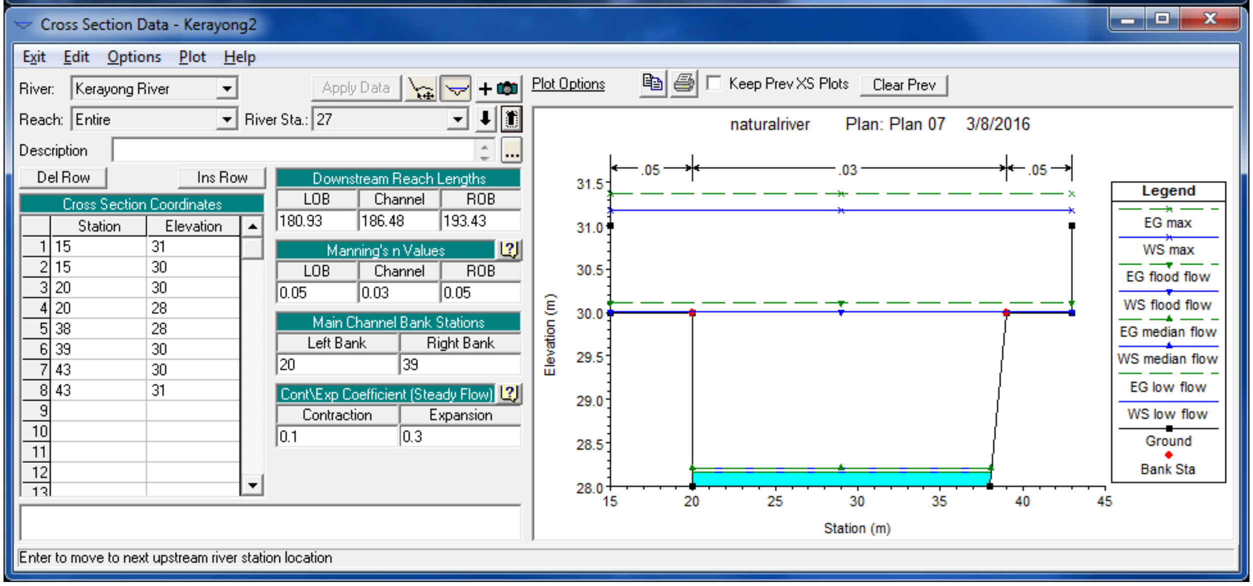
Main Channel Bank Stations

Left Bank	Right Bank
20	38

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire   River Sta.: 27

Description

Cross Section Coordinates

	Station	Elevation
1	15	31
2	15	30
3	20	30
4	20	28
5	38	28
6	39	30
7	43	30
8	43	31
9		
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
180.93	186.48	193.43

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

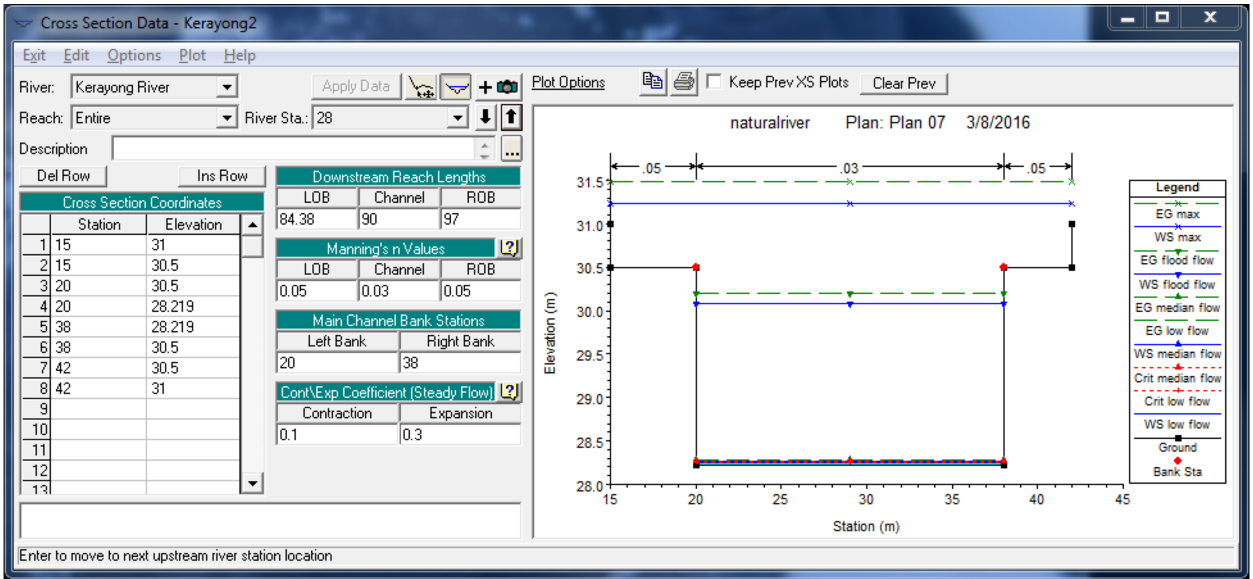
Main Channel Bank Stations

Left Bank	Right Bank
20	39

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 28

Description:

Cross Section Coordinates

	Station	Elevation
1	15	31
2	15	30.5
3	20	30.5
4	20	28.219
5	38	28.219
6	38	30.5
7	42	30.5
8	42	31
9		
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
84.38	90	97

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

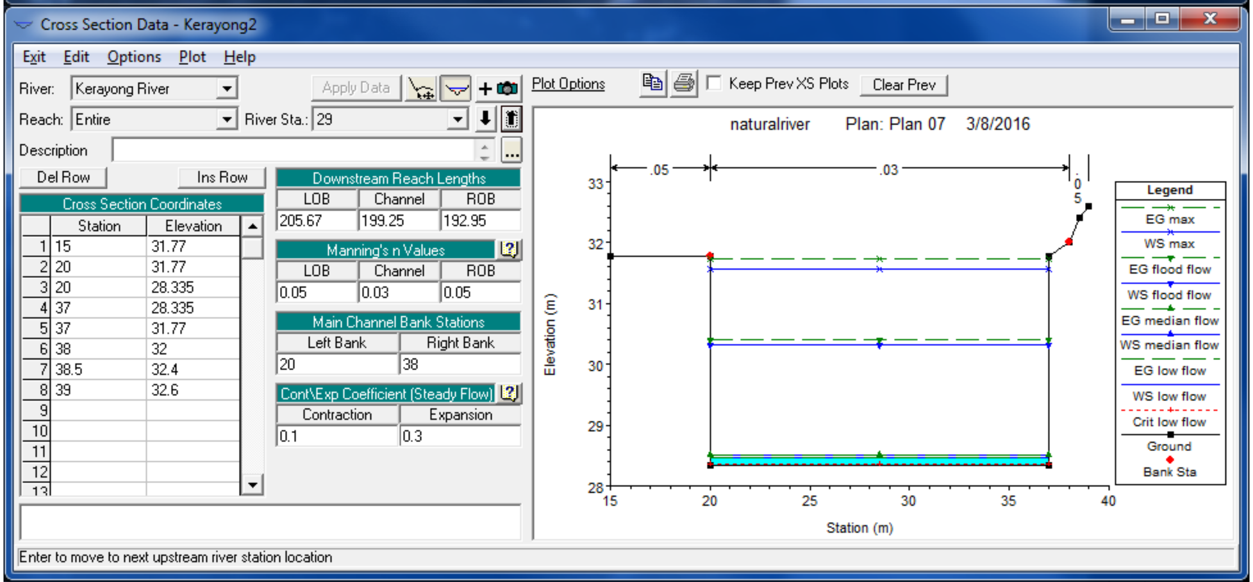
Main Channel Bank Stations

Left Bank	Right Bank
20	38

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 29

Description:

Cross Section Coordinates

	Station	Elevation
1	15	31.77
2	20	31.77
3	20	28.335
4	37	28.335
5	37	31.77
6	38	32
7	38.5	32.4
8	39	32.6
9		
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
205.67	199.25	192.95

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

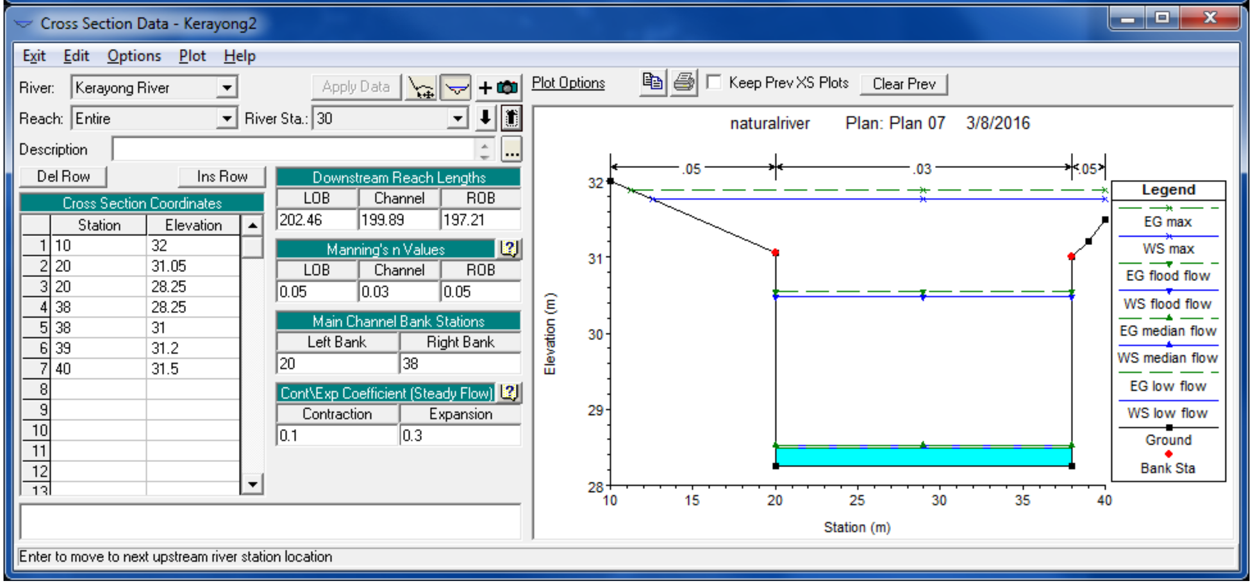
Main Channel Bank Stations

Left Bank	Right Bank
20	38

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 30

Description:

Cross Section Coordinates

	Station	Elevation
1	10	32
2	20	31.05
3	20	28.25
4	38	28.25
5	38	31
6	39	31.2
7	40	31.5
8		
9		
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
202.46	199.89	197.21

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

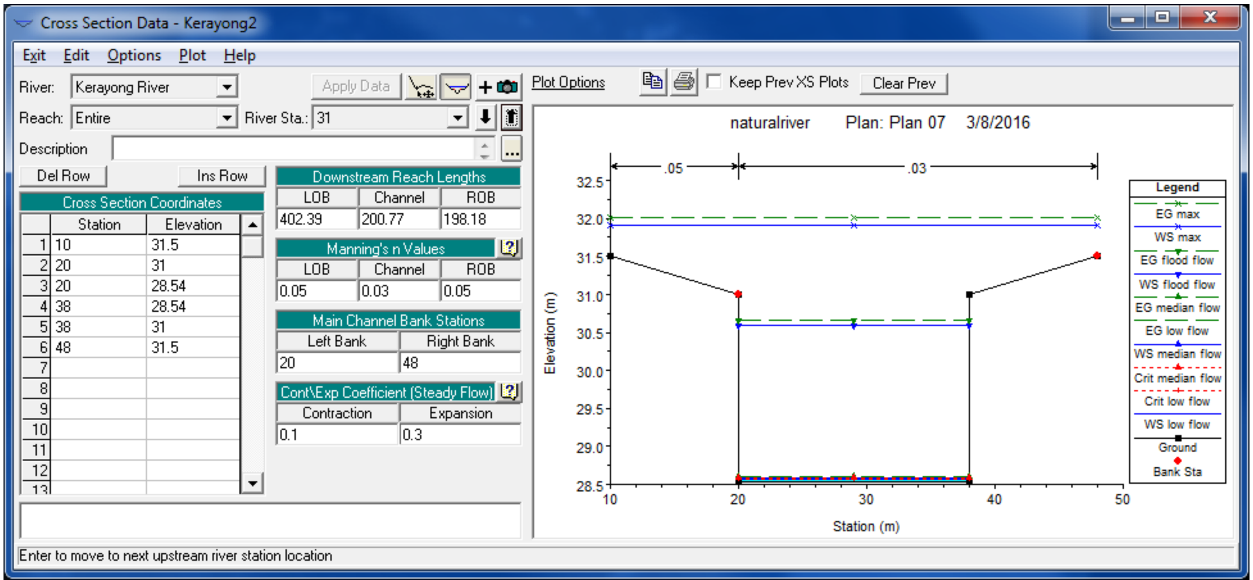
Main Channel Bank Stations

Left Bank	Right Bank
20	38

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire River Sta.: 31

Description

Cross Section Coordinates

	Station	Elevation
1	10	31.5
2	20	31
3	20	28.54
4	38	28.54
5	38	31
6	48	31.5
7		
8		
9		
10		
11		
12		

Downstream Reach Lengths

LOB	Channel	ROB
402.39	200.77	198.18

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

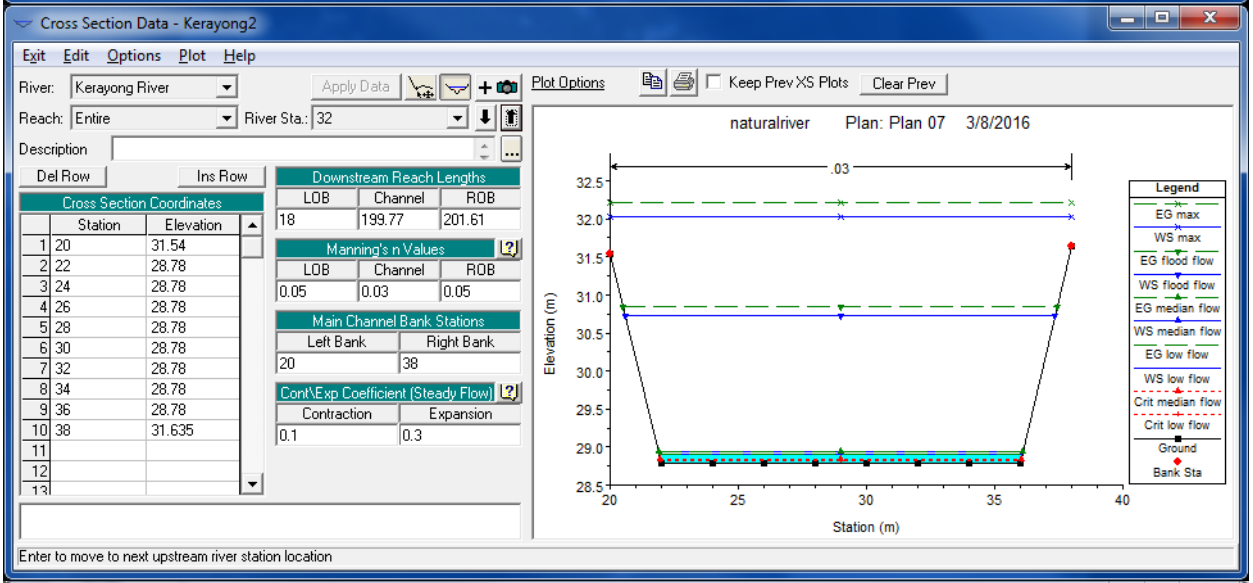
Main Channel Bank Stations

Left Bank	Right Bank
20	48

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire River Sta.: 32

Description

Cross Section Coordinates

	Station	Elevation
1	20	31.54
2	22	28.78
3	24	28.78
4	26	28.78
5	28	28.78
6	30	28.78
7	32	28.78
8	34	28.78
9	36	28.78
10	38	31.635
11		
12		

Downstream Reach Lengths

LOB	Channel	ROB
18	199.77	201.61

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

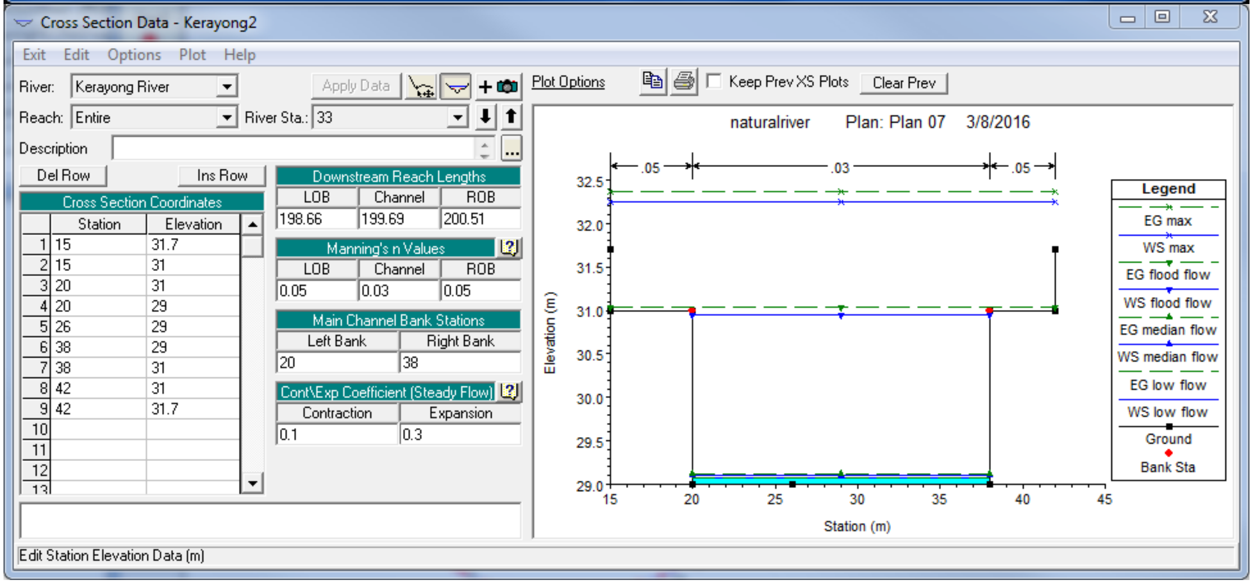
Main Channel Bank Stations

Left Bank	Right Bank
20	38

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire River Sta.: 33

Description

Cross Section Coordinates

	Station	Elevation
1	15	31.7
2	15	31
3	20	31
4	20	29
5	26	29
6	38	29
7	38	31
8	42	31
9	42	31.7
10		
11		
12		

Downstream Reach Lengths

LOB	Channel	ROB
198.66	199.69	200.51

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

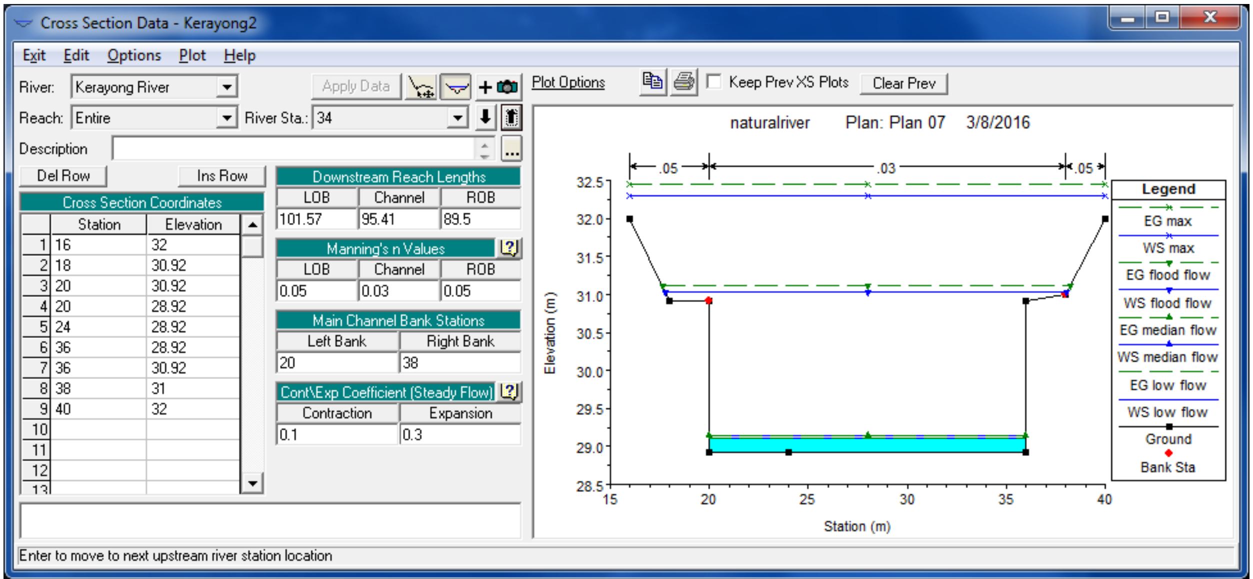
Main Channel Bank Stations

Left Bank	Right Bank
20	38

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Edit Station Elevation Data (m)



River: Kerayong River

Reach: Entire River Sta.: 34

Description

Cross Section Coordinates

	Station	Elevation
1	16	32
2	18	30.92
3	20	30.92
4	20	28.92
5	24	28.92
6	36	28.92
7	36	30.92
8	38	31
9	40	32
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
101.57	95.41	89.5

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

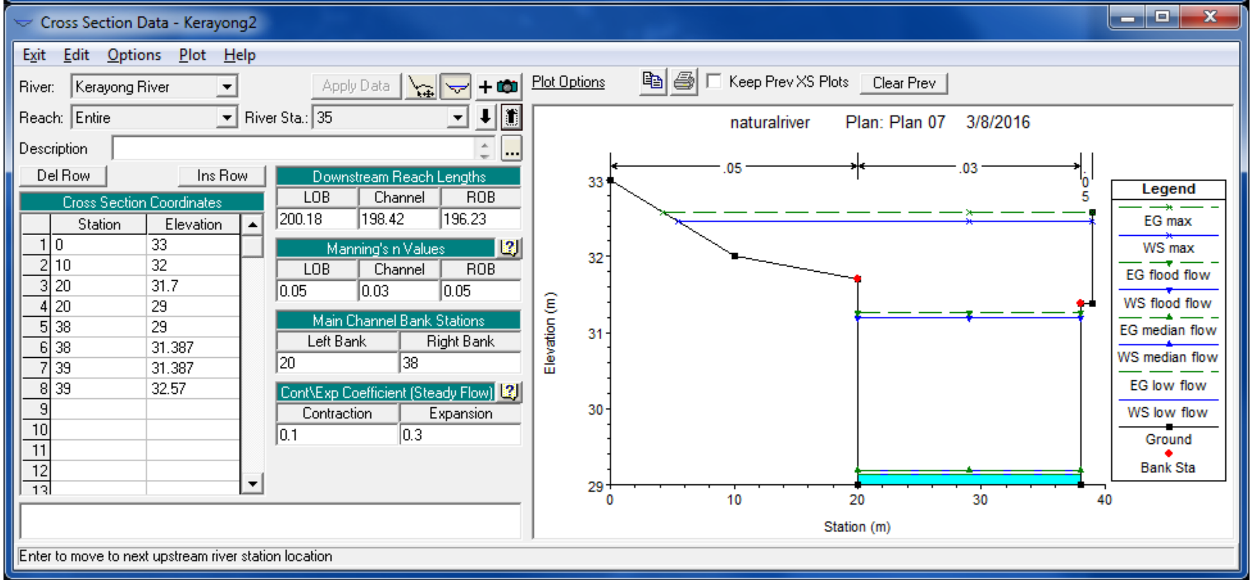
Main Channel Bank Stations

Left Bank	Right Bank
20	38

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire River Sta.: 35

Description

Cross Section Coordinates

	Station	Elevation
1	0	33
2	10	32
3	20	31.7
4	20	29
5	38	29
6	38	31.387
7	39	31.387
8	39	32.57
9		
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
200.18	198.42	196.23

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

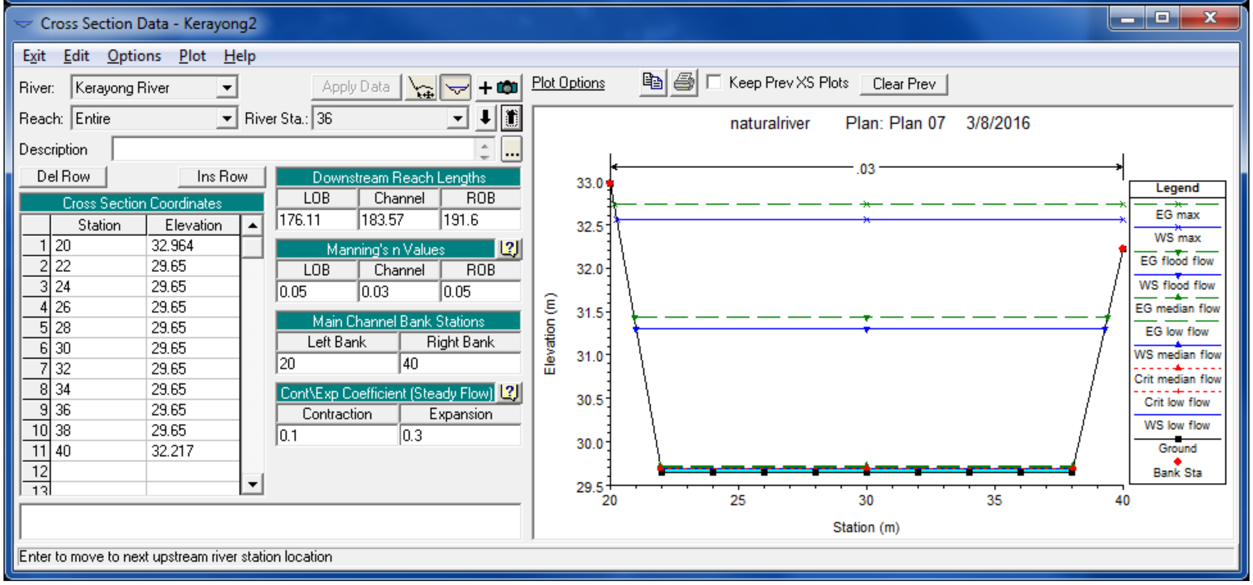
Main Channel Bank Stations

Left Bank	Right Bank
20	38

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire River Sta.: 36

Description

Cross Section Coordinates

	Station	Elevation
1	20	32.964
2	22	29.65
3	24	29.65
4	26	29.65
5	28	29.65
6	30	29.65
7	32	29.65
8	34	29.65
9	36	29.65
10	38	29.65
11	40	32.217
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
176.11	183.57	191.6

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

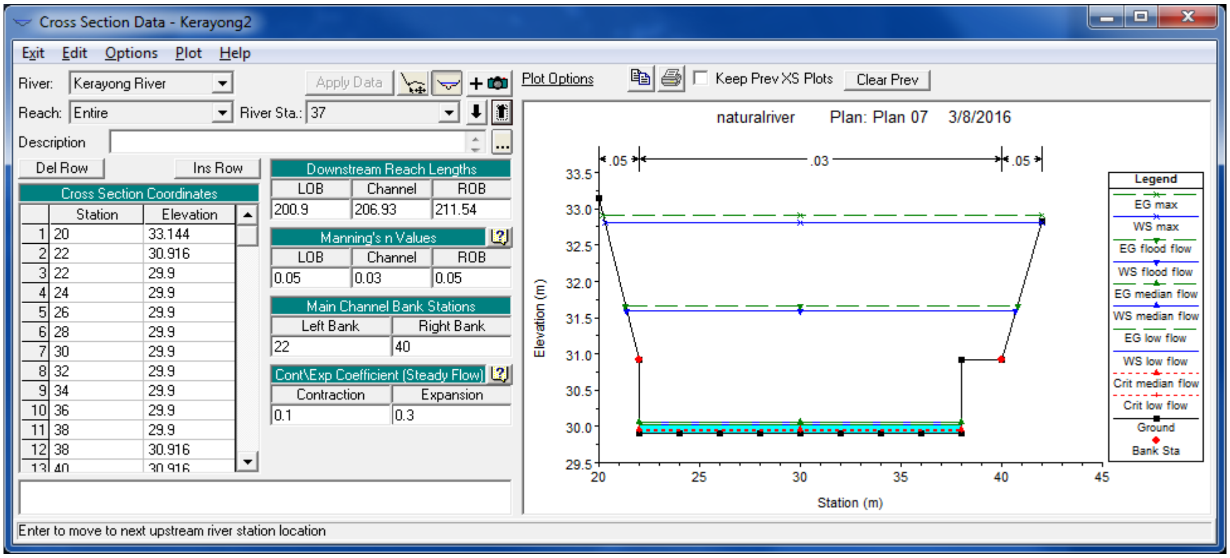
Main Channel Bank Stations

Left Bank	Right Bank
20	40

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 37

Description:

Cross Section Coordinates

	Station	Elevation
1	20	33.144
2	22	30.916
3	22	29.9
4	24	29.9
5	26	29.9
6	28	29.9
7	30	29.9
8	32	29.9
9	34	29.9
10	36	29.9
11	38	29.9
12	38	30.916
13	40	30.916

Downstream Reach Lengths

LOB	Channel	ROB
200.9	206.93	211.54

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

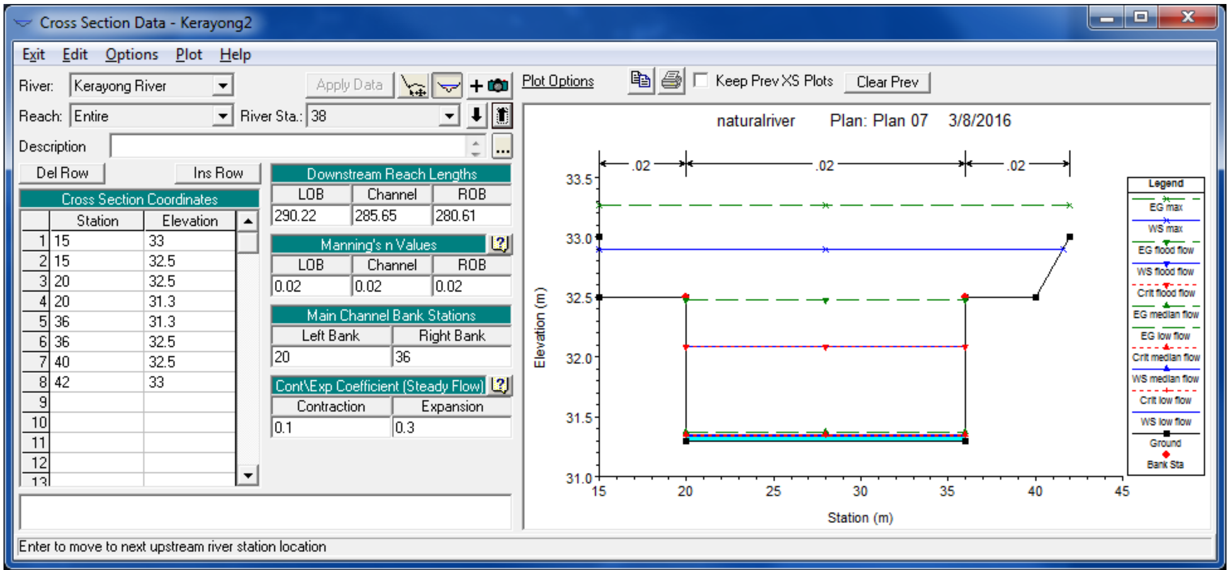
Main Channel Bank Stations

Left Bank	Right Bank
22	40

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 38

Description:

Cross Section Coordinates

	Station	Elevation
1	15	33
2	15	32.5
3	20	32.5
4	20	31.3
5	36	31.3
6	36	32.5
7	40	32.5
8	42	33
9		
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
290.22	285.65	280.61

Manning's n Values

LOB	Channel	ROB
0.02	0.02	0.02

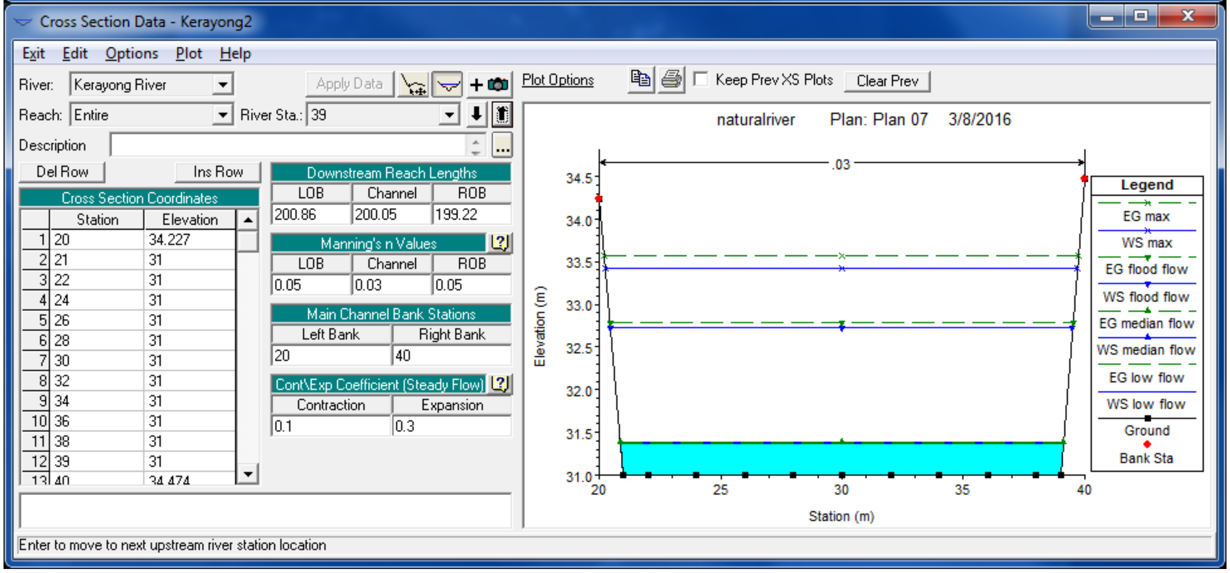
Main Channel Bank Stations

Left Bank	Right Bank
20	36

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 39

Description:

Cross Section Coordinates

	Station	Elevation
1	20	34.227
2	21	31
3	22	31
4	24	31
5	26	31
6	28	31
7	30	31
8	32	31
9	34	31
10	36	31
11	38	31
12	39	31
13	40	34.474

Downstream Reach Lengths

LOB	Channel	ROB
200.86	200.05	199.22

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

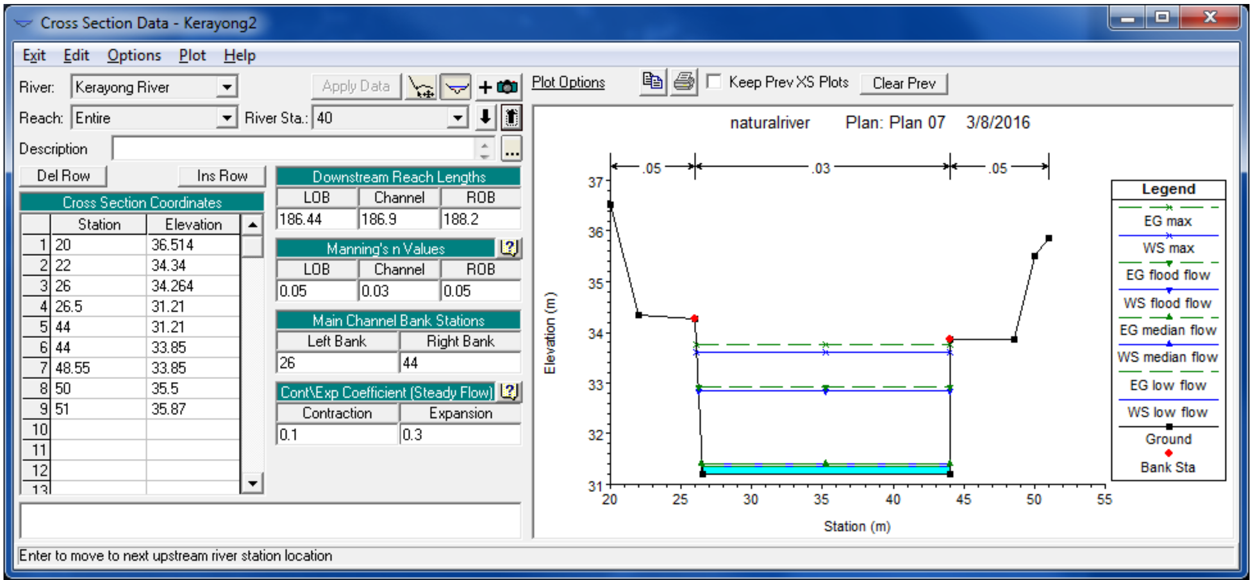
Main Channel Bank Stations

Left Bank	Right Bank
20	40

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 40

Description:

Cross Section Coordinates

	Station	Elevation
1	20	36.514
2	22	34.34
3	26	34.264
4	26.5	31.21
5	44	31.21
6	44	33.85
7	48.55	33.85
8	50	35.5
9	51	35.87
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
186.44	186.9	188.2

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

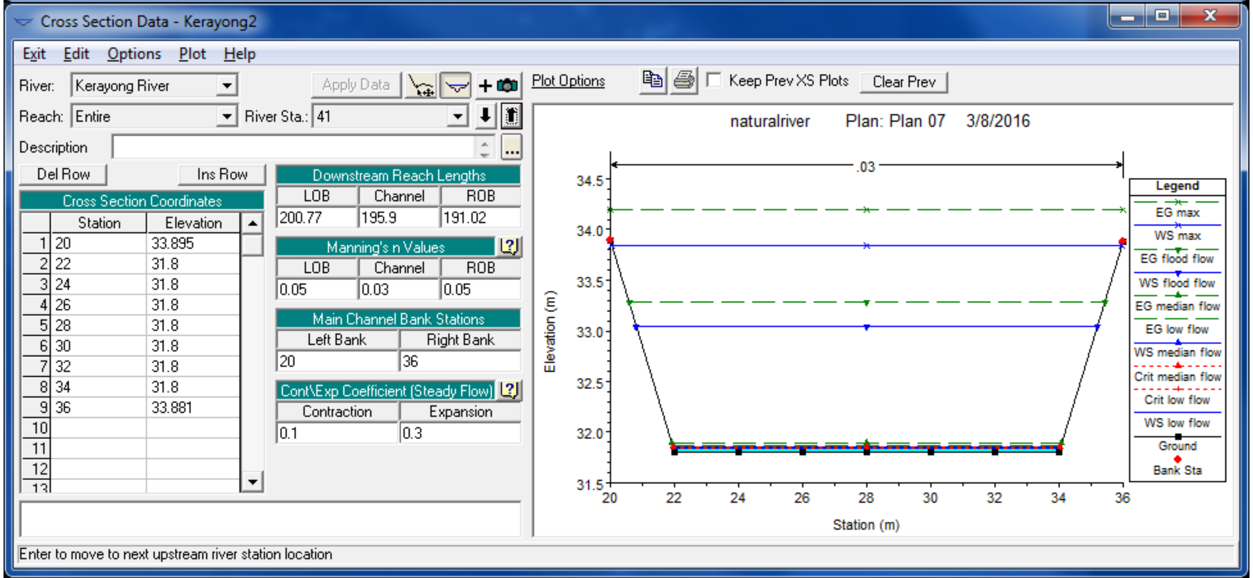
Main Channel Bank Stations

Left Bank	Right Bank
26	44

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 41

Description:

Cross Section Coordinates

	Station	Elevation
1	20	33.895
2	22	31.8
3	24	31.8
4	26	31.8
5	28	31.8
6	30	31.8
7	32	31.8
8	34	31.8
9	36	33.881
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
200.77	195.9	191.02

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

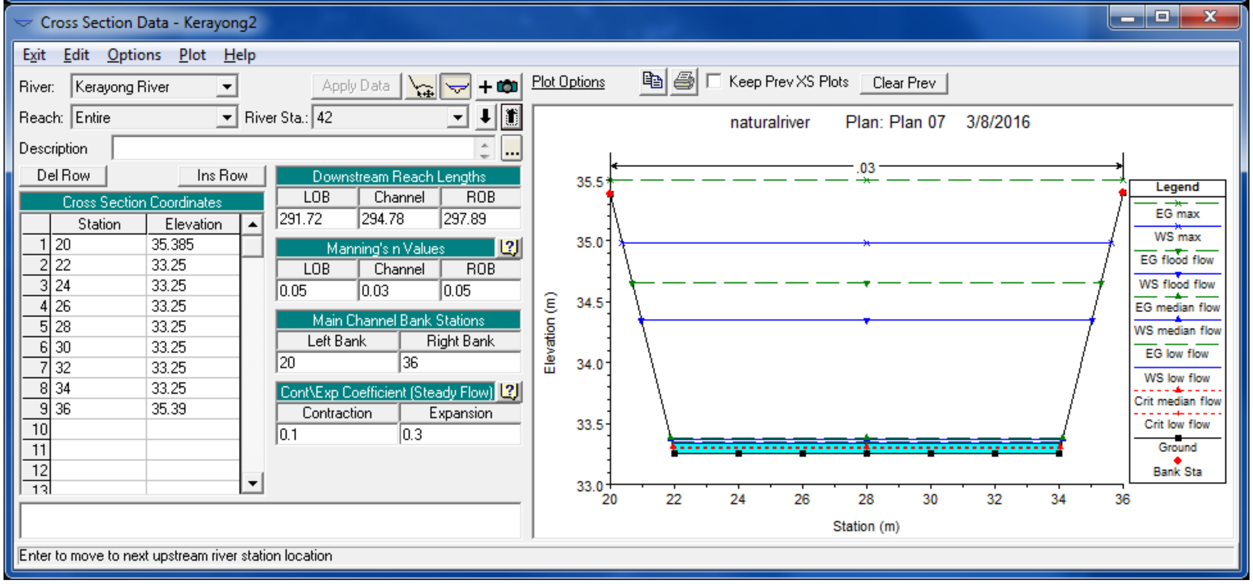
Main Channel Bank Stations

Left Bank	Right Bank
20	36

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 42

Description:

Cross Section Coordinates

	Station	Elevation
1	20	35.385
2	22	33.25
3	24	33.25
4	26	33.25
5	28	33.25
6	30	33.25
7	32	33.25
8	34	33.25
9	36	35.39
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
291.72	294.78	297.89

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

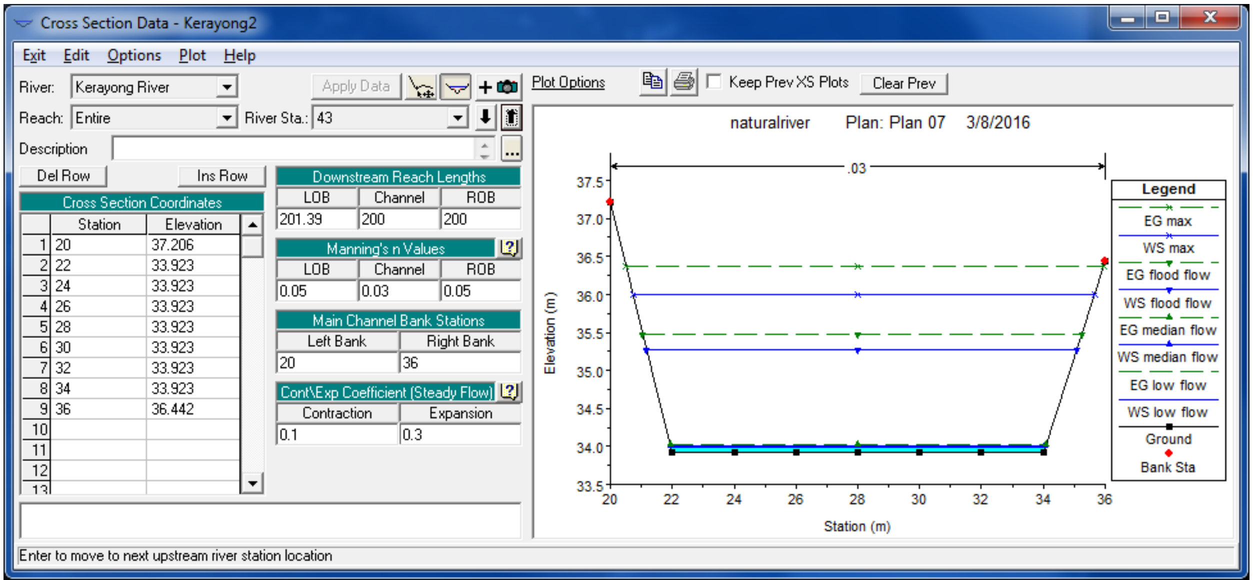
Main Channel Bank Stations

Left Bank	Right Bank
20	36

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire River Sta.: 43

Description

☐ Keep Prev XS Plots

Cross Section Coordinates

	Station	Elevation
1	20	37.206
2	22	33.923
3	24	33.923
4	26	33.923
5	28	33.923
6	30	33.923
7	32	33.923
8	34	33.923
9	36	36.442
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
201.39	200	200

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

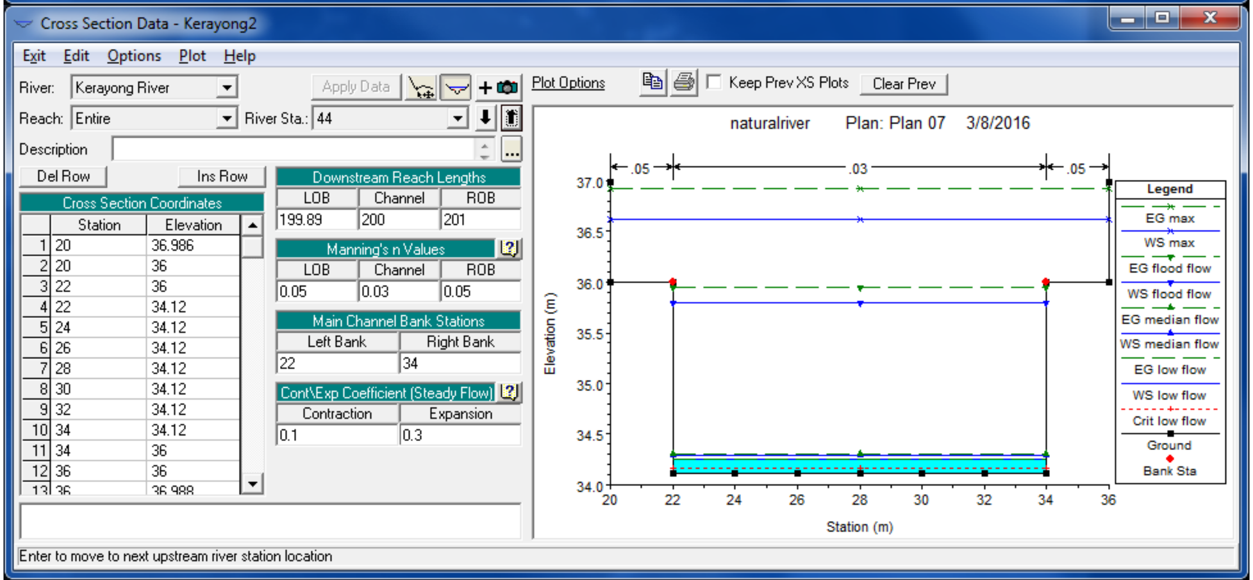
Main Channel Bank Stations

Left Bank	Right Bank
20	36

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire River Sta.: 44

Description

☐ Keep Prev XS Plots

Cross Section Coordinates

	Station	Elevation
1	20	36.986
2	20	36
3	22	36
4	22	34.12
5	24	34.12
6	26	34.12
7	28	34.12
8	30	34.12
9	32	34.12
10	34	34.12
11	34	36
12	36	36
13	36	36.988

Downstream Reach Lengths

LOB	Channel	ROB
199.89	200	201

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

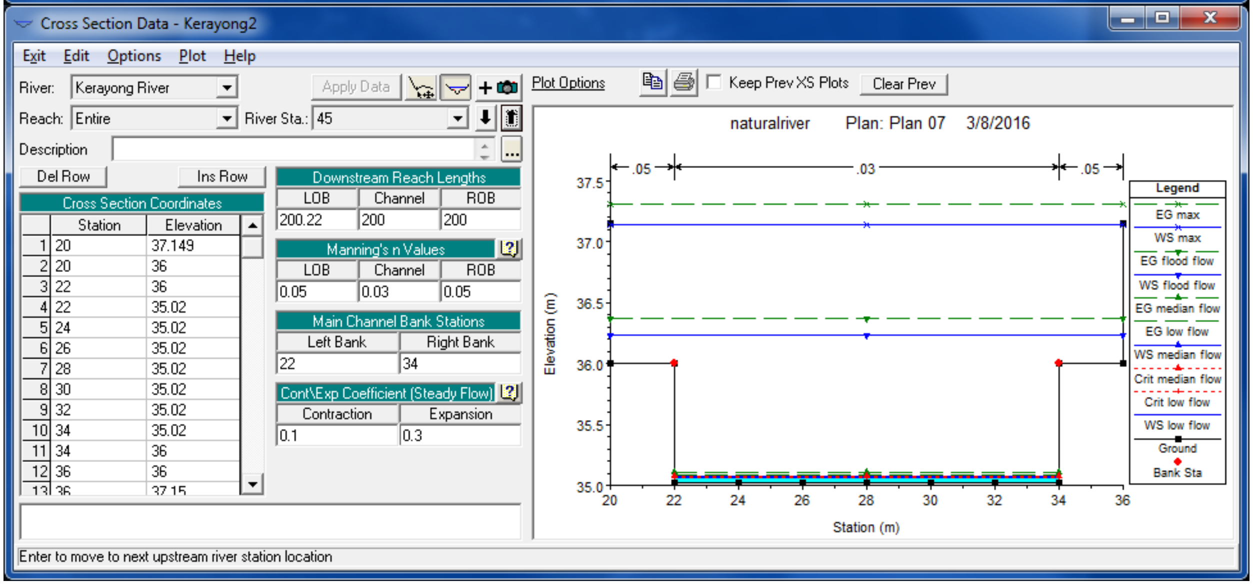
Main Channel Bank Stations

Left Bank	Right Bank
22	34

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire River Sta.: 45

Description

☐ Keep Prev XS Plots

Cross Section Coordinates

	Station	Elevation
1	20	37.149
2	20	36
3	22	36
4	22	35.02
5	24	35.02
6	26	35.02
7	28	35.02
8	30	35.02
9	32	35.02
10	34	35.02
11	34	36
12	36	36
13	36	37.15

Downstream Reach Lengths

LOB	Channel	ROB
200.22	200	200

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

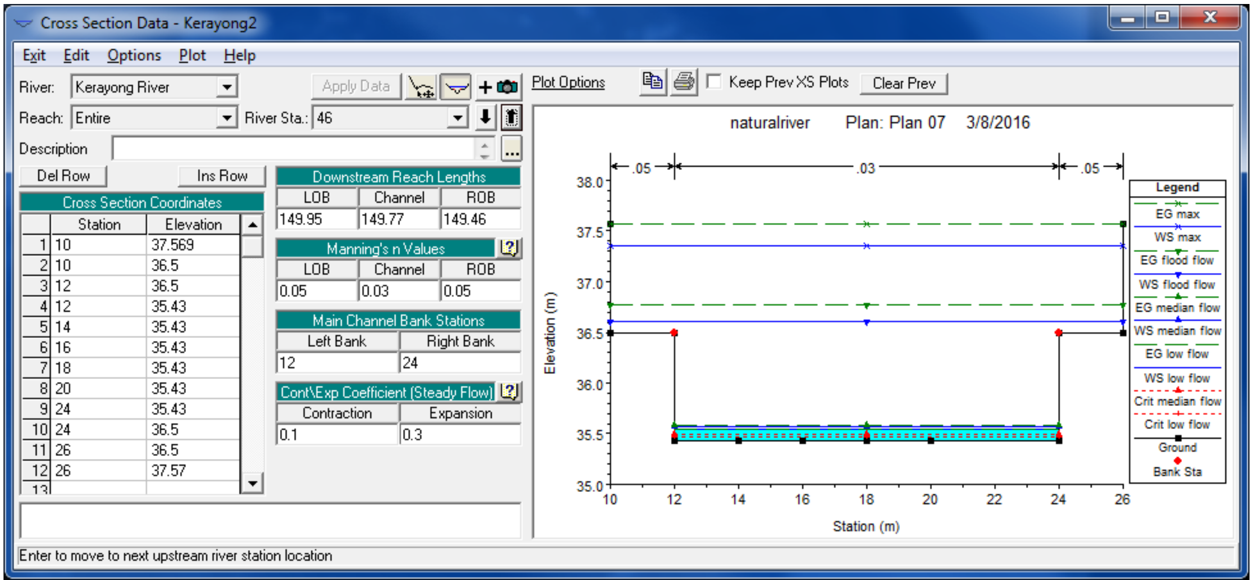
Main Channel Bank Stations

Left Bank	Right Bank
22	34

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River
Reach: Entire
River Sta.: 46
Description

Cross Section Coordinates

	Station	Elevation
1	10	37.569
2	10	36.5
3	12	36.5
4	12	35.43
5	14	35.43
6	16	35.43
7	18	35.43
8	20	35.43
9	24	35.43
10	24	36.5
11	26	36.5
12	26	37.57
13		

Downstream Reach Lengths

LOB	Channel	ROB
149.95	149.77	149.46

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

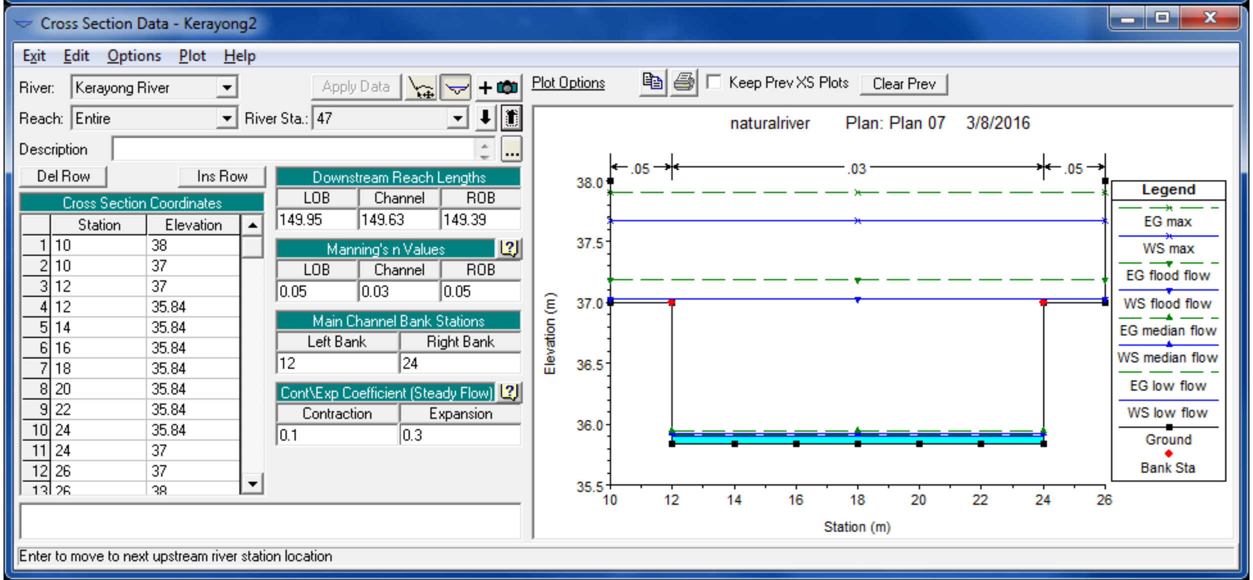
Main Channel Bank Stations

Left Bank	Right Bank
12	24

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River
Reach: Entire
River Sta.: 47
Description

Cross Section Coordinates

	Station	Elevation
1	10	38
2	10	37
3	12	37
4	12	35.84
5	14	35.84
6	16	35.84
7	18	35.84
8	20	35.84
9	22	35.84
10	24	35.84
11	24	37
12	26	37
13	26	38

Downstream Reach Lengths

LOB	Channel	ROB
149.95	149.63	149.39

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

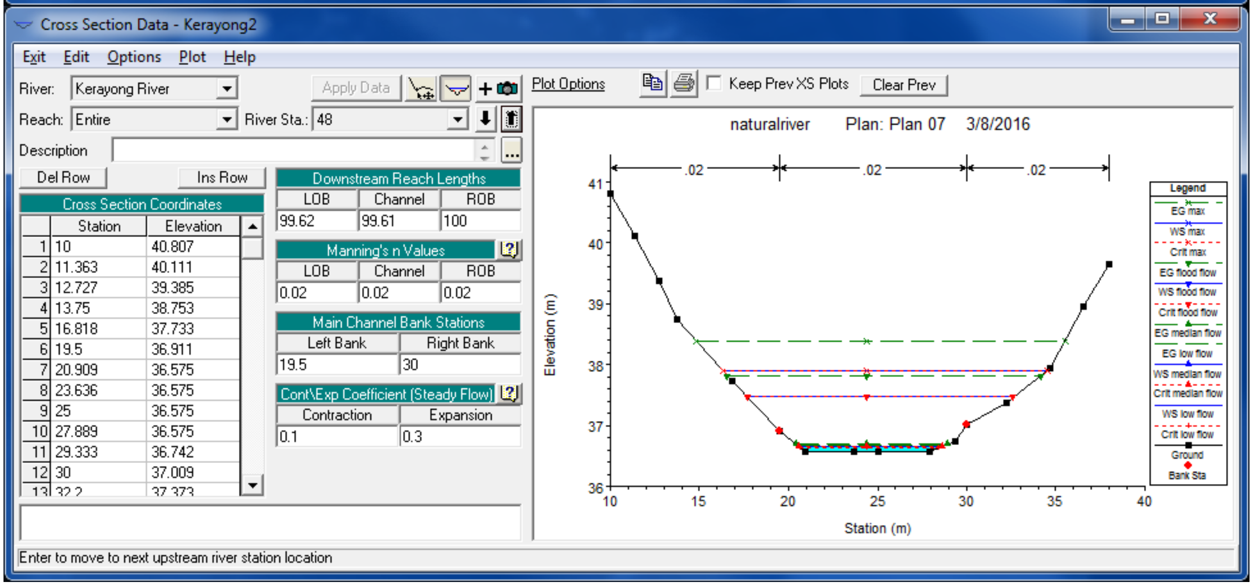
Main Channel Bank Stations

Left Bank	Right Bank
12	24

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River
Reach: Entire
River Sta.: 48
Description

Cross Section Coordinates

	Station	Elevation
1	10	40.807
2	11.363	40.111
3	12.727	39.385
4	13.75	38.753
5	16.818	37.733
6	19.5	36.911
7	20.909	36.575
8	23.636	36.575
9	25	36.575
10	27.889	36.575
11	29.333	36.742
12	30	37.009
13	32.2	37.373

Downstream Reach Lengths

LOB	Channel	ROB
99.62	99.61	100

Manning's n Values

LOB	Channel	ROB
0.02	0.02	0.02

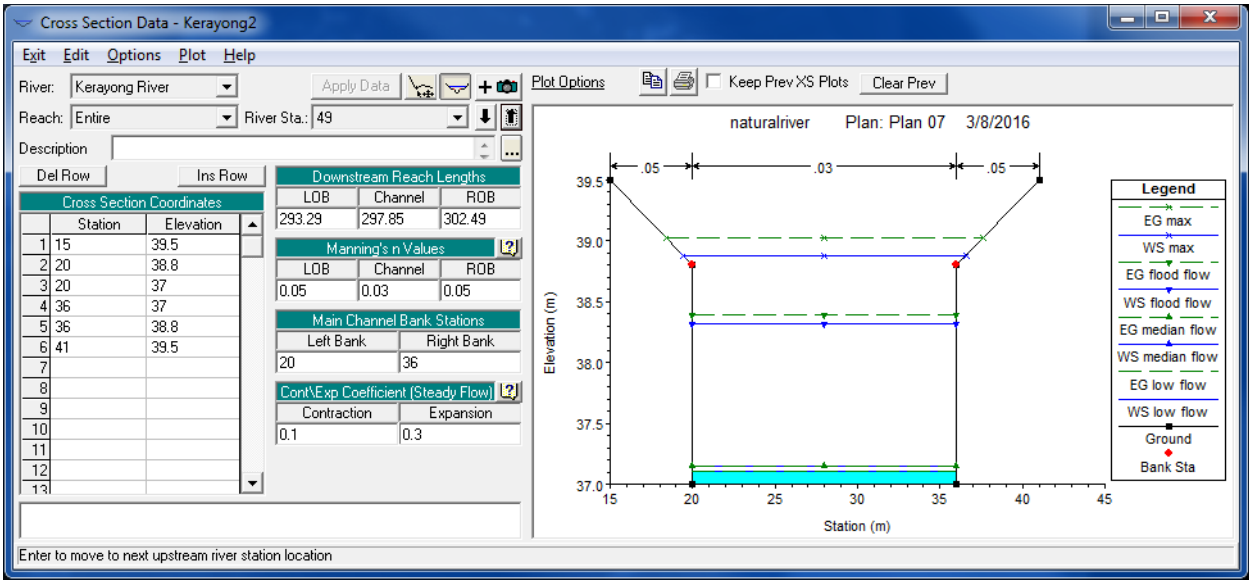
Main Channel Bank Stations

Left Bank	Right Bank
19.5	30

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 49

Description:

Cross Section Coordinates

	Station	Elevation
1	15	39.5
2	20	38.8
3	20	37
4	36	37
5	36	38.8
6	41	39.5
7		
8		
9		
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
293.29	297.85	302.49

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

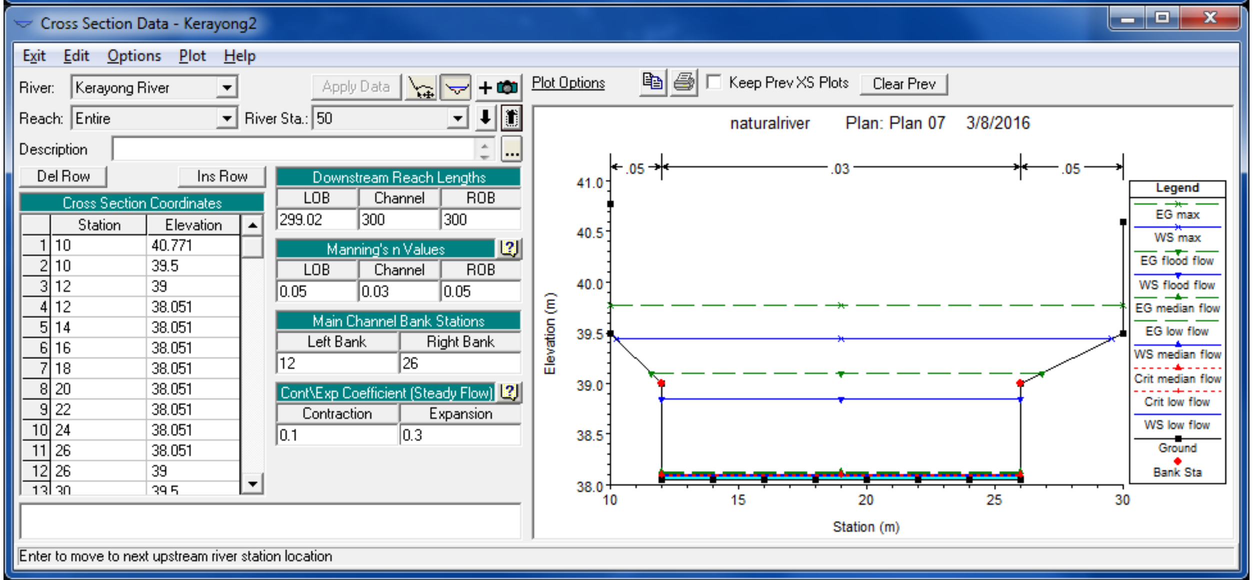
Main Channel Bank Stations

Left Bank	Right Bank
20	36

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 50

Description:

Cross Section Coordinates

	Station	Elevation
1	10	40.771
2	10	39.5
3	12	39
4	12	38.051
5	14	38.051
6	16	38.051
7	18	38.051
8	20	38.051
9	22	38.051
10	24	38.051
11	26	38.051
12	26	39
13	30	39.5

Downstream Reach Lengths

LOB	Channel	ROB
299.02	300	300

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

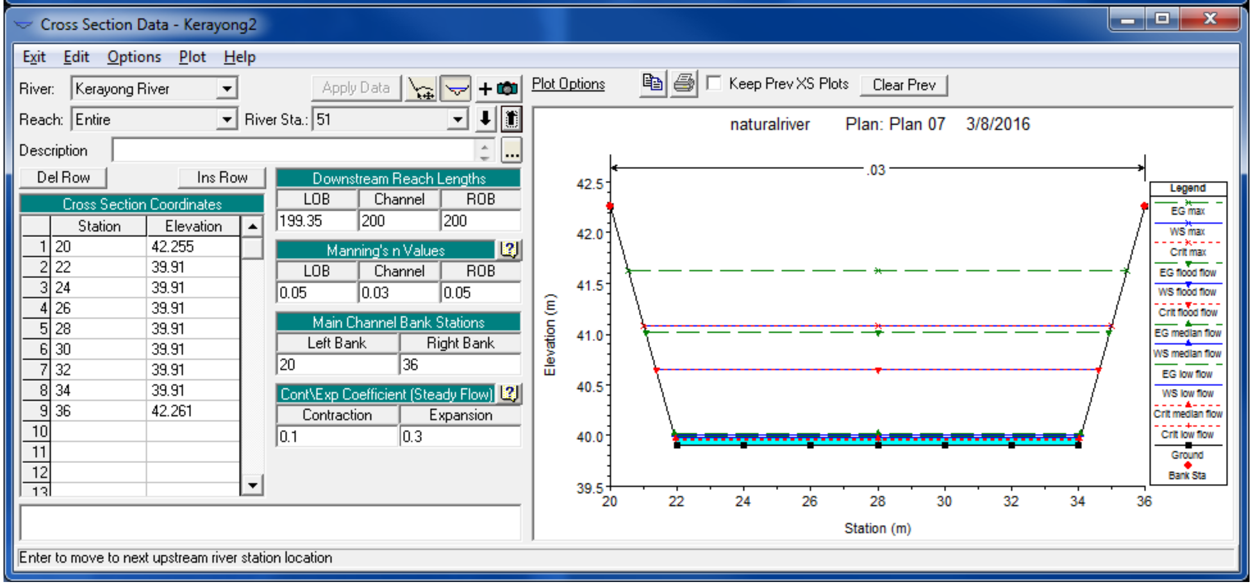
Main Channel Bank Stations

Left Bank	Right Bank
12	26

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 51

Description:

Cross Section Coordinates

	Station	Elevation
1	20	42.255
2	22	39.91
3	24	39.91
4	26	39.91
5	28	39.91
6	30	39.91
7	32	39.91
8	34	39.91
9	36	42.261
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
199.35	200	200

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

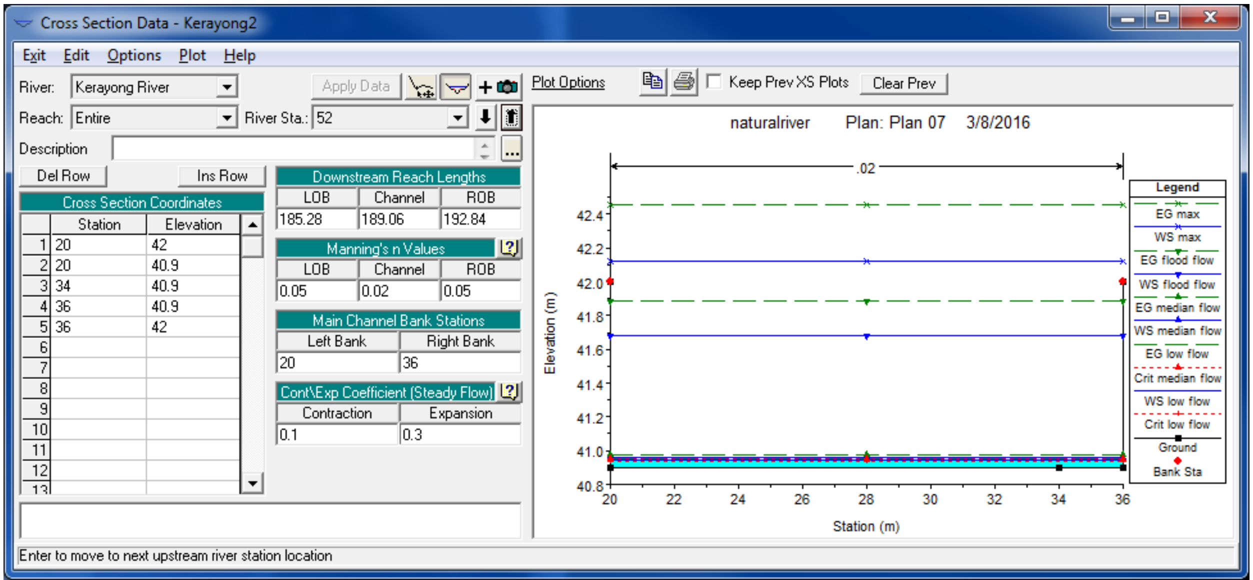
Main Channel Bank Stations

Left Bank	Right Bank
20	36

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River
Reach: Entire
River Sta.: 52
Description

naturalriver Plan: Plan 07 3/8/2016

Cross Section Coordinates

	Station	Elevation
1	20	42
2	20	40.9
3	34	40.9
4	36	40.9
5	36	42
6		
7		
8		
9		
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
185.28	189.06	192.84

Manning's n Values

LOB	Channel	ROB
0.05	0.02	0.05

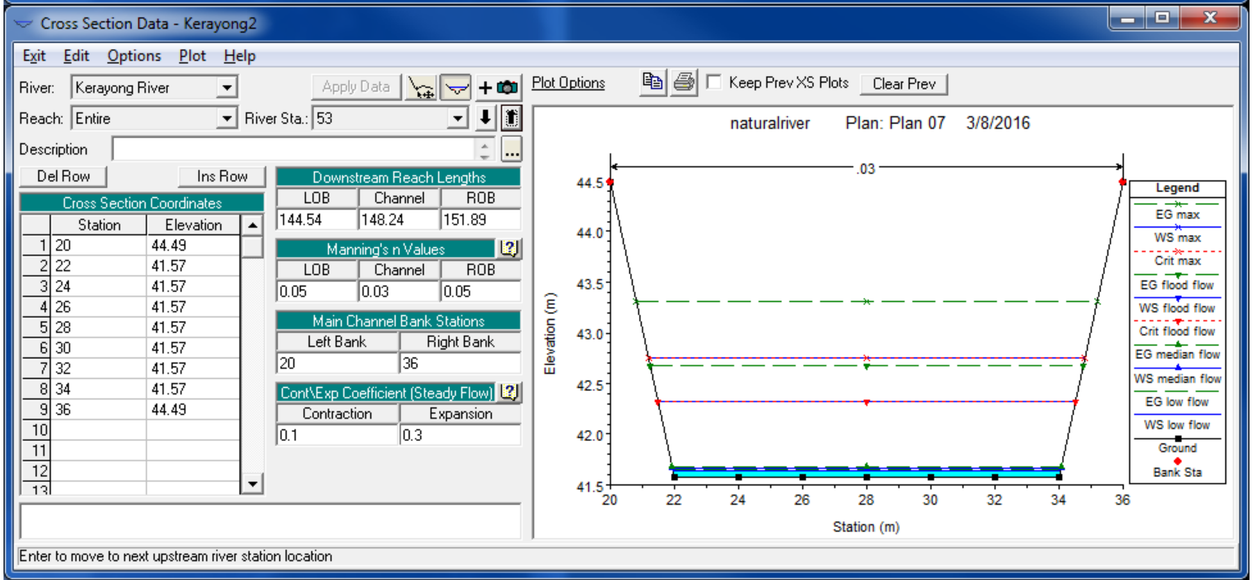
Main Channel Bank Stations

Left Bank	Right Bank
20	36

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River
Reach: Entire
River Sta.: 53
Description

naturalriver Plan: Plan 07 3/8/2016

Cross Section Coordinates

	Station	Elevation
1	20	44.49
2	22	41.57
3	24	41.57
4	26	41.57
5	28	41.57
6	30	41.57
7	32	41.57
8	34	41.57
9	36	44.49
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
144.54	148.24	151.89

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

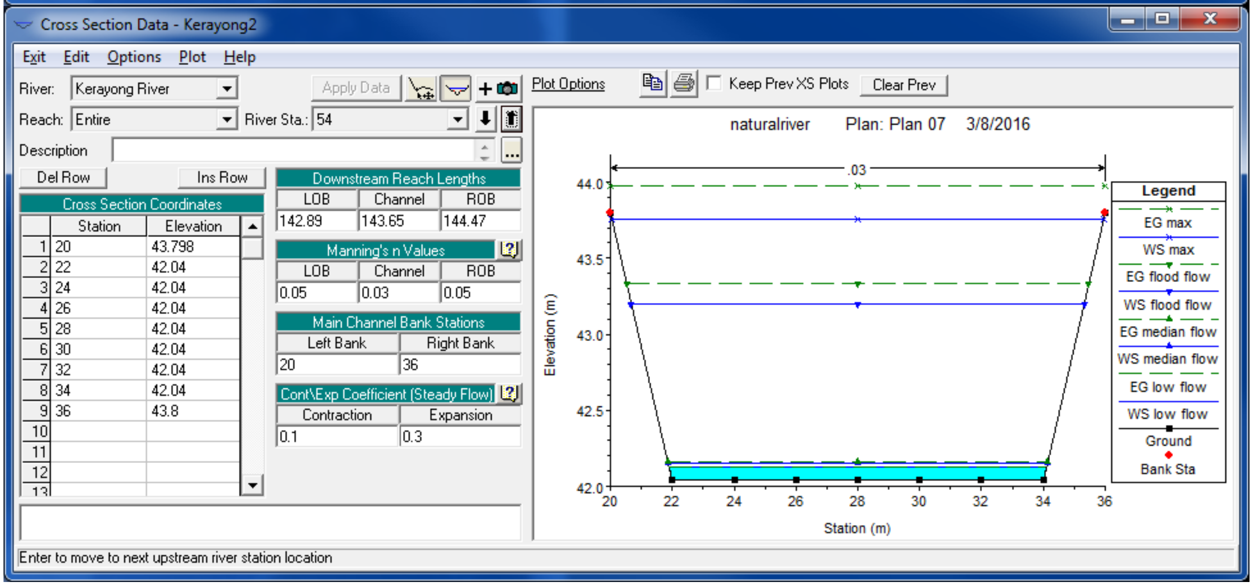
Main Channel Bank Stations

Left Bank	Right Bank
20	36

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River
Reach: Entire
River Sta.: 54
Description

naturalriver Plan: Plan 07 3/8/2016

Cross Section Coordinates

	Station	Elevation
1	20	43.798
2	22	42.04
3	24	42.04
4	26	42.04
5	28	42.04
6	30	42.04
7	32	42.04
8	34	42.04
9	36	43.8
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
142.89	143.65	144.47

Manning's n Values

LOB	Channel	ROB
0.05	0.03	0.05

Main Channel Bank Stations

Left Bank	Right Bank
20	36

Cont\Exp Coefficient (Steady Flow)

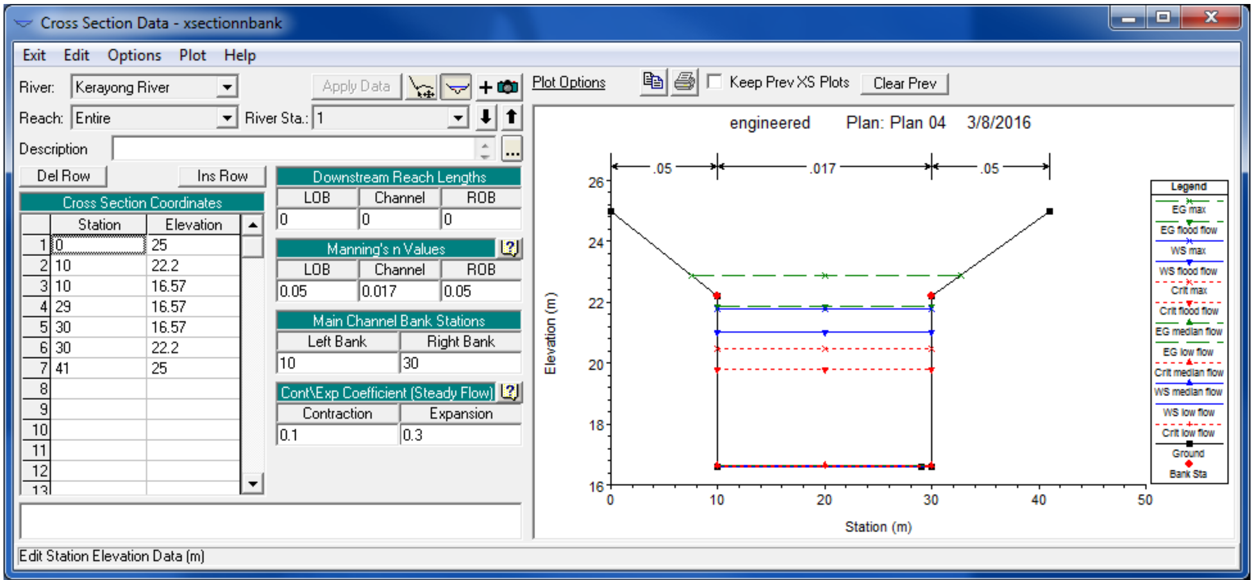
Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location

APPENDIX A-II

CROSS SECTION

Engineered



Cross Section Data - xsectionnbank

River: Kerayong River

Reach: Entire

River Sta.: 1

Description

Cross Section Coordinates

	Station	Elevation
1	0	25
2	10	22.2
3	10	16.57
4	29	16.57
5	30	16.57
6	30	22.2
7	41	25
8		
9		
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
0	0	0

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

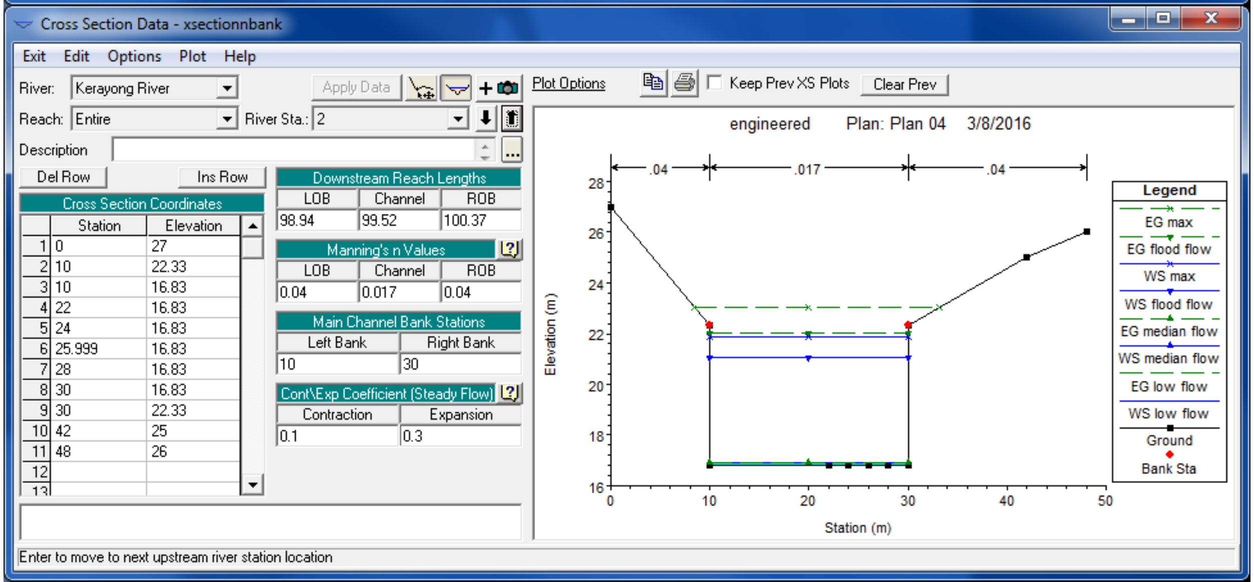
Main Channel Bank Stations

Left Bank	Right Bank
10	30

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Edit Station Elevation Data (m)



Cross Section Data - xsectionnbank

River: Kerayong River

Reach: Entire

River Sta.: 2

Description

Cross Section Coordinates

	Station	Elevation
1	0	27
2	10	22.33
3	10	16.83
4	22	16.83
5	24	16.83
6	25.999	16.83
7	28	16.83
8	30	16.83
9	30	22.33
10	42	25
11	48	26
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
98.94	99.52	100.37

Manning's n Values

LOB	Channel	ROB
0.04	0.017	0.04

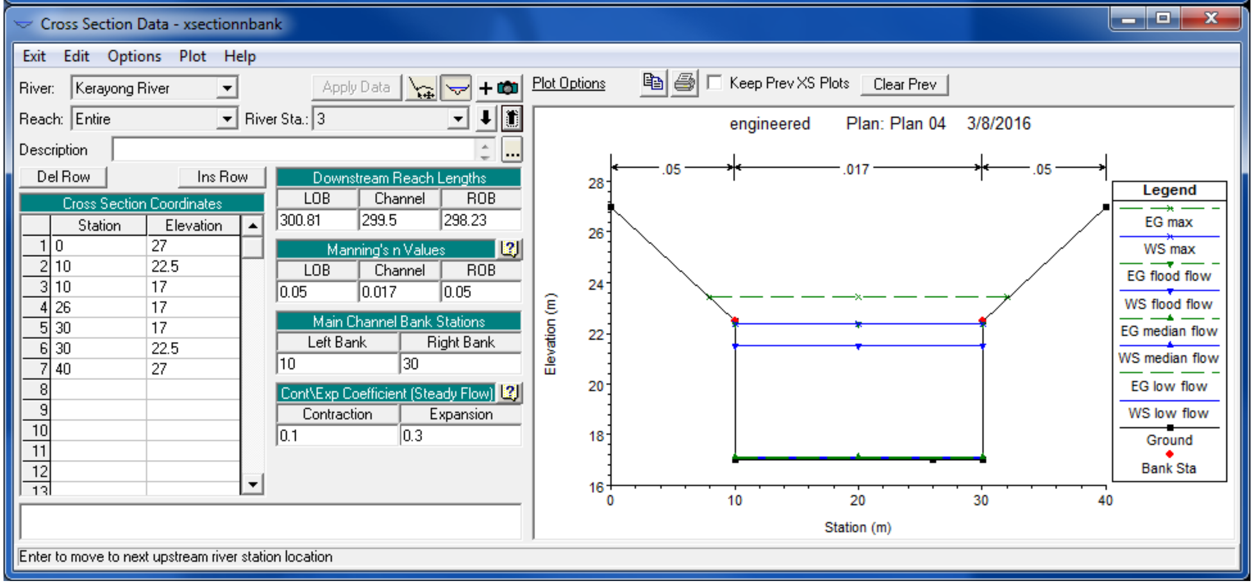
Main Channel Bank Stations

Left Bank	Right Bank
10	30

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



Cross Section Data - xsectionnbank

River: Kerayong River

Reach: Entire

River Sta.: 3

Description

Cross Section Coordinates

	Station	Elevation
1	0	27
2	10	22.5
3	10	17
4	26	17
5	30	17
6	30	22.5
7	40	27
8		
9		
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
300.81	299.5	298.23

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

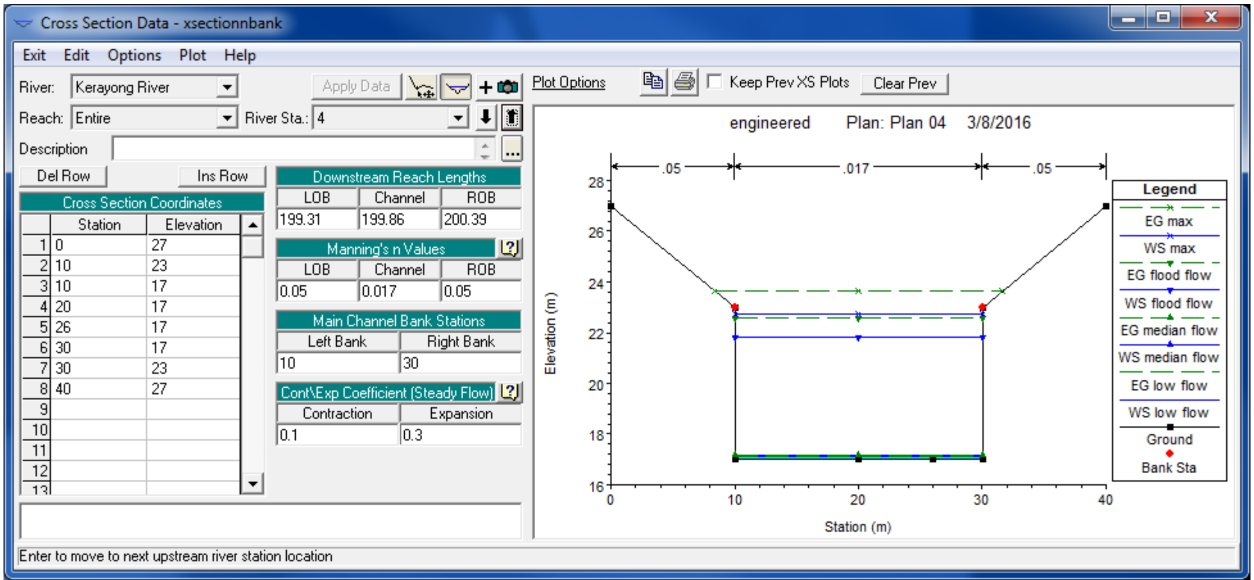
Main Channel Bank Stations

Left Bank	Right Bank
10	30

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire River Sta.: 4

Description:

Cross Section Coordinates

	Station	Elevation
1	0	27
2	10	23
3	10	17
4	20	17
5	26	17
6	30	17
7	30	23
8	40	27
9		
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
199.31	199.86	200.39

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

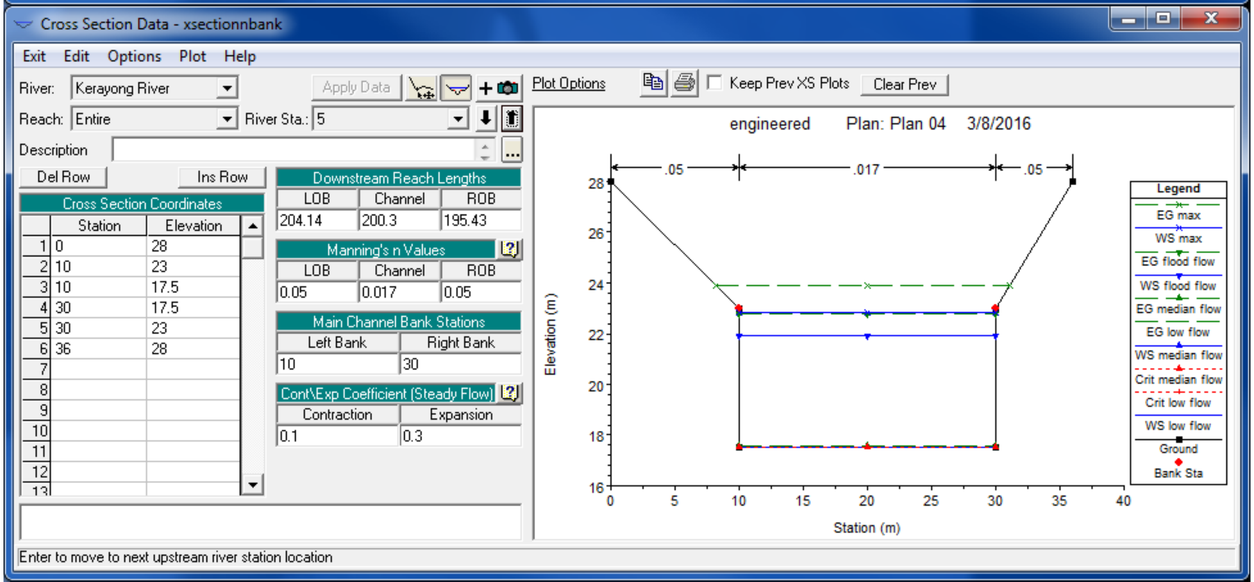
Main Channel Bank Stations

Left Bank	Right Bank
10	30

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire River Sta.: 5

Description:

Cross Section Coordinates

	Station	Elevation
1	0	28
2	10	23
3	10	17.5
4	30	17.5
5	30	23
6	36	28
7		
8		
9		
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
204.14	200.3	195.43

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

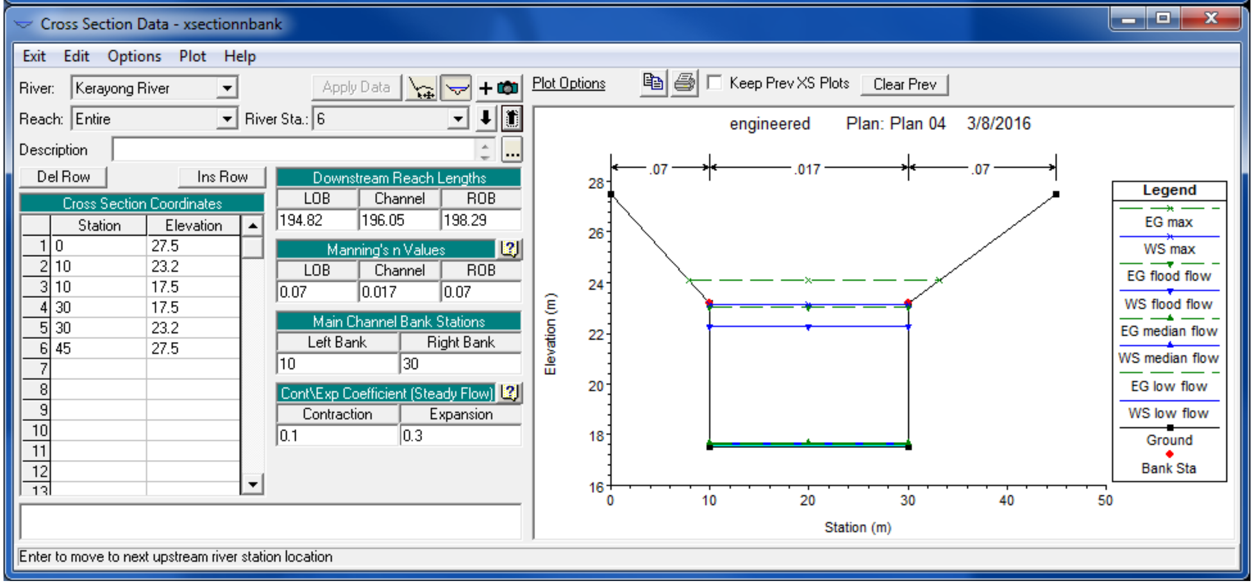
Main Channel Bank Stations

Left Bank	Right Bank
10	30

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire River Sta.: 6

Description:

Cross Section Coordinates

	Station	Elevation
1	0	27.5
2	10	23.2
3	10	17.5
4	30	17.5
5	30	23.2
6	45	27.5
7		
8		
9		
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
194.82	196.05	198.29

Manning's n Values

LOB	Channel	ROB
0.07	0.017	0.07

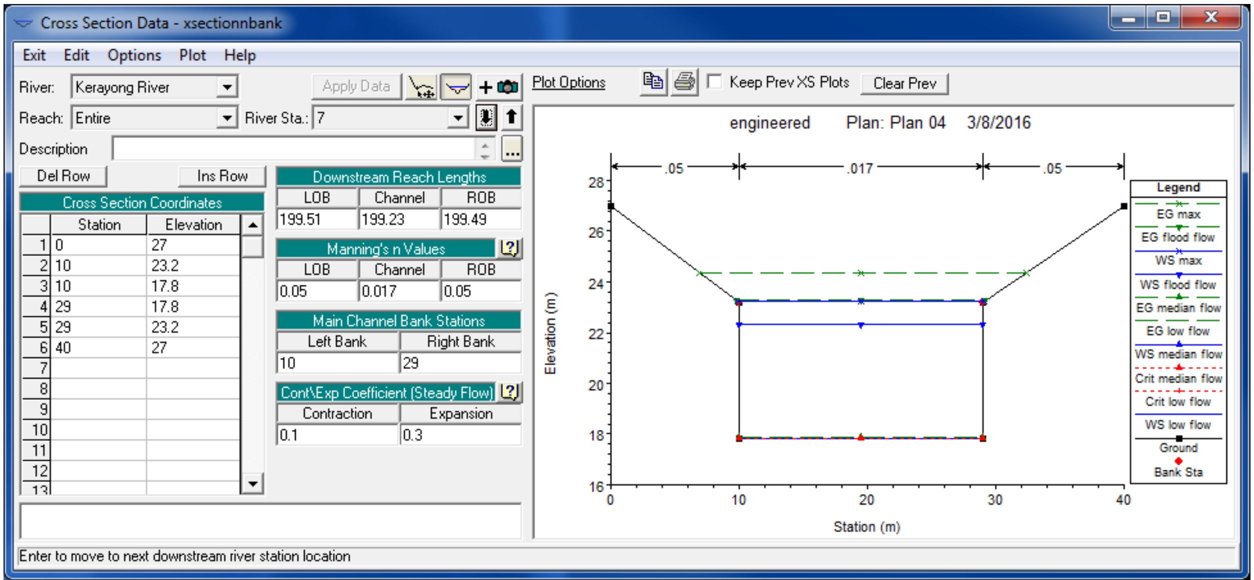
Main Channel Bank Stations

Left Bank	Right Bank
10	30

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 7

Description:

Cross Section Coordinates

	Station	Elevation
1	0	27
2	10	23.2
3	10	17.8
4	29	17.8
5	29	23.2
6	40	27

Downstream Reach Lengths

LOB	Channel	ROB
199.51	199.23	199.49

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

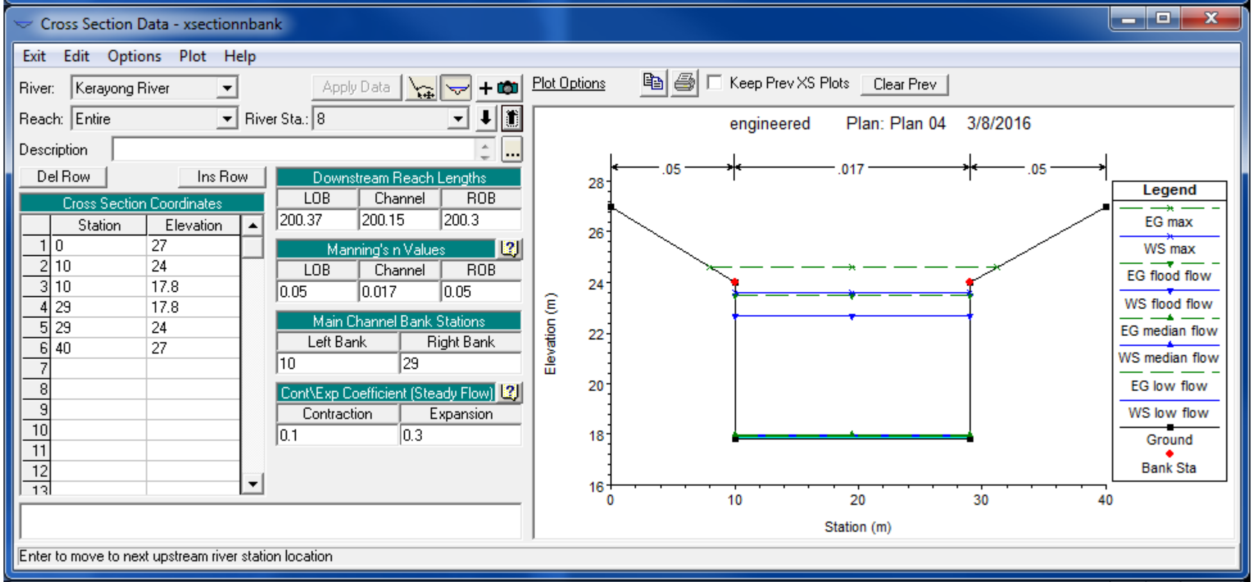
Main Channel Bank Stations

Left Bank	Right Bank
10	29

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next downstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 8

Description:

Cross Section Coordinates

	Station	Elevation
1	0	27
2	10	24
3	10	17.8
4	29	17.8
5	29	24
6	40	27

Downstream Reach Lengths

LOB	Channel	ROB
200.37	200.15	200.3

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

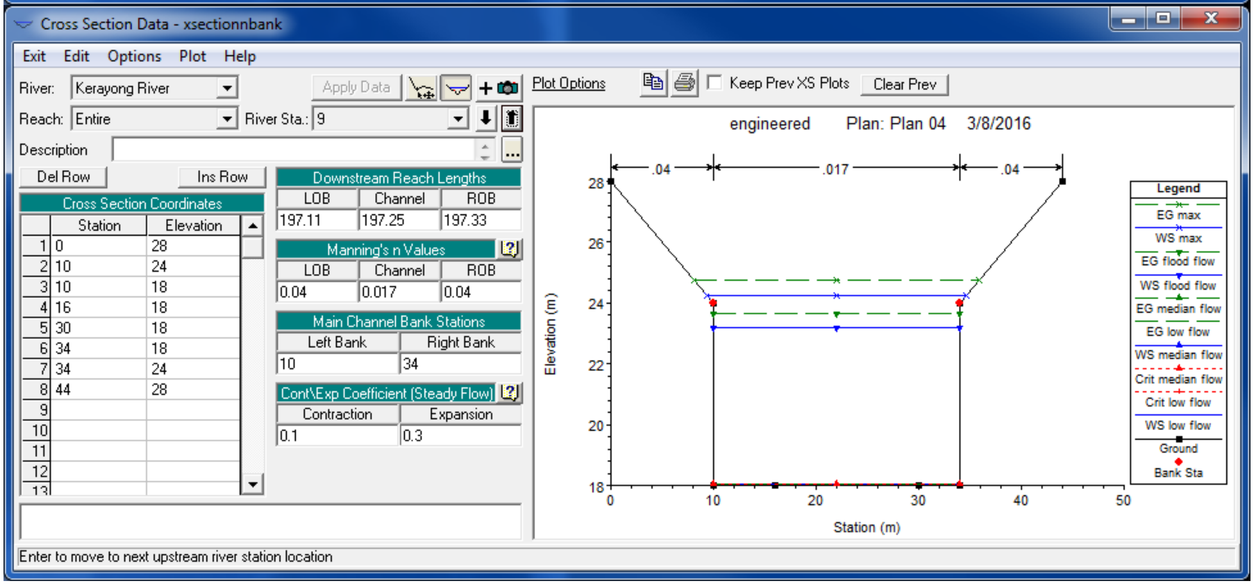
Main Channel Bank Stations

Left Bank	Right Bank
10	29

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 9

Description:

Cross Section Coordinates

	Station	Elevation
1	0	28
2	10	24
3	10	18
4	16	18
5	30	18
6	34	18
7	34	24
8	44	28

Downstream Reach Lengths

LOB	Channel	ROB
197.11	197.25	197.33

Manning's n Values

LOB	Channel	ROB
0.04	0.017	0.04

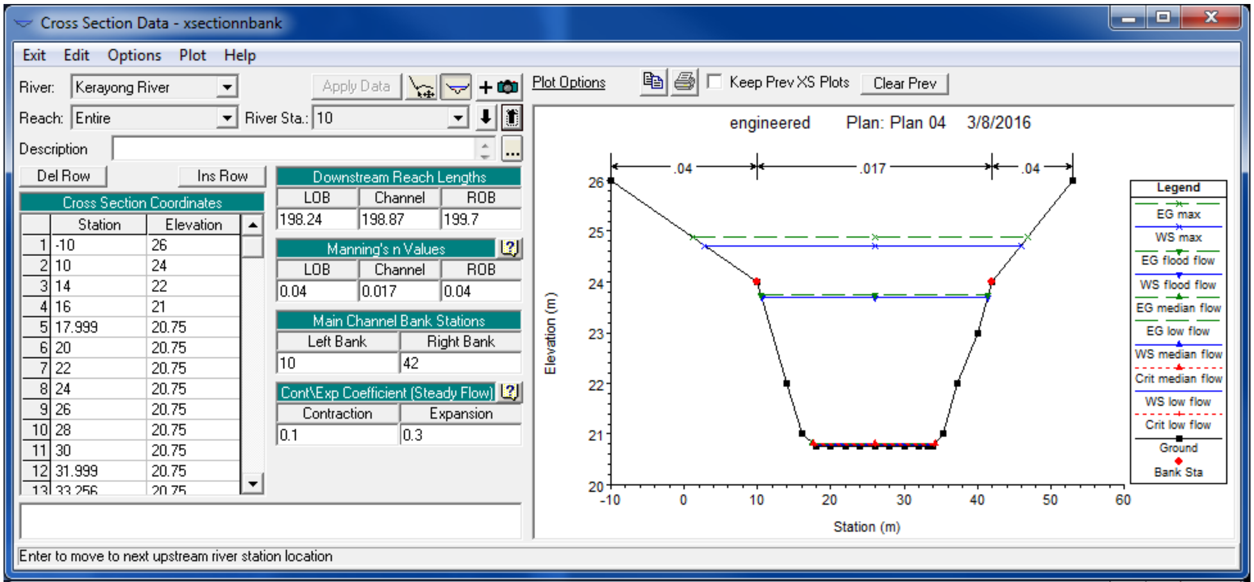
Main Channel Bank Stations

Left Bank	Right Bank
10	34

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



Cross Section Data - xsectionnbank

River: Kerayong River
Reach: Entire
River Sta.: 10
Description:

Cross Section Coordinates

	Station	Elevation
1	-10	26
2	10	24
3	14	22
4	16	21
5	17.999	20.75
6	20	20.75
7	22	20.75
8	24	20.75
9	26	20.75
10	28	20.75
11	30	20.75
12	31.999	20.75
13	33.256	20.75

Downstream Reach Lengths

LOB	Channel	ROB
198.24	198.87	199.7

Manning's n Values

LOB	Channel	ROB
0.04	0.017	0.04

Main Channel Bank Stations

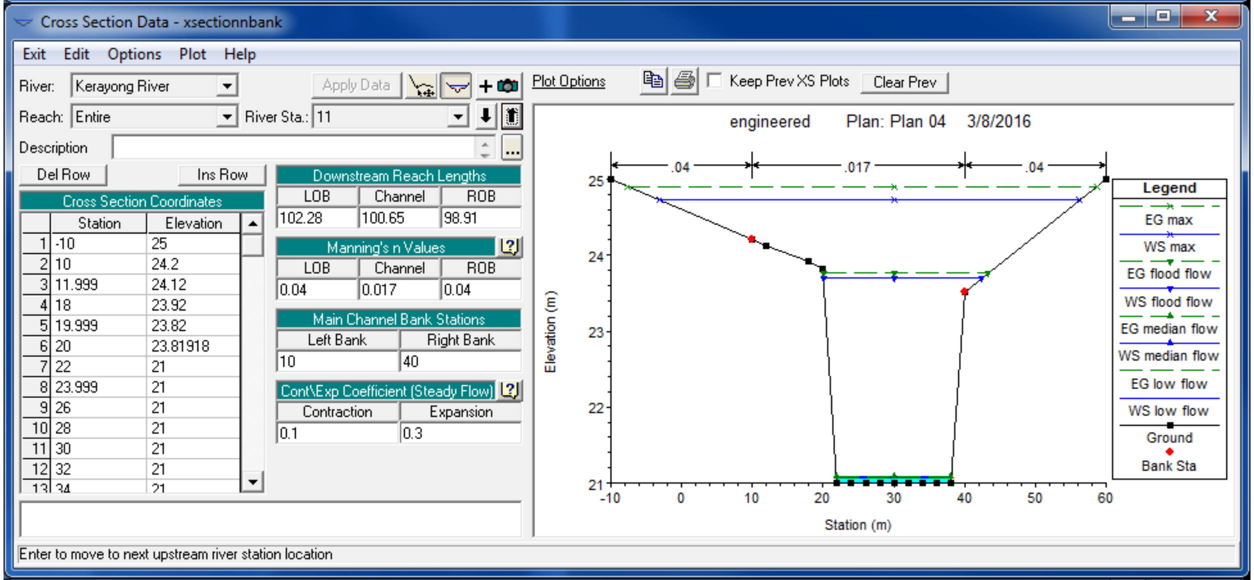
Left Bank	Right Bank
10	42

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

engineered Plan: Plan 04 3/8/2016

Enter to move to next upstream river station location



Cross Section Data - xsectionnbank

River: Kerayong River
Reach: Entire
River Sta.: 11
Description:

Cross Section Coordinates

	Station	Elevation
1	-10	25
2	10	24.2
3	11.999	24.12
4	18	23.92
5	19.999	23.82
6	20	23.81918
7	22	21
8	23.999	21
9	26	21
10	28	21
11	30	21
12	32	21
13	34	21

Downstream Reach Lengths

LOB	Channel	ROB
102.28	100.65	98.91

Manning's n Values

LOB	Channel	ROB
0.04	0.017	0.04

Main Channel Bank Stations

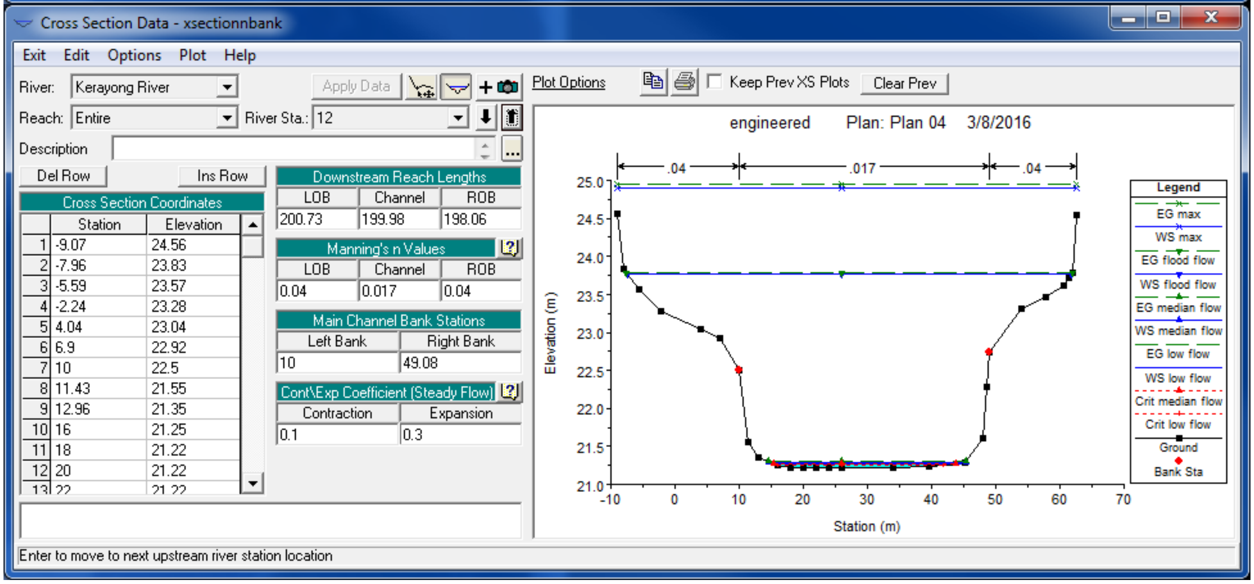
Left Bank	Right Bank
10	40

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

engineered Plan: Plan 04 3/8/2016

Enter to move to next upstream river station location



Cross Section Data - xsectionnbank

River: Kerayong River
Reach: Entire
River Sta.: 12
Description:

Cross Section Coordinates

	Station	Elevation
1	-9.07	24.56
2	-7.96	23.83
3	-5.59	23.57
4	-2.24	23.28
5	4.04	23.04
6	6.9	22.92
7	10	22.5
8	11.43	21.55
9	12.96	21.35
10	16	21.25
11	18	21.22
12	20	21.22
13	22	21.22

Downstream Reach Lengths

LOB	Channel	ROB
200.73	199.98	198.06

Manning's n Values

LOB	Channel	ROB
0.04	0.017	0.04

Main Channel Bank Stations

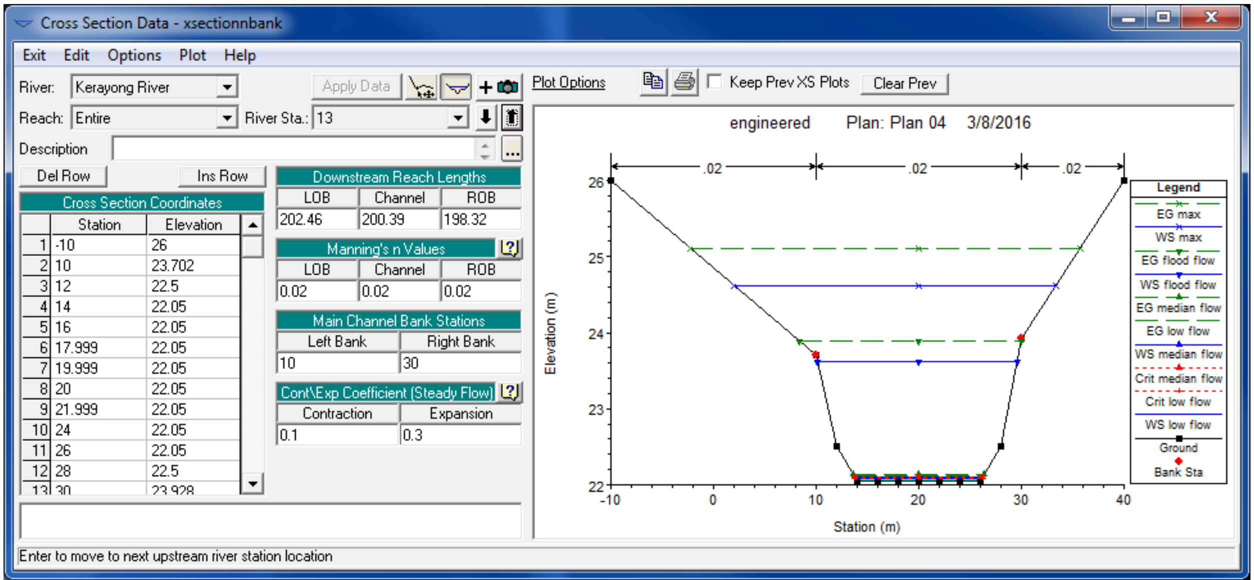
Left Bank	Right Bank
10	49.08

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

engineered Plan: Plan 04 3/8/2016

Enter to move to next upstream river station location



Cross Section Data - xsectionnbank

River: Kerayong River

Reach: Entire

River Sta.: 13

Description

Cross Section Coordinates

	Station	Elevation
1	-10	26
2	10	23.702
3	12	22.5
4	14	22.05
5	16	22.05
6	17.999	22.05
7	19.999	22.05
8	20	22.05
9	21.999	22.05
10	24	22.05
11	26	22.05
12	28	22.5
13	30	23.928

Downstream Reach Lengths

LOB	Channel	ROB
202.46	200.39	198.32

Manning's n Values

LOB	Channel	ROB
0.02	0.02	0.02

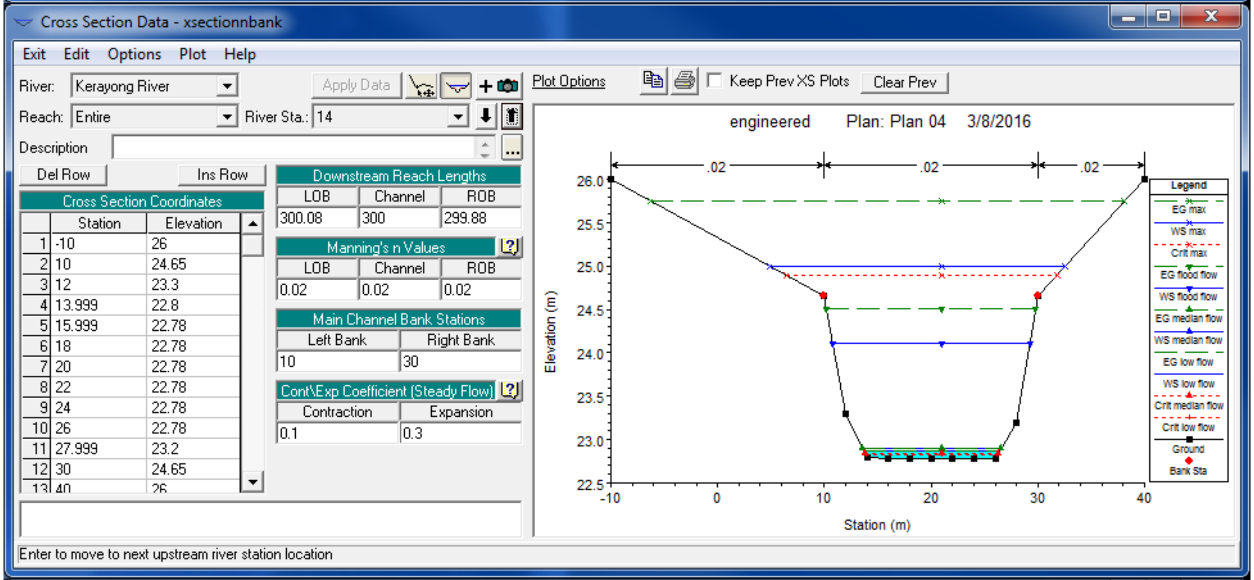
Main Channel Bank Stations

Left Bank	Right Bank
10	30

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



Cross Section Data - xsectionnbank

River: Kerayong River

Reach: Entire

River Sta.: 14

Description

Cross Section Coordinates

	Station	Elevation
1	-10	26
2	10	24.65
3	12	23.3
4	13.999	22.8
5	15.999	22.78
6	18	22.78
7	20	22.78
8	22	22.78
9	24	22.78
10	26	22.78
11	27.999	23.2
12	30	24.65
13	40	26

Downstream Reach Lengths

LOB	Channel	ROB
300.08	300	299.88

Manning's n Values

LOB	Channel	ROB
0.02	0.02	0.02

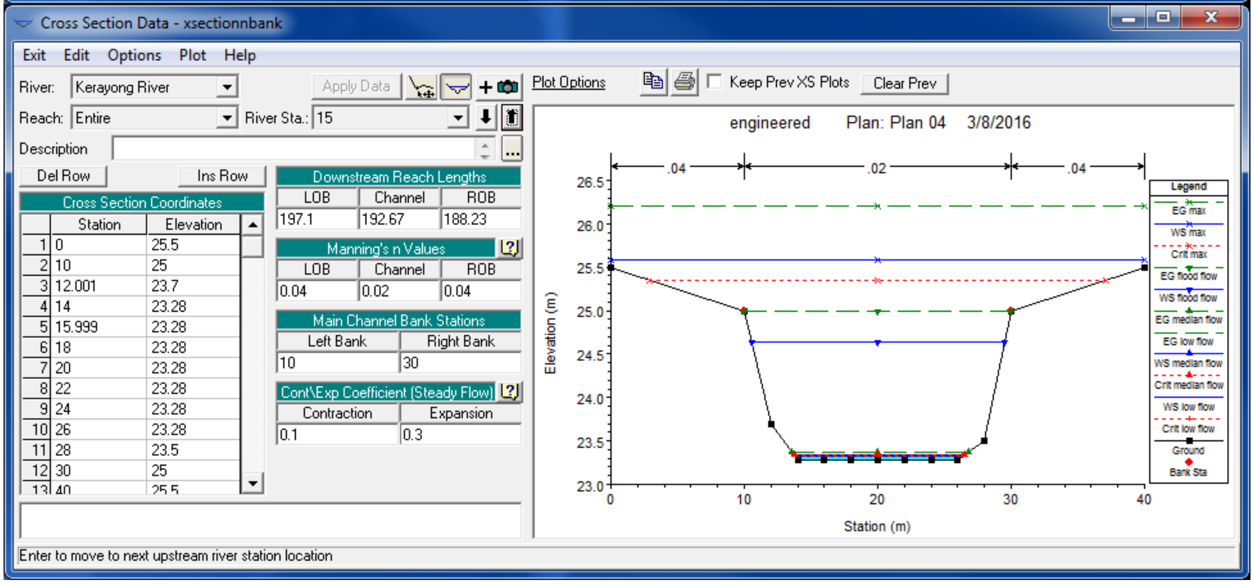
Main Channel Bank Stations

Left Bank	Right Bank
10	30

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



Cross Section Data - xsectionnbank

River: Kerayong River

Reach: Entire

River Sta.: 15

Description

Cross Section Coordinates

	Station	Elevation
1	0	25.5
2	10	25
3	12.001	23.7
4	14	23.28
5	15.999	23.28
6	18	23.28
7	20	23.28
8	22	23.28
9	24	23.28
10	26	23.28
11	28	23.5
12	30	25
13	40	25.5

Downstream Reach Lengths

LOB	Channel	ROB
197.1	192.67	188.23

Manning's n Values

LOB	Channel	ROB
0.04	0.02	0.04

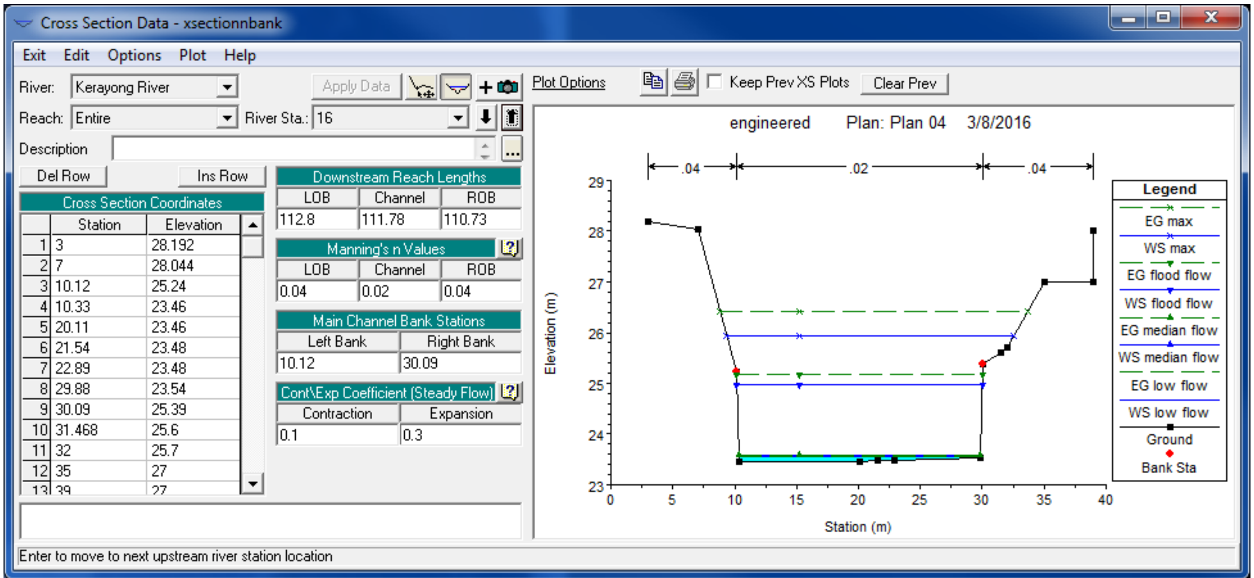
Main Channel Bank Stations

Left Bank	Right Bank
10	30

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 16

Description

Cross Section Coordinates

	Station	Elevation
1	3	28.192
2	7	28.044
3	10.12	25.24
4	10.33	23.46
5	20.11	23.46
6	21.54	23.48
7	22.89	23.48
8	29.88	23.54
9	30.09	25.39
10	31.468	25.6
11	32	25.7
12	35	27
13	39	27

Downstream Reach Lengths

LOB	Channel	ROB
112.8	111.78	110.73

Manning's n Values

LOB	Channel	ROB
0.04	0.02	0.04

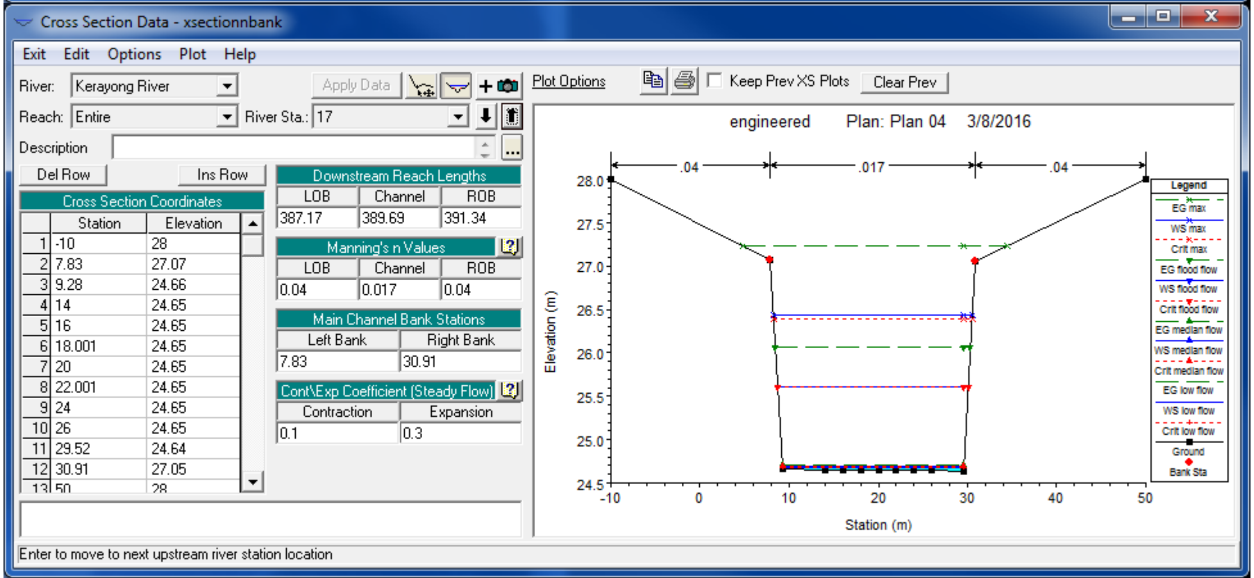
Main Channel Bank Stations

Left Bank	Right Bank
10.12	30.09

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 17

Description

Cross Section Coordinates

	Station	Elevation
1	-10	28
2	7.83	27.07
3	9.28	24.66
4	14	24.65
5	16	24.65
6	18.001	24.65
7	20	24.65
8	22.001	24.65
9	24	24.65
10	26	24.65
11	29.52	24.64
12	30.91	27.05
13	50	28

Downstream Reach Lengths

LOB	Channel	ROB
387.17	389.69	391.34

Manning's n Values

LOB	Channel	ROB
0.04	0.017	0.04

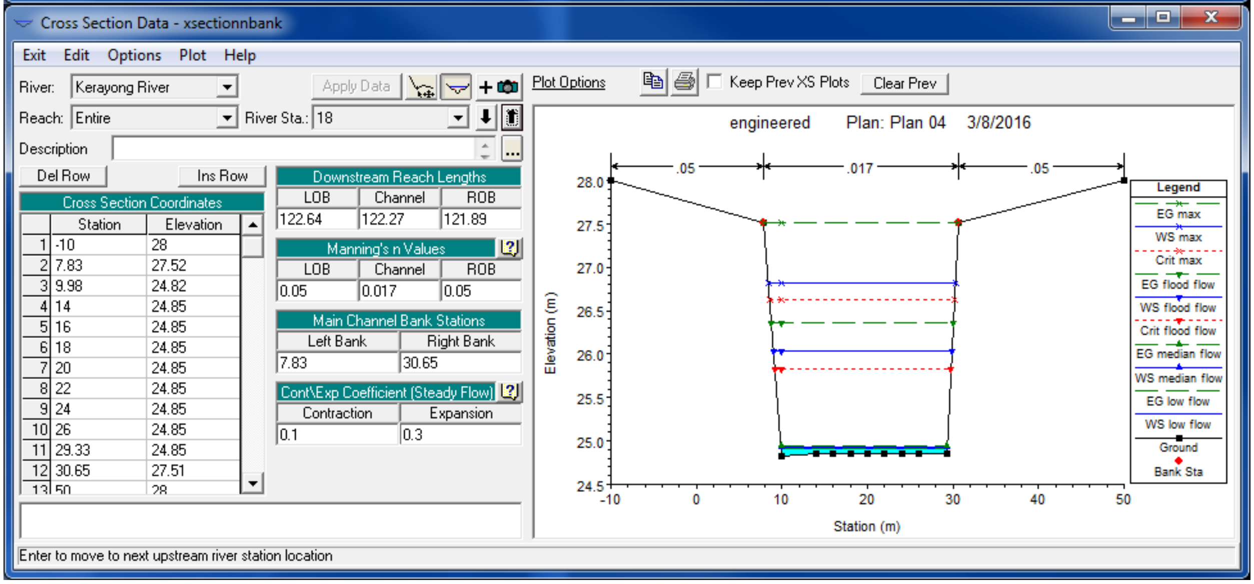
Main Channel Bank Stations

Left Bank	Right Bank
7.83	30.91

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 18

Description

Cross Section Coordinates

	Station	Elevation
1	-10	28
2	7.83	27.52
3	9.98	24.82
4	14	24.85
5	16	24.85
6	18	24.85
7	20	24.85
8	22	24.85
9	24	24.85
10	26	24.85
11	29.33	24.85
12	30.65	27.51
13	50	28

Downstream Reach Lengths

LOB	Channel	ROB
122.64	122.27	121.89

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

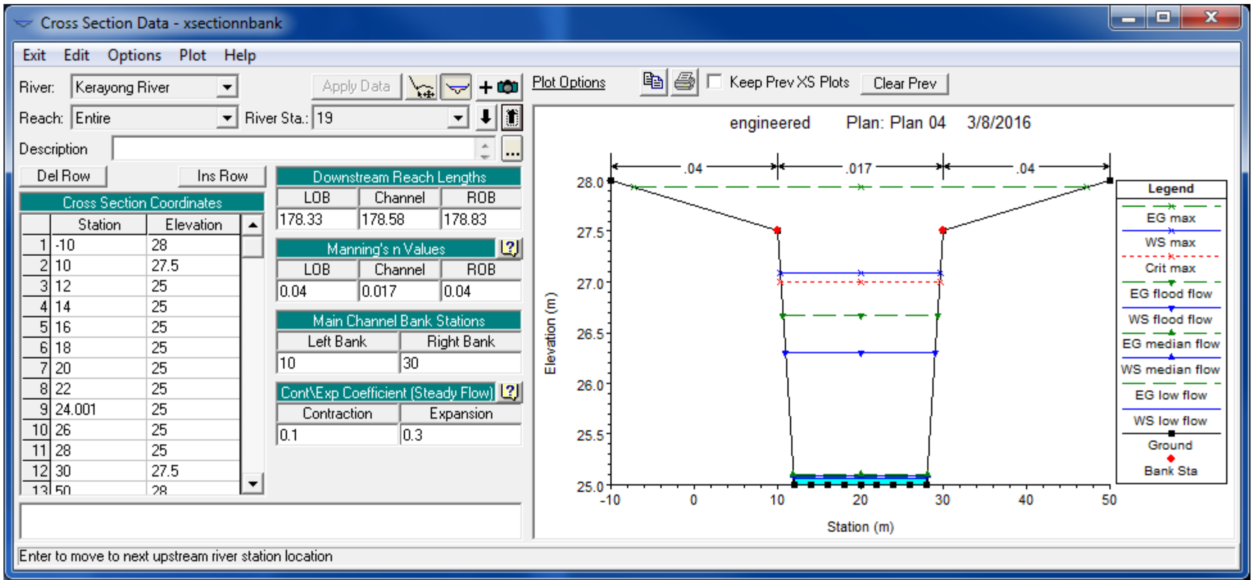
Main Channel Bank Stations

Left Bank	Right Bank
7.83	30.65

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 19

Description:

Cross Section Coordinates

	Station	Elevation
1	-10	28
2	10	27.5
3	12	25
4	14	25
5	16	25
6	18	25
7	20	25
8	22	25
9	24.001	25
10	26	25
11	28	25
12	30	27.5
13	50	28

Downstream Reach Lengths

LOB	Channel	ROB
178.33	178.58	178.83

Manning's n Values

LOB	Channel	ROB
0.04	0.017	0.04

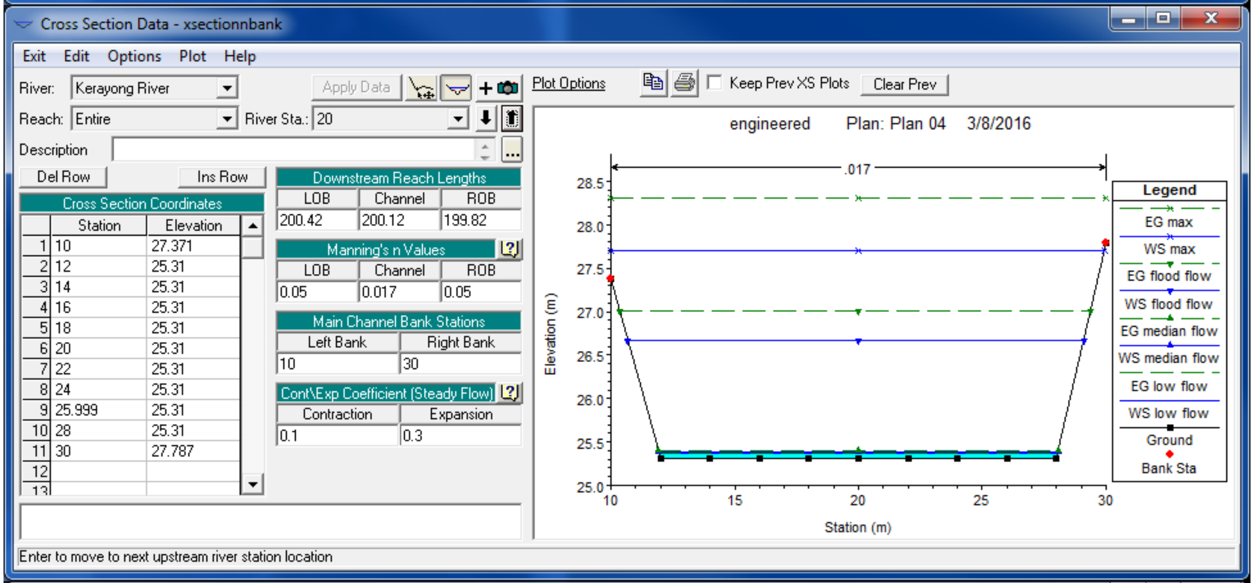
Main Channel Bank Stations

Left Bank	Right Bank
10	30

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 20

Description:

Cross Section Coordinates

	Station	Elevation
1	10	27.371
2	12	25.31
3	14	25.31
4	16	25.31
5	18	25.31
6	20	25.31
7	22	25.31
8	24	25.31
9	25.999	25.31
10	28	25.31
11	30	27.787
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
200.42	200.12	199.82

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

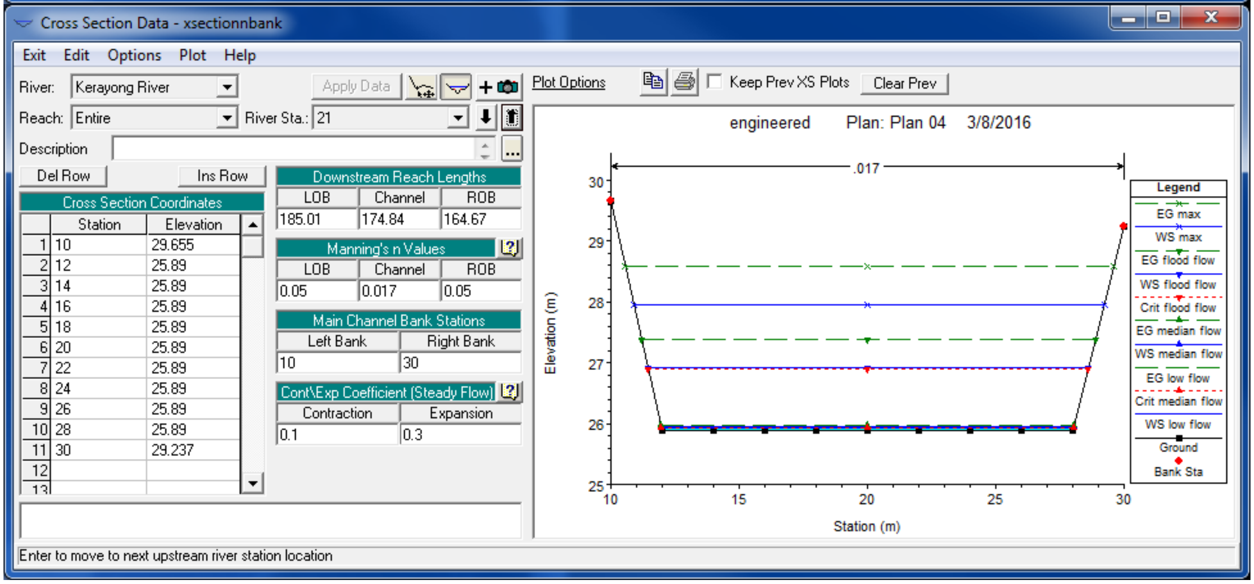
Main Channel Bank Stations

Left Bank	Right Bank
10	30

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 21

Description:

Cross Section Coordinates

	Station	Elevation
1	10	29.655
2	12	25.89
3	14	25.89
4	16	25.89
5	18	25.89
6	20	25.89
7	22	25.89
8	24	25.89
9	26	25.89
10	28	25.89
11	30	29.237
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
185.01	174.84	164.67

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

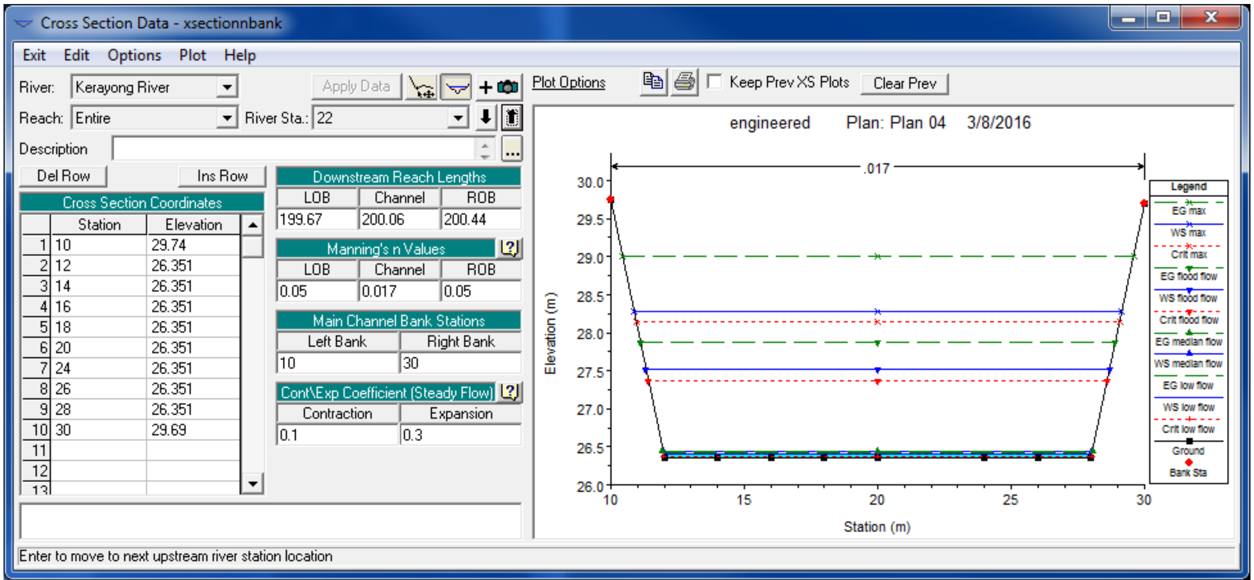
Main Channel Bank Stations

Left Bank	Right Bank
10	30

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 22

Description:

Cross Section Coordinates

	Station	Elevation
1	10	29.74
2	12	26.351
3	14	26.351
4	16	26.351
5	18	26.351
6	20	26.351
7	24	26.351
8	26	26.351
9	28	26.351
10	30	29.69
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
199.67	200.06	200.44

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

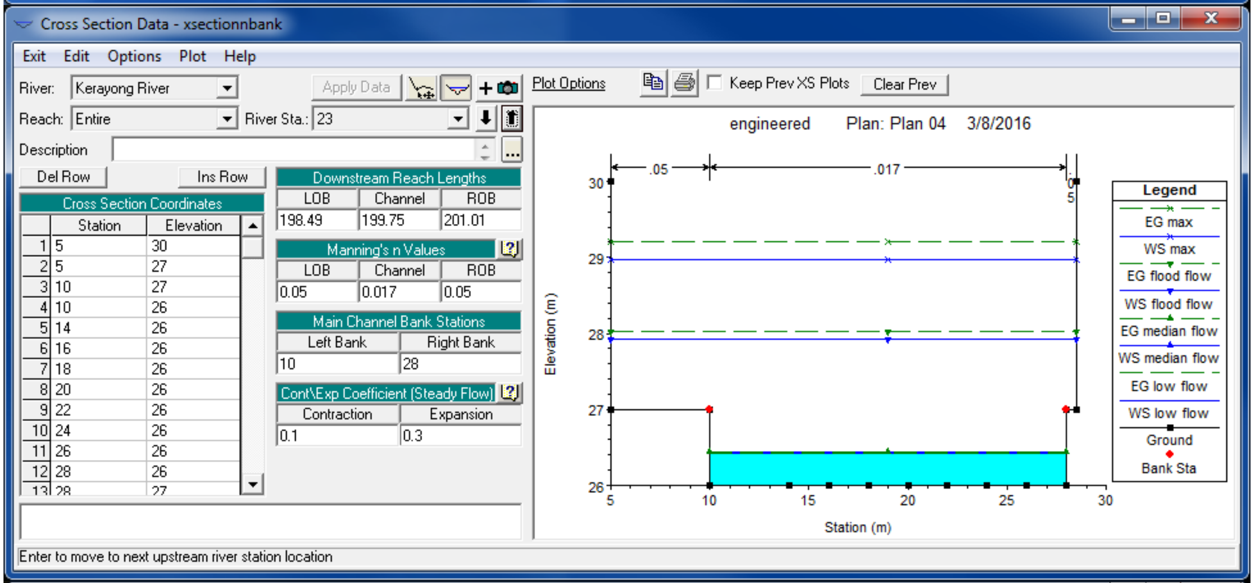
Main Channel Bank Stations

Left Bank	Right Bank
10	30

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 23

Description:

Cross Section Coordinates

	Station	Elevation
1	5	30
2	5	27
3	10	27
4	10	26
5	14	26
6	16	26
7	18	26
8	20	26
9	22	26
10	24	26
11	26	26
12	28	26
13	28	27

Downstream Reach Lengths

LOB	Channel	ROB
198.49	199.75	201.01

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

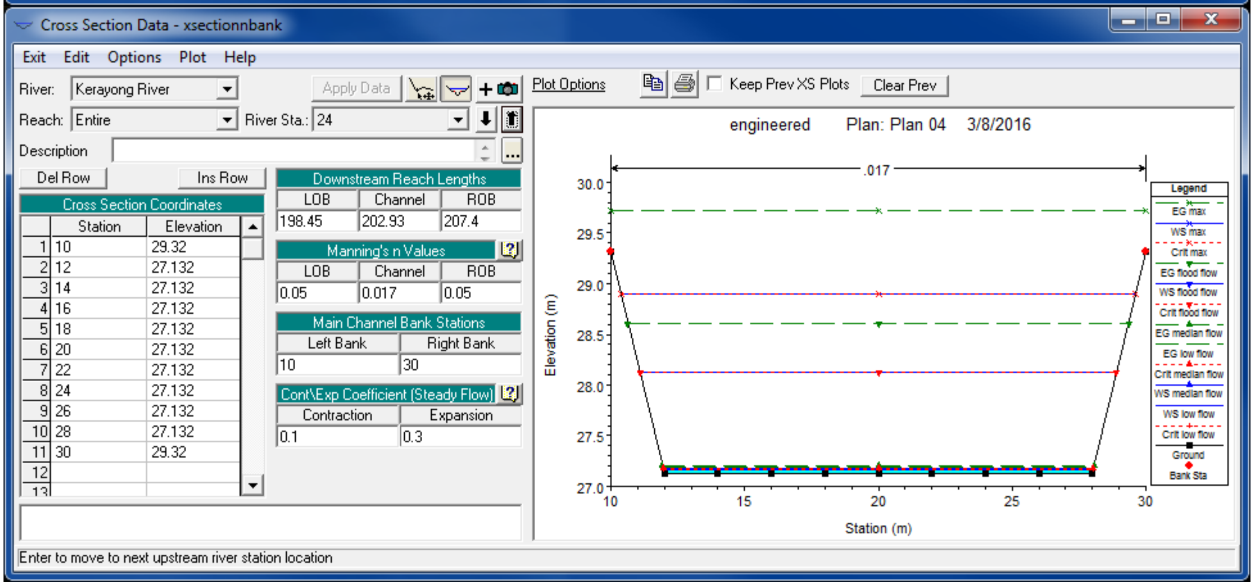
Main Channel Bank Stations

Left Bank	Right Bank
10	28

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 24

Description:

Cross Section Coordinates

	Station	Elevation
1	10	29.32
2	12	27.132
3	14	27.132
4	16	27.132
5	18	27.132
6	20	27.132
7	22	27.132
8	24	27.132
9	26	27.132
10	28	27.132
11	30	29.32
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
198.45	202.93	207.4

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

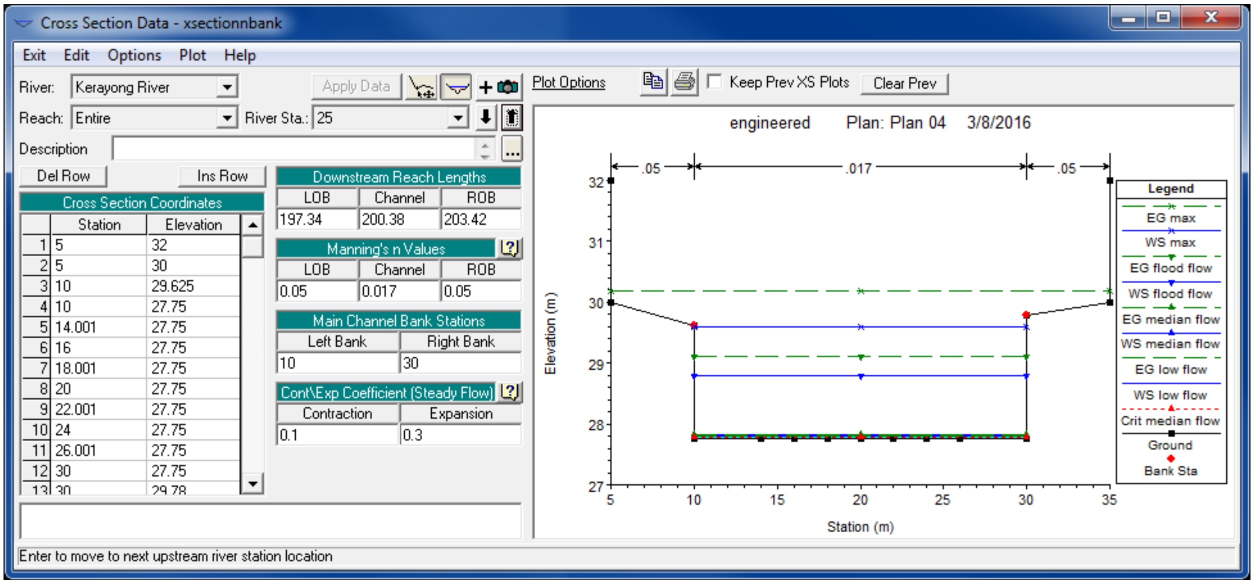
Main Channel Bank Stations

Left Bank	Right Bank
10	30

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 25

Description:

Cross Section Coordinates

	Station	Elevation
1	5	32
2	5	30
3	10	29.625
4	10	27.75
5	14.001	27.75
6	16	27.75
7	18.001	27.75
8	20	27.75
9	22.001	27.75
10	24	27.75
11	26.001	27.75
12	30	27.75
13	30	29.78

Downstream Reach Lengths

LOB	Channel	ROB
197.34	200.38	203.42

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

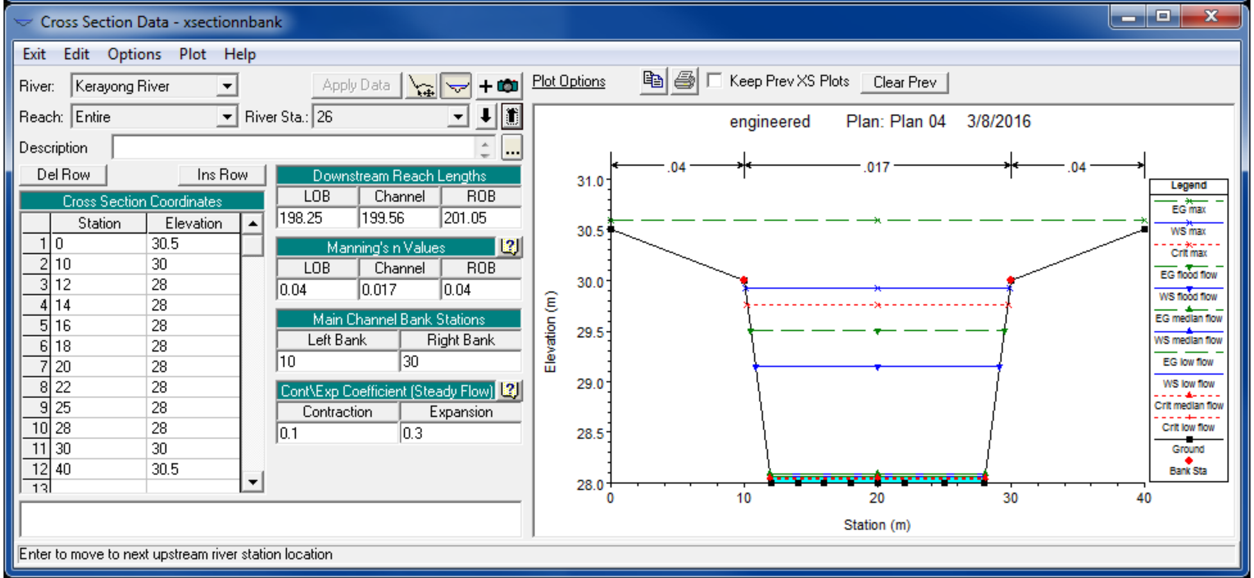
Main Channel Bank Stations

Left Bank	Right Bank
10	30

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 26

Description:

Cross Section Coordinates

	Station	Elevation
1	0	30.5
2	10	30
3	12	28
4	14	28
5	16	28
6	18	28
7	20	28
8	22	28
9	25	28
10	28	28
11	30	30
12	40	30.5
13		

Downstream Reach Lengths

LOB	Channel	ROB
198.25	199.56	201.05

Manning's n Values

LOB	Channel	ROB
0.04	0.017	0.04

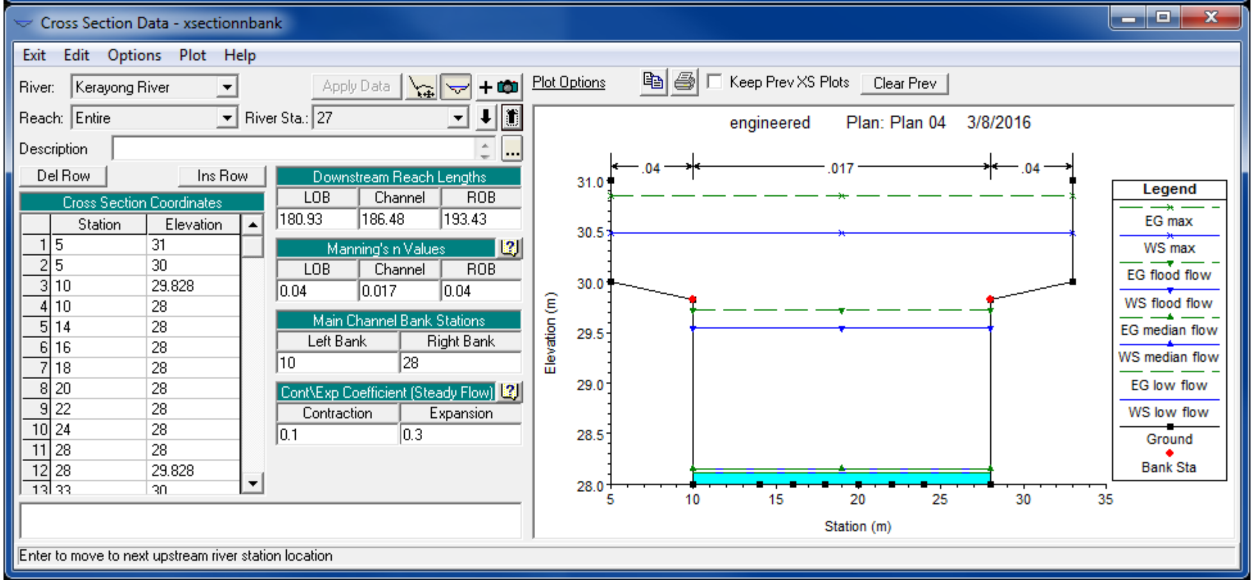
Main Channel Bank Stations

Left Bank	Right Bank
10	30

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 27

Description:

Cross Section Coordinates

	Station	Elevation
1	5	31
2	5	30
3	10	29.828
4	10	28
5	14	28
6	16	28
7	18	28
8	20	28
9	22	28
10	24	28
11	28	28
12	28	29.828
13	33	30

Downstream Reach Lengths

LOB	Channel	ROB
180.93	186.48	193.43

Manning's n Values

LOB	Channel	ROB
0.04	0.017	0.04

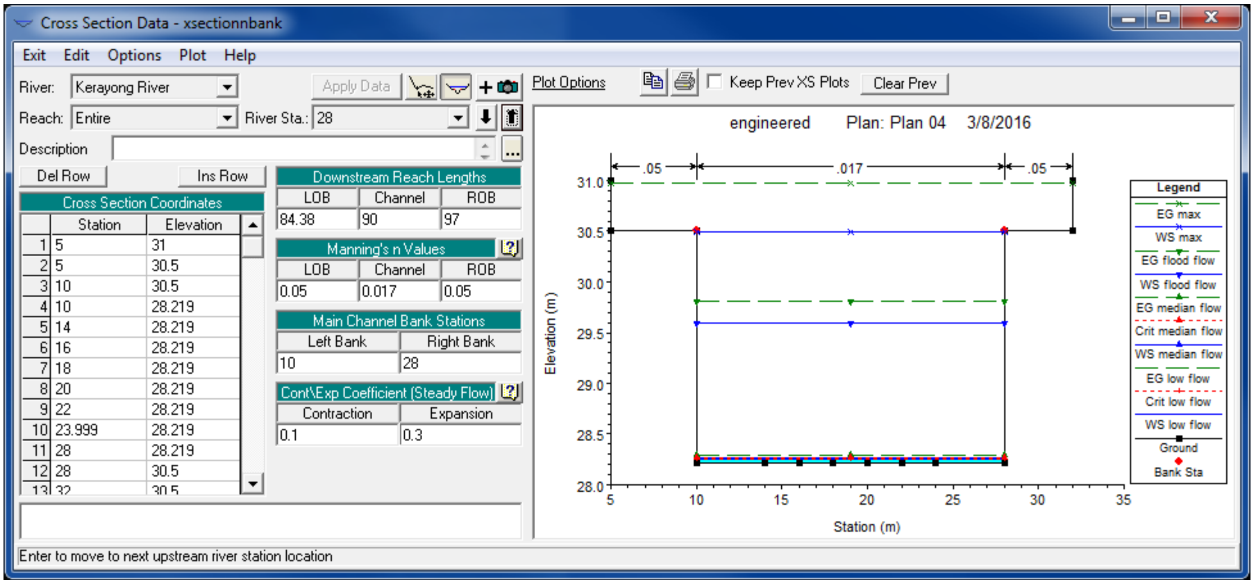
Main Channel Bank Stations

Left Bank	Right Bank
10	28

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River
Reach: Entire
River Sta.: 28
Description:

Cross Section Coordinates

	Station	Elevation
1	5	31
2	5	30.5
3	10	30.5
4	10	28.219
5	14	28.219
6	16	28.219
7	18	28.219
8	20	28.219
9	22	28.219
10	23.999	28.219
11	28	28.219
12	28	30.5
13	32	30.5

Downstream Reach Lengths

LOB	Channel	ROB
84.38	90	97

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

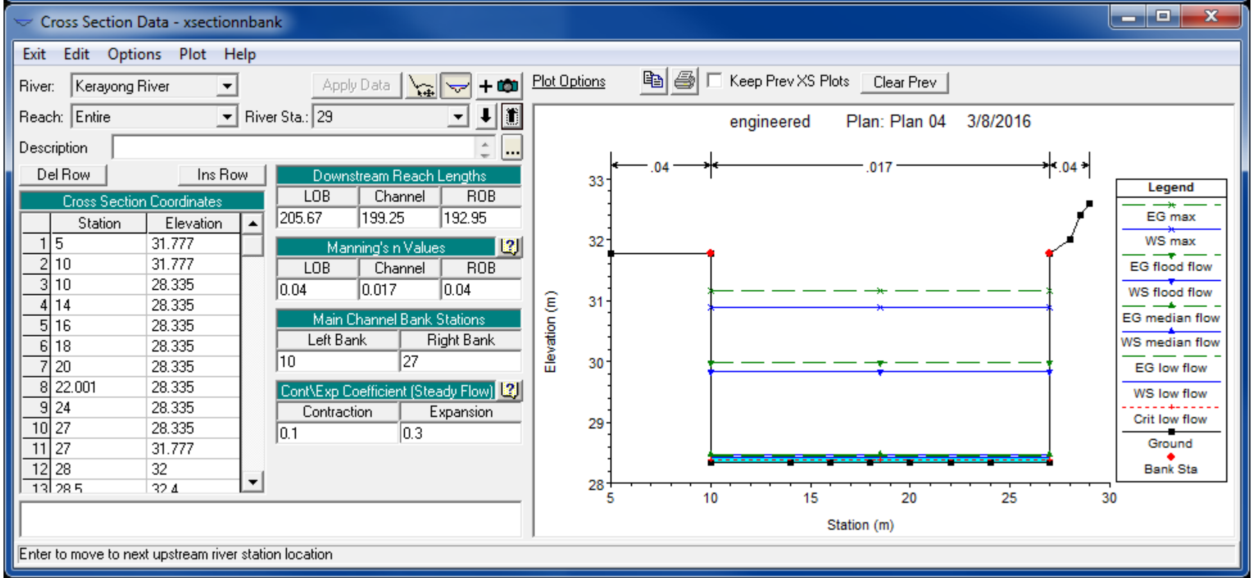
Main Channel Bank Stations

Left Bank	Right Bank
10	28

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River
Reach: Entire
River Sta.: 29
Description:

Cross Section Coordinates

	Station	Elevation
1	5	31.777
2	10	31.777
3	10	28.335
4	14	28.335
5	16	28.335
6	18	28.335
7	20	28.335
8	22.001	28.335
9	24	28.335
10	27	28.335
11	27	31.777
12	28	32
13	28.5	32.4

Downstream Reach Lengths

LOB	Channel	ROB
205.67	199.25	192.95

Manning's n Values

LOB	Channel	ROB
0.04	0.017	0.04

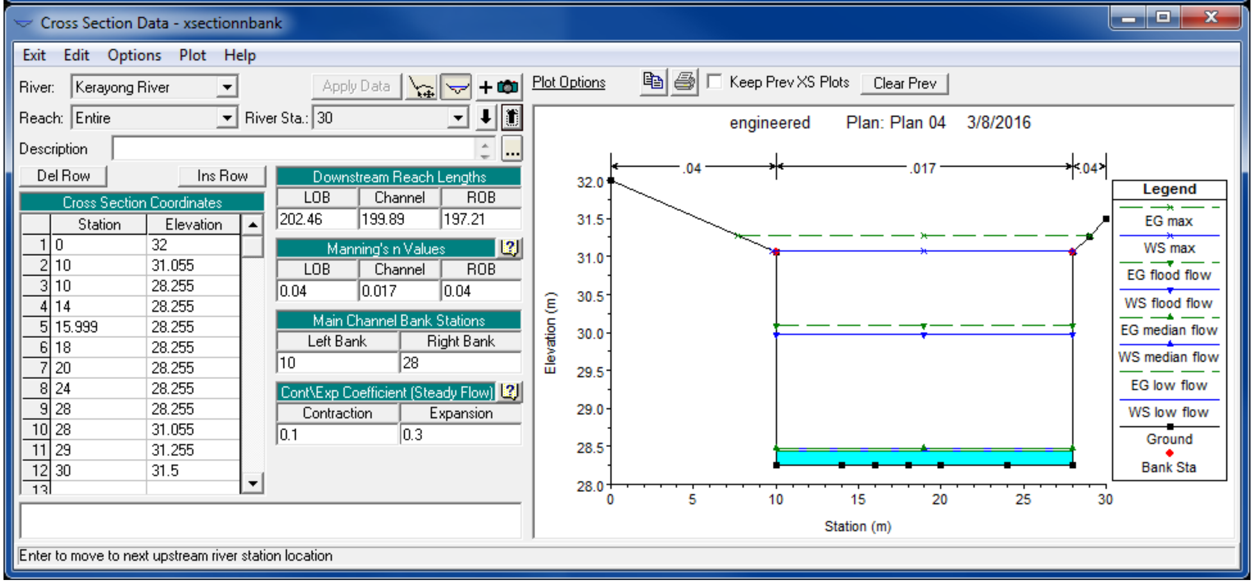
Main Channel Bank Stations

Left Bank	Right Bank
10	27

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River
Reach: Entire
River Sta.: 30
Description:

Cross Section Coordinates

	Station	Elevation
1	0	32
2	10	31.055
3	10	28.255
4	14	28.255
5	15.999	28.255
6	18	28.255
7	20	28.255
8	24	28.255
9	28	28.255
10	28	31.055
11	29	31.255
12	30	31.5
13		

Downstream Reach Lengths

LOB	Channel	ROB
202.46	199.89	197.21

Manning's n Values

LOB	Channel	ROB
0.04	0.017	0.04

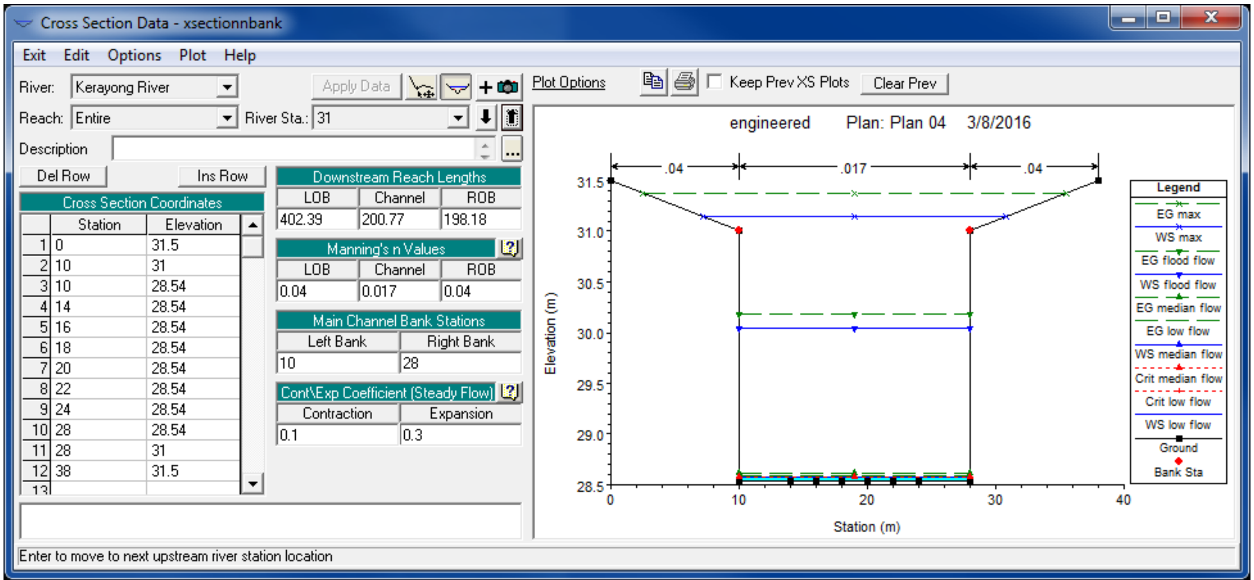
Main Channel Bank Stations

Left Bank	Right Bank
10	28

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire River Sta.: 31

Description:

Cross Section Coordinates

	Station	Elevation
1	0	31.5
2	10	31
3	10	28.54
4	14	28.54
5	16	28.54
6	18	28.54
7	20	28.54
8	22	28.54
9	24	28.54
10	28	28.54
11	28	31
12	38	31.5
13		

Downstream Reach Lengths

LOB	Channel	ROB
402.39	200.77	198.18

Manning's n Values

LOB	Channel	ROB
0.04	0.017	0.04

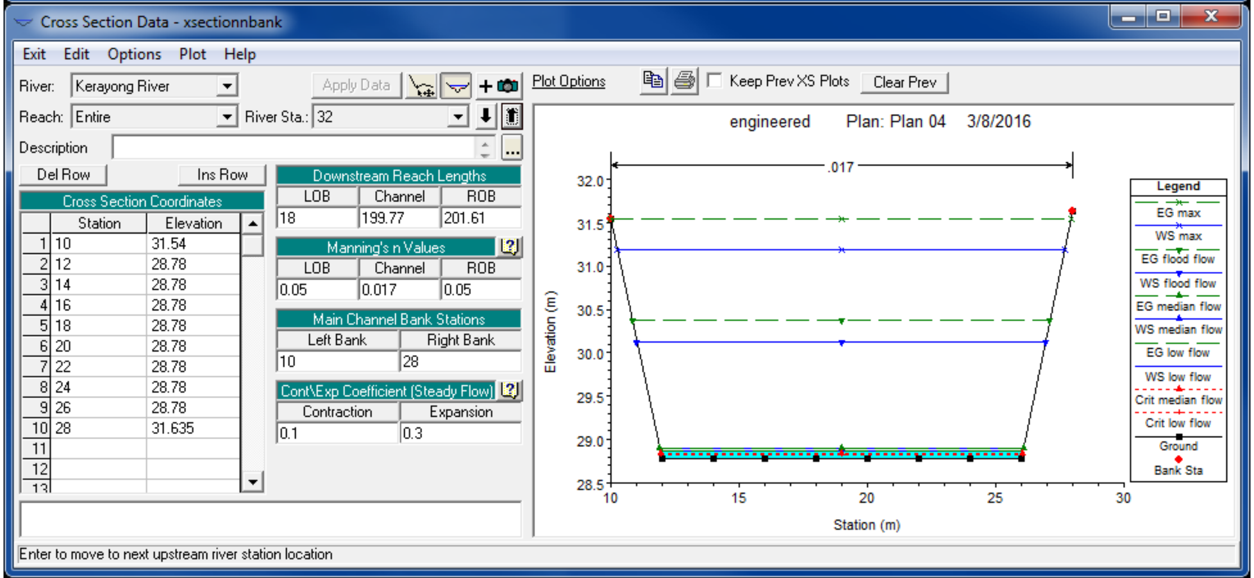
Main Channel Bank Stations

Left Bank	Right Bank
10	28

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire River Sta.: 32

Description:

Cross Section Coordinates

	Station	Elevation
1	10	31.54
2	12	28.78
3	14	28.78
4	16	28.78
5	18	28.78
6	20	28.78
7	22	28.78
8	24	28.78
9	26	28.78
10	28	31.635
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
18	199.77	201.61

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

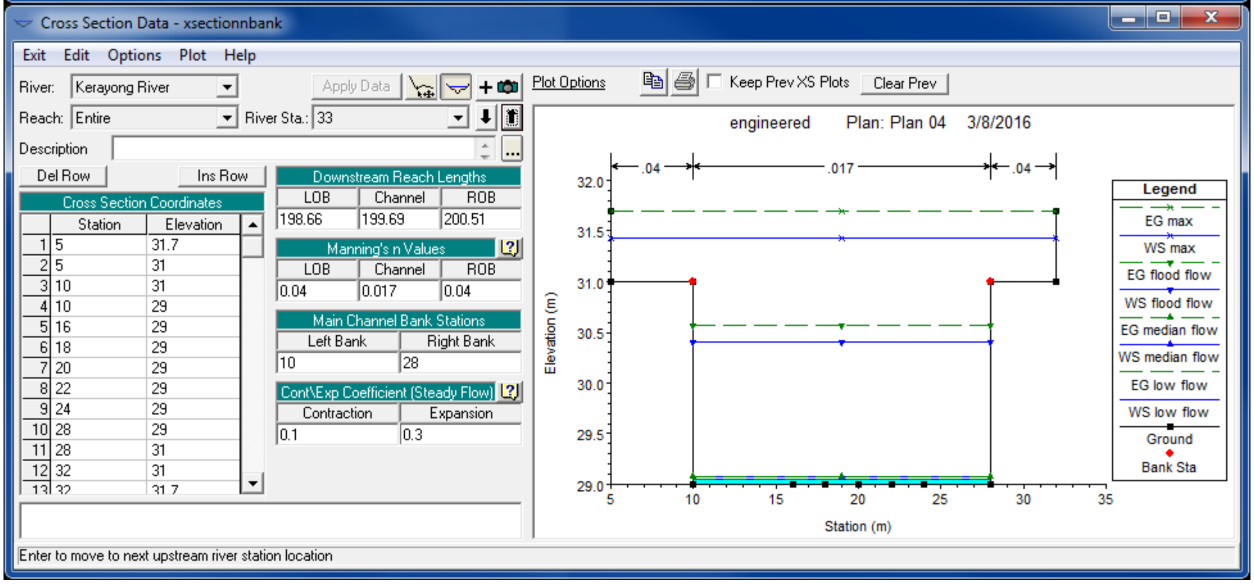
Main Channel Bank Stations

Left Bank	Right Bank
10	28

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire River Sta.: 33

Description:

Cross Section Coordinates

	Station	Elevation
1	5	31.7
2	5	31
3	10	31
4	10	29
5	16	29
6	18	29
7	20	29
8	22	29
9	24	29
10	28	29
11	28	31
12	32	31
13	32	31.7

Downstream Reach Lengths

LOB	Channel	ROB
198.66	199.69	200.51

Manning's n Values

LOB	Channel	ROB
0.04	0.017	0.04

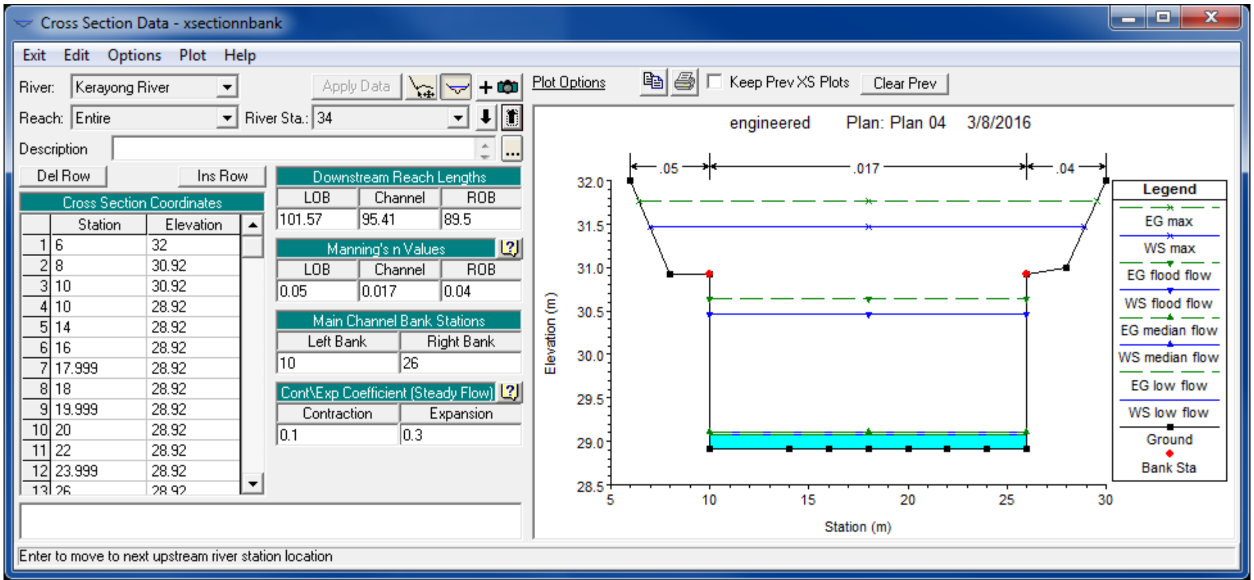
Main Channel Bank Stations

Left Bank	Right Bank
10	28

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 34

Description:

Cross Section Coordinates

	Station	Elevation
1	6	32
2	8	30.92
3	10	30.92
4	10	28.92
5	14	28.92
6	16	28.92
7	17.999	28.92
8	18	28.92
9	19.999	28.92
10	20	28.92
11	22	28.92
12	23.999	28.92
13	26	28.92

Downstream Reach Lengths

LOB	Channel	ROB
101.57	95.41	89.5

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.04

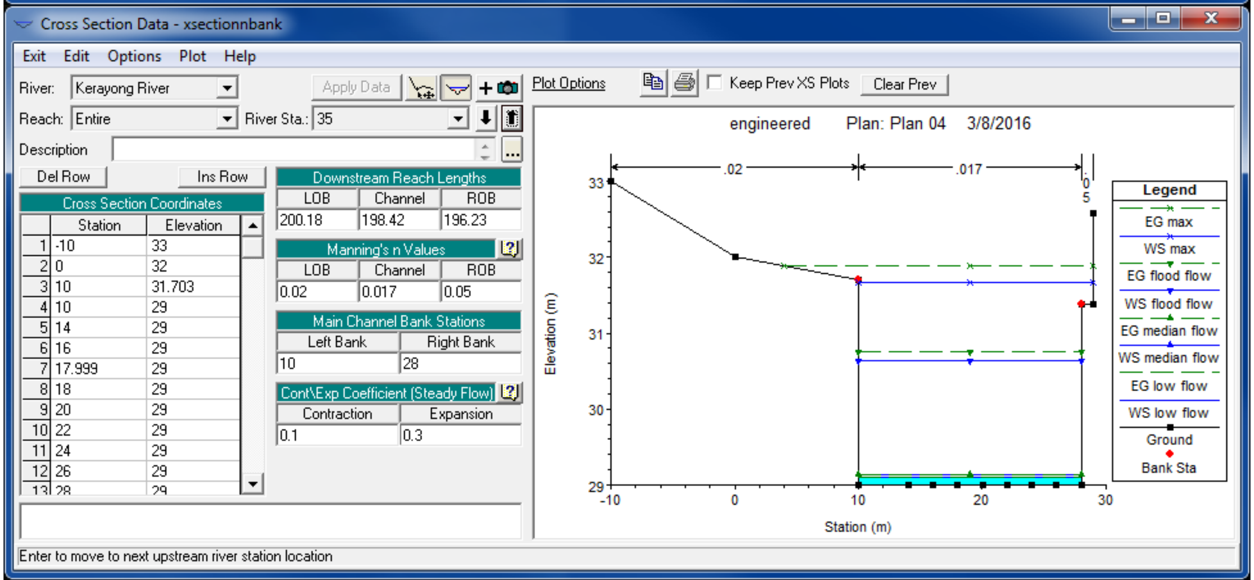
Main Channel Bank Stations

Left Bank	Right Bank
10	26

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 35

Description:

Cross Section Coordinates

	Station	Elevation
1	-10	33
2	0	32
3	10	31.703
4	10	29
5	14	29
6	16	29
7	17.999	29
8	18	29
9	20	29
10	22	29
11	24	29
12	26	29
13	28	29

Downstream Reach Lengths

LOB	Channel	ROB
200.18	198.42	196.23

Manning's n Values

LOB	Channel	ROB
0.02	0.017	0.05

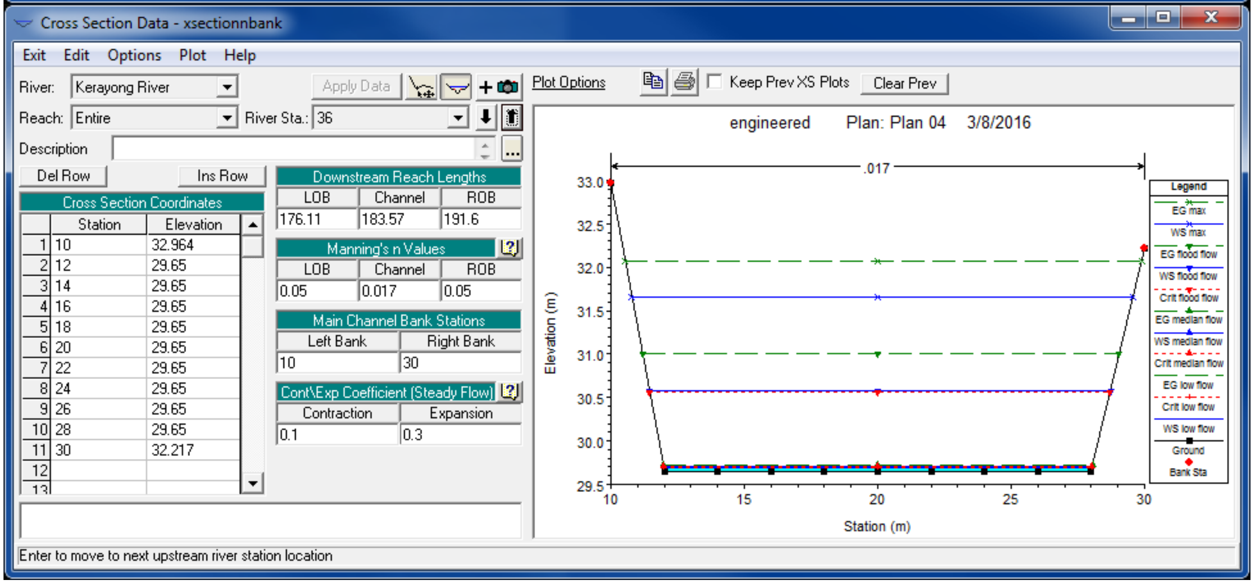
Main Channel Bank Stations

Left Bank	Right Bank
10	28

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 36

Description:

Cross Section Coordinates

	Station	Elevation
1	10	32.964
2	12	29.65
3	14	29.65
4	16	29.65
5	18	29.65
6	20	29.65
7	22	29.65
8	24	29.65
9	26	29.65
10	28	29.65
11	30	32.217
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
176.11	183.57	191.6

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

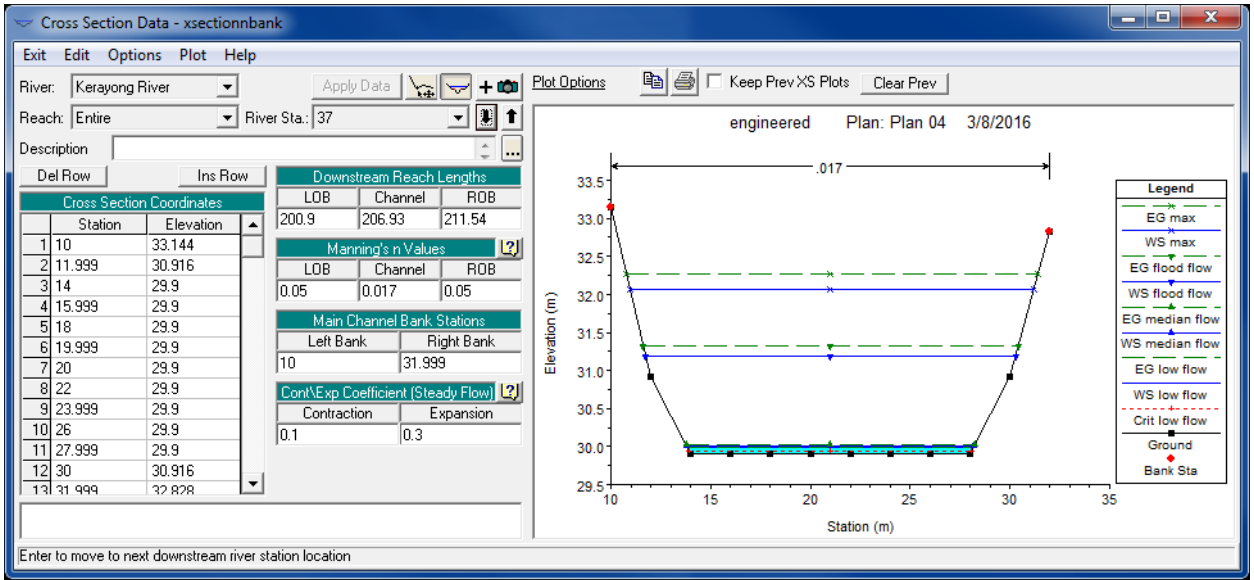
Main Channel Bank Stations

Left Bank	Right Bank
10	30

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 37

Description:

Cross Section Coordinates

	Station	Elevation
1	10	33.144
2	11.999	30.916
3	14	29.9
4	15.999	29.9
5	18	29.9
6	19.999	29.9
7	20	29.9
8	22	29.9
9	23.999	29.9
10	26	29.9
11	27.999	29.9
12	30	30.916
13	31.999	32.828

Downstream Reach Lengths

LOB	Channel	ROB
200.9	206.93	211.54

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

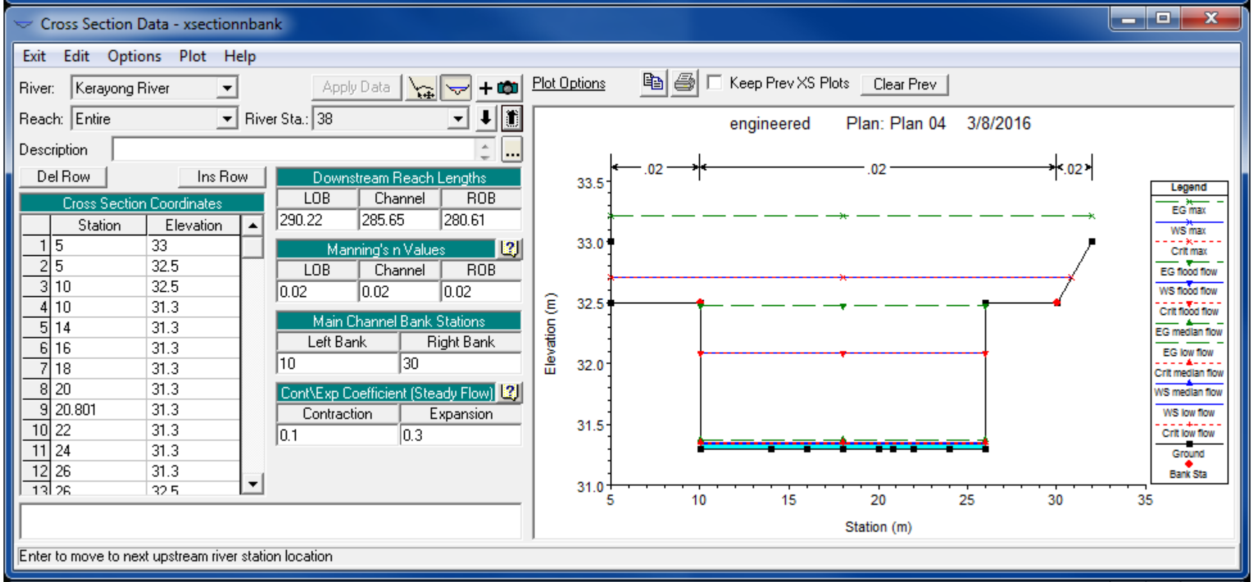
Main Channel Bank Stations

Left Bank	Right Bank
10	31.999

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next downstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 38

Description:

Cross Section Coordinates

	Station	Elevation
1	5	33
2	5	32.5
3	10	32.5
4	10	31.3
5	14	31.3
6	16	31.3
7	18	31.3
8	20	31.3
9	20.801	31.3
10	22	31.3
11	24	31.3
12	26	31.3
13	26	32.5

Downstream Reach Lengths

LOB	Channel	ROB
290.22	285.65	280.61

Manning's n Values

LOB	Channel	ROB
0.02	0.02	0.02

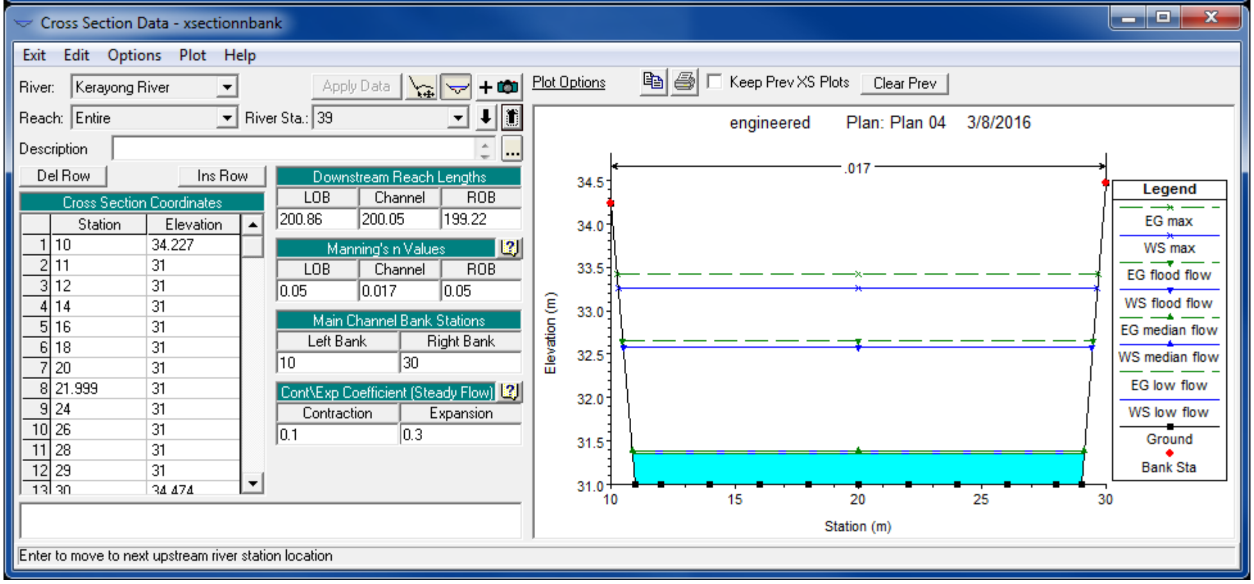
Main Channel Bank Stations

Left Bank	Right Bank
10	30

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 39

Description:

Cross Section Coordinates

	Station	Elevation
1	10	34.227
2	11	31
3	12	31
4	14	31
5	16	31
6	18	31
7	20	31
8	21.999	31
9	24	31
10	26	31
11	28	31
12	29	31
13	30	34.474

Downstream Reach Lengths

LOB	Channel	ROB
200.86	200.05	199.22

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

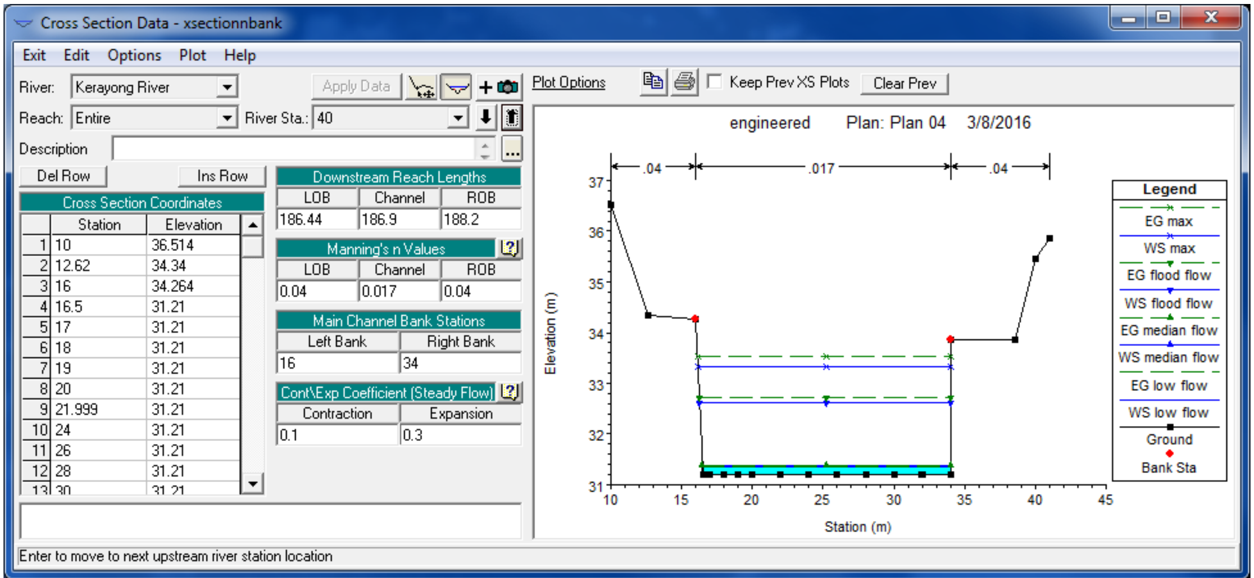
Main Channel Bank Stations

Left Bank	Right Bank
10	30

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 40

Description:

Cross Section Coordinates

	Station	Elevation
1	10	36.514
2	12.62	34.34
3	16	34.264
4	16.5	31.21
5	17	31.21
6	18	31.21
7	19	31.21
8	20	31.21
9	21.999	31.21
10	24	31.21
11	26	31.21
12	28	31.21
13	30	31.21

Downstream Reach Lengths

LOB	Channel	ROB
186.44	186.9	188.2

Manning's n Values

LOB	Channel	ROB
0.04	0.017	0.04

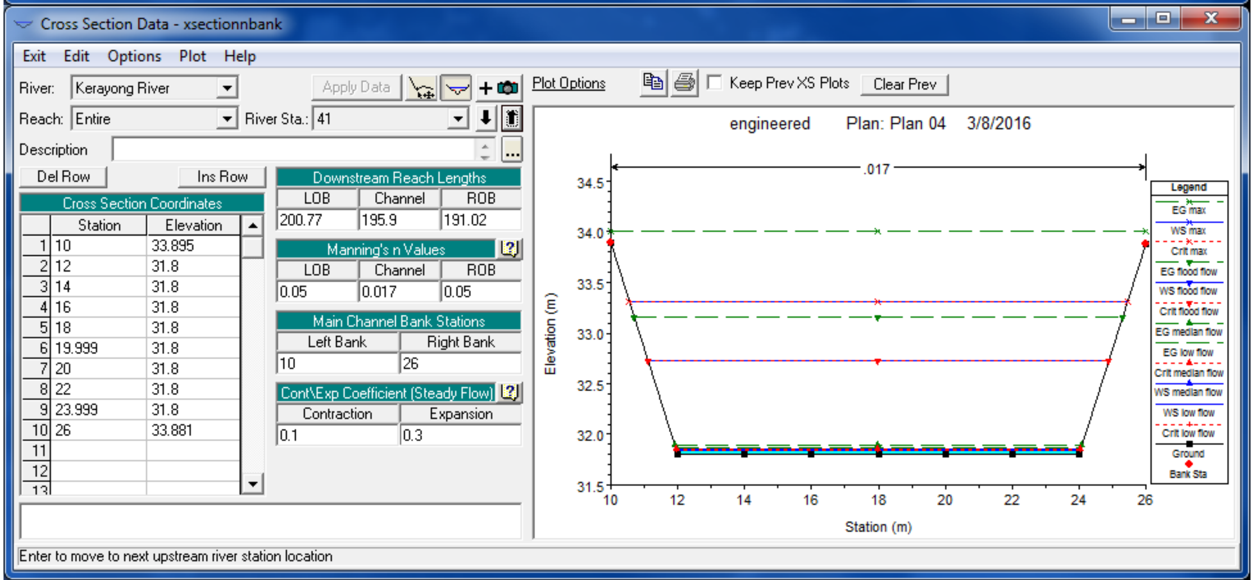
Main Channel Bank Stations

Left Bank	Right Bank
16	34

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 41

Description:

Cross Section Coordinates

	Station	Elevation
1	10	33.895
2	12	31.8
3	14	31.8
4	16	31.8
5	18	31.8
6	19.999	31.8
7	20	31.8
8	22	31.8
9	23.999	31.8
10	26	33.881
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
200.77	195.9	191.02

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

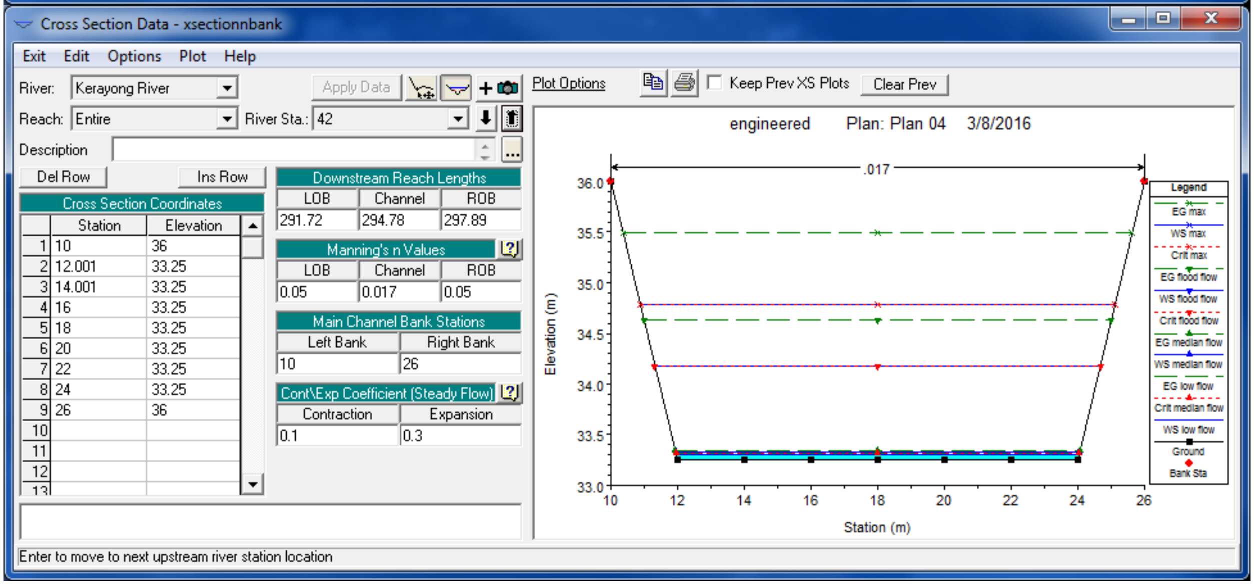
Main Channel Bank Stations

Left Bank	Right Bank
10	26

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 42

Description:

Cross Section Coordinates

	Station	Elevation
1	10	36
2	12.001	33.25
3	14.001	33.25
4	16	33.25
5	18	33.25
6	20	33.25
7	22	33.25
8	24	33.25
9	26	36
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
291.72	294.78	297.89

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

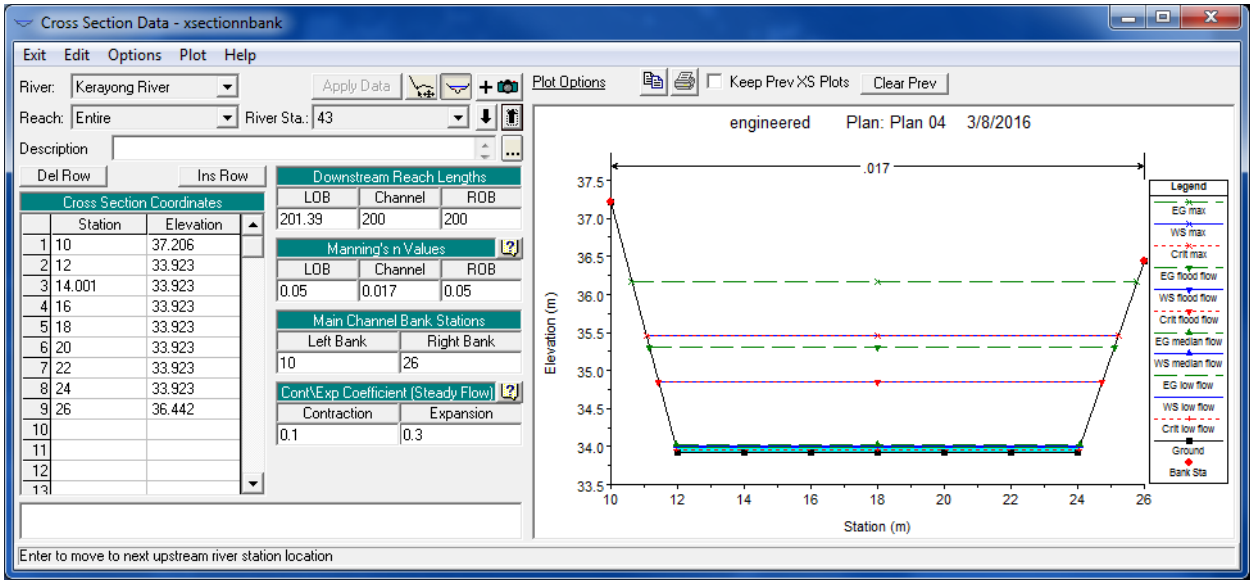
Main Channel Bank Stations

Left Bank	Right Bank
10	26

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 43

Description:

Cross Section Coordinates

	Station	Elevation
1	10	37.206
2	12	33.923
3	14.001	33.923
4	16	33.923
5	18	33.923
6	20	33.923
7	22	33.923
8	24	33.923
9	26	36.442
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
201.39	200	200

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

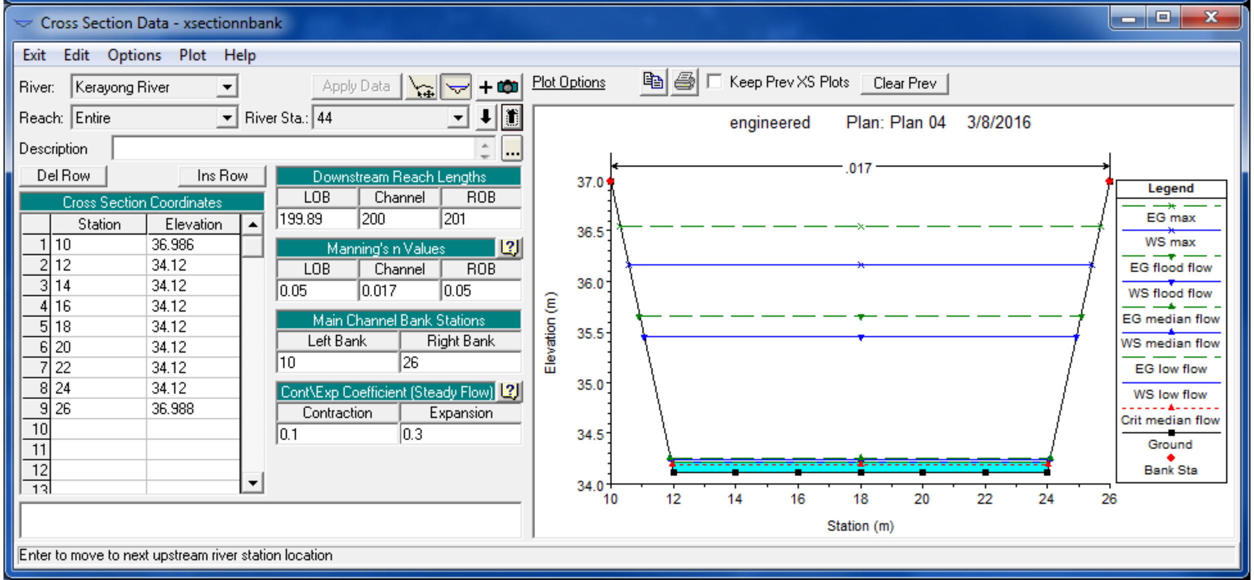
Main Channel Bank Stations

Left Bank	Right Bank
10	26

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 44

Description:

Cross Section Coordinates

	Station	Elevation
1	10	36.986
2	12	34.12
3	14	34.12
4	16	34.12
5	18	34.12
6	20	34.12
7	22	34.12
8	24	34.12
9	26	36.988
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
199.89	200	201

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

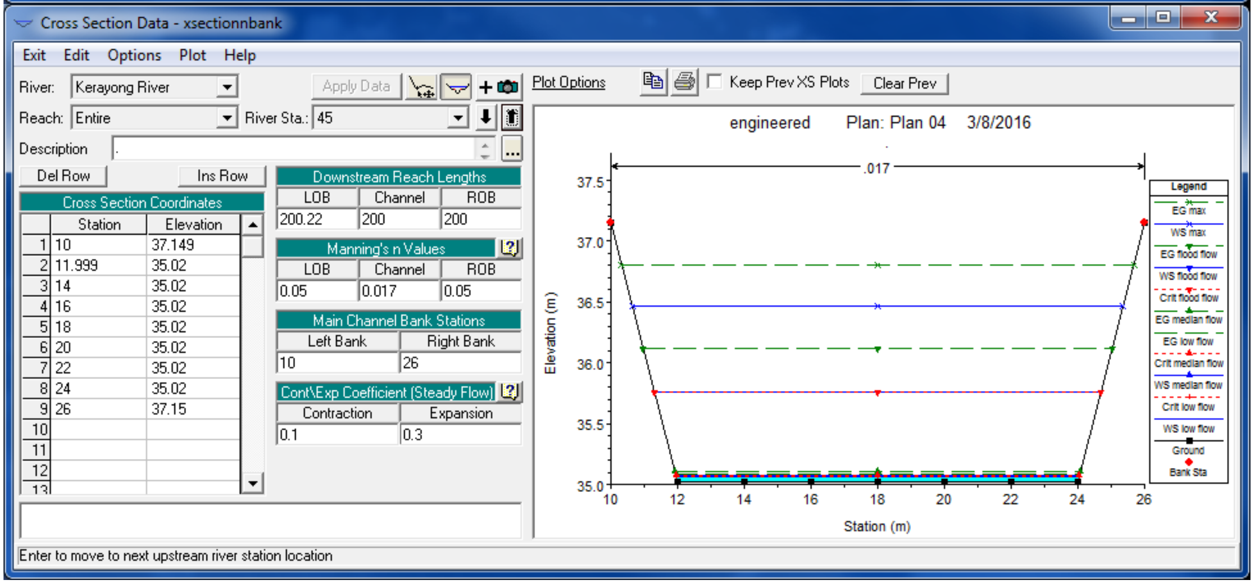
Main Channel Bank Stations

Left Bank	Right Bank
10	26

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 45

Description:

Cross Section Coordinates

	Station	Elevation
1	10	37.149
2	11.999	35.02
3	14	35.02
4	16	35.02
5	18	35.02
6	20	35.02
7	22	35.02
8	24	35.02
9	26	37.15
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
200.22	200	200

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

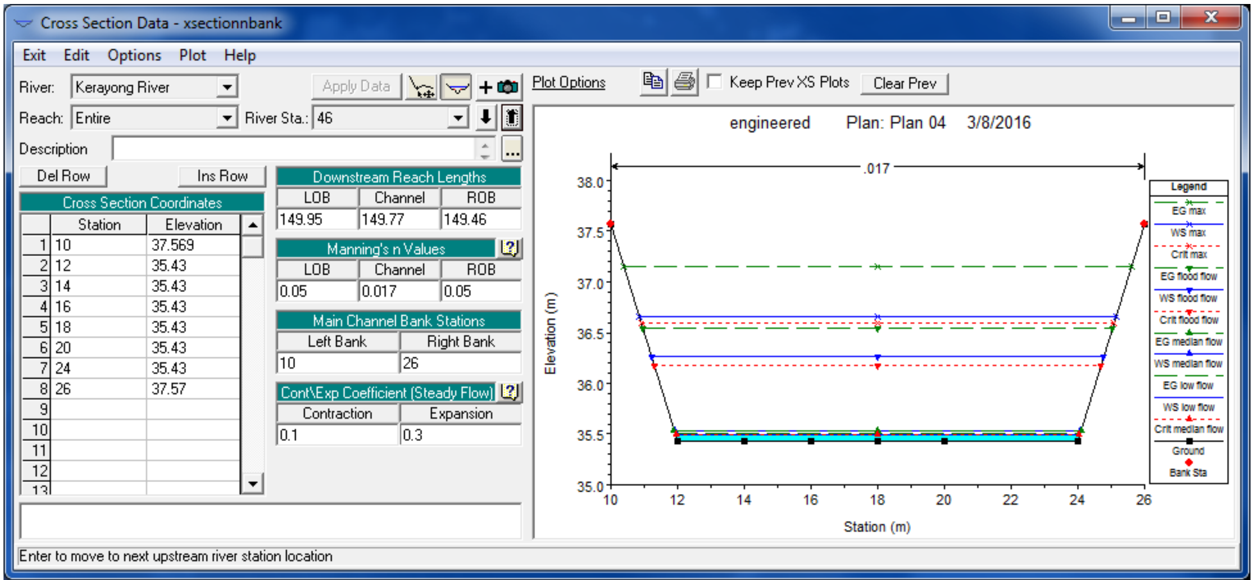
Main Channel Bank Stations

Left Bank	Right Bank
10	26

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 46

Description:

Cross Section Coordinates

	Station	Elevation
1	10	37.569
2	12	35.43
3	14	35.43
4	16	35.43
5	18	35.43
6	20	35.43
7	24	35.43
8	26	37.57
9		
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
149.95	149.77	149.46

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

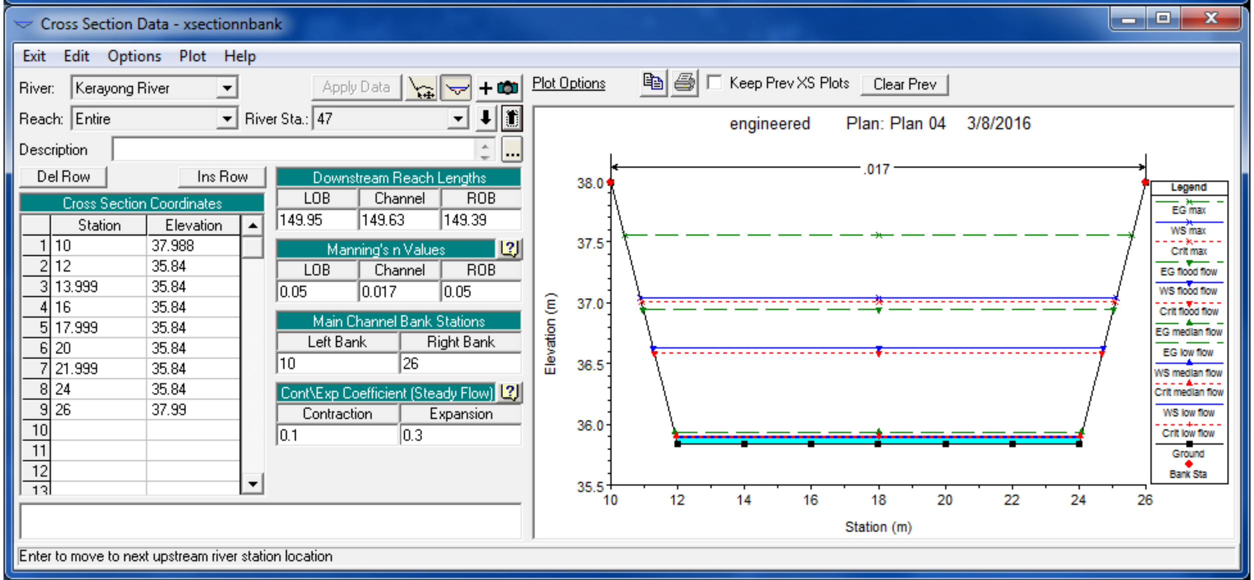
Main Channel Bank Stations

Left Bank	Right Bank
10	26

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 47

Description:

Cross Section Coordinates

	Station	Elevation
1	10	37.988
2	12	35.84
3	13.999	35.84
4	16	35.84
5	17.999	35.84
6	20	35.84
7	21.999	35.84
8	24	35.84
9	26	37.99
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
149.95	149.63	149.39

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

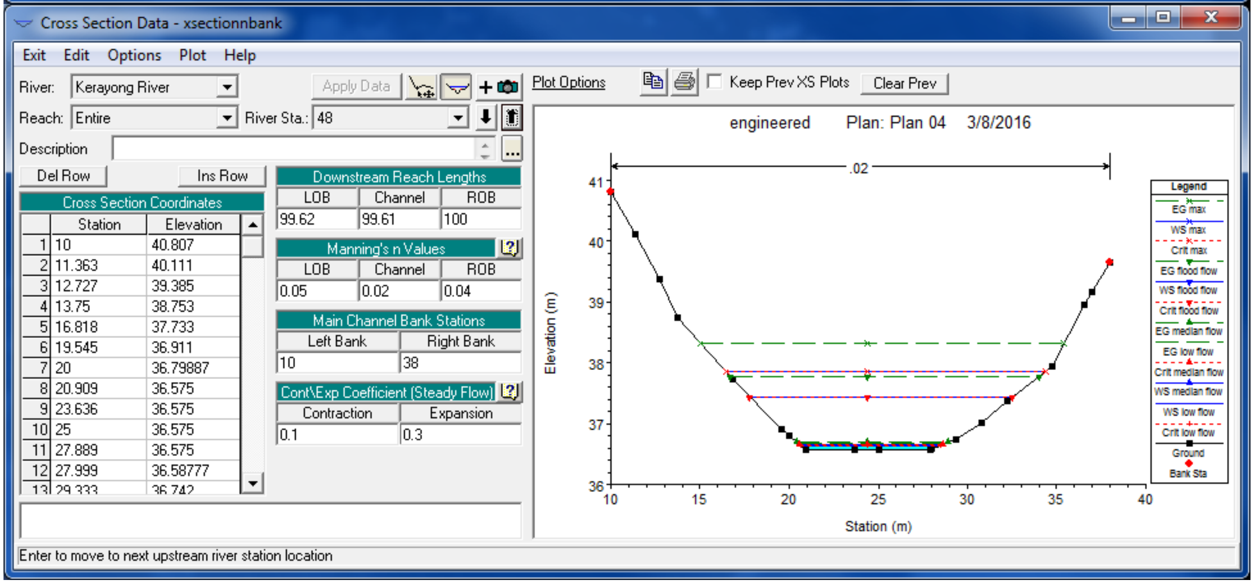
Main Channel Bank Stations

Left Bank	Right Bank
10	26

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 48

Description:

Cross Section Coordinates

	Station	Elevation
1	10	40.807
2	11.363	40.111
3	12.727	39.385
4	13.75	38.753
5	16.818	37.733
6	19.545	36.911
7	20	36.79887
8	20.909	36.575
9	23.636	36.575
10	25	36.575
11	27.889	36.575
12	27.999	36.58777
13	29.333	36.742

Downstream Reach Lengths

LOB	Channel	ROB
99.62	99.61	100

Manning's n Values

LOB	Channel	ROB
0.05	0.02	0.04

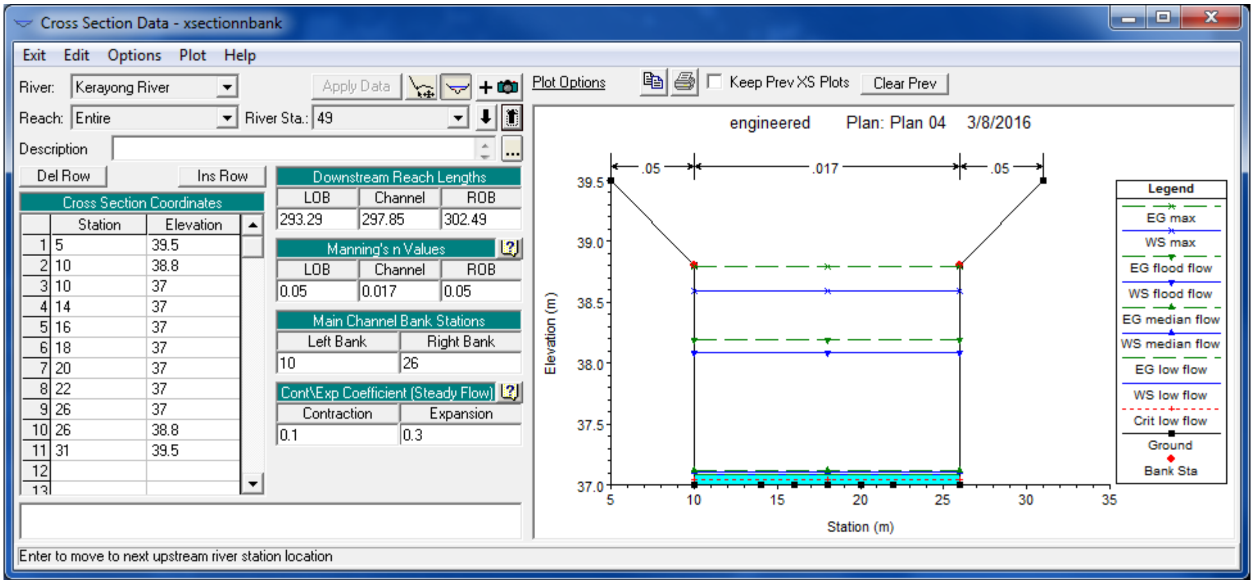
Main Channel Bank Stations

Left Bank	Right Bank
10	38

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 49

Description:

Cross Section Coordinates

	Station	Elevation
1	5	39.5
2	10	38.8
3	10	37
4	14	37
5	16	37
6	18	37
7	20	37
8	22	37
9	26	37
10	26	38.8
11	31	39.5
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
293.29	297.85	302.49

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

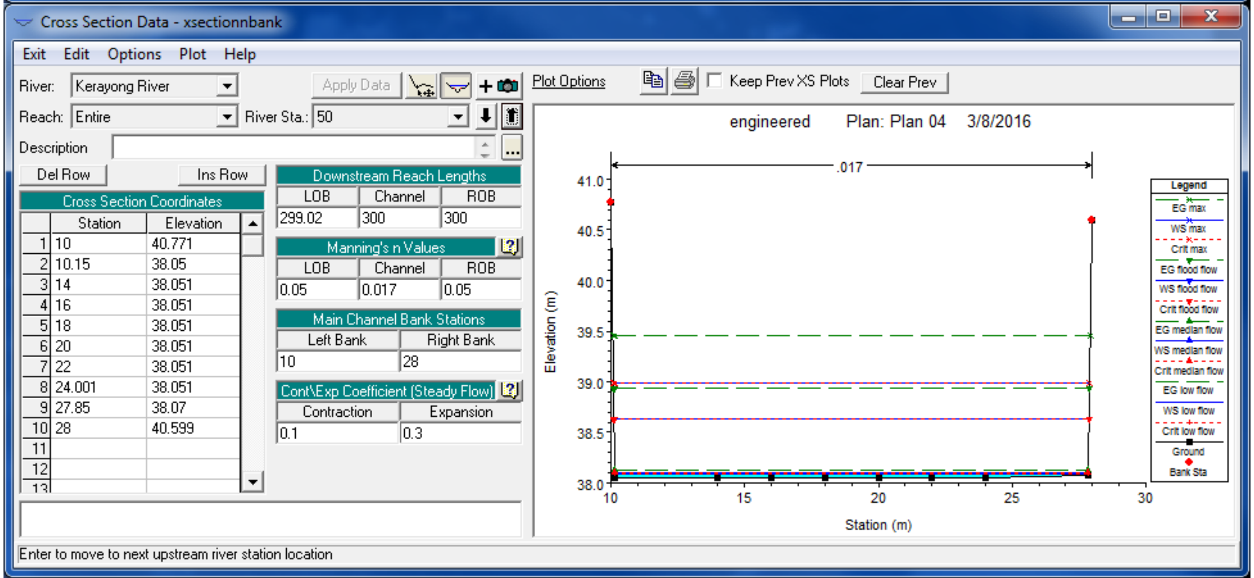
Main Channel Bank Stations

Left Bank	Right Bank
10	26

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 50

Description:

Cross Section Coordinates

	Station	Elevation
1	10	40.771
2	10.15	38.05
3	14	38.051
4	16	38.051
5	18	38.051
6	20	38.051
7	22	38.051
8	24.001	38.051
9	27.85	38.07
10	28	40.599
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
299.02	300	300

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

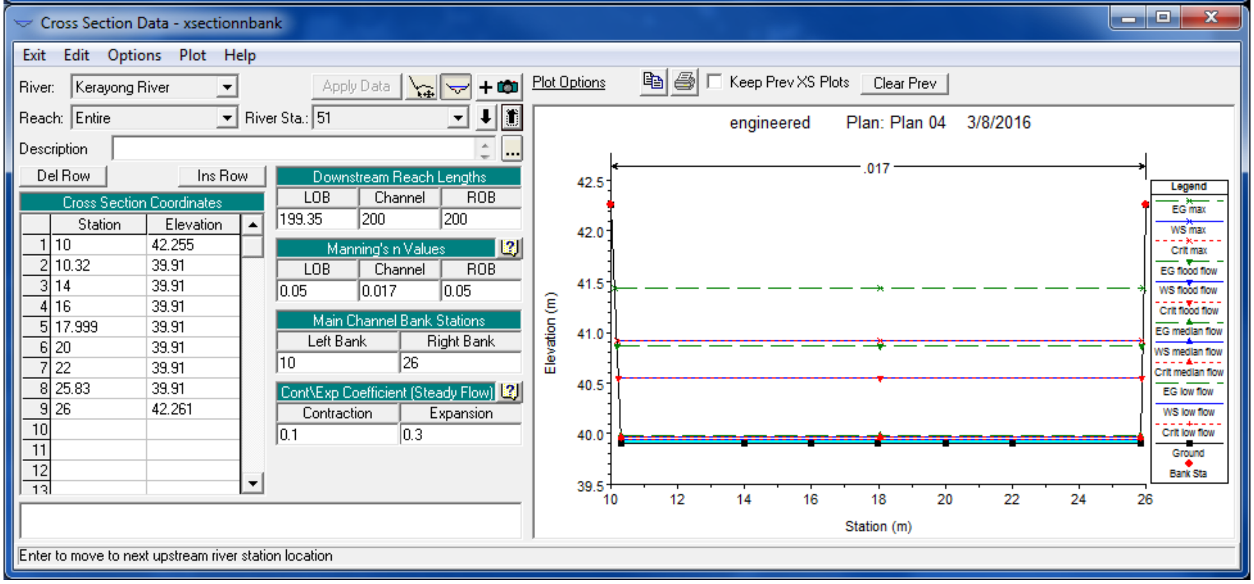
Main Channel Bank Stations

Left Bank	Right Bank
10	28

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 51

Description:

Cross Section Coordinates

	Station	Elevation
1	10	42.255
2	10.32	39.91
3	14	39.91
4	16	39.91
5	17.999	39.91
6	20	39.91
7	22	39.91
8	25.83	39.91
9	26	42.261
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
199.35	200	200

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

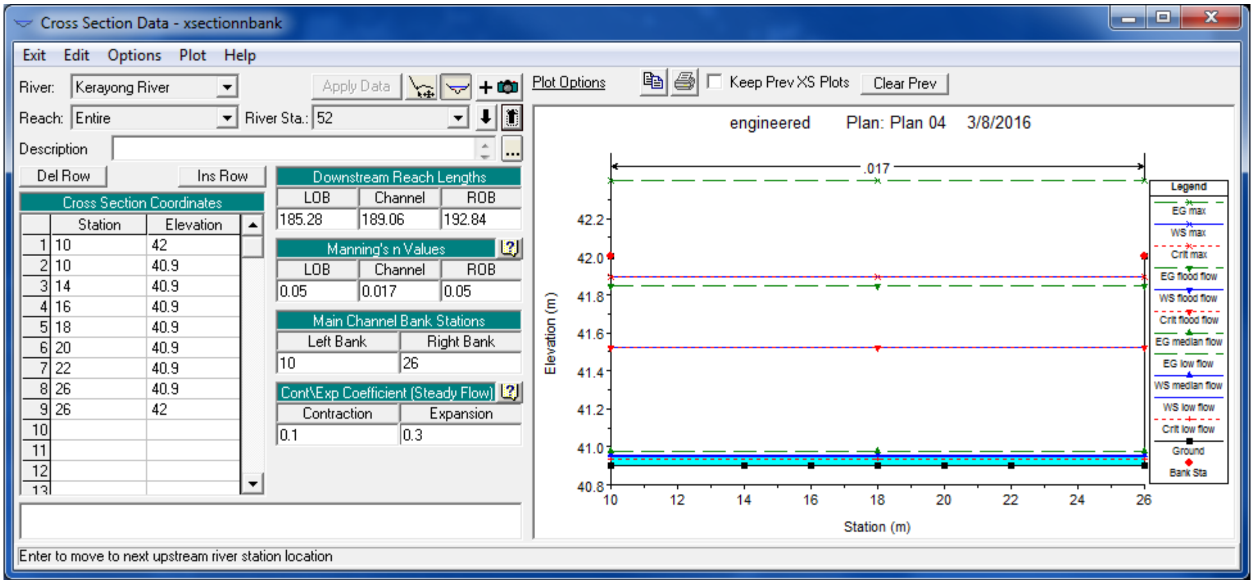
Main Channel Bank Stations

Left Bank	Right Bank
10	26

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 52

Description:

Cross Section Coordinates

	Station	Elevation
1	10	42
2	10	40.9
3	14	40.9
4	16	40.9
5	18	40.9
6	20	40.9
7	22	40.9
8	26	40.9
9	26	42
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
185.28	189.06	192.84

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

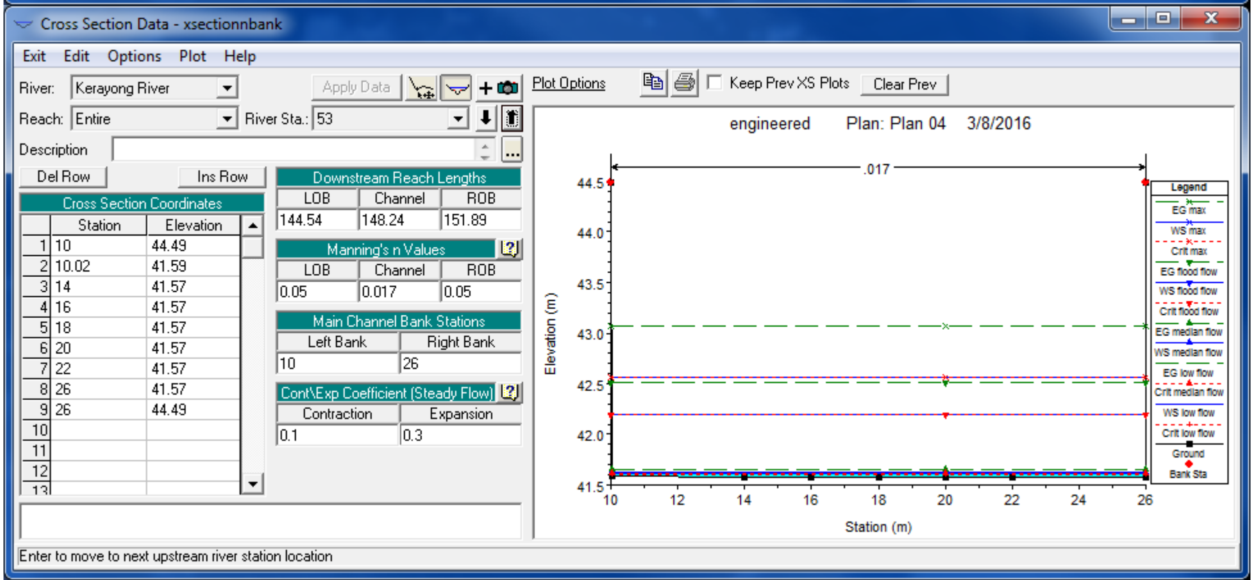
Main Channel Bank Stations

Left Bank	Right Bank
10	26

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 53

Description:

Cross Section Coordinates

	Station	Elevation
1	10	44.49
2	10.02	41.59
3	14	41.57
4	16	41.57
5	18	41.57
6	20	41.57
7	22	41.57
8	26	41.57
9	26	44.49
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
144.54	148.24	151.89

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

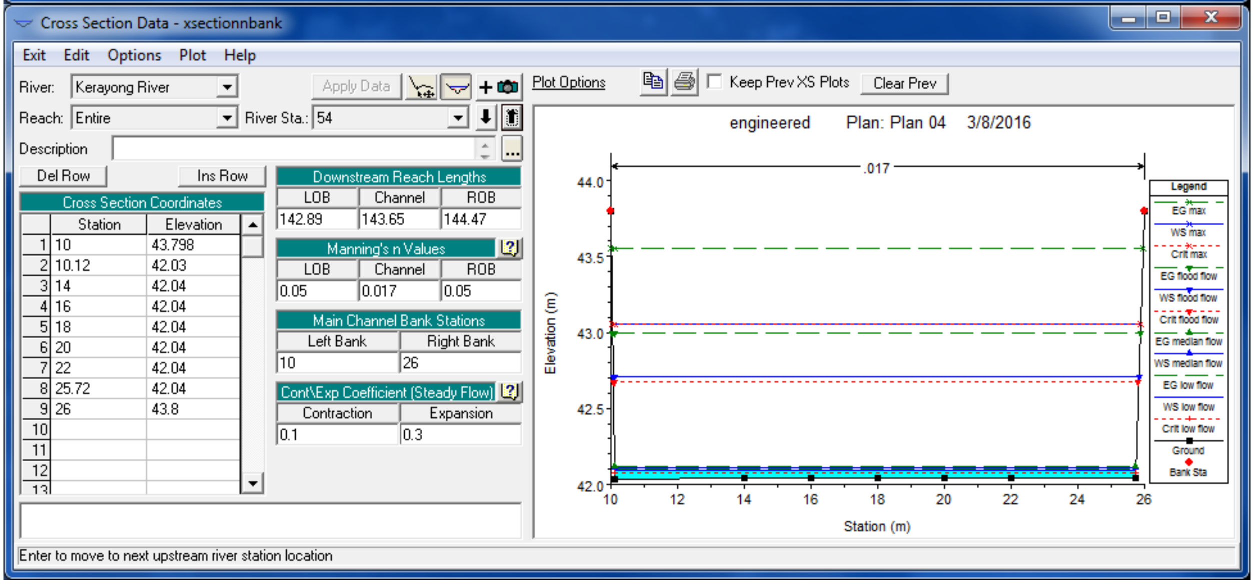
Main Channel Bank Stations

Left Bank	Right Bank
10	26

Cont\Exp Coefficient (Steady Flow)

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location



River: Kerayong River

Reach: Entire

River Sta.: 54

Description:

Cross Section Coordinates

	Station	Elevation
1	10	43.798
2	10.12	42.03
3	14	42.04
4	16	42.04
5	18	42.04
6	20	42.04
7	22	42.04
8	25.72	42.04
9	26	43.8
10		
11		
12		
13		

Downstream Reach Lengths

LOB	Channel	ROB
142.89	143.65	144.47

Manning's n Values

LOB	Channel	ROB
0.05	0.017	0.05

Main Channel Bank Stations

Left Bank	Right Bank
10	26

Cont\Exp Coefficient (Steady Flow)

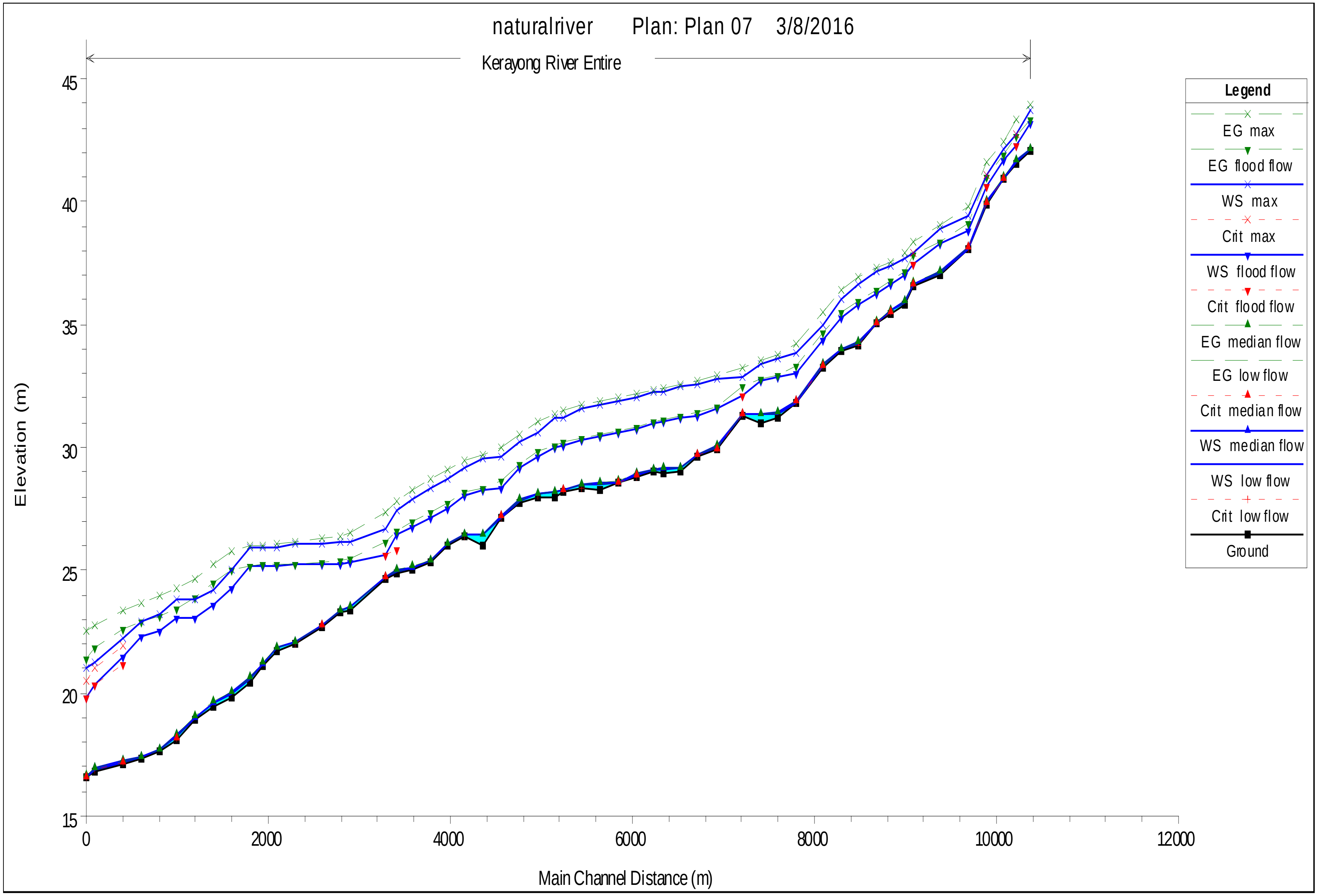
Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location

APPENDIX B-I

WATER SURFACE PROFILE

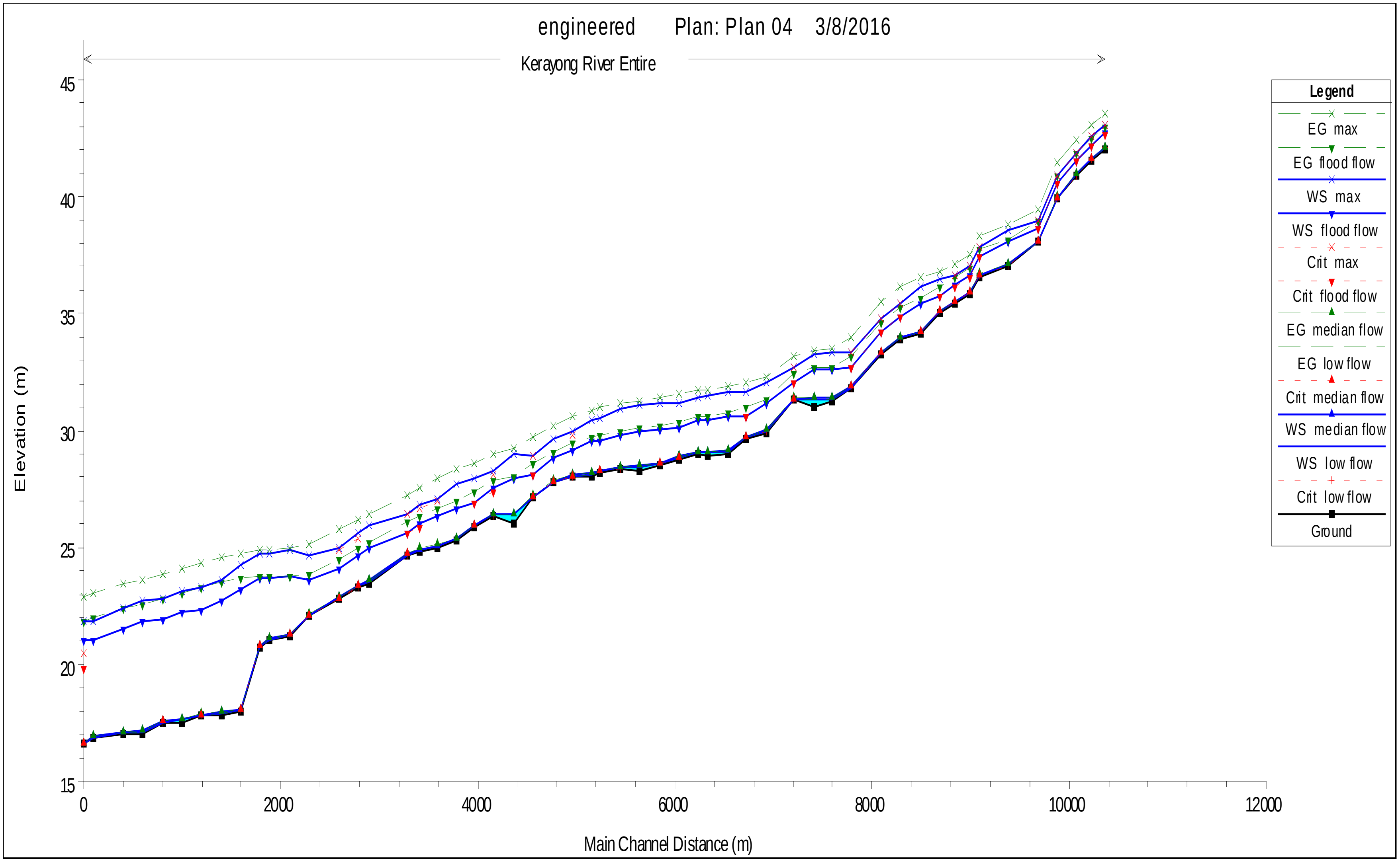
Pre-2009


naturalriver Plan: Plan 07 3/8/2016
Keraryong River Entire
Elevation (m)
45
40
35
30
25
20
15
0
2000
4000
6000
8000
10000
12000
Main Channel Distance (m)
Legend
EG max
EG flood flow
WS max
Crit max
WS flood flow
Crit flood flow
EG median flow
EG low flow
Crit median flow
WS median flow
WS low flow
Crit low flow
Ground

APPENDIX B-II

WATER SURFACE PROFILE

Engineered


engineered Plan: Plan 04 3/8/2016
Kerayong River Entire
Elevation (m)
45
40
35
30
25
20
15
0
2000
4000
6000
8000
10000
12000
Main Channel Distance (m)
Legend
EG max
EG flood flow
WS max
WS flood flow
Crit max
Crit flood flow
EG median flow
EG low flow
Crit median flow
WS median flow
WS low flow
Crit low flow
Ground

APPENDIX C

FLOW DATA

Date	Daily Flow (m3/s)	rank	Percent exceeded
4/2/2008	184.4405126	1	0.273224044
10/15/2008	110.71606	2	0.546448087
8/27/2008	97.18602017	3	0.819672131
4/16/2008	68.85018377	4	1.092896175
4/6/2008	60.96074657	5	1.366120219
4/12/2008	57.02834417	6	1.639344262
10/17/2008	54.16592357	7	1.912568306
5/29/2008	49.11156658	8	2.18579235
1/29/2008	48.21948437	9	2.459016393
3/22/2008	38.95269057	10	2.732240437
12/14/2008	36.09902633	11	3.005464481
2/26/2008	29.42986894	12	3.278688525
5/30/2008	26.92975438	13	3.551912568
10/4/2008	24.1665355	14	3.825136612
12/4/2008	23.08577229	15	4.098360656
11/27/2008	20.94217043	16	4.371584699
11/19/2008	18.06206146	17	4.644808743
8/21/2008	14.40338117	18	4.918032787
10/19/2008	14.40338117	18	4.918032787
11/4/2008	13.92915618	20	5.464480874
8/7/2008	13.85873609	21	5.737704918
5/21/2008	9.661375708	22	6.010928962
3/18/2008	9.468531248	23	6.284153005
8/26/2008	8.535337948	24	6.557377049
10/6/2008	7.826018108	25	6.830601093
1/31/2008	7.249119232	26	7.103825137
7/1/2008	7.249119232	26	7.103825137
12/13/2008	6.382018012	28	7.650273224
11/28/2008	6.243365623	29	7.923497268
4/17/2008	6.091272583	30	8.196721311
8/23/2008	5.941248143	31	8.469945355
7/14/2008	5.852226407	32	8.743169399
4/23/2008	5.404144192	33	9.016393443
6/5/2008	4.855347712	34	9.289617486
11/9/2008	4.684115183	35	9.56284153
6/4/2008	3.939113543	36	9.836065574
9/15/2008	3.903818288	37	10.10928962
9/5/2008	3.787512028	38	10.38251366
12/11/2008	3.684605047	39	10.6557377
10/3/2008	3.516816892	40	10.92896175
8/24/2008	3.418378087	41	11.20218579
12/16/2008	3.289732783	42	11.47540984
9/14/2008	2.728774175	43	11.74863388
10/10/2008	2.644670768	44	12.02185792
10/20/2008	2.517173692	45	12.29508197
4/1/2008	2.367806575	46	12.56830601
8/20/2008	2.291150128	47	12.84153005
12/6/2008	2.055544007	48	13.1147541
11/14/2008	2.047729948	49	13.38797814
9/4/2008	1.970727088	50	13.66120219
6/8/2008	1.895792828	51	13.93442623
3/24/2008	1.822927168	52	14.20765027
1/9/2008	1.663186487	53	14.48087432
10/21/2008	1.616741788	54	14.75409836
10/9/2008	1.471274447	55	15.0273224
11/5/2008	1.244352127	56	15.30054645
11/29/2008	1.172748623	57	15.57377049
10/22/2008	1.157932508	58	15.84699454
2/3/2008	1.003028032	59	16.12021858
8/25/2008	1.003028032	59	16.12021858
10/11/2008	0.826681847	61	16.66666667
11/23/2008	0.817109168	62	16.93989071
4/8/2008	0.8137337	63	17.21311475
12/18/2008	0.8137337	63	17.21311475
7/8/2008	0.807722663	65	17.75956284
3/10/2008	0.8075644	66	18.03278689
1/26/2008	0.805387	67	18.30601093
5/26/2008	0.8039354	68	18.57923497
8/28/2008	0.8024838	69	18.85245902
1/11/2008	0.7992177	70	19.12568306
10/13/2008	0.7992177	70	19.12568306
3/23/2008	0.798129	72	19.67213115
3/1/2008	0.7952258	73	19.94535519
3/30/2008	0.7952258	73	19.94535519
10/16/2008	0.7941371	75	20.49180328
12/19/2008	0.7897823	76	20.76502732
11/12/2008	0.7759921	77	21.03825137
10/24/2008	0.7749034	78	21.31147541
4/9/2008	0.7748983	79	21.58469945
12/5/2008	0.772726	80	21.8579235
11/11/2008	0.7723631	81	22.13114754
1/6/2008	0.7712744	82	22.40437158
5/22/2008	0.7712744	82	22.40437158
6/21/2008	0.7676454	84	22.95081967
10/23/2008	0.766380607	85	23.22404372
6/19/2008	0.7651051	86	23.49726776
9/27/2008	0.7629277	87	23.7704918
11/20/2008	0.7629277	87	23.7704918
4/7/2008	0.7614761	89	24.31693989
3/28/2008	0.7603874	90	24.59016393
4/15/2008	0.758049088	91	24.86338798
12/8/2008	0.7556697	92	25.13661202
12/10/2008	0.7556697	92	25.13661202
3/2/2008	0.7531294	94	25.68306011
8/22/2008	0.7520407	95	25.95628415
9/26/2008	0.750952	96	26.2295082
3/19/2008	0.749903743	97	26.50273224
1/13/2008	0.7484117	98	26.77595628
11/2/2008	0.7484117	98	26.77595628
11/15/2008	0.7484117	98	26.77595628
12/9/2008	0.7426053	101	27.59562842
12/15/2008	0.7426053	101	27.59562842
4/3/2008	0.7422424	103	28.1420765
11/16/2008	0.736436	104	28.41530055
1/10/2008	0.731621948	105	28.68852459
6/18/2008	0.731621948	105	28.68852459
1/30/2008	0.7313554	107	29.23497268
5/31/2008	0.7262748	108	29.50819672
10/14/2008	0.725319743	109	29.78142077
1/8/2008	0.72192	110	30.05464481
8/30/2008	0.7204684	111	30.32786885
1/16/2008	0.7179281	112	30.6010929
7/16/2008	0.7168394	113	30.87431694
12/2/2008	0.714662	114	31.14754098
10/7/2008	0.7095814	115	31.42076503
10/18/2008	0.7095814	115	31.42076503
10/5/2008	0.7084927	117	31.96721311
2/21/2008	0.7045008	118	32.24043716
6/9/2008	0.700359223	119	32.5136612
5/27/2008	0.700146	120	32.78688525
9/6/2008	0.6972428	121	33.06010929
1/4/2008	0.692888	122	33.33333333
12/25/2008	0.692888	122	33.33333333
1/14/2008	0.6914364	124	33.87978142
12/30/2008	0.6867187	125	34.15300546
4/18/2008	0.686022832	126	34.42622951
6/11/2008	0.68563	127	34.69945355
4/4/2008	0.6841784	128	34.9726776
1/19/2008	0.6794607	129	35.24590164
11/13/2008	0.6794607	129	35.24590164
12/12/2008	0.678372	131	35.79234973
12/17/2008	0.6772833	132	36.06557377
11/26/2008	0.6743801	133	36.33879781
6/26/2008	0.671114	134	36.61202186
1/12/2008	0.670601327	135	36.8852459
3/21/2008	0.6696624	136	37.15846995
12/3/2008	0.6660334	137	37.43169399
3/29/2008	0.663856	138	37.70491803
12/21/2008	0.6576867	139	37.97814208
4/11/2008	0.6515174	140	38.25136612
3/3/2008	0.6467997	141	38.52459016
6/3/2008	0.638453	142	38.79781421
11/24/2008	0.638453	142	38.79781421
4/10/2008	0.6322837	144	39.3442623
12/22/2008	0.627566	145	39.61748634
11/6/2008	0.6272031	146	39.89071038
12/26/2008	0.6264773	147	40.16393443
12/20/2008	0.623937	148	40.43715847
12/29/2008	0.620308	149	40.71038251
4/21/2008	0.616679	150	40.98360656
12/23/2008	0.6152274	151	41.2568306
12/24/2008	0.6141387	152	41.53005464
12/27/2008	0.61305	153	41.80327869
7/3/2008	0.6115984	154	42.07650273
12/31/2008	0.6105097	155	42.34972678
12/28/2008	0.6047033	156	42.62295082
8/16/2008	0.601881463	157	42.89617486
1/5/2008	0.5992598	158	43.16939891
1/24/2008	0.5981711	159	43.44262295
2/28/2008	0.5959937	160	43.71584699
7/9/2008	0.5865583	161	43.98907104
11/22/2008	0.5865583	161	43.98907104
1/1/2008	0.5836551	163	44.53551913
3/7/2008	0.5825664	164	44.80874317
1/7/2008	0.5814777	165	45.08196721
12/7/2008	0.580389	166	45.35519126
4/5/2008	0.573131	167	45.6284153
3/26/2008	0.5597037	168	45.90163934
11/21/2008	0.5560747	169	46.17486339
9/18/2008	0.5473651	170	46.44808743
6/28/2008	0.5462764	171	46.72131148
3/25/2008	0.5451877	172	46.99453552
2/2/2008	0.5415587	173	47.26775956
11/25/2008	0.5390184	174	47.54098361
8/19/2008	0.5379297	175	47.81420765
3/8/2008	0.5364781	176	48.08743169
6/29/2008	0.5317604	177	48.36065574
6/1/2008	0.5292201	178	48.63387978
4/22/2008	0.5270427	179	48.90710383
3/11/2008	0.525954	180	49.18032787
2/4/2008	0.5208734	181	49.45355191
3/20/2008	0.5147041	182	49.72677596
7/15/2008	0.5147041	182	49.72677596
7/22/2008	0.511438	184	50.27322404
4/19/2008	0.5103493	185	50.54644809
10/2/2008	0.5103493	185	50.54644809
4/20/2008	0.5088977	187	51.09289617
5/23/2008	0.5001881	188	51.36612022
8/8/2008	0.4980107	189	51.63934426
9/24/2008	0.4940188	190	51.91256831
2/27/2008	0.4929301	191	52.18579235
6/27/2008	0.4907527	192	52.45901639
8/18/2008	0.4907527	192	52.45901639
7/23/2008	0.4867608	194	53.00546448
11/10/2008	0.4856721	195	53.27868852
1/2/2008	0.4845834	196	53.55191257
7/21/2008	0.4845834	196	53.55191257
11/30/2008	0.4845834	196	53.55191257
2/29/2008	0.4834947	199	54.3715847
4/14/2008	0.4813173	200	54.64480874
11/18/2008	0.4773254	201	54.91803279
4/24/2008	0.4668013	202	55.19125683
11/17/2008	0.4638981	203	55.46448087
12/1/2008	0.4628094	204	55.73770492
3/12/2008	0.4617207	205	56.01092896
7/2/2008	0.460632	206	56.28415301
7/18/2008	0.4595433	207	56.55737705
1/15/2008	0.453374	208	56.83060109
1/27/2008	0.453374	208	56.83060109
1/20/2008	0.4482934	210	57.37704918
3/9/2008	0.4374064	211	57.65027322
7/24/2008	0.435229	212	57.92349727
6/2/2008	0.4316	213	58.19672131
3/27/2008	0.4301484	214	58.46994536
1/25/2008	0.4290597	215	58.7431694
3/31/2008	0.427971	216	59.01639344
1/21/2008	0.424342	217	59.28961749
3/14/2008	0.4228904	218	59.56284153
10/25/2008	0.4218017	219	59.83606557
7/25/2008	0.4192614	220	60.10928962
6/20/2008	0.4181727	221	60.38251366
3/4/2008	0.417084	222	60.6557377
4/27/2008	0.4145437	223	60.92896175
3/13/2008	0.413455	224	61.20218579
6/30/2008	0.4123663	225	61.47540984
11/3/2008	0.4123663	225	61.47540984
9/16/2008	0.4094631	227	62.02185792
8/11/2008	0.4036567	228	62.29508197
3/15/2008	0.4022051	229	62.56830601
6/6/2008	0.4022051	229	62.56830601
2/1/2008	0.4011164	231	63.1147541
8/9/2008	0.4011164	231	63.1147541
3/17/2008	0.4000277	233	63.66120219
5/18/2008	0.398939	234	63.93442623
6/10/2008	0.398939	234	63.93442623
9/7/2008	0.3963987	236	64.48087432
3/16/2008	0.3949471	237	64.75409836
7/20/2008	0.3949471	237	64.75409836
1/28/2008	0.3938584	239	65.30054645
8/29/2008	0.3927697	240	65.57377049
9/2/2008	0.3927697	240	65.57377049
7/26/2008	0.391681	242	66.12021858
10/1/2008	0.3876891	243	66.39344262
2/25/2008	0.3866004	244	66.66666667
3/6/2008	0.3866004	244	66.66666667
1/3/2008	0.384423	246	67.21311475
11/7/2008	0.3822456	247	67.4863388
10/12/2008	0.3804311	248	67.75956284
10/26/2008	0.3804311	248	67.75956284
9/1/2008	0.3793424	250	68.30601093
3/5/2008	0.3760763	251	68.57923497
9/3/2008	0.3760763	251	68.57923497
9/12/2008	0.3760763	251	68.57923497
6/22/2008	0.3742618	254	69.3989071
5/24/2008	0.3709957	255	69.67213115
6/7/2008	0.369907	256	69.94535519
7/4/2008	0.369907	256	69.94535519
2/24/2008	0.3688183	258	70.49180328
9/10/2008	0.3688183	258	70.49180328
10/28/2008	0.3673667	260	71.03825137
7/19/2008	0.3648264	261	71.31147541
1/22/2008	0.3637377	262	71.58469945
6/12/2008	0.3637377	262	71.58469945
6/16/2008	0.3637377	262	71.58469945
7/7/2008	0.3637377	262	71.58469945
2/5/2008	0.362649	266	72.67759563
8/15/2008	0.362649	266	72.67759563
8/31/2008	0.3601087	268	73.22404372
9/8/2008	0.3601087	268	73.22404372
9/29/2008	0.3601087	268	73.22404372
9/25/2008	0.3586571	271	74.04371585
11/8/2008	0.3586571	271	74.04371585
10/27/2008	0.3564797	273	74.59016393
1/17/2008	0.355391	274	74.86338798
4/26/2008	0.355391	274	74.86338798
10/8/2008	0.3543023	276	75.40983607
4/25/2008	0.3528507	277	75.68306011
8/12/2008	0.3528507	277	75.68306011
9/19/2008	0.3528507	277	75.68306011
7/5/2008	0.3492217	280	76.50273224
5/19/2008	0.348133	281	76.77595628
9/30/2008	0.348133	281	76.77595628
5/20/2008	0.3470443	283	77.32240437
9/21/2008	0.3470443	283	77.32240437
10/30/2008	0.3470443	283	77.32240437
2/6/2008	0.3430524	286	78.1420765
6/23/2008	0.3430524	286	78.1420765
7/17/2008	0.3430524	286	78.1420765
10/29/2008	0.340875	289	78.96174863
6/24/2008	0.3383347	290	79.23497268
10/31/2008	0.3383347	290	79.23497268
1/18/2008	0.337246	292	79.78142077
9/28/2008	0.337246	292	79.78142077
9/17/2008	0.3357944	294	80.32786885
9/9/2008	0.3347057	295	80.6010929
5/25/2008	0.333617	296	80.87431694
6/17/2008	0.3321654	297	81.14754098
5/3/2008	0.3310767	298	81.42076503
5/7/2008	0.3285364	299	81.69398907
9/11/2008	0.3274477	300	81.96721311
5/1/2008	0.326359	301	82.24043716
9/13/2008	0.326359	301	82.24043716
4/29/2008	0.3249074	303	82.78688525
8/17/2008	0.3249074	303	82.78688525
4/28/2008	0.3238187	305	83.33333333
11/1/2008	0.32273	306	83.60655738
5/2/2008	0.3165607	307	83.87978142
5/28/2008	0.3165607	307	83.87978142
9/20/2008	0.3165607	307	83.87978142
9/22/2008	0.3165607	307	83.87978142
5/4/2008	0.315472	311	84.9726776
9/23/2008	0.3129317	312	85.24590164
4/30/2008	0.3103914	313	85.51912568
6/25/2008	0.3093027	314	85.79234973
5/11/2008	0.3056737	315	86.06557377
8/10/2008	0.3056737	315	86.06557377
5/6/2008	0.304585	317	86.61202186
5/8/2008	0.304585	317	86.61202186
6/13/2008	0.304585	317	86.61202186
7/27/2008	0.304585	317	86.61202186
5/5/2008	0.3020447	321	87.70491803
7/11/2008	0.2984157	322	87.97814208
8/13/2008	0.297327	323	88.25136612
5/9/2008	0.2958754	324	88.52459016
5/14/2008	0.2958754	324	88.52459016
7/10/2008	0.2958754	324	88.52459016
7/28/2008	0.2958754	324	88.52459016
2/22/2008	0.2947867	328	89.61748634
2/23/2008	0.2947867	328	89.61748634
5/12/2008	0.2947867	328	89.61748634
5/10/2008	0.293698	331	90.43715847
8/3/2008	0.293698	331	90.43715847
5/17/2008	0.2926093	333	90.98360656
8/4/2008	0.2911577	334	91.2568306
7/29/2008	0.2886174	335	91.53005464
8/2/2008	0.2875287	336	91.80327869
8/14/2008	0.2875287	336	91.80327869
8/6/2008	0.28644	338	92.34972678
5/15/2008	0.2853513	339	92.62295082
8/5/2008	0.2853513	339	92.62295082
2/7/2008	0.2838997	341	93.16939891
1/23/2008	0.2802707	342	93.44262295
7/30/2008	0.2802707	342	93.44262295
2/8/2008	0.279182	344	93.98907104
2/16/2008	0.279182	344	93.98907104
2/17/2008	0.279182	344	93.98907104
7/31/2008	0.279182	344	93.98907104
5/13/2008	0.2780933	348	95.08196721
2/13/2008	0.2770046	349	95.35519126
2/18/2008	0.2770046	349	95.35519126
8/1/2008	0.2751901	351	95.90163934
2/10/2008	0.2741014	352	96.17486339
5/16/2008	0.2741014	352	96.17486339
7/6/2008	0.2741014	352	96.17486339
2/11/2008	0.271924	355	96.99453552
7/12/2008	0.2708353	356	97.26775956
7/13/2008	0.2697466	357	97.54098361
2/9/2008	0.2679321	358	97.81420765
2/12/2008	0.2668434	359	98.08743169
2/15/2008	0.264666	360	98.36065574
2/20/2008	0.264666	360	98.36065574
2/19/2008	0.2635773	362	98.90710383
2/14/2008	0.2595854	363	99.18032787
4/13/2008	0	364	99.45355191
6/14/2008	0	364	99.45355191
6/15/2008	0	364	99.45355191

APPENDIX D

KUALA LUMPUR FLOOD REPORT
APRIL 02 2008

LAPORAN BANJIR

Negeri: W.P Kuala Lunpur
Daerah: Kuala Lumpur

Tarikh Banjir: 02/04/2008
Masa Banjir : 6.00 ptg

Tarikh laporan disediakan : 03/04/2008
Masa : 9.00 pg

A) STATUS HUJAN

Nama Stesen Hujan	Data Hujan diambil dari jam______ - jam ______	Jumlah Lebat Hujan (mm)
Stesen hujan telemetri VHF (Dengan bacaan Tertinggi): 1. Jambatan Petaling @ Sg. Klang (Downstream)	4.00 ptg – 5.00 ptg (1jam) 5.00 ptg – 6.00 ptg (1jam) 6.00 ptg – 7.00 ptg (1jam)	21.0 58.0 14.0
Stesen hujan telemetri SMS (Dengan bacaan Tertinggi): 1. Taman Desa @ Sg. Kerayong	4.00 ptg – 5.00 ptg (1jam) 5.00 ptg – 6.00 ptg (1jam) 6.00 ptg – 7.00 ptg (1jam)	38.5 36.5 0.0
2. Kg. Cheras Baru @ Sg. Kerayong	4.00 ptg – 5.00 ptg (1jam) 5.00 ptg – 6.00 ptg (1jam) 6.00 ptg – 7.00 ptg (1jam)	48.5 13.0 0.0

B) STATUS ARAS AIR

Nama Sungai	Bacaan Aras Air Tertinggi (m)	Masa bacaan (jam)	Aras Waspada (m)	Aras Bahaya (m)
Sg. Kerayong @ Kg. Cheras Baru	62.55	5.50 ptg	62.00	63.00

C) STATUS BILIK GERAKAN BANJIR NEGERI / DAERAH

Adakah bilik gerakan banjir dibuka ?	: YA / ~~TIDAK~~
Jika YA, Bilik Gerakan Banjir JPS	: NEGERI / ~~DAERAH~~
Tarikh bilik gerakan dibuka	: Setiap Hari
Masa bilik gerakan dibuka	: 24jam

D) LAPORAN KAWASAN BANJIR

Kawasan Banjir	Koordinat	Kedalaman banjir (m)	Nama sungai yang melimpah (Jika ada)
Tmn. Lien Hoe (Bt4 Jln. Klang Lama)	N: E:	0.3 – 0.5	*Sg. Kerayong (*Flood Wall Pecah)
Pekan Sg. Besi	N: E:	0.3 – 0.6	-
SJK (T) Ladang Bukit Jalil, Puchong	N: E:	0.3 - 0.6	-

E) KEROSAKKAN AKIBAT BANJIR (JIKA ADA)

- Kira-kira 100 buah rumah di Tmn. Lien Hoe (Bt4 Jln. Klang Lama) telah ditenggalami air selama 1jam sedalam 0.3-0.5m.
- Ribuan kenderaan terperangkap dalam kesesakan lalulintas yang teruk.

F) JUMLAH PERPINDAHAN

Kawasan / Tempat / Kampung/ Daerah	Bilangan Orang	Pusat Perpindahan
-	-	-

G) JUMLAH KEMATIAN / KECEDERAAN

TIADA / ~~ADA~~ = - orang

H) ULASAN KEJADIAN BANJIR

Sebab-sebab banjir / lain-lain :

Punca Banjir-

1) Hujan lebat dengan keamatan tinggi terutamanya di lembangan Sungai Kerayong.
2) Limpahan air dari Sungai Kerayong di Tmn. Lien Hoe disebabkan "Flood Wall" pecah di kawasan tersebut.
3) Sistem saliran sedia ada tidak dapat menampung air larian permukaan.

Lain-Lain-

1) Banjir beransur surut mulai jam 7.00mlm.

Disediakan Oleh,

Nama : Faizul Hafizi Bin Omar
Jawatan : Penolong Pengarah

Translation

FLOOD REPORT

State: Kuala Lumpur

Date of Flood: Apr 02 2008 (Malaysian date format dd/mm/yyyy)

District: Kuala Lumpur

Time of Flood: 6 pm

Date of Report: Apr 03 2008

Time: 9 am

A) Rain Status

Rain Station (gage) Name	Rain data collection time	Cumulative Precipitation (mm)
VHF telemetry rain gage (With highest reading):		
1. Petaling Bridge @ Klang River (Downstream)	4pm-5pm (1hr)	21
	5pm-6pm (1hr)	58
	6pm-7pm (1hr)	14
SMS telemetry rain gage (With highest reading):		
1. Taman Desa @ Kerayong River	4pm-5pm (1hr)	38.5
	5pm-6pm (1hr)	36.5
	6pm-7pm (1hr)	0
2. Kg. Cheras Baru @ Kerayong River	4pm-5pm (1hr)	48.5
	5pm-6pm (1hr)	13.0
	6pm-7pm (1hr)	0

B) Water Level Status

River Name	Highest recorded water level (m)	Time of recorded	Warning level (m)	Danger level (m)
Kerayong River @ Kg. Cheras Baru	62.55	5.50 pm	62.00	63.00

C) State/District Flood Operation Center Status

Was the flood operation center open?	: Yes
If yes, which flood operation center?	: State
Date flood operation center is open	: Daily
Time flood operation center is open	: 24 hours

D) Flooded Area Report

Flooded Area	Coordinates	Flood depth (m)	Overflowed River (if any)
Tmn Lien Hoe (Mile 4 Old Klang Road)		0.3-0.5	*Kerayong River (Flood Wall Breach)
Sg. Besi Town		0.3-0.6	
Ladang Bukit Jalil Tamil Primary School, Puchong		0.3-0.6	

E) Damage caused by flood (if any)

- About 100 houses in Tmn. Lien Hoe (Mile 4 Old Klang Road) was flooded for an hour at depths of 0.3-0.5 m.
- Thousands of cars stuck in very bad traffic jam.

F) Relocation Count
(none)

G) Total deaths/injury
None = - people

H) Flood Incident Comment:
Reasons of flooding/ others:
Cause of Flood:

1) Very heavy rain especially in the Kerayong River Watershed
2) Overflow of floodwater from Kerayong at Tmn. Lien Hoe caused the flood wall to breach in the area.
3) Existing drainage system could not cope with surface runoff

Other:
1) Floodwater began to recede starting at 7pm

Prepared by,

Name: Faizul Hafizi Bin Omar

Position: Assistant Director

APPENDIX E

WATER LEVEL BEFORE AND AFTER SMART

Extracted From “Effects of SMART Tunnel on Flood Flow with MIKE 11 Application”. Undergraduate thesis by Ng Khai Hoong 2004. University of Technology, Malaysia

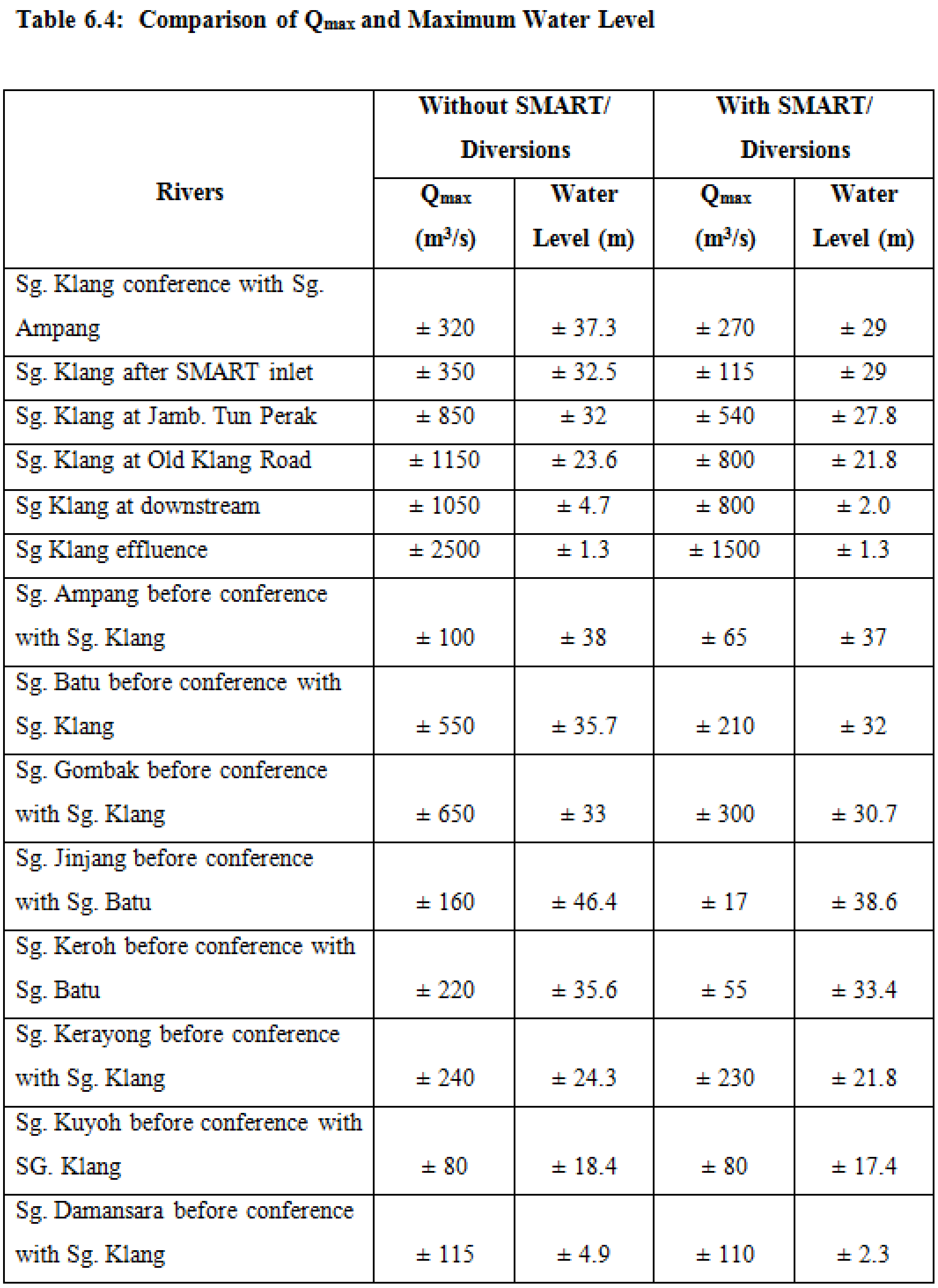


Table 6.4: Comparison of Q_{max} and Maximum Water Level

Rivers	Without SMART/ Diversions		With SMART/ Diversions	
	Q_{max} (m^3/s)	Water Level (m)	Q_{max} (m^3/s)	Water Level (m)
Sg. Klang conference with Sg. Ampang	± 320	± 37.3	± 270	± 29
Sg. Klang after SMART inlet	± 350	± 32.5	± 115	± 29
Sg. Klang at Jamb. Tun Perak	± 850	± 32	± 540	± 27.8
Sg. Klang at Old Klang Road	± 1150	± 23.6	± 800	± 21.8
Sg Klang at downstream	± 1050	± 4.7	± 800	± 2.0
Sg Klang effluence	± 2500	± 1.3	± 1500	± 1.3
Sg. Ampang before conference with Sg. Klang	± 100	± 38	± 65	± 37
Sg. Batu before conference with Sg. Klang	± 550	± 35.7	± 210	± 32
Sg. Gombak before conference with Sg. Klang	± 650	± 33	± 300	± 30.7
Sg. Jinjang before conference with Sg. Batu	± 160	± 46.4	± 17	± 38.6
Sg. Keroh before conference with Sg. Batu	± 220	± 35.6	± 55	± 33.4
Sg. Kerayong before conference with Sg. Klang	± 240	± 24.3	± 230	± 21.8
Sg. Kuyoh before conference with SG. Klang	± 80	± 18.4	± 80	± 17.4
Sg. Damansara before conference with Sg. Klang	± 115	± 4.9	± 110	± 2.3