2D SIMULATION OF SULTAN ABU BAKAR DAM RELEASE USING HEC-RAS

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By

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I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

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Date : 15/6/17

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ABSTRAK

Empangan dibina sebagai tempat simpanan air untuk mengimbangi kenaikan dan penurunan aliran di kawasan tadahan dan untuk menjana elektrik. Walau bagaimanapun, jumlah pelepasan yang dikeluarkan tidak terkawal dari pintu alur limpah empangan akan memberi kesan kepada kawasan hilir. Pada 23 Oktober 2013, banjir berlaku di kawasan hilir Sungai Bertam mungkin disebabkan oleh jumlah pelepasan yang tinggi yang dibebaskan dari empangan Sultan Abu Bakar (SAB). Kesan daripada banjir tersebut, tiga orang disahkan maut dan hampir 100 buah rumah musnah atau tenggelam manakala lebih 100 kenderaan rosak. Oleh itu, kajian mengenai pelbagai pelepasan maksimum yang dilepaskan sepanjang 4 km dan 200 m lebar sungai di kawasan hilir telah dijalankan. Objektif utama dalam kajian ini adalah untuk menentukan paras air banjir di sepanjang 4 km Sungai Bertam berdasarkan pelepasan empangan SAB. Paras air banjir dapat membantu menilai kesan banjir di kawasan tersebut yang disebabkan disebabkan oleh pelepasan empangan SAB. Simulasi berkomputer dilakukan untuk menganalisis pelbagai tahap pelepasan maksimum dari pintu alur limpah dengan menggunakan HEC-RAS yang dibangunkan oleh US Army Corp. Perisian HEC-RAS telah digunakan untuk membantu dalam menganalisis aliran saluran dan penentuan dataran banjir oleh penyelidik di seluruh dunia. Jumlah pelepasan air yang digunakan dalam simulasi ialah 10, 25, 30, 50, 100, 230 dan 300 m^3/s. Pelepasan air diambil berdasarkan cadangan pelepasan empangan oleh Tenaga Nasional Berhad (TNB). Hasilnya, peta kedalaman maksimum, halaju maksimum, masa ketibaan dan sempadan banjir telah dibangunkan. Penemuan ini menghasilkan peta bahaya banjir dan dapat meramal kawasan risiko banjir. Kajian ini dapat membantu pihak berkuasa terutama penguasa empangan SAB untuk mengawal jumlah pelepasan maksima yang dibenarkan dari empangan bagi mengelakkan banjir berlaku di hilir Sungai Bertam. Selain itu, kajian ini dapat memberikan kesedaran kepada penduduk tempatan kawasan yang berisiko mengenai masa perjalanan gelombang banjir.

ABSTRACT

Dams are constructed as water storage to compensate for fluctuations in catchment area and to generate electricity. However, uncontrollable amount of discharges released from the gated spillways of the dam would impact the downstream area. On October 23 2013, floods occured in downstream of Sungai Bertam probably due to a huge volume of discharges were released from Sultan Abu Bakar (SAB) dam. Impacts of that flood, three people were confirmed dead and nearly 100 houses destroyed or under water while over 100 vehicles badly damaged. Thus, study on various maximum discharges released along 4 km and 200 m width downstream river was conducted. The main objectives in this study are to determine flood water level along 4 km width of Sungai Bertam based on SAB dam release. The flood water level can helps evaluate effect of in that area due to SAB dam release. The computer simulation was done to analyse various maximum discharges released from the gated spillway by using HEC-RAS which is constructed by US Army Corp. HEC-RAS software was used to aid in channel flow analysis and floodplain determination by researchers around the world. The amount of water release used in the simulation were 10, 25, 30, 50, 100, 230 and 300 m^3/s. The water discharge were based on recommendation dam release by Tenaga Nasional Berhad (TNB). As a result, maximum depth, maximum velocity, arrival time and inundation boundary maps were produced. This finding will be able to produce flood hazard map and able to predict risk area of flooding. This study will also help authorities to control amount of maximum discharge level allowed from the dam as to prevent flood occur in downstream area of Sungai Bertam. Besides, this study can give awareness to local residents of risk area on flood wave travel time.

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LIST OF ABBREVIATIONS

SAB	**S**ultan **A**bu **B**akar
TNB	**T**enaga **N**asional **B**erhad
HEC-RAS	**H**ydarulic **E**ngineering **C**enter’s **R**iver **A**nalysis **S**ystem
ArcGIS	**G**eographic **I**nformation **S**ystem
MWe	**M**egawatt **E**lectric

NOMENCLATURES

Q	Flow discharge
U	Cross-sectional averaged velocity
A	Cross-section surface area
g	Acceleration of gravity
h	Cross-sectional averaged water depth
S_0	Bed slope in the longitudinal direction
S_f	Friction slope (the slope of the energy line).
f	Darcy-Weisbach friction factor
C	Chézy coefficient
n	Manning-Gauckler or Manning’s coefficient
R	hydraulic radius (R=A/P, where P is the wetted perimeter

CHAPTER 1

INTRODUCTION

1.1 General

Residents of Kg Bertam Valley experienced a tragic events when their village was inundated on October 2013. A huge volume of discharges released from Sultan Abu Bakar (SAB) dam that had caused unusual increased of water level in Sungai Bertam. These caused a large area of Sungai Bertam inundated with flood water. Figure 1.1 shows destroyed houses and damaged vehicles after the flood. On October 22 2013, high intensity rainfall fell continuously in the Bertam Valley and surrounding areas, that caused immense amount of water collected in the SAB dam. On the next day, the SAB dam had released a substantial amount of water at 12.20am into the Sungai Bertam without siren warning. A second torrent of water was released about an hour later and had caused flood to the downstream area. While the residents were grappling with the unexpected tragedy, the SAB dam then released a third torrent of water into the downstream river at about 2.45am, that caused a large area of the Bertam Valley inundated with flood water (New Straits Times, 2013). Three people were confirmed dead and nearly 100 houses destroyed or under water while over 100 vehicles badly damaged (The Star Online, 2013).

Figure 1.1 : A Damaged Car Among The Debris In The Aftermath of The Floods at Bertam Valley (Source : The Star Online, 2013)

Figure 1.1 shows the disaster caused by flooding event on October 23, 2013 that affected residents daily activities. Their properties and belongings have been swept away together with the flood.

1.2 Study Area

Cameron Highlands (Sultan Abu Bakar) Hydroelectric Power Project Malaysia is located at Sungai Bertam, Ringlet, Pahang, Malaysia and it locates at coordinates of Latitude= 4.4229, Longitude= 101.3894. This infrastructure is a Hydro Power Plant with a design capacity of 100 MWe. It has 6 unit(s) of turbine with capacity of 16.67 Mwe. The hydropower plant was commissioned in 1963. It is operated by Tenaga Nasional Berhad (TNB) (Ranjangupta, 2011). The SAB dam as shown in Figure 1.2 is situated on the Sungai Bertam in the mukim of Ringlet in the Cameron Highland district. The reservoir is formed by impounding the waters of the Sungai Bertam and its tributaries and those of Sungai Telom, Sungai Plau’ur, Sungai Kodol and Sungai Kial which have been diverted from the Telom catchment through the Telom Tunnel into the Bertam catchment.

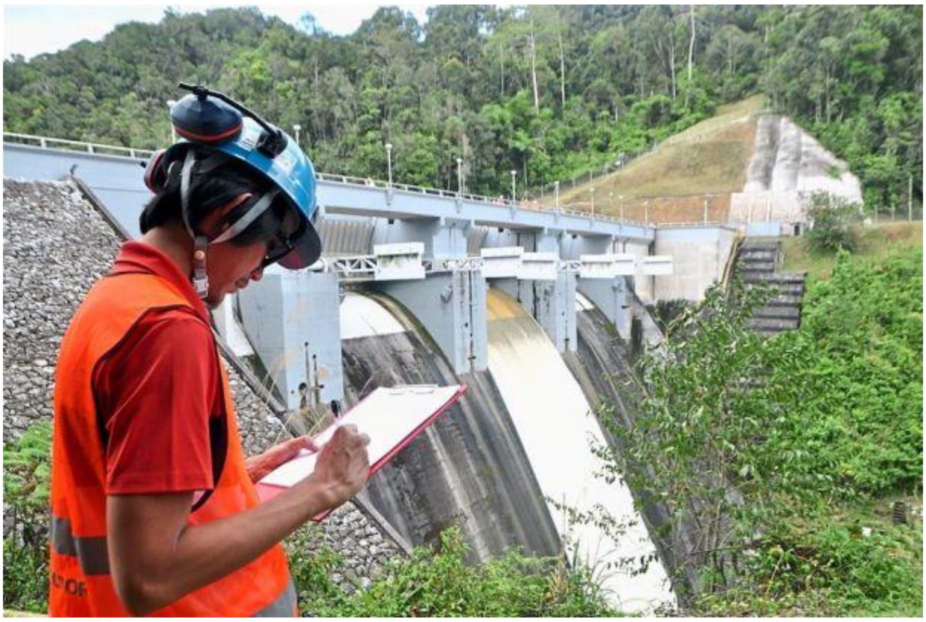


Figure 1.2 : A Control Radial Gate In Operation at Sultan Abu Bakar Dam

Bertam Valley is an agriculture village which is a home to a population of local and migrant farmers. Most of the residents operate numerous flower nurseries and vegetable farms perched along the banks of Sungai Bertam. Bertam Valley is located about 1.5 km off Ringlet town. The total catchment area of Cameron Highlands Scheme is 180 km^2 comprising of 110 km^2 of Telom Catchment and 70 km^2 of Bertam Catchment. Ringlet Reservoir was designed for a gross storage of 6.3 million m^3, of which 4.7 million m^3 is the active or live storage while 1.6 million m^3 is the inactive or dead storage. The dead storage was designed for a useful lifespan of approximately 80 years which can be translated to 20,000 m^3/year of sediment inflow (Luis et al., 2013).

Figure 1.3 : Area of Study In Sungai Bertam, Cameron Highland

1.3 Problem Statement

Dams are built across rivers and streams as massive barriers to confine and utilize the flow of water. One of reasons to build dams is to generate hydroelectricity. Dams also can control flooding known as detention dams, which are constructed to either stop or slow the amount of water in a river system. Dams also help in irrigation, which stop a river's natural course so that water can be sent to a different irrigation channels.

Floods occur in Sungai Bertam probably due to uncontrolled discharge release from SAB dam as unknown amount of discharges released from gated spillways of dam would give a negative impact to downstream area. The increasing of flood events in Sungai Bertam is probably due to uncontrolled discharge that will cause nuisance to residents and destroy agriculture farms. There was a large scale of destruction of flood that occured in October 23, 2013 caused damaged to the properties, assets and had claimed the lives of four people (Karim, 2015).

Thus, this study is to investigate the impact on various discharges released from SAB dam to 4 km range downstream river. It is important to choose model which need less comprehensive input data and gives reasonable precision results. HEC-RAS software is most suitable to be used in simulating the SAB dam release in 2D as it meets all the selection criteria and has been widely used in many hydrological studies.

1.4 Objective of Study

The main objectives in this study are :

a) To determine flood water level along 4 km and 200m width of Sungai Bertam based on Sultan Abu Bakar (SAB) dam release using HEC-RAS.
b) To evaluate flood inundation area due to SAB dam released.

1.5 Importance of Study

The significant result of this study is able to delineate flooding areas along Sg Bertam and can provide awareness to local residents of flood hazard map.

1.6 Scope of Work and Limitation

The scope of work for this study are :

a) Topography map (Digital Elevation Model, cross section)
b) Discharge from dam
c) Land use map (channel, floodplain)

The input data were processed by using Arc-GIS to get secondary data. The ArcGIS helps in preparing the geometric data for importing into HEC-RAS and processing results exported from HEC-RAS for performing more calculations such as flood inundation and hazard mapping.

There are several limitations that present along the process of simulating SAB dam release.

a) SAB dam is under supervision of Tenaga Nasional Berhad (TNB). This research topic requires exact amount of dam released in order to simulate the water flow along 4km and 200m width of Sungai Bertam. However, due to limitations source of data, the simulation is done based on the water discharge from the scaled physical model of SAB dam.
b) The software HEC-RAS requires exact time of simulation and due to limitations source of data, the simulation time is done based on the trial and error of the output map.
c) Surface roughness is not considered in this study.

1.7 Dissertation Outline

The research project consists of five chapters and are divided as the following:

Chapter 1 : The first chapter gives a general introduction and a sample of the layout of the research.

Chapter 2 : Chapter two is the literature review that covers the following areas :

- Sungai Bertam
- Landuse Change and Urbanization
- Relationship between Sedimentation and Water Level
- Hydrologic Modelling
- Digital Terrain Model

Chapter 3 : Chapter three explains the methodology which covers the data collection and the process in order to get output result.

Chapter 4 : Chapter four which is the biggest chapter in this research shows the result of difference six simulation cases and the findings of the simulation analysis are interpreted as the map that produce flood hazard map.

Chapter 5 : Chapter five is the last chapter. It includes the conclusions and recommendations of the researcher.

CHAPTER 2

LITERATURE REVIEW

2.1 General

Climate change, population growth, land use change, deforestation and urban development are causing floods to become increasingly severe and more frequent in flood plains (Huong and Pathirana, 2013; Chakravarty et al., 2012). As suggested by Vijayalakhsmi and Jinesh (2010), the extreme flood events could cause severe damages to property, agricultural productivity, industrial production, communication networks and infrastructure, especially in the downstream parts of the catchments.

2.2 Sungai Bertam Catchment

According to Sewajje (2016), Sungai Bertam is the main river that flows through Cameron Highlands. It consists of small mountain stream through Brinchang which cutting across the Sultan Ahmad Shah Golf Club. Sungai Bertam gather its catchment as it passes through Tanah Rata. It flows right through Tanah Rata with Persiaran Dayang Endah following in its course (Teh, 2011; Rasul et al., 2015). Between north and south of Tanah Rata, Sungai Bertam passes through Parit Falls and Robinson Falls. From the forested area of Robinson Falls, Sungai Bertam reemerges at Robinson falls Hydroelectric Station and continues its course through terrace farmland west of Boh’s Fairley Tea Plantations (Gasim et al., 2010).

Lai (2013) says that Sungai Bertam flows through the farming village of Habu where it begins to widen substantially. The river looks more like a lake in front of the Lakehouse hotel. This lake is narrow once again as the river approaches Ringlet and is obscured by farmland (Toriman et al., 2010; Sisun et al., 2015). The east branch continues into Bertam Valley until it flows into Sungai Telom says Salleh (2012). Figure 2.1 shows the flow of Sungai Bertam including location of Bertam Valley.

Figure 2.1 : Map of Cameron Highland (Source : Wikipedia)

Bertam Valley is an agricultural village about 1.5km off Ringlet town, home to a population of local and migrant farmers that operate numerous flower nurseries and vegetable farms perched along the banks of Bertam River - a precarious locale when it floods from heavy rains bursting the Sultan Abu Bakar dam upstream (Khalik et al., 2013; Sidek et al., 2012).

SAB dam is located at Ringlet-Bertam Valley Road, Ringlet creates a man-made lake called Ringlet reservoir on the upstream of dam. Ringlet reservoir is situated on the Sungai Bertam in the mukim of Ringlet in the Cameron Highlands district (Sidek, 2012). Figure 2.2 shows the study area of Sungai Bertam in Cameron Highland.

Figure 2.2 : Sungai Bertam Downstream of SAB Dam

2.3 Landuse Change and Urbanization

(Bhatta, 2010; United Nations, 2014) mentioned that the speed of urbanization is increasing as people began to build towns and cities and now many urban areas are growing at a record pace. The effects on the local hydrologic system when a rural area is turned into an area full of housing developments, shopping centres, industrial buildings, and roads that are increased in rate of erosion and volume of sedimentation in river channel at downstream (USGS, 2016; Karmakar and Das, 2012; Stagl et al., 2014). Wang et al., (2015) wrote that consequently, due to shallow of river system, the frequency of flood events are also increased.

Based on Jansen et al., (2013) since the commissioning of the dam in the 1968 the dam has been classified as a large dam having a high downstream hazard. A recent study by Opatoyinbo et al. (2015) described that the once designated flood plain is now occupied by human population and agricultural activities. The original river reserve downstream at Sungai Bertam was gazetted in 1996 at 60 m from each bank providing at least a total river width for flood flows at 130 – 150 m^3/s. Present field inspection reveals that at certain location of only having 2-3 m of river width as shown in Figure 2.3.

Figure 2.3 : Residents and agricultural farms
along Sungai Bertam in Kg Bertam Valley (Source : Manaf, 2014)

According to Fondriest Environmental, Inc. (2014) in “Sediment Transport and Deposition” , anthropogenic factors, such as dams and altered land use will affect both the sediment load and sediment transport rate. There is a large number of published studies (e.g., Blanchard et al., 2010; Czuba et al., 2011) stated that urban areas, agricultural farms and construction sites will not affect the transport rate but the sediment load. These effects are indirect, as they require heavy rainfall or flooding to carry their sediment into the waterway.

Study by Brovkin et al. (2013) and Smith et. al. (2015) showed that anthropogenic land use is one of the leading contributors to excessive sedimentation due to erosion and runoff as their increases occur because of "disturbed sites" (logging, construction and farm sites). According to Native Vegetation Establishment and Enhancement Guidelines (2017) and NSW Government (2013), these sites often expose or loosen top soil by removing native vegetation thus cause loose soil is then easily carried into a nearby river or stream by rainfall and runoff. The impact of urbanization over flood are shown in Table 2.1.

Table 2.1 : Urbanization Impacts over Flood (Miguez and de Magalhaes, 2011)

Natural vegetation removal	Higher runoff volumes and peak flow, greater flow velocity, increased soil erosion and consequent sedimentation in channels and galleries.
Increasing of impervious rates	Higher runoff volumes and peak flow, less surface depression detention and greater velocities of flow.
Construction of an artificial drainage net	Significant increasing of flow velocities reduction of time to peak.
River banks and floodplain occupation	Population directly exposed to periodic inundation at naturally flooded areas, the implication of extension, as there is less space to overbank flows and storage.
Solid waste and wastewater disposal on drainage net	Water quality degradation, diseases, drainage net obstruction and channel sedimentation.

Table 2.1 discuss about the causes and effects of urbanization which result in flood. One of the causes is natural vegetation removal. Based on study done by Hameed

(2017) and New Jersey Stormwater Best Management Practices Manual (2016), the effect of urbanization are higher runoff volumes and peak flow, greater flow velocity, increased soil erosion and consequent sedimentation in channels and galleries. Natural vegetation collect and store rainfall in soil column and as they are removed, the soil has less capacity to store rainfall. Another impact of urbanization is less surface depression detention and greater velocities of flow. This happen because of increasing of impervious rates (O’Driscoll, 2010). Roads and buildings have replaced most of the watershed surface and cause the rainfall to flow directly into the stream very quickly. Impervious area has decrease and rainfall cannot infiltrate into soil.

2.4 Relationship between Sedimentation and Water Level

Adeogun et al. (2015) and Bussi et al. (2013) found that sedimentation that occur due to deforestation and natural vegetation removal on the upstream of a catchment will eventually flow into dam and settled at the bottom of the dam. As time goes by, the increasing volume of sediment will affect the dam water level. This will cause the water level of dam to increase (Kondolf, 2014).

Previous research from Atmodjo and Suripin (2012), indicates that efforts to reduce the decrease of reservoir capacity because of the sedimentation, among others is preventing sediment inflow into the reservoir. This can be done by controlling upstream area, for example: upstream conservation, check dam construction, to build a diversion channel. Another effort is by removing the sediment which has already been in or settled inside the reservoir, namely by hydraulic flushing and dredging (Ji et al., 2011; Jyoti and Warudkar, (2016).

Analysis of reservoir sedimentation data shows that in just 35 years of operation since construction, 34% of its storage was already taken up by sediments which left the reservoir with a balance lifespan of 10 years. This represents a storage loss of 34.3% in 1999 and increased to 40% in 2005 and 45% in 2010. The long term annual capacity loss or sedimentation rate of Ringlet Reservoir in 1965 was estimated at 25,000 m^3/yr (Choy and Mohamad, 1990; Long, 1992) which has increased to an average of almost 6 fold to 139,712 m3/yr in 2008 (Jansen et al., 2011). Based on the bathymetric survey carried out in 2008, the longitudinal profile of the reservoir is plotted to show the elevation of the bed.

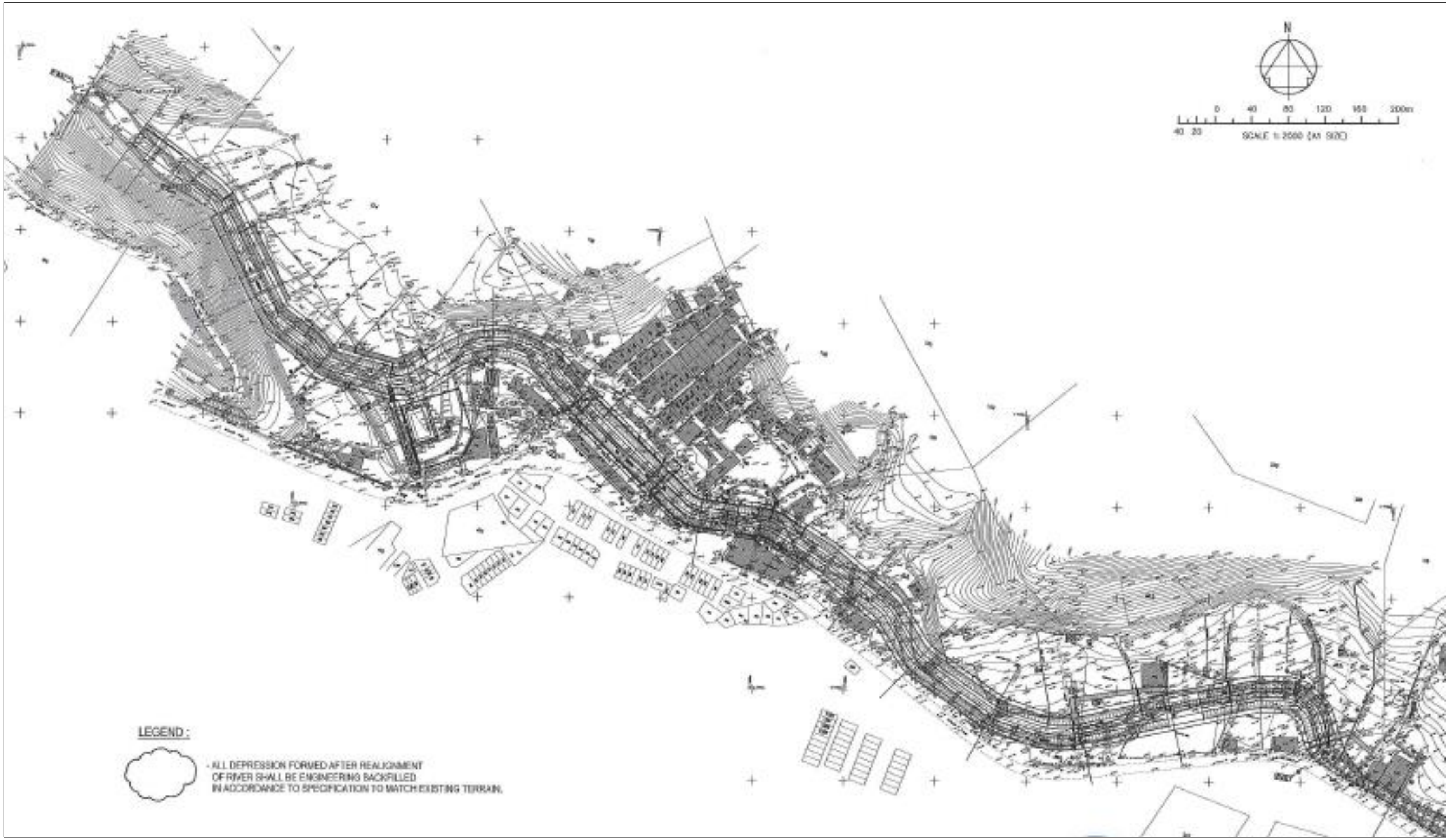


Figure 2.4 : Longitudinal Profile of Sungai Bertam

The reduction in storage capacity forces the requirement for control spilling (Abrishamchi et al., 2011). It is observed that as the reservoir level increases gradually, control spilling is initiated at an elevation of 3511 ft (1070.15 m). This operation is important to prevent a sudden surge of flood water flowing downstream in which the titling gate operates automatically when the level reaches 3513 ft (1070.76 m).

2.5 Sultan Abu Bakar Dam Release

Table 2.2 : The Control Discharge Scenarios of SAB Dam

Discharge, m^3/s	Action
10	When necessary
25-30	Full opening of hollow jet valve at 1070.76 m
50-100	Full opening of tilting gate located in spillway when water level reached 1071.07 m
230	Two radial gates in operation at 1071.09 m
300	All gates are in operation at 1071.37 m

2.6 Hydrologic Modelling

Al-Sabhan et al. (2003) defined the hydrological model is a mathematical representation of the flow of water and its constituents on some parts of the land surface or subsurface environment. Two major types of hydrologic models are primarily used for hydrologic prediction and for understanding hydrologic processes. Stochastic models play an important role in many engineering sciences and the processes quantifying dynamic relationships of sequence of an event (Ditlevsen and Samson, 2013). Sorlin (2013) and Cuddington et al. (2013) suggested that processed-based models is the mathematical representation of processes characterizing the functioning of well-delimited biological systems of fundamental interest. This types of models consist of a set of ordinary or partial differential equations. According to Pechlivanidis et al. (2011) hydrological modelling has the ability to do a mathematical simulations under any conditions and the output result is also decided by the researcher. Thus, researcher has a flexible options in order to do a simulation. Overall, Peel and Bloschl (2011) wrote that hydrologic modelling provides numerous benefits such as it explains the physical interaction, provides decision support to resources and hazard management and it guides experimentation and research for presenting complex ideas in accessible manners.

2.6.1 Hydrologic Engineering Centre River Analysis System (HEC-RAS)

The Hydrologic Engineering Centre’s River Analysis System, or HEC-RAS, is a widely-used one-dimensional method for studying stream reaches (Parsa et al., 2016). HEC-RAS is used within multiple water management groups throughout the United States for dam failure analyses within regulated catchments. Halgren (2011) presented that HEC-RAS also allows river forecasters to use recorded data to model river reaches for daily flow approximations.

As mentioned previously, HEC-RAS can be been used for a variety of types of river simulation studies, and for steady, unsteady, and mixed flow regimes (Agrawal and Regulwar, 2016). In the past, Iosub and Oana (2015) wrote that the program has been used for dam failure analyses, flood mapping, completing flood frequency studies, and to simulate everyday flows through a reach. Studying typical daily flow (low flow) conditions in a river allows a user to better understand typical elevations and flow patterns within a stream (Borah and Dickson, 2014). HEC-RAS also has the capability to be used with other software and programs, including the HEC Data Storage System (HEC-DSS) and GIS applications, among others (Sharkey, 2014).

Study done by Gharbi et al. (2016) showed that HEC-RAS uses the standard direct step method for water surface profile calculations, assuming that flow is one-dimensional, gradually varied, and steady. The program computes water surfaces as either a subcritical flow profile or a supercritical profile. Mixed subcritical and supercritical profiles are not computed simultaneously. If the computations indicate that the profile should cross critical depth, the water surface elevation used for continuing the computations to the next cross section is the critical water surface elevation.

Hicks and Peacock (2005) analysed the suitability of using HEC-RAS for a flood forecast and determined it to be appropriate in this application. In the case of a dam failure, models demonstrate the flows that could be witnessed if the dam failed. Much documentation is available about dam failure, but these scenarios are very different from low flow situations due to the massive amounts of water involved. Thus, low flow scenarios and dam failure to have very different objectives, parameters, and results as presented by Johnson (2012).

Table 2.3 : Detail Literature Review on HEC-RAS

Author	Study	Finding
Gharbi, 2016	Comparison of 1D and 2D Hydraulic Models for Floods Simulation on the Medjerda Riverin Tunisia	The water level obtained by HEC RAS (1D), MIKE 11 (1D), and TELEMAC 2D are compared and the flow maps obtained by HECGeoRAS (1D) and TELEMAC 2D are compared
Iosub and Oana, 2015	The Use of HEC-RAS 1modelling in Flood Risk Analysis	HEC-RAS is a software for one-dimension or two-dimensions simulations of the evolution of a flood, which could have a stable or an unstable flow rate, sediment transport, change of the river bed etc.
Agrawal and Regulwar, 2016	Unsteady Flow Analysis of Lower Dudhana River using HEC-RAS	Agrawal carried out steady flow analysis over Dudhana River and remedies based on steady water analysis for study area was recommended

Table 2.3 discuss on previous research done by using software HEC-RAS. In study of “Unsteady Flow Analysis of Lower Dudhana River using HEC-RAS” wrote by Agrawal and Regulwar stated that for flood forecasting and flood plain mapping, various hydrodynamic models have been developed and applied. As a result, steady flow analysis over Dudhana River and remedies was carried out based on steady water analysis.

2.6.2 Input and Output Data of HEC-RAS

The geometric data required to define in HEC-RAS includes:

I. Cross-section data

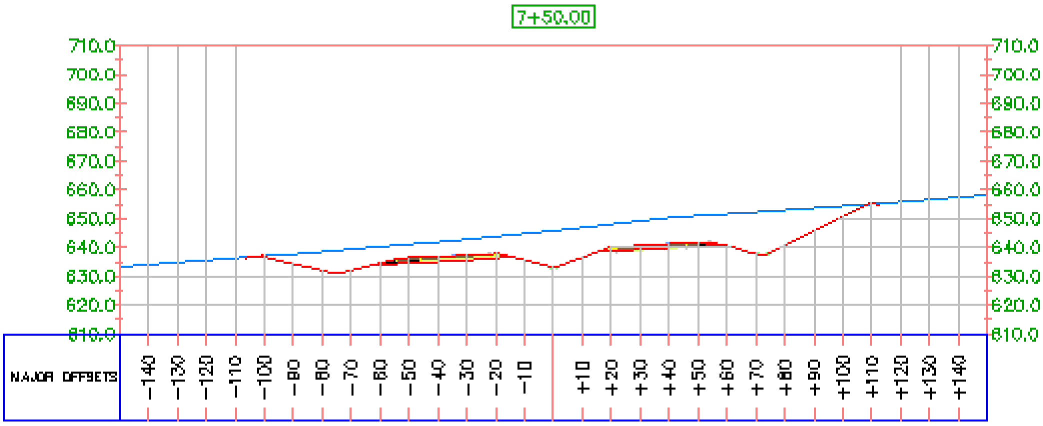


Figure 2.5 : Schematic Cross Section for HEC-RAS input

The first step in developing the HEC-RAS model was to create a geometry file. It describe the stream network, junctions, cross section station and geometries, as well as the downstream reach lengths of the channel and overbanks for each cross section. When two or more streams come together or split apart, junctions were used to note the locations. Each cross section station defines the location of the cross section distance in feet measured from its confluence along the respective stream. The cross section geometries are described by station and elevation points that portray the layout of the stream channel and floodplain. The downstream reach lengths of the channel define the distance to the next downstream cross section measured along the stream. The downstream reach lengths of the overbanks define the distance to the next downstream cross section measured along the path of the center of mass for the overbank flow.

II. Reach lengths (measured between cross sections)

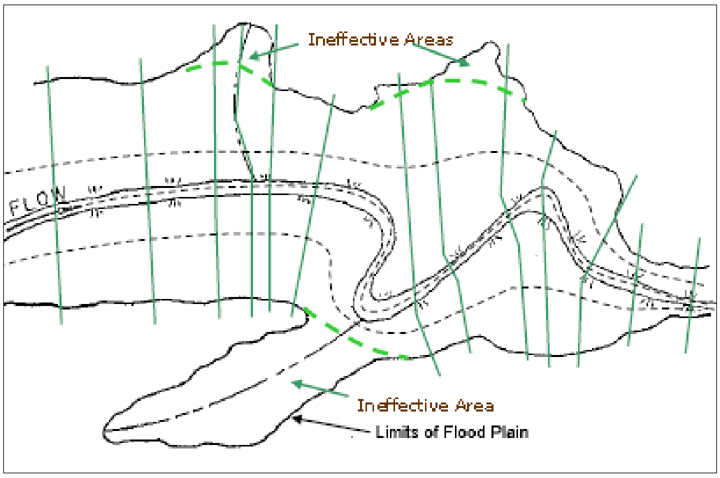


Figure 2.6 : Reach Lengths of a River as Geometry Input Data

III. Stream junction information (Reach lengths across junctions and tributary angles)

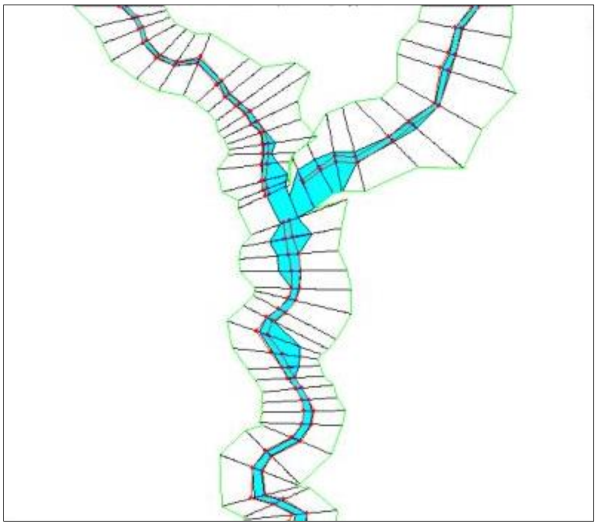


Figure 2.7 : 1D Stream Junction

IV. Invert Level

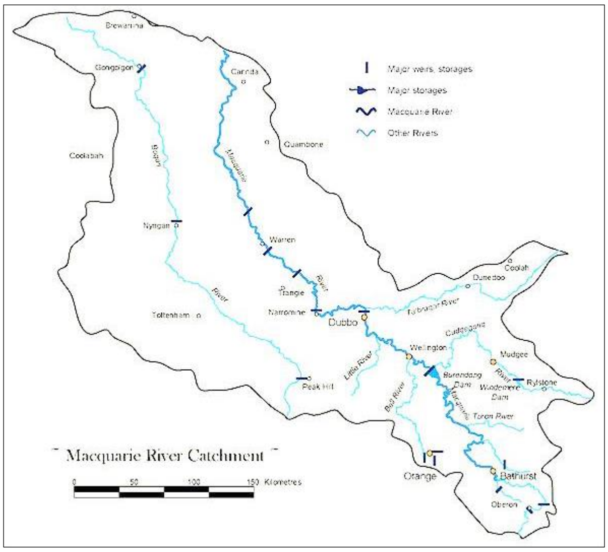


Figure 2.8 : Flow of Water from Upstream to Downstream

V. Digital Terrain Model (DTM)

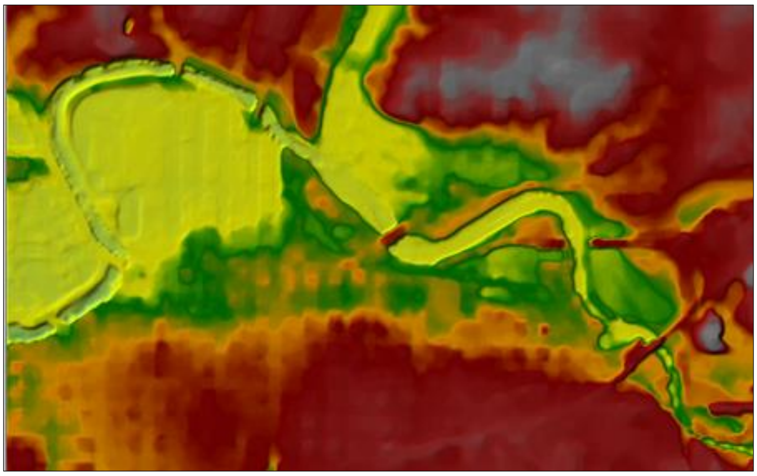
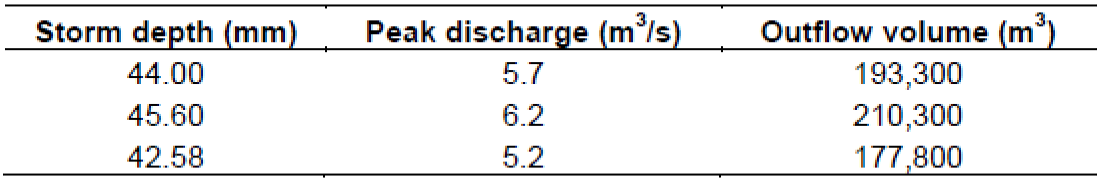


Figure 2.9 : Example of DTM data

VI. Dam release



Storm depth (mm)	Peak discharge (m^3/s)	Outflow volume (m^3)
44.00	5.7	193,300
45.60	6.2	210,300
42.58	5.2	177,800

Figure 2.10 : Water Released from Dam

After the simulation was done, the output can be obtained in terms of tables, figures and values. The output are longitudinal profiles, profile plots, perspective plot, flow and stage hydrograph and output tables. For longitudinal profiles, the output is as shown in Figure 2.11

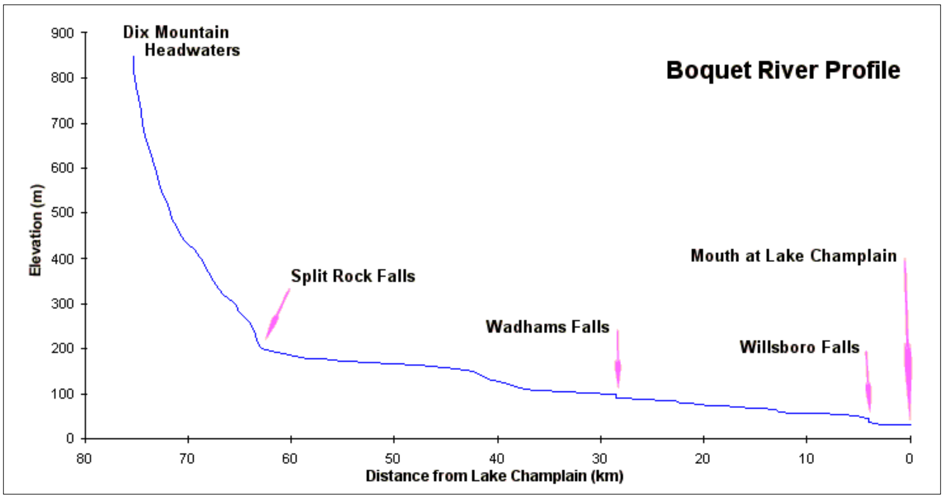


Figure 2.11 : Example of Longitudinal Profiles in Boquet River Profile

Longitudinal profiles allows the user to view the water surface profiles along the length of the channel for each flow profile. Figure 2.12 shows the other output can be obtained which is profile plots.

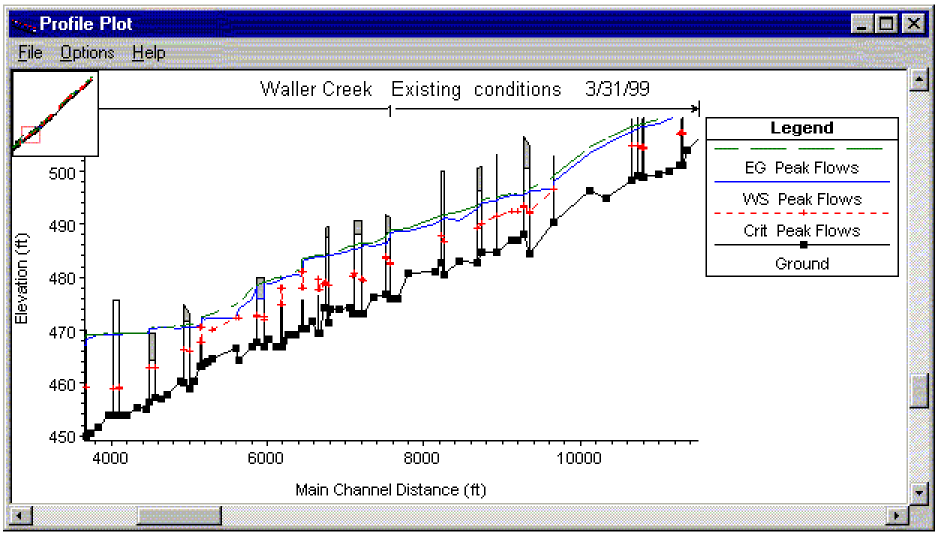


Figure 2.12 : Profile Plots from HEC-RAS software

Figure 2.10 indicates that the user can view the profiles of various parameters such as velocity, flow and depth in the longitudinal direction. For perspective plot, the output is as in Figure 2.11.

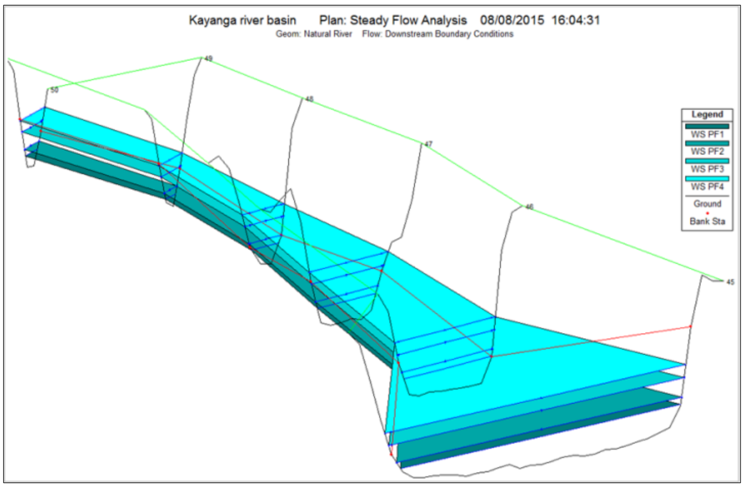
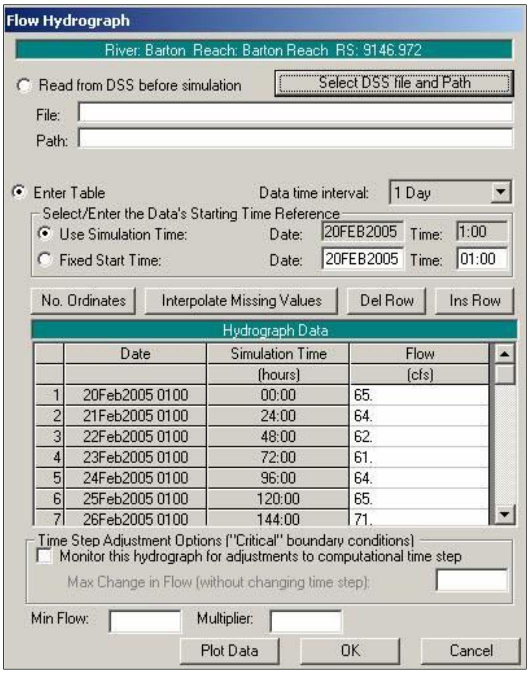


Figure 2.13 : Perspective Plot of Kayangan Basin in Steady Flow Analysis

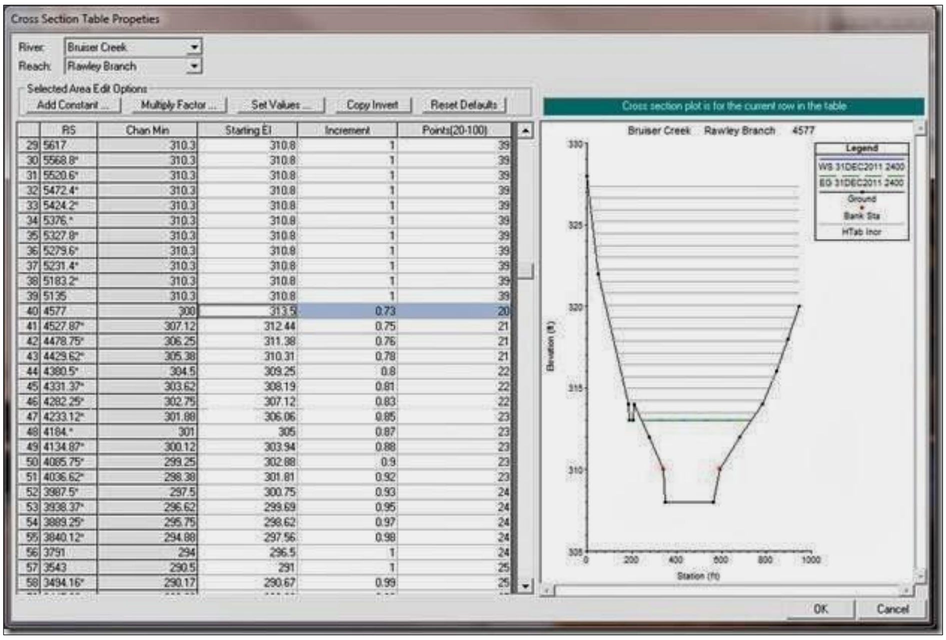
From the perspective plot, user may view a 2D perspective view of the river system and the water surface profiles. This helps in getting a clearer view of the profile. Flow and stage hydrograph may act as input or output data in HEC-RAS software.



	Date	Simulation Time (hours)	Flow (cfs)
1	20Feb2005 0100	00:00	65.
2	21Feb2005 0100	24:00	64.
3	22Feb2005 0100	48:00	62.
4	23Feb2005 0100	72:00	61.
5	24Feb2005 0100	96:00	64.
6	25Feb2005 0100	120:00	65.
7	26Feb2005 0100	144:00	71.

Figure 2.14 : Inflow Hydrograph to Simulate Dam Release

Based on Figure 2.14, user may visualize flow and stage hydrographs at each cross section for unsteady flow simulation. Other that hydrograph, an output tables also can be obtained from the simulation. Figure 2.15 shows the cross section table properties of HEC-RAS software.



	RS	Chan Min	Starting El	Increment	Points(20-100)
29	5617	310.3	310.8	1	39
30	5568.8*	310.3	310.8	1	39
31	5520.6*	310.3	310.8	1	39
32	5472.4*	310.3	310.8	1	39
33	5424.2*	310.3	310.8	1	39
34	5376.*	310.3	310.8	1	39
35	5327.8*	310.3	310.8	1	39
36	5279.6*	310.3	310.8	1	39
37	5231.4*	310.3	310.8	1	39
38	5183.2*	310.3	310.8	1	39
39	5135	310.3	310.8	1	39
40	4577	300	313.5	0.73	20
41	4527.87*	307.12	312.44	0.75	21
42	4478.75*	306.25	311.38	0.76	21
43	4429.62*	305.38	310.31	0.78	21
44	4380.5*	304.5	309.25	0.8	22
45	4331.37*	303.62	308.19	0.81	22
46	4282.25*	302.75	307.12	0.83	22
47	4233.12*	301.88	306.06	0.85	23
48	4184.*	301	305	0.87	23
49	4134.87*	300.12	303.94	0.88	23
50	4085.75*	299.25	302.88	0.9	23
51	4036.62*	298.38	301.81	0.92	23
52	3987.5*	297.5	300.75	0.93	24
53	3938.37*	296.62	299.69	0.95	24
54	3889.25*	295.75	298.62	0.97	24
55	3840.12*	294.88	297.56	0.98	24
56	3791	294	296.5	1	24
57	3543	290.5	291	1	25
58	3494.16*	290.17	290.67	0.99	25

Figure 2.15 : Example of Output Table of Cross Section Properties