# CHANNELIZATION IN A REACH OF BEAS RIVER - A CASE STUDY

A DISSERTATION
Submitted in partial fulfillment of the
requirements for the award of the degree
of
MASTER OF TECHNOLOGY
in
WATER RESOURCES DEVELOPMENT
(CIVIL)

By
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## CANDIDATE' S DECLARATION

I hereby declare that the dissertation titled "Channelization in a reach of Beas River – A case study" being submitted in partial fulfillment of the requirements for the award of degree of Master of Technology in Water Resources Development (Civil) to Water Resources Development Training Centre (WRDTC), Indian Institute of Technology (IIT), Roorkee is an authentic record of my own work carried out during the period of 24th July, 2003 to the date of submission under the supervision and guidance of Dr. Nayan Sharma, professor, WRDTC, IIT Roorkee.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

Place: Roorkee

Date: 29th......June, 2004

(Rabinath Babu Shrestha)
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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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## EXECUTIVE SUMMARY

Beas River at Kullu, in the Himachal Pradesh of India, is a perennial snow fed mountainous river. A small township called Bhuntar is located along the banks of this river. A domestic airport is situated at Bhuntar along the right floodplain of the river. Every year the flood in the river inundates a larger area and frequently inundates the airport often disrupting the air services. To mitigate the frequent recurring flood problem, the airport authority and the flood control department of Kullu district have been carrying out flood protection measures but the problem has not been solved yet. The flood of 1995 severely damaged the existing bank protection works in the river and also damaged the airport runway, interrupting the air service for a long time.

Kullu is an attractive tourist destination and the number of tourists is increasing every year. The existing runway is 1128 m long and 30.5 m wide and is suitable for landing of small 16-18 seated aircraft only. So the airport authority is planning to extend the runway to increase capacity for landing of bigger aircraft. Presently the airport authority has decided to extend the existing runway length by 1000 m and to increase the width to 200 m (100m on either side from the centerline of the runway).

In this dissertation titled "Channelization in a reach of Beas River- A case study" efforts are being made to analyse the hydraulic and morphological behavior of Beas River and to design a complete channelization work to accommodate the design flood and the extended runway.

The study reach starts from a steel bridge, located near the confluence of the Parbati River and the Beas River, to a length of 3.27 km downstream. The latest survey map of 2004 with a contour interval of 0.50 m has been used to gather required geometric data. The river is very steep with the average slope of about 0.0091. The width of the river varies from 40 m to 170 m. The bed material consists of silt, sand, cobbles and boulders. The gradation of the bed material has been determined by the Wolman sampling method. The grain-size distribution curve of the bed material shows the median size is equal to 32 mm.

The annual maximum flood discharge of Beas River for the period of 1965-1995 has been collected for flood frequency analysis. Floods of 2 year, 100 year, 500 year and 1000 year return period have been calculated for normal, lognormal, extreme value type-1 and log-pearson type-3 distributions. The variations of discharge for different distribution is significant, so the chi-square test has been carried out to find out which theoretical distributions is closest to the sample data. It is found that the sample data is closest to the log-pearson type-3 distribution. For this distribution, the 2-year, 100 year, 500 year and 1000 year flood discharges were found to be 777.40, 2783.19, 4671.52 and 5853.07 cumecs respectively. However for the design purpose the values are rounded to 800, 2800, 4700 and 5900 cumecs respectively.

The first and foremost important step for planning and design of any river channelization project is to determine the water surface profile for given flow in the given channel geometry. This can be achieved by employing various simulation models developed for this purpose. In the present study HEC-RAS and HEC-6 have been used for fixed bed simulation and HEC-6 for mobile bed simulation. In the fixed bed model, the bed and the banks are assumed to be fixed while in the mobile bed model it is assumed that the bed and the banks may be eroded or deposited with sediment. Thus to run hec-6 in mobile bed mode sediment data is required in addition to geometric and hydrologic data.

In this study roughness coefficient has been taken as 0.045 for the left and the right overbank and 0.04 for the channel. Similarly, the coefficients of expansion and contraction have been taken as 0.3 and 0.1 respectively. The stage discharge curve generated at the downstream end of the study reach has been used as the downstream boundary condition for the simulation. The results obtained, from both the above software are quite matching for fix bed application. However, the water surface profile obtained from HEC-6 for mobile bed application differs to some extent, as anticipated, with that calculated for fix bed application. This is due to the change in bed level as a result of scour or deposition of the bed material. Both the fix bed and the mobile bed simulation shows that the channel section is not adequate to carry the design flood of 4700 cumecs throughout reach under investigation. Earthen dikes shall be provided to prevent spillage of water over the banks. The dike shall be provided with a side slope of

2 horizontal in 1 vertical and it's top shall be kept 1.5 m above the design water surface profile. The top width of the dikes shall be kept 3.0 m wide to allow for vehicular movement during construction and subsequently for inspection and maintenance.

The computations of stable channel parameters show that the stable channel width, depth and longitudinal slope are respectively 120 m, 3.5 m and 1/270. So the channel has been designed with a trapezoidal section of 120 m bottom width with side slope of 2 horizontal in 1 vertical. However, the stable longitudinal slope could not be provided in the channel, as the existing channel is much steeper than it with the value of about 1/110. To accommodate this stable slope in the channel it has to be designed with longer meandering length, which will be very uneconomical. So the channel has been designed with the existing slope of 1/110 from chainage 0+000 to 1+900 and then after the diversion channel has been designed with the available slope of 1/99 (=0.01007). This will lead to instability of the channel in its natural condition. It is expected that the concrete blocks designed for slope protection will strict the channel in its designed course.

As already mentioned, to accommodate the extension of the runway the existing channel has to be diverted along a new diversion channel. The diversion channel has been designed as a smooth cosine curve instead of a straight channel because of the inherent instability of the later. A computer program has been developed in fortran to compute co-ordinates of points along the cosine curve for given minimum radius, $R_{min}$ and curve length, L. A cosine curve for the given field situation is designed by trial assuming different values of $R_{min}$ and L within certain prescribed limits.

A diversion channel comprising of two cosine curves with $R_{min}$ equal to 400 m and L equal to 1750 m and $R_{min}$ equal to 500 m and L equal to 1600 m has been proposed for the present case. The existing channel of 1800 m length shall be replaced by the diversion channel of length 1700 m. In this case the reduction in channel length by diversion of the existing channel is not significant, so a pilot channel may not enlarge satisfactorily. Further, it is not possible to allow sufficient time for development of channel to ultimate section. So the full section of the channel will be excavated before diverting the flow into it.

Three different types of cover layer, namely the stone rip-rap, the gabion mattress and the cement concrete blocks have been designed for protection of the embankment slope. The nominal thickness of stone rip-rap, gabion mattress and cement concrete blocks are found to be 1.80 m, 1.25 m and 0.80 m. However, the cement concrete blocks have been recommended for protection of the embankment slope as it requires less frequent maintenance in comparison to that for the stone rip-rap and the gabion mattress.

A tentative cost estimate has been prepared for the channelization works. It includes the cost of excavation of the design channel section from chainage 0+000 to 1+900 and a diversion channel from chainage 1+900 to 3+600. It also includes the cost of dikes and P.C.C. concrete block for slope protection works. It also includes the cost of earthworks in filling for construction of airport runway and also includes the cost of relocation of about 2.5 km of Garsa gravel road. It however does not include the cost of runway and the cost of land acquisition and compensation. The cost of channelization for extension of the runway comes out to be Rs. 608,140,074.77. The total project cost with 5 % contingencies and workcharge staff comes out to be Rs. 638,547,078.50.

There is another option to accomplish the extension of runway without channelization of the existing river. This option requires construction of two bridges at the river crossings and the extended runway shall be placed over the bridges. The maximum depth of scour around the bridge piers has been calculated for this case and is found to be 4.7 m below the river bed level. The hydrodynamic force acting horizontally on the bridge piers has also been calculated and is found to be 183.31 KN/m.

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# CHAPTER-1

## INTRODUCTION

### 1.1 STATEMENT OF THE PROBLEM

Beas River in the Himachal Pradesh of India is a perennial snow fed mountainous river. A small township called Bhuntar is located along the banks of this river. A domestic airport is situated at Bhuntar along the right floodplain of the river. Every year the flood in the river inundates a larger area and frequently inundates the airport often disrupting the air services. To mitigate the frequent recurring flood problem, the airport authority and the flood control department of Kullu district have been carrying out flood protection measures but the problem has not been solved yet. The flood of 1995 severely damaged the existing bank protection works in the river and also damaged the airport runway, interrupting the air service for a long time.

Kullu is an attractive tourist destination and the number of tourists is increasing every year. The existing runway is 1128 m long and 30.5 m wide and is suitable for landing of small 16-18 seated aircraft only. So the airport authority is planning to extend the runway to increase capacity for landing of bigger aircraft. Presently the airport authority has decided to extend the existing runway length by 1000 m and to increase the width to 200 m (100m on either side from the centerline of the runway).

In this dissertation titled "Channelization in a reach of Beas River - A case study" attempt has been made to analyse the hydraulic and morphological behavior of Beas River and to design a complete channelization work to accommodate the design flood and the extended runway.

## 1.2 DESCRIPTION OF THE STUDY AREA

The study area consists of a reach of Beas River of length 3.27 km downstream of the steel bridge at Bhuntar of Kullu district in Himanchal Pradesh. It is situated at the latitude of 77° 9' E and 31° 53' N. The Beas River is a perennial and snow fed river. It originates from Beas Kund situated within the Himalayan range about 20 km upstream from Nehru Kund. The study reach of the Beas River is generally characterised by steep slope, high flow velocity and coarse bed material. The left bank of the river is higher than the right bank in the upstream portion of the study reach; hence there is often inundation at the right floodplain during flood.

The Kullu-Manali national highway runs parallel to the right bank and a motorable gravel road, called Garsa road along the left bank of the river. A steel bridge has been constructed just down stream of the confluence of the Parbati and the Beas River connecting the two roads. The study reach starts from this bridge to a length of 3.27 km downstream. There is an old suspension bridge about 600 m downstream of this steel bridge and a domestic airport further 200 m downstream of this suspension bridge at the right floodplain.

## 1.3 OBJECTIVES OF THE STUDY

The main objective of this study is to design a complete channelization work for the Beas River at Bhuntar to accommodate the design flood and the extended runway. Other objectives of this study are as follows:

- To study the general behavior of river including river morphology and sediment transportation.
- To study different methods of river channelization and their effects in terms of hydraulics and morphological changes.
- To carryout the flood frequency analysis and workout the design flood.
- To determine the water surface profile and hence to check the adequacy of the existing channel section against the design flood.
- To workout the stable channel parameters and suggest a suitable channel section to convey the design flood, in case the existing section is inadequate to do so.

- To design a smooth cosine curve for the diversion of the existing channel to accommodate the extended runway
- To design various types of cover-layer for riverbank protection and recommend a suitable one for the present case.

## 1.4 METHODOLOGY

To study and analyse the hydraulic and sediment transportation behavior of river and to design suitable control measures about 3.27 km of Beas River along Bhuntar Bazaar near the airport of Kullu district of Himanchal Pradesh was selected as a case study. The detail methodology adopted to meet the desired objectives of the study is explained below.

### 1.4.1 GEOMETRIC DATA

The latest survey map of 2004 with a contour interval of 0.50 m has been used to gather required geometric data. The cross-sections were obtained at 100-200 m intervals. The river width, depth and the water surface level were noted and the reach length between successive cross-sections measured along the left bank, right bank and along the channel. The variation of longitudinal slope of Beas River along its length is given in table-4.1.

### 1.4.2 SEDIMENT DATA

To determine the flow resistance, sediment transport rates and hence to predict the bed level changes, we require the gradation of bed and suspended sediment. For collection of a representative bed sample, the Wolman sampling method is generally adopted for the gravel bed river like Beas. Then to determine the gradation of the collected sample, manual measurement are carried out for the coarse material and the sieve analysis is carried out for the fine material. The grain size distribution table and the gradation curve used for this study are given in table-4.8 and fig.-4.1 respectively. The available suspended load record of Beas River for the period of 1985-1995 is given in appendix-12.

### 1.4.3 HYDROLOGIC DATA

The annual maximum flood discharge of Beas River for the period of 1965 -1995 is given in table-4.2. The frequency analysis can be carried out with these flood data and floods of different recurrent intervals can be found. To determine the value of Manning's roughness coefficient different methods suggested by Bray, Meyer, Strickler and Limerinos can be used. The stage discharge data required for simulation of water surface profile can be generated from the available cross-sections, longitudinal slope and roughness coefficient using Manning's formula.

### 1.4.4 WATER SURFACE PROFILE SIMULATION

The first and foremost important step for planning and design of any river channelization project is to determine the water surface profile for given flow in the given channel geometry. This can be achieved by employing various simulation models developed for this purpose. In the present study HEC-RAS and HEC-6 have been used for fixed bed simulation and HEC-6 for mobile bed simulation.

## 1.5 ASSUMPTIONS AND LIMITATIONS OF THE STUDY

Some of the assumption and limitations of the study are as follows:

- The detail cross-sections of the river actually measured in the field was not available, so the cross-section obtained from the contour map of the study area has been employed for the present study.
- The flood frequency analysis has been carried out with the available 31 years annual maximum flood. If relatively longer data were available the predicted floods would have been more realistic.
- The roughness coefficient varies along the length of the channel and it also varies with flow and season. However due to non-availability of such detail data, the roughness coefficient has been assumed to be constant throughout the channel for different flows.
- Similarly, the gradation of bed material varies along the channel but it has been assumed to be constant throughout the study reach.

## 1.6 ORGANIZATION OF THESIS

This thesis has been organized in the following five chapters and appendixes:

**CHAPTER-1, INTRODUCTION:** In this chapter the statement of the problem, description of the study area, objectives of the study, methodology and assumptions and limitations of the study have been presented.

**CHAPTER-2, REVIEW OF LITERATURE:** In this chapter the basic concepts of river channelization such as methods of channelization, planning and design of channelization works, effects of channelization, recommendation to minimise adverse effects of channelization etc. have been explained. Additionally some theoretical concepts of gravel bed stream have also been included in this chapter.

**CHAPTER-3, DESCRIPTION OF MODELS USED:** The basic principles and methods of simulation with HEC-RAS and HEC-6 have been presented in this chapter.

**CHAPTER-4, ANALYSIS AND DESIGN:** This chapter comprises of two parts. In the first part analysis of data for computation of design flood, generation of ratting curve, simulation for water surface profile using HEC-RAS and HEC-6 etc. have been covered. Similarly, in the second part design of cosine-generated curve for alignment of new channel and the design of earthen embankment, revetments launching apron and filter etc. have been presented. A tentative cost of the channelization works has also been worked out in this chapter.

**CHAPTER-5, CONCLUSIONS AND RECOMMENDATIONS:** The final results of the design and analysis along with some recommendations have been given in this final chapter.

**APPENDIX:** Input and output of HEC-RAS and HEC-6 have been included at the end of this thesis. The computer programme (in fortran) for design of cosine generated curve has also been given in the appendix.

CHAPTER-2

# REVIEW OF LITERATURE

## 2.1 THEORETICAL CONCEPTS OF GRAVEL BED RIVER

### 2.1.1 GENERAL

A study on behavior of rivers is essential before carrying out any engineering works in a river. Different rivers and different reaches of the same river have different channel patterns, channel cross-section shape, bed and bank material, slope and valley characteristics. In general the longitudinal slope of a natural river shows a continual decrease along its length. Similarly, the size of the bed material in a stream is found to decrease continually along the length of the stream. Thus streams can be categorised into sand-bed, gravel-bed, boulder-bed and cobble-bed streams. However, such detail categorisation is not significant as far as the process of sediment transport, armoring, resistance to flow and river training analysis are concerned. Hence, streams are broadly classified into sand-bed rivers and gravel-bed rivers, which include all rivers with coarse bed material including cobbles and boulders.

The gravel-bed rivers are mountain rivers, which are generally found near the head of most of the river system in upland areas. They are steeper, possess greater energy to transport sediment, generally have higher turbulent velocities and have the energy to maintain the channel basically in its original form unless flows are dramatically reduced. They possess a surface bed layer that is considerably coarser than the sub-surface material, while the sand bed streams are characterised by uniformity of material in the vertical direction. The existence of such a layer plays an important role in the sediment transport mechanism of gravel bed streams.

The median diameter, $D_{50}$ is often adopted as the bed size to distinguish gravel rivers from the sand bed rivers. Chang (1980) defines gravel bed streams as those, which have bed materials with a median diameter exceeding 16 mm. According to Bray (1982) the river containing $D_{50}$ size more than 2 mm in the bed material is categorised as gravel-bed river. In particular, gravel-bed rivers are characterised by macro bed forms, pools and riffles and the general absence of smaller scale ripple, dune and antidune features.

According to Simons the gravel-bed rivers are different from the sand-bed rivers in the following aspects:

## I) VARIATION IN BED MATERIAL SIZE

The bed material of gravel bed rivers is coarser than that of sand bed rivers. The sediment size in sand bed rivers ranges from 0.0625 mm to 2.0 mm where as in gravel bed river it ranges from 2 mm to 100 mm or more. With respect to grain size variability, sand is normally well sorted but since sand and fine particles are also present in gravel-bed rivers, gravelly sediment are poorly sorted. These characteristics of the gravel-bed rivers make them behave differently compared to sand-bed rivers in respect of flow resistance, sediment transport, armor layer formation and bed packing. Thus, in case of gravel-bed rivers, sediment transport calculation can not always be based on single characteristic sediment size (such as median diameter) and sediment routing may have to be carried out for each size fraction in turn.

## II) VARIATION IN CHANNEL SLOPE

The longitudinal slope of a gravel bed channel is generally steeper than that of sand-bed channel. The slope of the stream can be co-related with the median diameter of the bed material forming the stream; the steeper the river the coarser the material on the bed of the channel.

## III) VARIATION IN BED ARMORING

It is not possible to form an effective armor in sand bed rivers, where as in gravel-bed rivers, due to sorting of material in the transport process, fairly significant armoring may occur. However the armoring observed may not be continuous across the full width of the riverbed. As such the armoring is not going to be as effective in controlling the vertical elevation of the bed as might be imagined. Nevertheless, the size of the material and the formation of armoring can play a significant role in terms of influencing the magnitude of transport through the system, particularly when considering sizes smaller than those, which form the bed or the bed armor.

## IV) VARIATION IN BED FORMS

In sand bed rivers various bed forms such as ripples, dunes, standing waves and antidunes are commonly observed. But in gravel bed rivers, ripples do not form. However, at high velocities, when gravel is transported, it is possible to form typical dunes in a gravel-bed river. Conventional ripples and dunes are not found under any of the usual circumstances in boulder-bed channels.

## V) VARIATION IN BAR FORMS

In sand bed rivers various bar forms are commonly encountered. The most common types are the point bars which form on the inside of bends, alternate bars which are a precursor of meandering in many systems, middle bars that subsequently may become islands where the river is exceptionally wide and tributary bars where steep tributaries carrying heavy sediment loads deposit material in the mainstream at the confluence. All these bar forms may also be observed in gravel bed rivers. However, in cobble and boulder bed channels it is unusual to find middle bars.

## VI) VARIATION IN SEDIMENT TRANSPORT

In gravel-bed rivers, there are long periods of low flow with no sediment transport, during which the sediment is able to settle, interlock and generally become consolidated. However during the periods of high flow, movement of coarse material occurs. But in sand-bed rivers sediment transport occurs at almost all flows. In gravel-bed channels the bed load accounts for larger proportion of the total load in comparison to sand-bed channels. The presence of wash load significantly affects the geomorphic and hydraulic response of sand-bed channels. Large concentration of wash load in sand-bed rivers can significantly alter the viscosity, reduce the fall velocity and increase the ability of the river to transport sand. Conversely in gravel bed rivers even though the wash load significantly affects the viscosity of the water, it has small effect on the movement of the bed material.

## VII) VARIATION IN BED SCOUR AND FILL

In sand bed rivers the rate of change of bed elevation can be both large and rapid. This may be due to downstream movement of a large bar or local aggradation or degradation resulting from natural or man-induced changes. On boulder-bed rivers, bed elevation changes can be significant, but they are not usually as large as in sand-bed rivers. These changes are usually associated with large events, ice-jams that have failed, dam breaches and major storms.

## VIII) VARIATION IN PLAN FORMS

Sand-bed rivers can be meandering, transitional or braided, and they may change dramatically from one plan form to another as significant changes in discharge are experienced. Gravel-bed rivers have a much greater tendency to be transitional, braided or somewhere between these limits while for boulder-bed rivers it is rare to find reaches that meander significantly. Moreover, it is very easy to define the thalweg of sand bed stream but for boulder bed river it is virtually impossible to define its location.

## IX) VARIATION IN REGIME OF FLOW

The magnitude of the Froude number at which the sand-bed channel changes from lower regime to the upper regime may be in the order of 0.2, 0.3 or 0.4 depending upon the size of the bed material. In mountain streams where the beds are formed of coarse material, the Froude number has to be greater than 1 before the stream has sufficient energy to cause any general movement of the bed material.

## X) VARIATION IN RESISTANCE TO FLOW

The resistance to flow for the sand bed channels is a function of the form of the river, the discharge and its duration, the type of bed forms, the size and gradation of bed material, the bars, their geometry, their location, etc. Whereas the resistance for the gravel rivers is largely a function of the grain size, the grain size distribution and the degree to which the space between the larger particles may be filled will finer sediment.

## 2.1.2 RIVER MORPHOLOGY

The river morphology is concerned with river plan-form, channel geometry, bed form and longitudinal profiles. It changes with time and is affected by water and sediment discharges including sediment characteristics, composition of bed and bank material and vegetation. Because of the complex inter-relation between river channel variables it is still not possible to give a complete physical and mathematical description of various morphological processes.

### PLAN-FORM OF RIVERS

Rivers can be classified according to their plan-form into straight, meandering or braided. A meandering river has a single channel, while a braided has a number of channels. This division is in part arbitrary as it is difficult to distinguish between straight channel and a meandering channel of low sinuosity and it is still a matter of debate on what constitutes of meandering or a braided channel. Sand-bed rivers can be meandering, transitional or braided, but they may change dramatically from one plan-form to another as significant changes in discharge are experienced. Whereas, gravel-bed rivers have much greater tendency to be transitional, braided or somewhere between these limits and due to which it is very difficult to define the thalweg of such stream.

Brotherton (1979) developed a theory of origin of channel patterns. He concluded that channel meandering occurs where discharge erodes and transports bank materials easily. Braided channel occurs when the channel banks are highly erodible. In both cases, the bank erosion can be induced either by deposition of input sediments (deposition meander or braid) or directly by a discharge with excess energy (erosion meander or braid). Deposition meanders form where the bank material is fine grained relative to the deposited sediment. Deposition braids form where the bank material is coarse grained or where banks are incoherent and fine-grained. Erosion meanders carry a flow, which entrains bank particles in preference to bed grain and transport them downstream. Erosion braids carry a flow, which moves bank material to bed without downstream transport.

White (1987) indicates that braiding occurred when valley slope exceeded equilibrium slope indicated by the division of the main channel into three sub-channels. Accordingly, if $S_v < S_1$ it leads to a straight channel, if $S_1 < S_v < S_3$ it leads to a meandering channel and if $S_3 < S_v$ it leads to a braided channel.

Where, $S_v$ = Valley slope

$S_1$ = Equilibrium slope of single channel

$S_2$ = Equilibrium slope of double channels

$S_3$ = Equilibrium slope of triple channels

Bed topography and plan-form geometry are the results of the complex interaction of the fluid flow with the channel boundaries and sediment transport The bed disturbances forces the thalweg to follow a sinusoidal path. The result of the varying curvature of this path is a secondary flow. The lateral velocity component tends to amplify the bed disturbances and contributes to its downstream propagation, and thus the amplification is intensified as the friction forces become more important. The secondary flow component also contributes to the growth of bed perturbation; Lateral bed slope opposes the growth of the bed deformations. The reaction between these three mechanisms for a given flow will determine whether the channel will remain stable or not. For an unstable channel the bed deformation dictates whether the channel will meander or braid.

Parker (1976) observed the development of meandering in an initially straight channel with erodible banks in the laboratory. An alternate bar pattern developed first while the channel was still straight. Later, the growth of the bars caused bank erosion and channel meandering without altering the wavelength of the bars. Thus bar development appears to be a precursor of incipient meandering and/ or braiding.

## THRESHOLD BETWEEN MEANDERING AND BRAIDING

Calander (1969) and Parker (1976) developed a two-dimensional flow model to explain the origin of meandering. They treat the meandering or braiding tendencies of straight channels as a stability problem. But they did not account for the effect of secondary current. Engelund and Skorgaard (1973) used a three-dimensional flow model to describe the instability. The model was based on the theory that an important property of the instability mechanism was the helical flow. The result of their analysis was that all straight runs are unstable and will form either a meander pattern or braided pattern depending on whether the width of the channel is smaller than some threshold value or not.

Fredsoe (1978) used a 2D-flow model and proposed planform classification diagram. He concluded that the prevailing mode of instability depends only on the Shields' parameter $\theta$ and the width-depth ration $B/h_o$. The former is not as important in establishing the thresholds of straight-meandering and meandering-braiding regimes. It influences considerably the streamwise wavelength, $L/h_o$ selected by the dominant bed deformation which increases as the Shields' parameter does, though $L/h_o$ approaches a constant value for $\theta > 1.2$. Fredsoe recommends the following stability criteria:

- for $B/h_o < 8$ - straight
- for $B/h_o > 60$ - braiding
- for $5 < L/B < 15$ - meandering

Blondeaux and Seminara (1983), based on 2D flow model with bed load transport, extended Parker's work by including the effect of the lateral bed slope on bed-load transport and the influence of the secondary flow on the direction of the bed shear stress.

They concluded that the stability of a stream depends on three parameters: $\theta$, $h_o/D$ (D = sediment size) and $h_o/B$.

### 2.1.3 FLOW RESISTANCE IN GRAVEL BED RIVERS

The relationship between the mean velocity of flow U, the hydraulic radius R, the water surface slope S, and the characteristics of channel boundary is known as a resistance equation. A resistance equation is required in the design of river improvement works, sediment transport studies, etc. The most common resistance equation for gravel-bed rivers is Manning's equation, which is given as:

$$U = 1/n\, R^{2/3} S^{1/2}$$

Where, n is the Manning's roughness coefficient. A detail list of n values for channels of various kinds are available in open channels hydraulics by Ven Te Chow. It gives the following values of n pertaining to gravel-bed streams:

| Types of Channel and Description | n Values |
|---|---|
| **Natural Streams** | |
| a) Minor Streams (Top width at flood stage < 100 ft) | |
| Mountain streams, no vegetation in channel, | |
| Banks usually steep, trees and brush along banks | |
| Submerged at high stages | |
| i) Bottom: gravel, cobbles and few boulder | 0.030-0.050 |
| ii) Bottom: cobbles with large boulders | 0.040-0.070 |
| b) Major Streams (Top width at flood stage > 100 ft) | |
| i) Regular section with no boulders or brush | 0.025-0.060 |
| ii) Irregular and rough section | 0.035-0.100 |

The flow resistance may be assumed to consist of two components: grain roughness and form roughness. The former is due to the shear force and the latter is attributed to the pressure difference in the presence of larger elements such as bed forms.

In channels paved with sand or gravel, the resistance to flow in the absence of bed forms can be considered to be mainly caused by grain roughness. Formulas that relate grain roughness to Manning's "n" are given below:

## I) STRICKLER'S FORMULA

It is based on data from gravel bed rivers and fixed bed channels, with grains pasted on the bottom and walls. It defines Manning's n as a function of the particle size in meter as:

$$n = (d_{50})^{1/6}/21.1$$

## II) MEYER-PETER AND MULLER FORMULA

$$n = (d_{90})^{1/6}/26$$

## III) BRAY'S FORMULA

It is based on study carried out with 67 gravel-bed river data of Alberta, Canada and it relates the roughness coefficient with the slope as:

$$n = 0.104\, S^{0.177} \qquad \text{for } 0.0002 < S < 0.01$$

## IV) LIMERINOS' FORMULA

It is based on study of gravel-bed rivers in California and is given as:

$$n = (0.113\, D^{1/6})/\{1.16 + 2.0 \log (D/d_{84})\}$$

Where, D = depth of flow

Flow resistance in gravel-bed rivers is primarily a result of grain roughness since dunes tend to be poorly developed. For this reason, resistance formulas developed for gravel-bed rivers are similar to those for fixed bed grain roughness. Of course, the total roughness in a river consists of contributions from other sources such as bars, curvature and other forms of irregularity. Numerous resistance equations have been developed in terms of Manning's coefficient or the friction factor.

Hey (1979) developed the following relationship for flow resistance in gravel-bed rivers:

$$1/f^{1/2} = 2.03 \log \{(a\,R)/(3.5\,d_{84})\}$$

Where, $d_{84}$ is used as the representative roughness height of non-uniform gravel material. The coefficient a is used to define the effect of cross-sectional geometry on flow resistance. Its value ranges from 11.1 to 13.46 in reverse relation to the width-depth ratio. The Hey equation is substantiated with data from certain British rivers with discharge from more than 1 to 444 $m^3/s$. Therefore it should not be used for very large rivers.

Using the data from 67 gravel bed rivers in Alberta, Canada Bray (1979) obtained the best-fit coefficients for a logarithmic resistance equation as given below:

$$1/f^{1/2} = 0.248 + 2.36 \log (D/d_{50})$$

Where, D is the depth of flow. The best-fit power form of resistance equation based on $d_{50}$ obtained by Bray is:

$$1/f^{1/2} = 1.36\,(D/d_{50})^{0.281}$$

### 2.1.4 SEDIMENT TRANSPORTATION

When the average shear stress on the bed of a channel exceeds the critical tractive stress for the bed material, the particles on the bed move in the direction of flow. The particles move in different ways depending on flow conditions, ratio of densities of the fluid and the sediment and size of the sediment. One mode of movement of sediment particles is by rolling or sliding along the bed of a channel. Sediment transported in this way is known as contact load. A second mode of sediment movement is by hopping or bouncing along the bed. Thus for sometime the particle losses contact with the bed. Material transported in this way is known as saltation load. The contact load and the saltation load are grouped together as bed load. Thus bed load is the material transported on or near the bed. The third mode of transport is in a state of suspension, in which the particles are supported by the turbulent fluctuations. Material supported in this way and transported by the flow is known as suspended load. Again, there is another category of sediment moving in a stream, which is known as the wash load. The wash load refers to the finest portion of sediment that is washed through the channel, with an insignificant amount of it being found in the bed. The total load is the sum of the bed load, suspended load and wash load.

A knowledge of the rate of total sediment transport for given flow, fluid and sediment characteristics is necessary in the study of problems of aggradation and degradation, channel changes, river training, etc. Thus, attempts have been made to relate the sediment transport rate to the hydraulic conditions and the sediment characteristics. A large numbers of formulas have been developed for predicting sediment discharge. These formulas have been developed based on three different approaches, which are given as follows together with their respective formulas:

## I) SHEAR STRESS APPROACH

Duboys formula, Shields formula, Einstein bed load function, Meyer-Petter-Muller foumula, Einstein-Brown formula and Parker et. all formula for gravel fall in this category.

## II) POWER APPROACH

Engelund-Hansen formula, Ackers-White formula and Yang formula fall in this category.

## III) PARAMETRIC APPROACH

Colby relation falls in this category.

Because of the large number of sediment transport formulas now in existence, it is very difficult to select a reliable formula for a particular application in the field problem. It requires a thorough understanding of theoretical and empirical foundation on which each equation was developed. Basic assumptions and physical limitations of each equation must be known. Further, comparison of sediment discharge prediction with the field measurement is highly desirable. Yang (1988) and Raphelt (1990) based on the literature review on sediment transport formulae stated that there is no sediment relationship that would consistently predict the sediment discharge correctly for all ranges of sediment from very fine sand to cobble. Raphelt (1990) general guidance developed from the literature is as follows:

- Gravel streams (bed material coarser than 2 mm):
  - Yang (2 mm < D < 10 mm)
  - Meyer-Peter Muller (D50 > 5 mm)

- Large rivers (channel width > 800 ft, i.e. 224 m, depth > 25 ft, i.e. 7.6 m):
  - Toffaleti
  - Laursen (Copeland)
  - Laursen (Madden)

- Small rivers and streams:
  - Laursen (Copeland)
  - Ackers and White
  - Colby

Alonso (1980) tested eight sediment transport formulas. This comparison was based on 40 field measurements and 225 flume experiments. The Yang (1973) formula was the most reliable over the entire data range. The formulas developed by Ackers and White, Engulund and Hansen and Laursen also were found reliable but gave relatively higher errors.

### 2.1.5 SEDIMENT SAMPLING

The sediment transport rate in a channel can be determined by using an appropriate sediment transport equation. But such equations only give approximate values. For obtaining more reliable data for design of river engineering projects field measurements of sediment samples are required. Such field measurements also enable us for checking and modification of existing methods of computation of sediment.

Both the transport rate and grain size distribution of sediment show temporal and spatial variations. Movements of bed load particles change the bed shape and bed form (ripples, dunes, plane bed, bars etc.) which in turn affect the flow and bed load transport. Particles moving as bed load in one reach may not move in another reach or may move as suspended load. Thus, bed load observations in a given reach do not necessarily represent bed load discharge in other reaches. To obtain a representative bed load discharge at a section repetitive measurements are required at a number of different lateral locations across the section.

The amount of sediment passing a section can be determined either directly or indirectly. The direct method involves the determination of the weight of sediment passing a section in a particular time. The indirect method requires the measurement of the concentration of sediment, the area of cross-section and the velocity of the particles in motion. The bed load in a stream can be conveniently measured by the direct method while the indirect method is not suited for bed load measurement because of the difficulty of measuring the velocity of particles moving as bed load. The indirect method is well suited for suspended load measurement since the suspended particles travel with the flow velocity.

The early types of direct measuring samplers are box or basket type, tray or pan type and the pressure difference type. Most of the recent direct measuring bed load samplers are improved versions of the early pressure-difference type. Fine sediments can be sampled easily by these samplers. But in gravel bed streams as the bed consists of coarser materials, penetration by samplers is difficult. Further, as large quantities of material are to be collected from the gravel-bed stream, manual collection and measurement is necessary to determine representative sample of such material. The stream must be dry or easily wadable for this purpose.

The grid sampling method is generally recommended for wadable gravel-bed streams to locate sampling points. This method was first developed by Wolman (1954) and hence is called Wolman Walk Method of sampling. In this method, grid system is established over the desired length of the reach by pacing or with the help of actual lines. Then the stones found at specific grid points or during pacing, just underneath the toe of the operator are to be picked up by hands.

The particles picked up from each grid point are measured from its intermediate axis. When a grid point is over sand or finer material, a small volume about 15 ml is collected and combined with samples from other points for sieve analysis. The coarser material collected by grid sampling is usually analysed as a frequency distribution by number. Hey and Throne (1983) recommended the use of template to aid in classifying the particles in terms of size. Kellerhal and Bray (1971), showed that if particles of various sizes are randomly dispersed throughout a deposit, the number percentage for surface grain are equal to weight percentage of a three-dimensional sample of the deposit, assuming that all particles have the same specific gravity. Therefore, sizes determined by hand measurements could be combined with size that determined by sieving into a continuous frequency distribution.

## 2.2 CHANNELIZATION OF RIVERS

### 2.2.1 INTRODUCTION

River Channelization is an engineering technique, which either enlarges (widens and/or deepens), straighten, embank or protect an existing channel or which involve the creation of new channels. It also refers to river channel maintenance including dredging, clearing and snagging or the removal of obstructions in the channel. The term channelization in USA is known as kanalisation in Germany, chenalisation in France and canalization in UK. Channelization of rivers is carried out for the purposes of flood control, drainage improvement, maintenance of navigation or reduction of bank erosion etc.

### 2.2.2 HISTORY OF RIVER CHANNELIZATION

There is a long history of channelization throughout the world. The earliest form of channelization comprises of canals and ditches built to carry water into and sewage out of ancient cities. The construction of embankment to control flooding of agricultural land and settlement is recorded in the histories of most early civilizations. Flood banks were constructed on the Yellow River in China as early as 600 BC.

The environmental impact of the earliest works was minimal due to the limitation of hand and animal labour. The revolution in the practice of channelization came as a result of several factors. These were the availability of heavy equipment such as bulldozers and draglines, the involvement of government agencies and the increased demand placed on floodplain lands either for agricultural productivity or for urban development. Many of the channelized works needed constant maintenance, probably because disrupted system attempted to regain equilibrium.

River channelization is extensive in many countries throughout the world. But the historical background and geographical distributions about it are well documented for only a relatively few countries. The United States of America has undergone an intense period of channelization during the past 150 years. Most of the early modification was highly fragmented, being carried out by a variety of bodies and was not properly planned and engineered. The later works were more planned engineered and substantial following improvements in dredging technology. It was only in the 19$^{th}$ century that channel improvements became widespread in the United States. The primary purpose of these efforts was to drain land for agriculture, to control flood and to provide for the waterborne transportation of goods.

In UK channelization have been carried out by a number of organizations for flood control and agricultural drainage during the past 550 years. However major rivers were changed in the late 19$^{th}$ century for agricultural or navigation purposes. Cutoffs were long recognized as a means of improving navigation by shortening the length of channel, although this method was not widely used until the 17$^{th}$ century.

In Denmark only 2.2% (880 km) of the total 40000 km channel is sinuous, the remaining 97.8% has been straightened (Brookes 1987). This is equivalent to a density of modified watercourses of 0.9 km/ km$^2$ in the USA (Leopold, 1977). Denmark thus has a density of channelised river 15 times greater than England and 300 times greater than the USA. These differences can be attributed mainly to the intensities of land use: the majority of the surface area in Denmark is either intensively farmed or developed for residential or industrial purposes.

### 2.2.3 ENGINEERING METHODS OF CHANNELIZATION

Several methods of channelization exist for the purpose of flood relief, agricultural drainage, erosion control or navigation. The more conventional types of it are discussed below.

#### I) RESECTIONING BY WIDENING AND DEEPENING

This involves enlargement of a channel by widening and/or deepening to increase the conveying channel cross-section so that water, which would previously have spread onto the floodplain, is contained. Widening or deepening of a channel permits a given quantity of water to flow through at a lower level than in the unimproved channel. For flood control purposes the size of the modified channel is determined by the flood discharge, which is to be contained. Resectioning of a river is usually combined with regrading of the bed. In theory a channel should have a cross-section area, which provides the maximum efficiency in discharge with the minimum of excavation. But in practice this is not always possible due to factors such as bank instability, porosity of the bed and the proximity of structures, which restrict the width or depth to which the channel can be constructed. Channel with unlined earth banks are often designed with trapezoidal cross-sections to provide side slope for stability. Since the rectangle has vertical sides it is commonly used for channel built of stable material such as concrete.

## II) REALIGNMENT OR STRAIGHTENING

Several scales of channel realignment can be distinguished, ranging from an improved alignment introduced by dredging, to the more conventional form of cutting-off bends in rivers. The objective may be to design an adequate channel to convey flood flows. The technique is intended to reduce the flood level in a reach by increasing the velocity of flow. A certain degree of realignment can be introduced into a channel as a result of maintenance dredging, being achieved by the removal of shoal, which may have accumulated as point bars on the inside of bends. A more significant form of realignment involves the shortening of a river by means of a cutoff, often at the scale of an individual meander. Program of cutoffs have been carried out on a number of rivers worldwide. In extreme cases straightening may extend for several hundred kilometers. Cutoffs are used to reduce the flood height by increasing the gradient and therefore the velocity. They are also used to improve maneuverability during navigation.

## III) DIVERSION CHANNEL

River channel has been constructed which has the purpose of diverting only the flood flow away from an area to be protected, the existing channel carrying the normal flow. It is favoured in urban areas where it is not possible to widen the existing channel due to development. Das (1976) described a cut made on the River Bhargavi in India, which was used to bypass flood flow. A diversion is only effective in reducing the flood stage if the distance between the point of diversion and point of return is sufficiently large to overcome backwater effects. Another consideration in such a diversion is the availability of adequate head for the diversion channel to develop the necessary velocity. If the velocity is too low, the channel section has to be large and hence the diversion channel will be expensive. If local condition permit, a small dam can be built slightly downstream of the diversion to raise the water level and create adequate head for diversion. Depending on the terrain through which the artificial diversion channel has to pass, it can be either in complete cutting or partly in cutting and partly in embankment.

Cutoff channels can be used as an entirely separate system for the purpose of diversion of all flow away from an area. A classic example is the Great Ouse Flood Protection Scheme in England, which directs the flow of the River Lark, Little Ouse and Wissey along a 43 km long cutoff channel from Mildenhall to Denver Sluice.

## IV) EMBANKMENTS OR LEVEES

Embankments are also known as flood banks, levees, bunds or stopbanks. Their purpose is to artificially increase the capacity of a channel so that high flows, which would normally have spread onto an adjacent floodplain, are now confined. They are one of the oldest forms of flood protection measures used in either rural or urban areas provided that there is sufficient space for construction. Some of the great rivers of the world have extensive embankment systems such as those that extend for more than 1000 km alongside the Nile and 1400 km on the Red River in Vietnam.

Historical observation of all the great levee systems in the world have a few aspects in common, namely i) the levees have been extended gradually, ii) there has been a gradual enlargement in the cross section of levees and iii) none of the levee systems has been free from breaches. The main advantage of the levees is that they can be constructed of locally available materials and labour, so it is fairly inexpensive and simple method of flood control. Also, levees can be extended gradually to cover more and more area and need not be executed in one stretch. As against these advantages there are also a few disadvantages. Levees being made up of earth are susceptible to boring action by animals and thus vulnerable to piping failure. Levee breaches, especially in the upper reaches, can result in flooding of the entire area, which depends on levees for protection. Consequently, levees need very careful supervision especially during floods and any breaches need to be plugged almost on a war footing. Generally, levees of height greater than about 40 feet are uneconomical.

Embankments are built to contain a design discharge and the entire floodplain may be protected when two banks are located sufficiently close together, although this is extremely expensive because the banks need to be very high. In other circumstances the embankments are placed just outside the meander belt of a migrating river to avoid erosion and if a high discharge capacity is required for a given stage then the embankments are placed far apart. Both the topography and human infrastructure on a floodplain influence the alignment of embankments. The elevation is primarily selected according to the design flood discharge and its accepted probability of exceedance, the design flood being routed through a section and flood stage calculated at desired positions along the channel. An embankment cannot be built too high because of the increased danger to the population if the banks were to be overtopped or breached during an extreme flow event. To allow for subsidence following construction a freeboard may be incorporated above the design level but in general the slope must not be over-steep, otherwise failure may occur. Trapezoidal sections have been used, typically with 1:2 side slopes, although in rural areas it is recommended that a bank top width of 3.0m be used. Berms may be incorporated between the channel and the foot of the structure, thus allowing for improved access and a higher discharge capacity for a given stage. Top width should exceed 2m and this often has to be wide enough to allow maintenance traffic. Embankments are normally constructed from material excavated either from the channel or from a borrow pit in the floodplain, but also can be built from imported materials.

## V) STABILIZATION AND RECTIFICATION OF RIVER

Bank stabilization and rectification works may be undertaken to protect the banks against abrasion and slip and to fix the channel along the desired alignment permanently. To be successful, the bank stabilization and rectification works must control the river by guiding it along a natural alignment with channel cross-sections that accommodate the river's water and sediment regime rather than forcing it into unnatural conditions. Bank stabilization and channel rectification works are of three broad types; a brief discussion of it follows:

### REVETMENTS

Revetments are structures parallel to the current and are used for such purposes as stabilizing concave banks of bends. Revetments provide direct protection to the channel by armoring the banks and protecting the underlying soil layer against erosion. Revetments can be broadly classified into rigid revetments and flexible revetments. The rigid revetments are made of concrete (plain, reinforced or pre-cast slabs), cement mortar, soil cement, sheet pile (steel or timber), brick works or stone works. These are mainly impermeable unless water and soil movement is possible through the joints or special pressure relief holes. The flexible revetments are made up of rip-rap (loose or bound or grouted stone), concrete blocks (loose, interlocked, cable connected or anchored), fabric and other containers (bags, blankets, fabric mattresses, tubes, wire, bamboo or polymer gabion baskets and mattresses), bitumen (asphalt, bound or grouted stone or willow) and many other materials (old tires, oil drums etc.).

In constructing a revetment, irregularities are first removed and banks graded to acceptable slopes so that the structure will not be damaged due to improper support. Theoretically the slope must be less than the critical angle of repose of the material. In designing revetments, consideration should be given to the following:

- The stream bank should be graded to a slope in the order of 1V: 2H to 1V: 4H depending on the bank material to ensure stability of the protected bank and the protective material.
- Protective blankets on the bank should be porous so that the bank drains through the blanket without the build up of excessive pore pressure, which would lift and damage the blanket.
- A filter should be placed under the blanket, using either graded gravel or synthetic filter cloth, where bank material is likely to be leached out through the protective blanket. The design criteria for the filter element are also discussed below.
- Where erosion at the toe of the bank is a contribution factor to bank erosion, protective measures should either extend sufficiently riverward into the channel to protect the toe of the bank or excess material (usually stone) should be placed along the toe of the bank in such a manner as to slide into the developing scour hole.

## FILTER ELEMENT

The main function of the filter element is the retention of subsoil without generation of unacceptable excess pore water pressures. The filter also acts as a separation layer and as soil reinforcement. The filters are mainly of two types: granular filters (made of loose, bounded or packed grains) and fibre filters (synthetic or natural materials).

The granular filter is the traditional filter, which is constructed using aggregates with certain specific gradation. It must be fine enough to prevent the base materials from being escaped through the filter, but at the same time it must be more permeable than the base material. The requirements of these filters corresponding to the gradation of subsoil being protected, as given by US Corps of Engineers, are as follows:

- $D_{15\ filter} < 5\ D_{85\ soil}$ - retention criterion
- $D_{50\ filter} < 25\ D_{50\ soil}$ - uniformity criterion
- $4 < D_{15\ filter}/D_{15\ soil} < 20 - 40$ - uniformity criterion

Where, $D_n$ is the particle size of filter or subsoil from a particle size distribution plot at n % finer.

The fibre (geo-textile) filter is made from artificial fibres such as polyamide, polyester, polyethylene, polypropylene, PVC etc. The geo-textile may be of woven or unwoven types. Its popularity against the granular filter is increasing day by day. The requirements of fibre filters are similar to that of granular filters. The fibre must be soil-tight and permeable during its whole lifetime. According to Ingold it is more practical to assume that only the larger particle size such as $D_{90}$ should be positively retained. The filter criteria suggested by Ingold are:

- For $1 < Cu < 50$, $O_{90}/D_{50} = 2\ Cu \exp(1-\sqrt{2}/Cu)$

Where, $Cu = D60/D10$ is the coefficient of non-uniformity.

$O_{90}$ = Effective fibre pore.

- For Cu < 5, $O_{90} < D_{90}$
- For 5 < Cu < 50, $O_{90}/D_{90} = 2\ Cu\ \exp(0.2-\sqrt{2}/Cu)$.
- For non-cohesive soils containing more than 50 % by weight of silt, $O_{90} < 0.2$ mm.

**DIKES**

Dikes, groynes or spurs are structures, which are built, transverse to the river flow and extend from the banks into the channel. Their purpose is, to guide or deflect the axis of flow, create a desired channel width, promote scour or build up the riverbanks by trapping the sediment load and inducing deposition. The groynes are generally used in braided river to establish a well-defined channel. They are also used in meandering rivers to control flow into or out of a bend or through a crossing. But they are useless for regularising mountain rivers of strong current, in which as a rule, continuous longitudinal structure that do not directly obstruct the flow should be used. Further, maintenance of groynes is difficult since the currents deflected by them deepen the bottoms at their heads forming scour holes. Due to such possibilities of scour holes being formed at the groynes, they should be made strong and provided with gentle head slope (such that they are protected from being knocked out) and launching apron of sufficient length.

Groynes vary greatly in their construction, appearance and action on stream flow. Their different classification is given as follows:

- Based on the method and material of construction, they are classified as permeable and impermeable groynes. The permeable groynes have ability to transmit the flow and they slow down the current. They are most often fabricated from piles, bamboo or timber. Thy are most effective in alluvial stream with considerable bed load and sediment concentration, which favor rapid deposition around the groynes. The impermeable groynes are solid obstructions made up of rock or river bed materials with a scour resisting outer surface. They are primarily used to protect a section of eroding bank and to deflect the current toward a more suitable alignment.

- Based on design condition they are classified as submerged and non-submerged groynes. In most instances the impermeable groynes are designed to be non-submerged, whereas, permeable groynes are better suited to submerged condition, as they do not create severe flow disturbance as created by solid groynes.

- Based on their action on the stream flow they may be classified as attracting, deflecting and repelling groynes. An attracting groyne points downstream and attracts the flow toward itself. This type of groyne does not repel the flow towards the opposite bank and therefore should never be placed on a concave bank. A deflecting groyne, usually of short length, changes only the direction of flow without repelling it, and gives only local protection. A repelling groyne points upstream and has the property of repelling the river flow away from it. Generally this type of groyne is used to protect the concave bank, which is susceptible to erosion.

- Based on their appearance in plan, they are classified as: straight, T-head, L-head and hockey stick shaped groynes.

The length of a dike depends on its location (in a crossing, a bend, across an old channel, etc.) the amount of channel constriction desired and the spacing of dikes in a system. Dike spacing is usually 1.5 to 6 times the dike length, however 1.5 to 2.0 times the length gives the well-defined channel for navigation and flood control.

The U.P.I.R.I. has given an empirical relation for the spacing of groynes based on its research conducted in Gandak River. Accordingly, the groyne spacing depends not only on the length of the groyne but also on the are-chord ratio of the embayment line between two successive groynes. The relation is as follow:

$$L = S/2 * (\rho^2-1)^{1/2}$$

Where, L= groyne length, S= groyne Spacing and ρ= arc-chord ratio for the river.

## CUTOFFS

Cutoffs are short channels across the neck of bends. They may occur naturally at long, looping bends, but are also man-made to improve river alignment for navigation or as a flood control measure. The natural cutoffs are usually not preferred as they

- Disrupt the established river regimen.
- Aggravate bank recession upstream
- Increase shoaling downstream as a result of accelerated bank erosion and thus increase stages downstream.
- Tend to result in poor channel alignment that produced currents, which is difficult and some time hazardous to navigate.

Man-made cutoffs had been constructed in Europe for sometime but they were channels excavated in the dry to full dimensions and the river was then diverted into the cutoff. The concept of excavating a limited pilot channel of relatively small cross-sectional area and letting the river develop and enlarge the excavated cut to full channel dimensions was first suggested in 1930 by General H.B. Ferguson, corps of engineers, and was first used later on the lower Mississippi River under his direction as president of the Mississippi River Commission. Since then many (man-made) cutoffs were successfully constructed using a narrow pilot channel excavated on desired alignment of the river, with the river completing enlargement of the cut to full channel dimensions. A plug or plugs were left in the excavated cut until construction was completed. On the lower Mississippi the plugs were removed by blasting: at some cutoff on the Arkansas the plugs were designed to be overtopped and washed out by the river at a specific design discharge.

Under some conditions, such as where the difference in water surface elevation across the neck of a bend is small and where surface and subsurface soils are resistant to erosion, a pilot channel will not enlarge satisfactorily and essentially the full cross-section of the channel must be excavated. Also if flow conditions are such that navigation cannot continue to use the old bend channel after a cutoff is opened, it is necessary to excavate the cutoff to full dimensions.

## DESIGN PROCEDURE FOR PILOT CHANNELS

The excavated pilot channel cross-section is designed in such a way that the sediment transport capacity of the channel is greater than required to transport the sediment load entering the pilot channel. It facilitates the erosion of the pilot channel and the channel gets widen. The sediment transport capacity is a function of the tractive force, to (which is proportional to the product of hydraulic radius and slope), and the greater the ratio of tractive force, pilot channel to natural river bend, the more favorable are conditions for development of the cutoff. Further, to minimize diversion of bed load to an excavated pilot channel, the entrance should be located in the concave bank of the bend well upstream from the point of inflection.

For each pilot channel, a number of excavated cross-sections are investigated to determine the most economical section that will assume erosion and development. Where the length around the natural river bend is long compared to that through the pilot channel, the slope ratio is favorable for enlargement of the cut and an excavated pilot channel of narrow width and mild grade is adequate, if there is sufficient time for development to ultimate section. Where there is little length or slope advantage, a larger, deeper cross-section must be excavated to ensure development. The pilot channel can be cut with 1V: 3H side slope up to the average water table elevation and 1V: 2H side slope above that point.

## DEVELOPMENT OF FLOW CAPACITY OF CUTOFF

Arkansas River data indicate that with favorable stream flow conditions, the flow capacity of a pilot channel develops as a function of the length ratio, river bend to pilot channel, for channel in sandy materials. The discharge capacity of the range of 150000 cfs is plotted as a function of accumulated river discharge after opening of each pilot channel. Morrilton, Holla Bend and Brodie Bend pilot channels were all subjected to high discharges shortly after being opened. Hensley Bar cutoff was opened in November 1951, and no significant rises occurred on the river until 1957, by which time, the cutoff carried about 60 percent of a river discharge of 150000 cfs, and the Hansley Bar curve on Fig. 2-1 is appreciably flatter than the preceding four. The slow development of Mclean Bottom cutoff can probably be attributed to gravelly material in the cutoff area and to the fact that caving of the right bank above the entrance to the pilot channel produced a flow configuration which tended to transport much of the natural sediment load of the river through the cutoff rather than diverting it into old river bend.

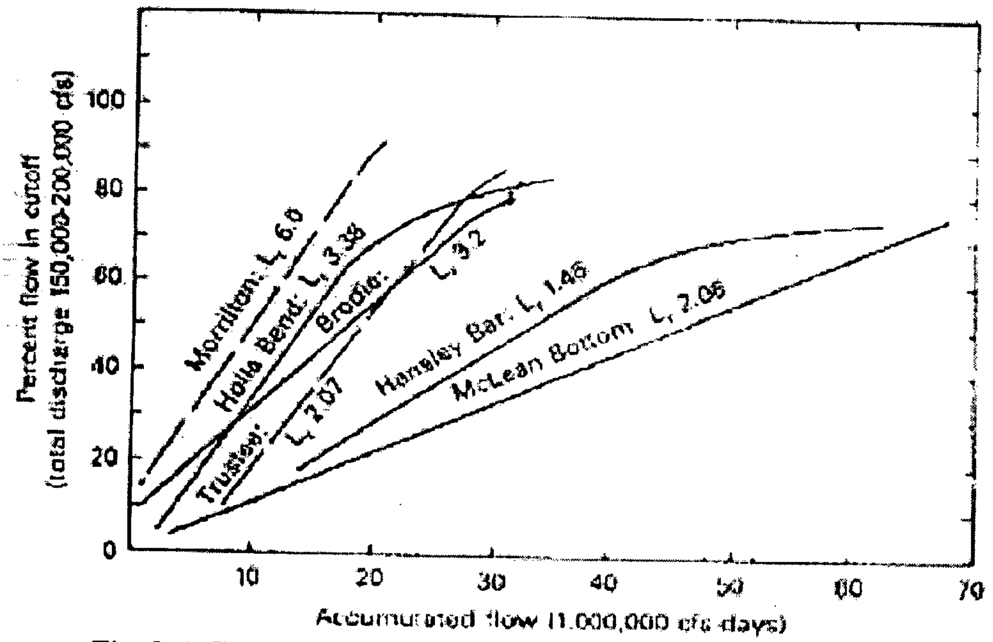


Fig. 2-1 Cutoff Flow Capacity Versus Accumulated Streamflow

## FILLING OF OLD RIVER BENDS

Accretion in cubic yards per mile in four old river bends cutoff of the Arkansas River is plotted as a function of time in Fig. 2-2. The data indicate that deposition per unit length is a function of the length ratio for several years following opening of cutoffs, but that after about 5 years all bends were filled approximately the same amount regardless of the pattern of stream flow. The rate of accretion at Mclean Bottom was slower than at the other areas investigated, indicating that probably a larger percent of the sediment load was transported through Mclean Bottom cutoff than through the other cutoffs.

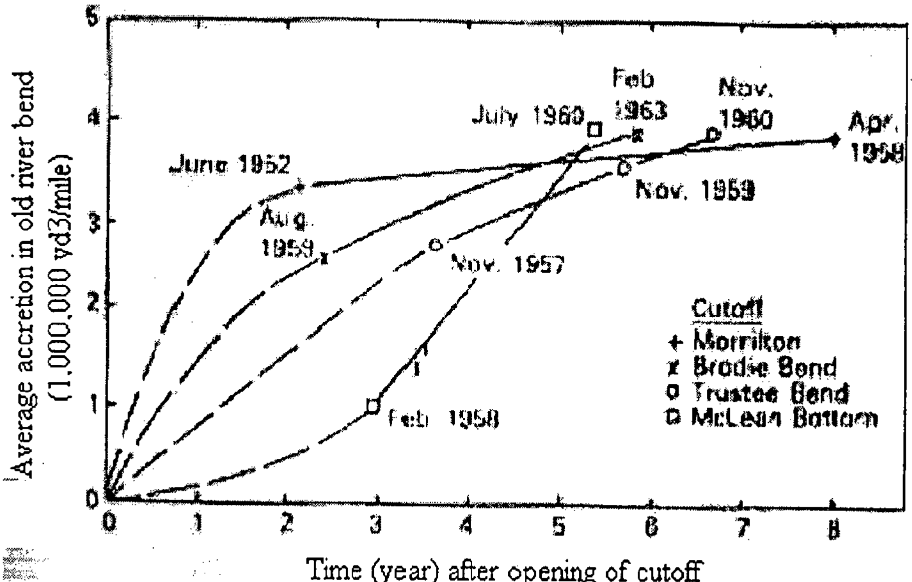


Fig. 2-2 Accretion in Old River Bends at Cutoffs

## 2.2.2 PLANNING AND DESIGN OF CHANNELIZATION WORKS

### BASIC CONCEPTS

The following points should be kept in mind while planning and designing the channelization works.

### ALIGNMENT

To minimize attack by the stream on stabilization and rectification structures, the river is shaped to an alignment consisting of a series of easy bends, with the flow directed from one bend into the next bend downstream in such a way as to maintain a direction essentially parallel to the channel control line. Straight reaches and reaches of very flat curvature should be avoided, insofar as practicable, because there is a tendency for flows to shift from side to side in such reaches.

Planning of the alignment depends upon geologic conditions, but it also dependent upon the requirements of human settlements, industrial establishments, harbours, barge terminals, sports clubs, bridges, tributaries etc. The alignment should be carried at a suitable distance from the existing levees and communication lines so that even at certain amount of bank erosion they could not be endangered.

## COSINE-GENERATED CURVE

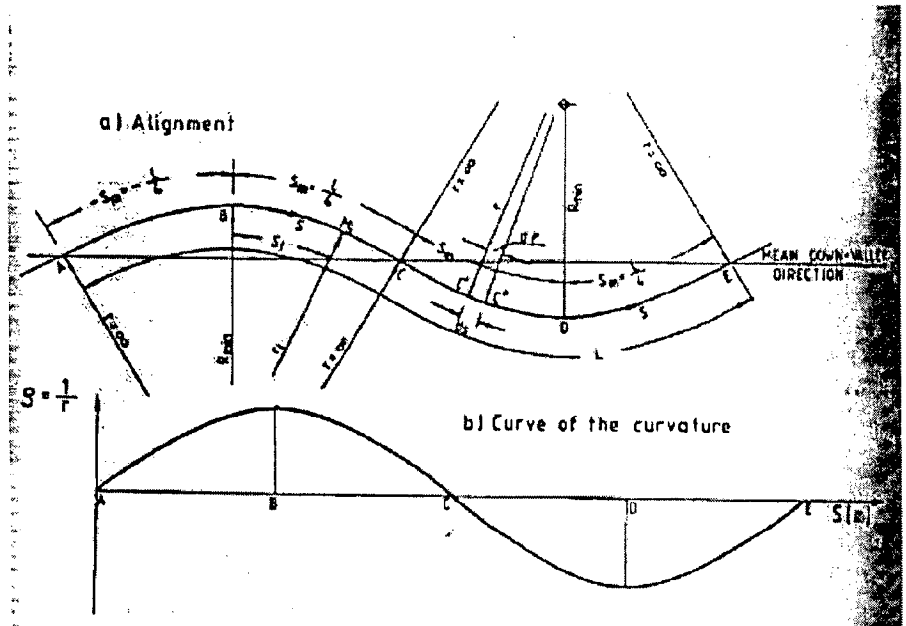


Fig. 2-3 Symmetrical arc according to cosine-generated curve

According to Leopold and Langbein the cosine generated curve is a close approximation of the shape of river bends and meanders. They found that the cosine-generated curve minimises the sum of the square of the changes in direction and hence it is also a curve at which the river spends the minimum of total work in bending. With properly selected values of curve radius (Rm) and arc length (L), the cosine-generated curve fits the shape of river meanders quite well (Chang, 1988).

The equation of cosine- generated curve in a system of curvilinear co-ordinates (Fig. 2-3) has the form of (Engelund, 1974; Przedwojski, 1988):

$$\frac{1}{r_i} = \frac{1}{R_{min}} \cos(l_o s_i) \qquad (2.1)$$

Where, $l_o = 2\pi/L$ (2.2)

and $r_i$ is the radius of curvature at a distance $s_i$ from the apex, $R_{min}$ is the minimum curvature radius on the bend apex. The cosine-generated curve is a periodic curve of $2\pi$ period and L is the meander length. It follows from eq. (2.1) that the curve shape depends on two parameters R and L, and the curvature is a function of distance s from the apex.

In the curvilinear system of co-ordinates (Fig. 2-3a) the infinitely small increase in curve length between points c' and c" can be expressed approximately by the arc differential ds:

$$ds = r\, d\phi \qquad (2.3)$$

Where r is the radius of curvature in c' point, $d\phi$ is the angle differential, $\phi$ is the angle expressed in radians. The curvature of a curve in point c':

$$\frac{1}{r} = \frac{d\phi}{ds} \qquad (2.4)$$

We have from eqs (2.1) and (2.4):

$$d\phi = \left[\frac{1}{R_{min}}\cos(l_o s)\right] ds \qquad (2.5)$$

Integration of eq. (2.5) leads to a solution:

$$l_o R_{min} \phi = \sin(l_o s) \qquad (2.6)$$

Raising the left and right term of eqs (2.1) and (2.6) to a square and adding the equations with their respective terms we obtain:

$$\frac{R_{min}^2}{r^2} + R_{min}^2 (l_o \phi)^2 = 1 \qquad (2.7)$$

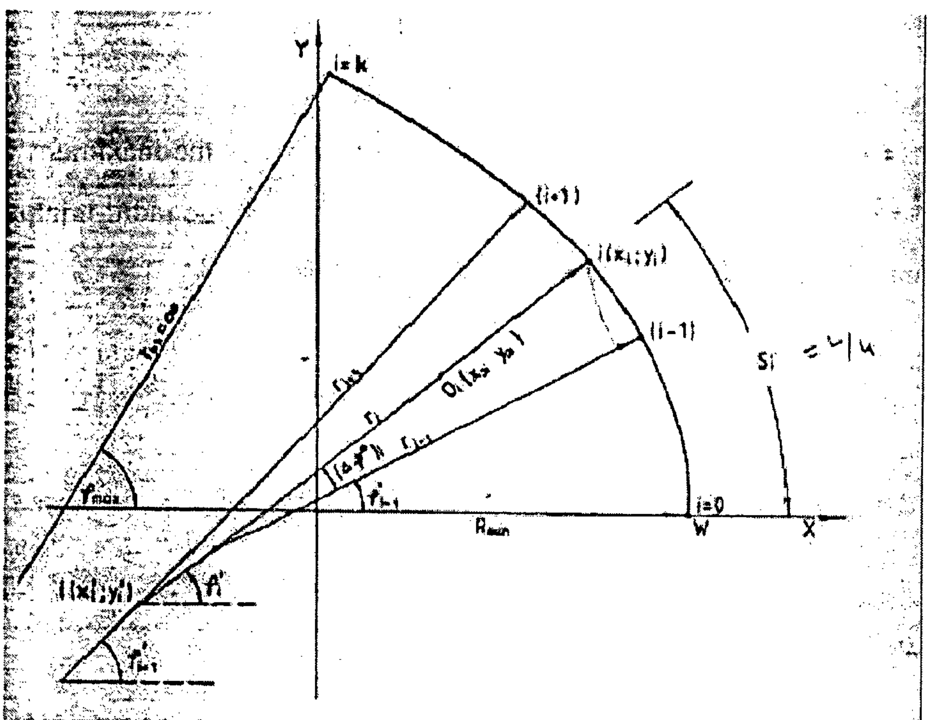


Fig. 2-4 Scheme for curve ranging in the cartesian coordinate

Hence the curvature radius in point 'i' (Fig. 2-4) in the function of the angle $\phi_i$ contained between the positive directions of the radii $R_{min}$ and $r_i$ can be expressed with a formula:

$$r_i = \frac{R_{min}}{\sqrt{1-(l_o R_{min}\phi)^2}} \qquad (2.8)$$

Substitution of formula (2.8) in place of the radius r in eq. (2.3) provides:

$$ds = \frac{R_{min}}{\sqrt{1-(l_o R_{min}\phi)^2}} d\phi \qquad (2.9)$$

Equation (2.9) in the interval from 0 to $\phi$ leads to the formula:

$$s_i = \frac{L}{2\pi} \arcsin(l_o R_{min}\phi_i) \qquad (2.10)$$

in which the distance $s_i$ (Fig. 2-4) for the assigned values of $R_{min}$ and L is a function of the $\phi_i$ angle expressed in radians. Equation (2.10) can also be transformed into:

$$l_o R_{min} \phi_i = \sin(l_o s_i) \qquad (2.11)$$

If $s_i = s_m = L/4$ then $\sin(l_o s_i) = \sin((2\pi/L)s_i) = \sin\pi/2 = 1$ and the maximum values of the angle $\phi_i = \phi_{max}$ contained between the positive directions of the radii: minimum $R_{min}$ and maximum $r=\infty$ (Fig. 2-4) is determined with a formula:

$$\phi_{max} = \frac{L}{2\pi R_{min}} \qquad (2.12)$$

Where the angle $\phi_{max}$ is expressed in radians or in the form of:

$$\phi^o_{max} = \frac{180°}{2\pi^2 R_{min}} L \qquad (2.13)$$

Where, the angle $\phi^o$ is expressed in degrees. In the system of curvilinear co-ordinates the eqs. (2.8) and (2.10) determine the parameters of the curve s and r in the function of the angle $\phi$ , which changes within the interval $\phi_i \le \phi_{max}$. But setting out of the curve in the curvilinear set of coordinates is very tiresome and unpractical. In order to facilitate the method of setting out the curve according to a cosine-generated one the formulae were determined to specify location of any point of a curve in the system of cartesian coordinates x, y (Fig. 2-4). It follows from Fig. 2-4 that the co-ordinates of the point 'i' are determined with the following dependencies:

$$x_i = r_i \cos\phi_i + x_i' \qquad (2.14)$$

$$y_i = r_i \sin\phi_i + y_i' \qquad (2.15)$$

Where,

$$x_i' = (r_{i-1} - r_i)\cos\phi_i' + x_{i-1}' \qquad (2.16)$$

$$y_i' = (r_{i-1} - r_i)\sin\phi_i' + y_{i-1}' \qquad (2.17)$$

The co-ordinates of the point $o_i$ determine the direction of the radius $r_i$ and are located at a distance ½ $R_{min}$ from the point 'i' measured along the radius. The co-ordinates of the point are determined from the formulae:

$$x'_{oi} = (r_i - 1/2R_{min})\cos\phi'_i + x'_{i-1} \quad (2.18)$$

$$y'_{oi} = (r_i - 1/2R_{min})\sin\phi'_i + y'_{i-1} \quad (2.19)$$

**FIXED POINT**

One of the essential requirements in designing a system of stabilization works is that construction start at a stable, fixed point on the bank and continue downstream to another stable location or to some point below which the river can safely be left uncontrolled. Construction of relatively short isolated stabilization work has often proved unsuccessful because eventual changes in the direction of flow inherent in bank caving in the upstream uncontrolled reach either will set up a direct attack against the isolated protective work and severely damage or destroy it or will shift the attack to some other nearby reach of bank, requiring additional work and possible abandonment of the original work.

**TRACE WIDTH**

Optimum channel width, especially through crossings, is another essential consideration in assuring a suitable alignment of flow and minimum attack on the structures. Design trace widths for a rectified channel should be based on examination of widths characteristic of naturally stable sections of the river, and the design should be sufficiently flexible to permit modification of the controlled width in the future if required.

**RADIUS OF CURVATURE**

The most appropriate radius of curvature for rectification and stabilization varies from river to river and from reach to reach for a given river. It must be determined on the basis of relatively stable natural bends for each stream.

The shorter the radius of curvature of a bend the deeper the channel will be adjacent to the concave bank. The deeper the channel, the greater the possibility of undermining the bank protection work in the bend and the greater the cost of maintaining the structure. Therefore, sharp curvature of bends should be avoided to obtain the most economical control of the river.

## STABLE CHANNEL SECTION

A stable channel is defined as a channel that transports water and sediment without objectionable deposition and scour of sediment in the channel. It means minor de position or scour can take place in the channel, but over a long period of time the banks and bed must be stable. The design of such stable channels is based on laws governing the resistance and sediment transport or on equations derived empirically from data on channels, which have carved for themselves the stable sections. Some of the methods of stable channel design are as follows:

- Regime theory method
- Permissible velocity method
- Tractive force method
- Extremal hypotheses method

## REGIME THEORY METHOD

Various investigators, such as Kennedy, Lindley, Lacey, Blench, Simons etc. have proposed different empirical relationships for design of stable channels. These relationships are based on study and analysis of limited flume and canal data. As such application of regime method is limited to narrow range of flow and sediment variables. It must be emphasised that these regime equations were never intended for application to a stream where the discharge varies. In other word, the regime equations are strictly valid for only one discharge condition. The discharge to be used in regime equations is either the sustained discharge for irrigation channel or the dominant discharge for alluvial streams.

Bray (1982) presents four sets of final equation for estimating channel width B, channel depth h, channel slope I, and mean flow velocity u. These equations are based on 67 gravel bed river reaches in Alberta, Canada. According to Bray the third and the fourth set of final equations can be used for the design of stable gravel-bed channels with small sediment transport. These equations are as follows:

- Best-fit dimensionless expressions

  $B= 2.68\ Q_2^{0.496}\ D_{50}^{-0.241}$

  $h= 0.20\ Q_2^{0.397}\ D_{50}^{0.008}$

  $u= 1.87\ Q_2^{0.107}\ D_{50}^{0.233}$

  $I= 0.063\ Q_2^{-0.375}\ D_{50}^{0.937}$

- Best-fit expressions

  $B= 3.83\ Q_2^{0.528}\ D_{50}^{-0.07}$

  $h= 0.246\ Q_2^{0.331}\ D_{50}^{-0.025}$

  $u= 1.05\ Q_2^{0.14}\ D_{50}^{0.095}$

  $I= 0.018\ Q_2^{-0.334}\ D_{50}^{0.586}$

  Where, $Q_2$= 2-year flood flow

The importance of bank vegetation for controlling width and the fact that slope responds to changes in bed load transport through erosion and deposition in gravel bed rivers was considered by Hey (1985). Hey introduced four classes of bank vegetation:

| | | |
|---|---|---|
| Vegetation I | : | 0 per cent tree or shrub cover |
| Vegetation II | : | 1-5 per cent tree or shrub cover |
| Vegetation III | : | 5-50 per cent tree or shrub cover |
| Vegetation IV | : | greater than50 per cent tree or shrub cover |

The regime formula suggested by Hey (1985) for design of gravel-bed rivers with bank side vegetation are presented below:

$B= 4.33\ Q_{bf}^{\ 0.50}$, for vegetation I

$B= 3.33\ Q_{bf}^{\ 0.50}$, for vegetation II

$B = 2.73\ Q_{bf}^{0.50}$, for vegetation III

$B = 2.34\ Q_{bf}^{0.50}$, for vegetation IV

$h = 0.22\ Q_{bf}^{0.37}\ D_{50}^{-0.11}$

$h_{max} = 0.20^{0.37\ \sigma D}\ Q_{bf}^{0.36}\ D_{50}^{-0.21}$

$I = 0.087^{0.84\ \sigma D}\ Q_{bf}^{-0.43}\ D_{50}^{0.75}\ S_b^{0.10}$

Where, $S_b$= bed load transport rate and $\sigma D = ½ \log (D_{84}/ D_{16})$.

## PERMISSIBLE VELOCITY METHOD

Four characteristic velocities are often used in designing channel cross-sections, namely: critical shear velocity, permissible bottom velocity, maximum permissible mean velocity and lowest permissible velocity. The critical shear velocity, $u_{*c}$ can be expressed by the bottom critical shear stress, $\tau c = \rho\ u_{*c}^2$, in which $\tau c = \rho\ g\ R_h\ I_c$. The critical bottom velocity, $u_{bc}$ can be expressed as $u_{bc} = \phi \sqrt{D}$. Where, D is the diameter of particles, in m and $\phi$ is a constant of value 4 to 6.

The maximum permissible velocity is the maximum mean velocity for incipient motion for bed sediment. This velocity is more convenient for practical design work. The Institute of Hydraulic Design, USSR has specified the maximum permissible mean velocity for loose granular bed material, cohesive soil and lined canals. The velocity limit for coarse gravel bed river with sediment size range from 10 mm to 100 mm, varies from 0.8 m/s to 2.7 m/s for a flow depth of 1 m. In case, the depth varies from 1 m, the actual permissible maximum mean velocity, u is obtained from tabulated values, $u_1$ (Pilarczyk 1995) as $u = \alpha\ u_1$ where, $\alpha$ is a coefficient varying from 0.80 to 1.25 for flow depth of 0.3 to 3.0 m.

The lowest permissible velocity, $u_l$ should also be determined in order to prevent the canal from silting. For the computation of non-silting, i.e. lowest permissible velocity, no generally accepted formula or tabulation has as yet been developed. However, no sedimentation is likely to occur if the mean velocity:

$u_l$= 0.3 m/s for silty water

$u_l$= 0.3- 0.5 m/s for water carrying fine sand.

## TRACTIVE FORCE METHOD

Ikeda and Kimura (1987) developed a mathematical model for stable straight gravel bed river (sinuosity less than 1.2), in which heterogeneous bed materials are transported without altering their channel cross-section. The shape of the cross-section is shown in Fig. 2-5 and its parameters are described by the following equations:

Depth, $h= 0.0615\{\log (19\ \sigma)\}^{-2} \sigma\ \Delta\ D_{50}\ I^{-1}$

Width, $B= Q/(2.5\ L_h\ h_{u*}) + [2.571+ 2.066/L_h]\ h$

Wetted perimeter, $P= (1 + 5.048\ h/B_0)\ B_0$

Cross-sectional Area, $A= (1 + 2.982\ h/B_0)\ h\ B_0$

Hydraulic radius, $R= A/P= (1-2.066\ h/B_0)\ h$

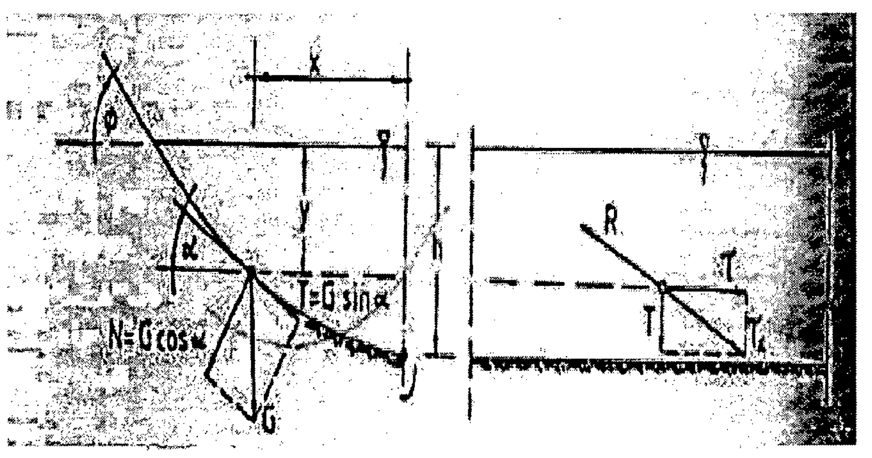


Fig. 2-5 Forces diagram on particle resting on a bank

Bank profile ( Parker's equation):

$Y/h= 1/(I-\phi_t)\ [\cos \{\{(2x-(B-B_s))/(B_s)\}\ \cos^{-1}\phi_t\}- \phi_t]$

Shield parameter:

$\theta = hI/(D_{90}\,\Delta)$

Where, $L_h = \ln(11\,h/k)$; $\sigma = D_{90}/D_{50}$

$k = 1.5\,D_{90} = 1.5\,\sigma\,D_{50}$

$B_s = 4.52\,h$; $u_* = \sqrt{ghI}$

And Q is the discharge of flow, $\phi_t = \tan\phi = 0.714$ for a lateral bank inclination at the water margin $\phi = 40°$, I is the surface slope, h is the depth at the junction J, x is th e lateral co-ordinate taken from the channel centre-line, Y is the local vertical depth, B is the total channel width, $B_s$ is the total width of the bank regions, $B_0$ is the bottom width, $\rho$, $\rho_s$ are the density of water and the density of sediment, $D_{50}$ is the median size of mixture, $D_{90}$ is the grain size for which 90 % is finer.

The assumptions in this model are:

a) The longitudinal bed-load transport along the channel bottom is weak.
b) The channel banks are stable and its shape is described by a cosine curve (Parker's equation).
c) The relation of Shields parameter to its critical value is $\theta/\theta_c = 1.23$.
d) The model is valid for the relations:
   $B_s/B < 0.6$ and $5 < h/k < 100$.

**EXTREMAL METHODS**

In contrast to regime concept, which relate canal or river width to discharge and sediment in the bed, recently different concepts have been put forth:

i. Minimum energy dissipation rate
ii. Minimum stream power
iii. Maximum sediment transport rate

The theory of minimum rate of energy dissipation was developed by Yang and Song (1986), which states that for a closed and dissipative system under dynamic equilibrium conditions, the system's total rate of energy dissipation is a minimum. This minimum value is dependent upon the constraints applied to the system. If the system is not at its equilibrium condition, its total rate of energy dissipation is not at its minimum value. However, the system will adjust itself in such a manner that its rate of energy dissipation can be reduced to reach a minimum value, which is compatible with the constraints and regain equilibrium.

The concept of minimum stream power was developed by Chang (1986). The hypothesis of Chang is that the necessary and sufficient condition for regime is that the stream power per unit length of channel, $\gamma QI$ be a minimum subject to constraints, where $\gamma$ is the unit weight of fluid and I is the slope of the channel bed. Given a water and sediment inflow, the channel establishes its width, depth and slope such that the stream power or in case Q is a constant, slope is a minimum.

The concept of maximum sediment transport rate was developed by White et al. (1982). It states that channel for a specific slope will adjust its cross-sectional geometry such that its ability to transport sediment is a maximum. The channel geometry including the slope go on adjusting until the sediment transport capacity of the channel is equal to the value supplied from upstream.

### 2.2.5 EFFECTS OF CHANNELIZATION

The various effects of channelization can be broadly classified into physical effects and biological effects. The details of each of the category are given below.

### I) PHYSICAL EFFECTS

Channelization involves changing one or more of the interdependent hydraulic variables of slope, width, depth, roughness or size of the sediment load. This changing one or more of the interdependent hydraulic variable disrupts the existing equilibrium and to compensate for this there will be natural change in the remaining hydraulic variables in an attempt to attain a new state of equilibrium. Thus channelization induces instability not only in the improved channel reach but also upstream and downstream of the reach unless modified channels which are adjusting are regularly maintained then the hydraulic efficiency may be decreased. The physical impacts and subsequent adjustment of channels which have been realigned, enlarged, lined, embanked, diverted, or affected by clearing and snagging follows:

## EFFECTS OF CHANNEL REALIGNMENT

Lane (1947) demonstrated the effects of cutoffs in both non-erodible and erodibe channels. Non-erodible channels do not adjust. However long term changes occur after straightening of erodible channels. For the East and West Prairie Rivers in Alberta (Canada), Parker and Andrews (1976) found that straightening a meandering stream increased the slope by providing a shorter channel path (Fig. 2-6). This increase of slope enabled the transport of more sediment than was supplied at the upstream end of the channelized reach and the difference was obtained from the bed, causing degradation, which progressed upstream as a nickpoint. An excess of load was then supplied to the downstream part of the channelized reach and because the flatter natural reach downstream could not transport this sediment it was deposited on the bed. The excess may be deposited in gradually decreasing quantities with distance downstream. Degradation within the straightened reach may also cause bank collapse. The range of adjustments which might occur in response to straightening are summarized in Table 2-1 and include local effects within the engineered reach such as a steeper slope, higher velocities, increased transport and channel degradation.

**Table 2-1, Effects of Straightening a Reach by Cutoffs**

| Local Effects | Upstream Effects | Downstream Effects |
|---|---|---|
| 1. Steeper slope<br>2. Higher velocity<br>3. Increased transport<br>4. Degradation and possible head cutting<br>5. Bank unstable<br>6. River may braid<br>7. Degradation in tributary | Same as the local effects | 1. Deposition downstream of straightened channel<br>2. Increased flood stage<br>3. Loss of channel capacity |

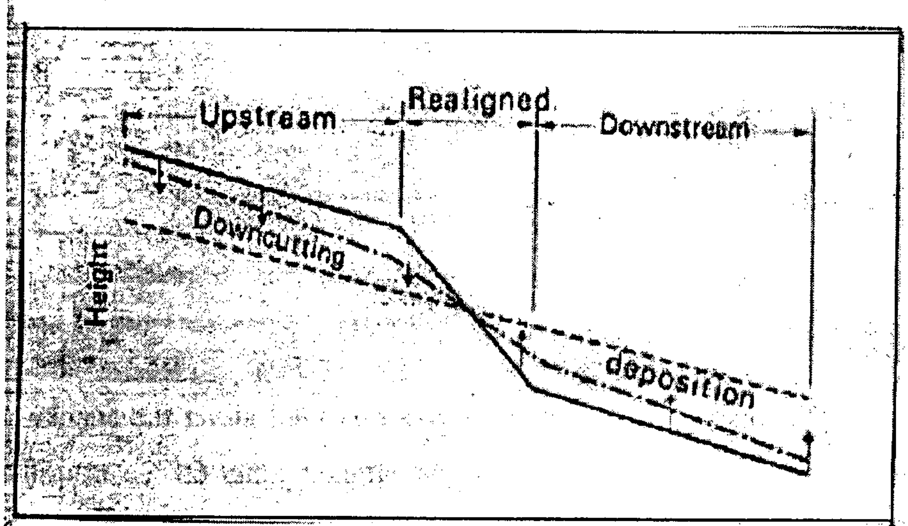


Fig. 2-6 Degradation in straight alluvial channels

## CASE STUDIES

The Willow River in Harrison County, Iowa was straightened during 1919-20 over a distance of approximately 42.1 km. The gradient of the original river was 1.0 m per km in the lower reaches and 1.4 m per km in a reach further upstream. The average slope of the river, which replaced these two reaches, was 1.5 m per km and 1.7m per km respectively. The ditch had a trapezoidal section with 1:1 side slopes. A comparison of the original profile of the ditch and a survey of the ditch in 1958 showed a maximum increase in channel size of 440 % between 1919-20 and 1958 in the upper reaches (Fig. 2-7). At the Monona- Harison County line the ditch had increased from an original depth of 3.4 m to a depth of 13 m. The 1920 top width of 9 m had increased to 33.5-36.6 m. Nickpoints were observed to move upstream rapidly during period of high flow. Passage of nickpoint caused the channel banks to collapse through slumping.

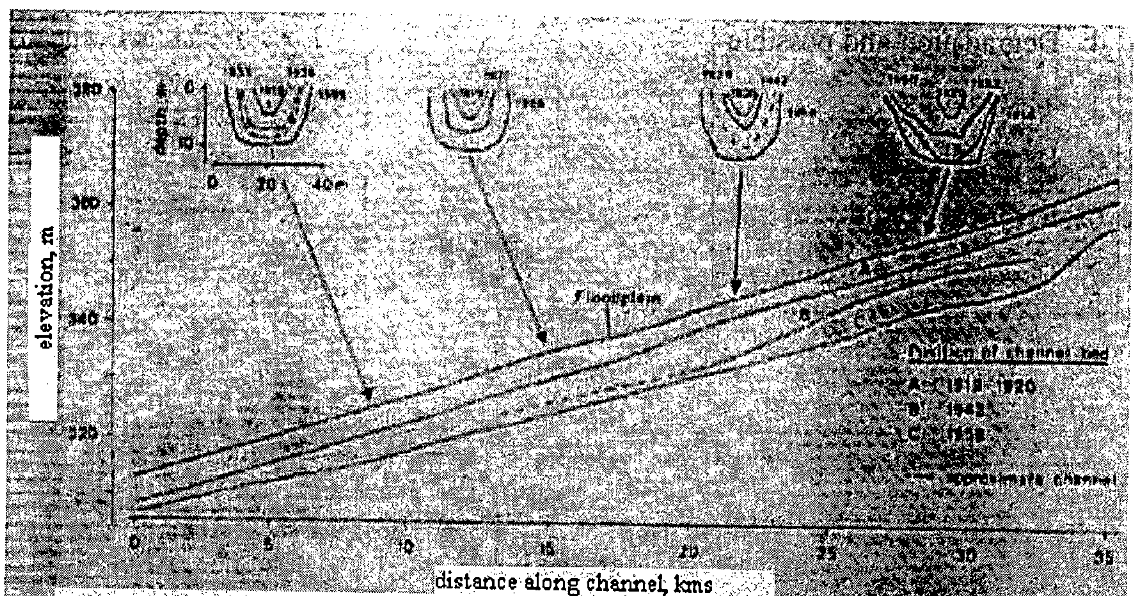


Fig. 2-7 Morphological adjustment of the Willow Drainage Ditch, Harrison County, Iowa

Drastic channel incision and enlargement was observed along the Blackwater River in Johnson County, Missouri, as a result of straightening 60 years previously. The shortened course was 24.6 km less than the original and the gradient was nearly doubled. The present channel had increased from a cross-section of 125 $m^2$ when newly dredged to a size ranging from 525 to 1589 $m^2$. The maximum value represents an increase in area of 1173 % over 60 years.

The Peabody River in New Hampshire was shortened by approximately 260 m and immediately after construction the channel began to adjust through erosion and scour. However, major changes occurred within the first year and adjustments were of decreasing significance in subsequent years (Fig. 2-8). The original channel had a fall of 10 m per km and the relocated channel was steepened to 15 m per km. The channel adjusted itself to 14 m per km after two years and to 13 m per km seven years after construction.

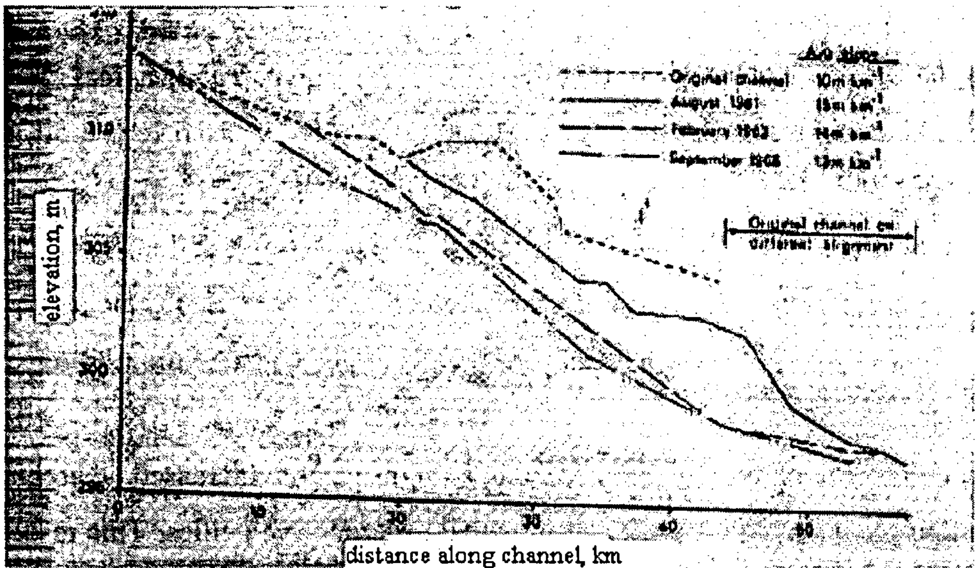


Fig. 2-8 Morphological adjustment along a relocated segment of the Peabody River, New Hampshire

Brice (1981) assesses the stability of 103 streams in different regions of the united states that were realigned for purposes of road or bridge construction, mostly during the period of 1960-70. The length of natural channel relocated ranges from 70 to 4200 m (8 to 550 m channel width). Stability of the relocated channel was rated as good at 36 sites, fair to good at 41 sites, fair at 15 sites and poor at 8 sites. Three sites were totally lined with concrete. In comparison with bank stability of the prior channel, bank stability of the relocated channel was about the same at 45 sites (52 %), better at 28 sites (32 %) and worse at 14 sites (16 %).

## EFFECTS ON TRIBUTARIES

The lower reaches of tributary streams of the Black River in Johnson County, Missouri, underwent down cutting in response to entrenchment, sixty years after channelization. For example, the cross-section area of honey creek had increased from 12 $m^2$ immediately after dredging to 255 $m^2$. Table 2-2 summarizes the effects on a tributary stream of lowering the base level in the main river channel, which can result from straightening..

**Table 2-2, Effects of Main Channel Straightening on its Tributary Stream**

| Local Effect | Upstream Effect | Downstream Effect |
|---|---|---|
| 1. Head cutting<br>2. Scour<br>3. Bank instability | 1. Increased velocity<br>2. Increased bed load<br>3. Unstable channel<br>4. Channel morphology changes | 1. Increased transport to main channel<br>2. Aggradations<br>3. Increased flood stage<br>4. Channel morphology changes |

The local gradient of the tributary stream is significantly increased, thereby inducing head cutting and causing a significantly increase in water velocities. This results in bank instability, possibly with major changes in the morphology of the tributary stream and increased local scour.

## CONTROL ON CHANNEL CHANGES

Degradation by the upstream migration of nickpoints is the main process by which over-steepened channel gradients are reduced, thereby enabling the channels to evolve to a new condition of dynamic equilibrium. Schumm and other (1984) attempted to determine the number of head cut events, which had occurred in the channelized reaches of Oaklimiter Creek. For a given reach the total increase in depth following construction was calculated. Based on field observation the assumption was made that each head cut event increased the channel depth by 1.2 m. Therefore the number of head cut events was calculated by dividing the total increase in depth by 1.2 m. Fig. 2-9 plots distance along the straightened channel against the number of head cut events. A plot of valley slope against distance is also included and it can be seen that a greater number of head cut events have been associated with steepen valley reaches.

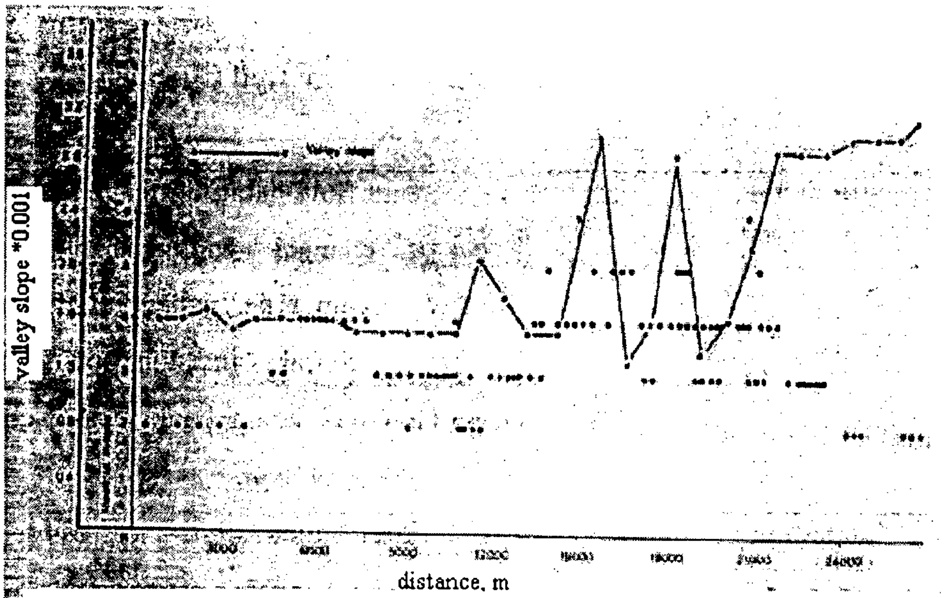


Fig. 2-9 Number of assumed headcut events (dots) related to valley slope with distance along Oaklimiter Creek, Northern Mississippi

The behavior of straightened stream channels depends on the character of the bed and bank sediments, their erodibility and stratification. Bray and Cullen (1976) observed that degradation following a cutoff on the Coverdale River in New Brunswick was controlled by bedrock outcrops, which prevented a nickpoint from migrating upstream and affecting the foundations of a bridge. Computed degradation rates indicated that problems might have occurred if there were no controls. Similarly it is expected that bed degradation will be restricted where a coarse segregated or armored layer develops.

The nature of sediment load conveyed through the channel and the change in character of the sediment load as the channel adjusts might also be important. Sediment is initially derived from incision, followed by bank collapse. Subsequently, rejuvenation of the tributaries upstream becomes a source of sediment. A line of trees adjacent to the bank may have the effect of inhibiting adjustment.

Brice (1981) identified three types of factor important to bank stability, namely site factors existing before modification, alteration factors, which may be relevant to stability after alteration and post alteration factors. These three factors are defined as given in the Table 2-3.

**Table 2-3, Factors Important to the Stability of Relocated Channels**

| | |
|---|---|
| **1. Site factor:** | Stream flow habit, drainage area, water discharge, channel width, bank height, sinuosity, stream type, valley relief, channel boundary material, incision of channel, vegetation cover along banks, prior channel stability, works of man. |
| **2. Alteration factor:** | Length of relocation, slope and cross sections of relocated channels, aspects of channel alignment, measures for erosion control and environmental purposes. |
| **3. Post alteration factor:** | Length of performance period, stream flows during performance period, post constructions, maintenance and addition of countermeasures, growth of vegetation along the channel. |

Brice (1981) further listed 13 factors contributing to the stability and 15 factors responsible for instability of relocated channels. These factors (given in Table 2-4) are ranked in order of importance for the 103 relocated channels, which Brice studied in North America.

**Table 2-4, Critical Factors Contributing to the Stability and Instability of Relocated Channels**

| **Stability** | | **Instability** | |
|---|---|---|---|
| 1. Growth of vegetation on banks | 41 Sites | 1. Bends in relocated channel | 21 Sites |
| 2. Bank revetment | 33 Sites | 2. Floods of large recurrence interval | 17 Sites |
| 3. Stability of prior channel | 20 Sites | | |

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|---|---|---|---|
| 4. Straightness of channel | 20 Sites | 3. Erodibility of bed or bank material | 16 Sites |
| 5. Low channel slope | 16 Sites | 4. High channel side, susceptible to slumping | 9 Sites |
| 6. Erosion resistance of bed or bank material | 15 Sites | 5. Instability of prior channel | 8 Sites |
| 7. Minimum channel shortening | 15 Sites | 6. Sharp decrease in channel length | 8 Sites |
| 8. Bed rock control | 13 Sites | 7. Failure of revetment | 7 Sites |
| 9. Check dam or drop structure | 11 Sites | 8. Width change factor too high or too low | 6 Sites |
| 10. Natural or artificial discharge regulation | 10 Sites | 9. Cleared field at bank line | 5 Sites |
| 11. Number of floods in first few years after construction | 6 Sites | 10. Flood soon after construction | 5 Sites |
| 12. Preservation of original vegetation | 3 Sites | 11. Lack of continuity in vegetal cover along banks | 5 Sites |
| 13. Dual channel | 3 Sites | 12. Turbulence at check dam or drop structure | 4 Sites |
| | | 13. Flow constriction at bridge | 4 Sites |
| | | 14. Non-linear junction with natural channel | 3 Sites |
| | | 15. Steep channel slope | 2 Sites |

## ENGINEERING CONSEQUENCES

Adjustments arising from channelization can have serious implications for structures built adjacent to or across the channel. The Lang Lang River in Victoria, Australia, was modified in 1920-23 to be 12 m wide by 2.5 m deep and straightened. After flooding, further straightening was undertaken in 1926 by a new cut, 18 m wide and 2 m deep, most of the excavated material being used to construct a levee bank. Erosion along the Lang Lang River has caused the damage or destruction of seven bridges. The erosion is generally 7-9 m with a minimum of 15 m. Erosion took place in the new cut almost as soon as it was excavated. A bridge 12.2 m wide built in 1924 at this section had to be strengthened in 1931 because of scouring of the riverbed. Three month later it was expanded 7.3 m to span the rapidly enlarging channel. From the 1940s onwards it required annual repairs until in 1968 a new reinforced concrete bridge 55.5 m wide was built.

## PREDICTION

Attempts have been made to predict the average rate of degradation using bed load equations and flow duration curves. However, predicted rates may differ substantially from the observed rates where bedrock or armoring restricts down cutting. Without a set of deterministic equations it is not possible to precisely predict the morphological response to alterations of width, depth, slope, roughness or plan form caused by channelization. However, behavior can be deduced to a certain extend by observing responses of stream channels that have already been altered. Channels stable priors to channelization are more likely to remain so, however, an initially unstable channel will probably require extensive engineering and maintenance following construction.

Chang (1986) described a method for prediction river channel adjustments based upon the qualitative relationships among the variables of water discharge, bed material discharge, slope, sediment size, channel width and depth for sand bed rivers in equilibrium. In response to changes of certain variables, the directions and magnitudes of adjustments for the other could be determined. The method was applied to a reach of the Mississippi River near Greenville, where a number of cutoffs have been made between 1933 and 1937, and it was determined that the original channel width of 1310 m was sensitive to channel slope along this reach. Since slope was increased by the cutoffs. Then this should have been accompanied by significant increased of width and width-depth ratio to avoid subsequent channel adjustment. In practice it was desirable to maintain an adequate depth for navigation and the channel was not widened. However, following straightening the channel adjusted naturally by substantial widening and even braiding, with the result that an extensive bank protection programme was subsequently undertaken to maintain the unnatural alignment. Chang (1986) showed that the predicted width of 2800 m for the 1975 channel was greater than the measured value of 2000 m, probably because the bank protection inhibited width development.

## EFFECTS OF CHANNEL ENLARGEMENT

Adjustments of channel morphology have been noted within reaches, which have been enlarged (widened and/ or deepened). The River Tame near Birmingham, in Central England was widen to increase its capacity under a flood alleviation scheme. The channel riverted to its original capacity in less than 30 years in the absence of maintenance. This was due to the enlarged channel being in equilibrium with a particular design flow event, while out of equilibrium with the normal range of flows. Widening a channel reduces the unit stream power, thereby decreasing the sediment discharge. The low flows, which tend to predominate for most of the time deposit sediment because of the reduced velocities in an over widened channel, and the deposits may become stabilized to form permanent morphological features. Extensive aggradations in some rivers has caused the development of mid channel bars and braided flow at low discharges.

Continuous dredging causes a riverbed to degrade until the balance between the sediment load supplied to the river reach and the sediment transport capacity is restored (Fig. 2-10). In the long term the bed degrades to a gentler slope and greater depth downstream from the point of dredging. Degradation also occurs upstream, resulting in a lower riverbed with the initial slope. Deepening the main channel also lowers tributary base levels and increases tributary slopes and head cut may develop. Rapid tributary erosion may result in aggradations within the main channel.

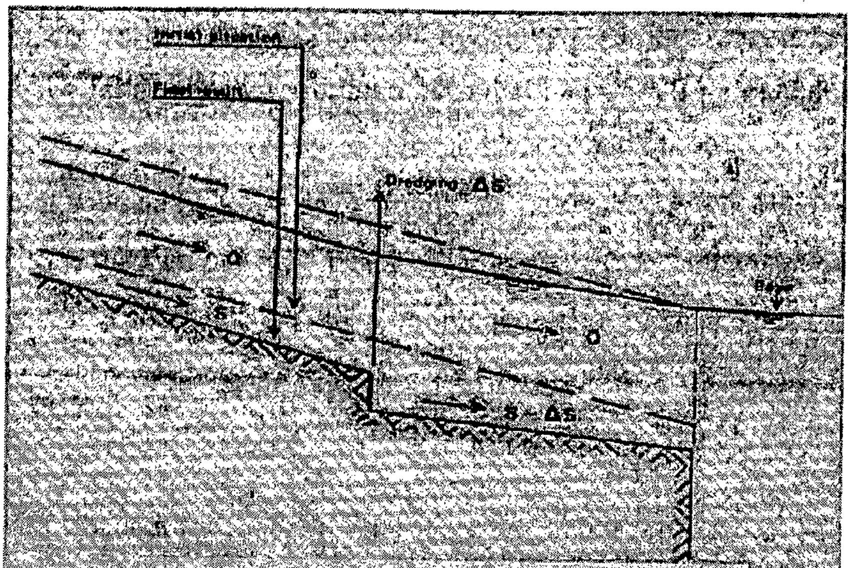


Fig. 2-10 Degradation due to continuous derdging

Griggs and Paris (1982) reported that within 10 years of completion of a flood channel on the San Lorenzo River at Santa Cruz in California, 350000 m3 of sediment had been deposited. This reduced the capacity from the designed 100-year flood to a 25-30 year flood. The project had involved deepening the channel by some 0.9 to 2.1 m below the original channel bottom, thus functioning as sediment trap for the large volumes of sand and silt derived from the urbanized watershed.

## EFFECTS OF CHANNEL LINING

Adjustments occurring specifically within concrete-lined channels are less well documented, although there is often a requirement to remove sediment, which has accumulated above the artificial substrate. Where the banks of an actively migrating channel have been protected by riprap, gabions or similar protection materials, then adjustments during flood events may destroy these structures. The Little Choconut Creek, near Binghamton, New York was rip rapped during the construction of a highway. The flood of 1975 caused the banks behind the riprap to be washed away.

## EFFECTS OF CHANNEL EMBANKING

Adjustments may arise from embanking a channel because larger flows are confined than previously and the greater velocities associated with these flow may cause degradation of the bed and/ or banks.

## EFFECTS DUE TO CONSTRUCTION OF DIKES

Dikes reduce the flow area and increase the velocity, as a result, shoals in the channel are scoured and secondary channels and chutes are closed such that all flow is confined to the main channel. Dikes have been used extensively on the lower Mississippi to help maintain navigation channels, principally since 1960. By using photographs and hydrographic surveys taken between 1962 and 1976, Nunnally and Benerly (1983) demonstrated the morphological changes in diked and undiked reaches. The total surface area of the river between river miles 320 and 954 remained relatively constant between 1962 and 1976. However, this area was classified on the based of main channel used for navigation, secondary channels which carry flow all year, sloughs on slack- water areas with a single inlet or outlet, chute or narrow channel with relatively little flow and pools which were found on sand banks. Within the diked areas secondary channel area decreased by 38.6 %, but this was offset by increases in sloughs (53.2 %) chutes (44.8 %) and pools (2423.8 %). Pools, sloughs and chutes are all considered as valuable types, while secondary channels are considered as less valuable type of aquatic habitat.

## EFFECTS OF CHANNEL CLEARING AND SNAGGING

Trees, snags and logjams have a significant impact on channel morphology. Trees have been shown to retard bank erosion, whilst fallen trees and logjams may trigger bank erosion and bed erosion, particularly in small stream. In meandering channels, it has been shown that logjam frequently result in local channel widening, deposition and mid channel bars downstream of the obstruction. Removal of debris and bank side vegetation increases the hydraulic efficiency, increases current velocity adjacent to the bank and reduces bank resistance to erosion. Changes in Manning's 'n' following the removal of vegetation, snags, log jams and mid channel bars are summarized in Table 2-5.

**Table 2-5, Changes in Manning's 'n' Following Clearing and Snagging and after Regrowth**

| Source | Location | Condition | Manning's 'n' |
|---|---|---|---|
| Wilson (1973) | 15 m wide, 3.6 m deep channelized stream near Jackson, Mississippi | Clean | 0.022 |
| | | After one growing season | 0.045 |
| | | After 6 years (summer foliage) | 0.070 |
| | | After 8 years (winter foliage) | 0.070 |
| Pickles (1931) | 4.5-16.8 m wide drainage ditch in central Illinois | Clear weeds and willow | 0.032 |
| | | 1.2 m height weeds | 0.050 |
| Burkham (1976) | Gila River during a flood | Dense growth of mesquite and salt-cedar | 0.080 |
| | | After eradication | 0.024 |

## II) HYDROLOGICAL EFFECTS

Channelization affects the timing and magnitude of downstream flood flow. Channelization eliminates a certain amount of local storage such that water, which should previously have spread on to an adjoining floodplain, is now contained in the channel and as passed downstream. Peak and near peak flows are therefore increased.

The effects of straightening on flood flows have been examined for the Boyer river in western Iowa, where the total channel length was reduced from approximately 400 km to 160 km between 1900 and 1950 (Komura, 1970; Campbell et al., 1972). Using a unit hydrograph approach and flood routing procedures it was demonstrated at a total of 36 cross-sections that straightening increased the peak discharge in the range 90- 190%, depending on the roughness value of the floodplain. The time base of the discharge hydrograph was significantly shortened and the time of travel of the flood wave down the river was greatly reduced.

Permanent wetlands such as swamps and bogs are important regulators of streamflow, since organic soils can store large amount of water during wet periods and sustain baseflow during dry periods (Hill, 1976). Simmel et al. (1966) calculated that during the spring more than 17 billion litres of water was retained by the floodplain swamps of the Iplswich River in the northeast United States, thereby reducing downstream floodpeaks. The Massachusetts Water Resources Commission (1971) estimated that a reduction of only 10% of the wetland flood storage of the Neponset River basin would cause a 46 cm increase of flood stage.

## III) EFFECTS ON WATER QUALITY

Channelization of river alters the water quality variables such as sediment concentration, temperature and water chemistry. The effects on these variables are site specific, reflecting watershed land use, the severity of modification and the length of the recovery period.

## SEDIMENTATION

Channelization over a specific length of a river increases downstream sediment load. Hill (1976) stated that increased sediment loads downstream from channelization works are probably at a peak during dredging and in the immediate post-construction phase when erosion of unvegetated banks is at a maximum. A study of sites undergoing channelization in England reported suspended sediment concentration up to a maximum of 340 times in excess of those measured simultaneously in the natural channel above each of the works (Brookes 1983).

The river Wylye in UK was realigned for a short distance of 95 m to facilitate road improvements over a period of 15 working days in January and February 1982. The spoil excavated from the new channel was used to backfill the old river course. Fig 51 depicts suspended sediment concentrations for the points monitored above and below the reach undergoing channelization. The amount of sediment released was at a maximum during working hours. Concentrations were high during the first three days of construction (January 25-27) of the pilot channel, cut along the new course. Higher concentrations were recorded on January 28 when spoil excavated from the new course were used to backfill the old channel and eroded by flowing water. All flow was eventually diverted to the new course by plugging the old channel (January 29- February 1). Between February 3 and 11 the new channel was enlarged and suspended sediment values remained relatively low but higher that those recorded upstream. The new cut had a cross-sectional area 160% larger than the old channel, creating a very deep pool with low flow velocities unable to erode the new channel and remove sediment in suspension to the downstream reach. Suspended sediment concentrations were found to decline with distance downstream during construction, which could by attributed to localised deposition of sediment and to the dilution effect of tributaries carrying relatively little suspended sediment entering the mainstream.

## TEMPERATURE

The reduction of shade immediately following construction, as a result of removal of trees/ undercut banks and debris, usually results in an increased mean and daily fluctuation of temperature. Duvel et al. (1976) indicated that where substantial lengths of modified channel exists a rise in water temperature would occur. For the Yellow Creek in northeast Mississippi, which was relocated over a distance of 9.6 km, the average daily maximum stream temperature was 4° C greater after construction.

## WATER CHEMISTRY

The removal of organic substrate, increased velocity and more turbulent flow arising from channelization increase dissolved oxygen levels. Dredging may cut through the oxidised layer of the substrate and expose a deep unoxidised layer. Sediment removed in suspension from this layer is in a chemically reduced state and has very high chemical and biological oxygen demands.

For the Yellow Creek in northeast Mississippi, Shield and Sanders (1986) observed that mean values of specific conductance, turbidity, colour, COD, total alkalinity, hardness, ammonia, phosphorus, sulphate, iron, lead and manganese were 50- 100% greater during construction of a cut than before. The changes of water quality at Yellow 'Creek reflected not only the increased sediment input but also the changed nature of the sediments. The changes in mean dissolved calcium, sulphate, iron and manganese level were probably a reflection of the character of the soils exposed by excavation of the new cut. The slightly higher BOD and COD level probably reflected the small amount of organic matter present in exposed soils.

## IV) BIOLOGICAL EFFECTS

Channelization can destroy or alter the habitat of plants and animals in watercourses. A comparison of the morphology and hydrology of a natural stream with a typical channelized watercourse is shown in Fig. 2-11. Channlization changes a heterogeneous system into a homogeneous one. Bank cover is eliminated, pools are lost, flow approaches a laminar character and the substrate approaches homogeneity throughout the channel due to channelization. The result in ecosystem terms is that habitat diversity is reduced.

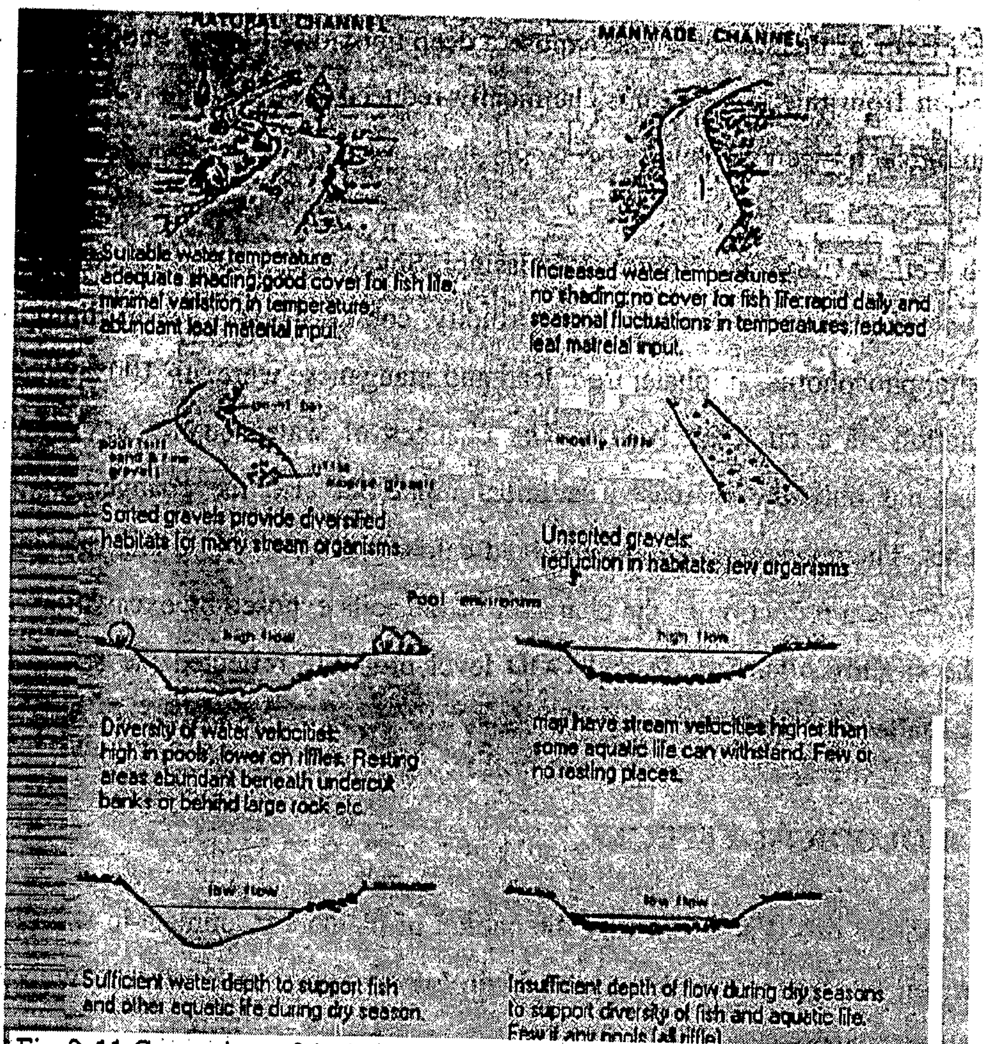



Fig. 2-11 Comparison of th channel morphology and hydrology of a natural stream with a channlized watercourse

The impact on the invertebrates, fish and aquatic plants within a channel arise mainly from channel excavation and dredging, the lining of channels, clearing and snagging and weed cutting. The habitat of birds and mammals may also be destroyed by the removal during construction of bank side trees, bushes and plants. The draining of wetlands can have very serious consequences for mammals, amphibians, insects and birds.

Many factors, which can be changed by channelization, include velocity of flow, temperature, and the substrate, including vegetation and dissolved substances. Velocity controls the occurrence and abundance of species. It is found that certain species are confined to fairly definite ranges of velocity. There are other species, which can only occurs in stony substrate. Species such as the burrowing mayfly nymph requires fine particles, particularly coarse sand. Whereas large number of burrowing worms require silty substrate. Similarly detritus, partly caused by the accumulation of leaf litter from overhanging trees is important for certain species. Vegetation also affects the fauna. Several studies have shown that there are more animals in moss, rooted plants and filamentous algae than there are on stones.

A few studies have reported a correlation between shade and the occurrence of abundance of particular species. This may be due to indirect effect of temperature or organic detritus from overhanging trees. The leaves and needles, which fall into the stream, provide organic material, which contributes to the aquatic insect production. The rise of temperature reduces the solubility of oxygen in fresh water. It means there is a direct relation between the respiratory rate of aquatic lives and temperature of water. Consequently some species require relatively more oxygen for respiration and can not survive in high temperature water.

Animals may be physically removed during the process of excavation. Silt deposition as a consequence of channelization may kill many invertebrates, standing crop, productivity, species diversity and numbers of macro-invertebrates were lower in channelized section of the Luxapalila River even 52 years later. This was attributed to differences in the substrate, pebbles being common in natural reaches and fine sand typifying channelized sections. Recovery of the macro-invertebrate fauna following channelization has been shown to occur where there is no substantial changes in the substrate size and stability. A study of the Bunyip River in Australia revealed no significant and consistent differences in the density, biomass and composition of the macro-invertebrates at channelized and unchannelized sites. This was because the two channelized sites of the Bunyip River had the most stable substrates composed of clay bedrock.

## 2.2.6 RECOMMENDATIONS TO MINIMISE THE ADVERSE EFFECTS OF CHANNELIZATION

The adverse effects of conventional channelization methods may be minimised by careful selection of option at the planing stage or by limiting the degree to which a channel is modified. The selection of engineering options may depend on the type of river channel for which solution is sought. A river channel may be classified into number of zones based on valley cross-section, channel pattern, gradient and bed load size. The boulder zone is a river environment adjusted to transport water and sediment through a steep, resistant 'V' shaped valley. The river is self-maintaining and intrusions such as landslides and rockfalls are soon flushed out. By contrast the floodway zone is more problematical since high energy and low bank resistance combine to make a dynamic channel. Efforts to straighten such channel will intensify the velocities and create adverse effects. In the pastoral zone, the channel is more stable because of the cohesive strength of the finer sediment load and a gentler gradient. The rate of meander migration in this zone is considerably less.

The selection of engineering options also depends on economic, social, political and environmental consideration. Table-6 lists the conventional engineering practices most commonly used on alluvial rivers, tentatively ranked in order of increasing environmental impact.

**Table-6, Types of Channel Modification Listed in Ascending Order of Impact on Fish and Wild Life Resources**

1. Rip-rapping (placement of rocks as bank protection)
2. Selective snagging (selective removal of objects such as fallen trees)
3. Clearing and snagging (removal of debris such as shoal and vegetation)
4. Widening (enlargement of channel by widening)
5. Deepening (enlargement of channel by deepening)
6. Realignment (construction of a new channel)
7. Lining (placement of non-vegetative smooth lining)

Some recommendation to minimise the adverse effects of conventional engineering procedure are given below:

## I) CHANNEL REALIGNMENT

The biological impact of realignment can be reduced if guidelines relating to the design, construction and clean-up phase are followed. At the design stage there should be minimal reduction of channel length, the amount of excavation and fill should be controlled and equipment, which minimises destruction of banks and streamside growth should be used. Banks should be replanted whenever possible and riprap placed such that the growth of vegetation close to the stream edge is not impeded. During construction, access by vehicles should be strictly controlled and disruption to the streambed and banks should be minimised, which can be attained by educating the foremen and specifying the types of equipment that can be used in particular areas. Finally, in the 'clean-up 'phase it is recommended that gravel and large rocks be placed in the streambed to approximate conditions existing prior to construction and to restore stability. Replanting and/ or reseeding of banks with native trees, plants or grass provides shelter and cover for wildlife.

## II) CHANNEL ENLARGEMENT

Enlargement of channels by modifying only one bank and leaving the opposite bank almost entirely untouched, is now a commonly used practice so that the vegetation on the opposite bank remain undisturbed as far as possible. The bank from which the work is undertaken can be designated on the bases of habitat value of the vegetation, aesthetics, shade and bank stability. If work is alternated from one bank to the other the aesthetic appearance may be improved and this enables avoidance of sensitive habitats. Retention of tall vegetation will shade out aquatic vegetation and thereby reduce maintenance costs.

The impact of excavation on the aquatic vegetation have been shown to be minimised by avoiding the creation of very deep pools, which may serve as silt trap or preclude light from reaching the channel bed. It is also recommended that excessive widening be avoided since this is likely to reduce the depth of water in a channel for a given discharge and thus limit the space for growth of vegetation.

The preservation of the substrate is critical for the macro-invertebrate fauna. This can be achieved by stockpiling the original substrate and reinstating the same after excavation has been completed. For maximum diversity of species it is necessary to preserve or recreate morphological diversity, a pool and riffle sequence and a variety of substrates. Retention of stands of aquatic plants along the margins of a channel will be beneficial to the diversity and stability of macro-invertebrate habitats. Limiting the removal of bankside vegetation, including trees will allow organic litter input to the stream, which is an important food source. Preserving bankside vegetation and revegetating the disturbed vegetation will also avoid excess water temperatures and luxuriant growth of aquatic vegetation, which may otherwise limit habitat diversity.

## III) CHANNEL EMBANKMENTS

Embanking may have the least impact where banks are constructed of imported materials and the original channel is left intact. Preserving trees and shrubs with unique wildlife value for fooding, nesting or resting during construction of embankment is always recommended as it maintain scenic and ecological values and minimise the need for revegetation. The borrow pits may be developed in the form of fish ponds or marshes useful as habitats for birds etc. Turfing the inner and outer slopes of embankments enhance visual appearance and stability of embankments.

## IV) CHANNEL LINING

Lining of channel disturbs the original substrate and retards the regrowth of vegetation. So use of artificial lining should be avoided as far as possible. The choice of material for bank protection is important from environmental viewpoint. Rigid linings such as reinforced concrete, grouted riprap, bagged cement and filled mats and membranes have perhaps the most detrimental effect on the aquatic habitat. By contrast riprap of stones, gabions, gravel armoring and woody vegetation are more desirable. Concrete lining can be alternated with short lengths of natural channel, which provide and acceptable habitat for fish.

## V) DIKES

The major objective of dikes has been to stabilise long length of rivers. Recently studies have shown that dikes can provide an extremely valuable habitat for fish and macroinvertebrates. The main problem is to design dike fields, which do not fill with sediment. This can be achieved by varying the length and height, but constriction gaps or notches in dikes are the most widely employed environmental feature at present (shield, 1983). These allow water to flow through the dike at intermediate stages and prevent sediment accretion by scouring. A variety of notch widths, shapes and depths are recommended through a reach to provide spatial and temporal habitat diversity. Notches should be wide enough to develop the desirable habitat, yet not so wide that erosion damage occurs.

# DESCRIPTION OF MODELS USED

## 3.1 HEC-RAS

### 3.1.1 GENERAL INTRODUCTION

The U.S. Army Corps of Engineers River Analysis System (HEC-RAS) is a software developed by the Hydrologic Engineering Center to perform one-dimensional hydraulic calculation for a full network of natural channels. The current version of HEC-RAS (Version 3.0) supports only the steady and unsteady water surface profile calculations. However it will ultimately contain three one-dimensional hydraulic analysis components for: i) Steady flow water surface profile computations; ii) Unsteady flow simulation and iii) Movable boundary sediment transport computation. A key element is that all three components will use a common geometric data representation and common geometric and hydraulic computation routines. In addition to the three hydraulic analysis components, the system contains several hydraulic design features that can be invoked once the basic water surface profiles are computed.

### 3.1.2 OVERVIEW OF PROGRAM CAPABILITIES

HEC-RAS comprises of a graphical user interface, separate hydraulic analysis components, data storage and management capabilities, graphics and reporting facilities.

#### I) USER INTERFACE

The user interacts with HEC-RAS through a graphical user interface. The interface provides for the following functions:

- File management
- Data entry and editing

- Hydraulic analysis
- Tabulation and graphical displays of input and output data
- Reporting facilities
- On-line help

## II) HYDRAULIC ANALYSIS COMPONENTS

### STEADY FLOW WATER SURFACE PROFILES

This component of the modeling system is intended for calculating water surface profiles for steady gradually varied flow. The system can handle a full network of channels, a dandritic system or a single river reach. The steady flow component is capable of modeling sub-critical, super-critical and mixed flow regime water surface profile.

The basic computation procedure is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/ expansion (coefficient multiplied by the change in velocity head). The momentum equation is utilised in situations where the water surface profile is rapidly varied. These situations include mixed flow regime calculations (i.e. hydraulic jumps), hydraulics of bridges and evaluating profiles at river confluences (stream junctions).

The effects of various obstructions such as bridges, culverts, weirs and structures in the floodplain may be considered in the computations. The steady flow system is designed for application in floodplain management and flood insurance studies to evaluate floodway encroachments. Also capabilities are available for assessing the change in water surface profiles due to channel improvements and levees.

### UNSTEADY FLOW SIMULATION

This component of the HEC-RAS modeling system is capable of simulating one-dimensional unsteady flow through a full network of open channels. This unsteady flow component was developed primarily for sub-critical flow regime calculation. The hydraulic calculation for cross-sections, bridge, culverts and other hydraulic structures for the unsteady flow module are the same as that for the steady flow component.

## SEDIMENT TRANSPORT/ MOVABLE BOUNDARY COMPUTATIONS

This component of the modeling system is intended for the simulation of one dimensional sediment transport/movable boundary calculations resulting from scour and deposition over moderate time periods. The sediment transport potential is computed by grain size fraction, thereby allowing the simulation of hydraulic sorting and armoring. Major features will include the ability to model a network of streams, channel dredging, various levee and encroachment alternatives and the use of several different equations for computation of sediment transport.

The model will be designed to simulate long term trends of scour and deposition in a stream channel that might result from modifying the frequency and duration of the water discharge and stage, or modifying the channel geometry. This system can be used to evaluate deposition in reservoirs, design channel contractions required to maintain navigation depths, predict the influence of dredging on the rate of deposition, estimate maximum possible scour during large flood events, and evaluate sedimentation in fixed channels

## III) DATA STORAGE AND MANAGEMENT

Data Storage is accomplished through the use of "flat" files as well as the HEC-DSS. User input data are stored in flat files under separate categories of project, plan, geometry, steady flow, unsteady flow, and sediment data. Output data is predominantly stored in separate binary files. Data can be transferred between HEC-RAS and other programs by utilising the HEC-DSS.

Data management is accomplished through the user interface. The modeler is requested to enter a single filename for the project being developed. Once the project filename is entered, all other files are automatically created and named by the interface as needed.

The interface provides for renaming, moving and deletion of files on a project-by-project basis.

### IV) GRAPHICS AND REPORTING

Graphics include X-Y plots of the river system schematic, cross-sections, profiles, rating curves, hydrographs, and many other hydraulic variables. A three-dimensional plot of multiple cross-sections is also provided. Tabular output is available. Users can select from pre-defined tables or develop their own customised tables. All graphical and tabular output can be displayed on the screen, sent directly to a printer or passed through the Windows Clipboard to other software, such as a word-processor or spreadsheet.

Reporting facilities allow for printed output of input data as well as output data. Reports can be customised as to the amount and type of information desired.

## 3.1.3 STEPS IN DEVELOPING A HDRAULIC MODEL WITH HEC-RAS

There are five main steps in creating a hydraulic model with HEC-RAS. These are:

- Starting a new project
- Entering geometric data
- Entering flow data an boundary conditions
- Performing the hydraulic calculation
- View and printing results

### STARTING A NEW PROJECT

The first step in developing a hydraulic model with HEC-RAS is to establish the directory to work in and to enter a title for the new project. In HEC-RAS terminology, a project is a set of data files associated with a particular river system. The data files for a project are categorised as plan data, geometric data, steady flow data, unsteady flow data, sediment data and hydraulic design data. To start a new project, we go to the **File** menu on the HEC-RAS window and select **New Project**. This will bring up a new project window, in which, the drive and path are selected to work in. Next a project title and file name is entered in the same window. After entering all the above information, the **OK** botton is pressed. This will bring a message box with the title of the project and the directory that the project is going to be placed in. If this information is correct the **OK** botton is pressed otherwise the **Cancel** botton is pressed to return to the **New Project** window.

Finally, the unit system (English or Metric) is selected before entering any geometric or flow data. This step can be accomplished by selecting **Unit System** from the **Options** menu of the main HEC-RAS window.

## ENTERING GEOMETRIC DATA

The next step is to enter the necessary geometric data, which consist of connectivity information for the stream system (River System Schematic), cross-section data and hydraulic structure data (bridges, culverts, weirs etc.). Geometric data are entered by selecting **Geometric Data** from the **Edit** menu on the main HEC-RAS window. The geometric data is developed by first drawing the river system schematic. This is accomplished on a reach-by reach basic by pressing the **River Reach** button and then drawing a reach from upstream to downstream. After the reach is drawn, the user is prompted to enter a river and reach identifiers. As reaches are connected together, junctions are automatically formed by the interface. The user is also prompted to enter an identifier for each junction.

After the river system schematic is drawn, the cross-section and hydraulic structure data can be entered. Pressing the **Cross-section** botton causes the cross-section editor to pop up. In the cross-section editor, each cross-section has a river name, reach name, river station and a description. The river, reach and river station identifiers are used to describe where the cross-section is located in the river system. The river station identifier does not have to be the actual river station at which the cross-section is located on the stream, but it does have to be a numeric value e.g. 1.1, 2, 3.5 etc. The numerical value is used to place cross-sections in the appropriate order within a reach, cross-sections are ordered within a reach from the highest river station upstream to the lowest river station downstream.

The basic data required for each cross-section are stations and elevations of all the points in the cross-sections, downstream reach length, Manning's "n" values and the bank stations. Different cross-section features are available under **Options** from the menu bar. Also available from the cross-section data editor is the ability to plot any cross-section or reach profile. Once the cross-section data are entered, any hydraulic structures such as bridges, culverts, weirs etc. can be added. Data editors, similar to the cross-section data editor, are available for the various types of hydraulic structures. If there are any stream junctions in the river system, additional data are required for each junction.

Once the geometric data are entered, the data should be saved to a file on the hard disk. This is accomplished by selecting the **Save Geometric Data As** option from the **File** menu or the geometric data editor. This option allows the user to enter a title for the geometric data. A filename is automatically established for the geometric data and then saved to the disk. Once a title is established, geometric data can be saved periodically by selecting **Save Geometric Data** from the **File** menu or the geometric data editor.

## ENTERING FLOW DATA AND BOUNDARY CONDITIONS

Once the geometric data are entered, then either steady flow or unsteady flow data can be entered. The type of flow data entered depends upon the type of analyses to be performed. In case a steady flow analysis is to be performed, the data entry form for steady flow data is available under the **Edit** menu on the HEC-RAS main window. The steady flow data consist of; the number of profiles to be computed, the flow data, and the river system boundary conditions. At least one flow must be entered for every reach within the system. Additionally, flow can by changed at any location within the river system. Flow values must by entered for all profiles.

Boundary conditions are required in order to perform the calculations. If a sub-critical flow analysis is going to be performed, then only the downstream boundary condition are required. It a super-critical flow analysis is going to be performed, then only the upstream boundary conditions are required. If a mixed flow regime is going to be performed, then both upstream and downstream boundary conditions are required. The boundary condition data entry form can be brought up by pressing the **Enter Boundary Conditions** button from the steady flow data entry form.

Once all the steady flow data and boundary conditions are entered the data should be saved to the hard disk. This can be accomplished by selecting **Save Flow Data As** from the **File** option of the steady flow data menu bar. Flow data is saved in a separate file. We are only required to enter a title for the flow data, the filename is automatically assigned.

## PERFORMING THE HYDRAULIC COMPUTATION

Once all of the geometric data and flow data are entered the hydraulic calculations can be started. As stated previously there are three types of calculations that can be performed in the current version of HEC-RAS: steady flow analysis, unsteady flow analysis and hydraulic design functions. Any of the available hydraulic analysis can be selected from the **Run** menu bar option on the HEC-RAS main window.

To perform steady flow analyses the **Steady Flow Analysis** window is first activated. Then a plan can be formed by selecting a specific set of geometric data and flow data. A plan can be put together by selecting **New Plan** from the **File** menu bar option of the steady flow analysis window. Once a plan title and short identifier have been entered a flow regime for which the model will perform calculations, can be selected. The flow regime may be sub-critical, supercritical or mixed regime.

Once a plan is selected and all of the calculation options are set, the steady flow calculations can be performed by pressing the **Compute** botton at the bottom of the steady flow analysis window. When this button is pressed, the HEC-RAS system packages up all the data for the selected plan and write it to a run file. The system then runs the steady flow model and passed it the name of the run file. This process is executed in a separate window. Therefore, the modeler can work on other tasks while it is executing.

## VIEWING AND PRINTING RESULTS

Once the model has finished all of the computations, the results can be viewed in graphical form or in tabular form. Several output features are available under the **View** option from the main window. These options include; cross-section plots, profile plots, ratting curve plots, X-Y-Z perspective plots, tabular output at specific locations (Detail Output Tables), tabular output for many locations (Profile Summary Tables) and the summary of errors, warnings and notes.

Any cross-section can be viewed by simply selecting the appropriate river, reach and river station from the list boxes at the top of the plot. The user can also step through the plots by using up and down arrow buttons. Several plotting features are available under the **Options** menu of the cross-section plot. These options include: zoom in; zoom out; full plot; pan; animate; selecting which plans, profiles and variables to plot; velocity distribution; viewing interpolated cross-sections and control over the lines, symbols labels, scaling and grid options.

A profile plot can be achieved by selecting the **Profile Plot** under the **View** menu of the main window. All of the options available in the cross-section plot are also available in the profile plot. Additionally specific reach to plot can be selected, when a multiple-reach river system is being modeled.

Similarly an X-Y-Z perspective plot can be achieved. The user has the option of defining the starting and ending location for the extent of the plot. The plot can be rotated left or right and up or down, in order to get different perspectives of the river reach. The computed water surface profiles can be overlaid on top of the cross-section data.

Hard copy outputs of the graphics can be obtained in two different ways. Graphical plots can be sent directly from HEC-RAS to the printer or plotter or to the window clipboard.

Once the plot is in the clipboard it can then be pasted into other programs, such as a word processor. Both of these options are available from the **File** menu on the various plot windows.

The tabular output is available in two different formats. The first type of tabular output provides detailed hydraulic results at a specific cross-section location (detailed Output Table). The second type of tabular output shows a limited number of hydraulic variables for several cross-sections and multiple profiles (Profile summary Tables). Users can also define their own tables by specifying what variables they would like to have in a table. User specified table headings can be saved and then selected later as one of the standard tables available to the project.

Tabular output can be sent directly to the printer or passed through the clipboard in the same manner as the graphical output described previously.

## 3.2 HEC-6

### 3.2.1 INTRODUCTION

Hec-6 is a one-dimensional movable boundary open channel flow numerical model designed to simulate and predict changes in river profiles resulting from scour and/ or deposition over moderate time periods. A continuous flow record is partitioned into a series of steady flows of variable discharges and durations. For each flow a water surface profile is calculated thereby providing energy slope, velocity, depth etc. at each cross-section, potential sediment transport rates are then computed at each section. These rates combined with the duration of the flow permit a volumetric accounting of sediment within each reach. The amount of scour or deposition at each section is then computed and the cross-section adjusted accordingly. The computation then proceeds to the next flow in the sequence and the cycle is repeated beginning with the updated geometry. The sediment calculations are performed by grain size fraction there by allowing the simulation of hydraulic sorting and armoring. Features of HEC-6 include: capability to analyse networks of streams; channel dredging; various levees and encroachment alternatives and to use several methods for computation of sediment transport rates.

HEC-6 simulates the capability of a stream to transport sediment given the yield from upstream sources. This computation of transport includes both bed and suspended load. Using the hydraulic properties of the flow and the characteristics of the sediment material, one can compute the rate of sediment transport. HEC-6 implements similar concepts to compute the movement of sediment materials for a temporal sequence of flows and through volume conservation of bed material, changes in channel dimensions. The transport, deposition and erosion of silts and clay may also be calculated. Effects of the creation and removal of an armor layer are also simulated.

### 3.2.2 APPLICATIONS OF HEC-6

A dynamic balance exists between the sediment moving in a natural stream, the size and gradation of sediment material in the stream's boundaries and the flow hydraulics. When a reservoir is constructed, flood damage reduction measures are implemented, or a minimum depth of flow is maintained for navigation, that balance may be changed. HEC-6 can be used to predict the impact of making one or more of those changes on the river hydraulics, sediment transport rates and channel geometry.

HEC-6 is designed to simulate long-term trends of scour and/or deposition in a stream channel that might result from modifying the frequency and duration of the water discharge and/ or stage, or from modifying the channel geometry. HEC-6 can be used to evaluate deposition in reservoirs, design channel contractions required to maintain navigation depths or decrease the volume of maintenance dredging, predict the influence that dredging has on the rate of deposition, estimate possible maximum scour during large flood events and evaluate sedimentation in fixed channels.

### 3.2.3 SUMMARY OF HEC-6 CAPABILITIES

#### GEOMETRY

A river system consisting of a main stem, tributaries and local inflow/ outflow points can be simulated. Such a system in which tributary sediment is calculated is referred to as a network model. Sediment transport is calculated by HEC-6 in primary rivers and tributaries. The upper limits on number of network branches, number of cross sections, etc., in the present version, due to computer memory limitations are as follow:

- 10 Stream Segments (Main Stem + Tributaries)
- 150 Cross Sections
- 100 Elevation/Station Points per Cross Section
- 20 Grain Sizes
- 10 Control Points

#### HYDRAULICS

The one-dimensional energy equation is used by HEC-6 for water surface profile computations. Manning's equation and $n$ values for overbank and channel areas may be specified by discharge or elevation. Manning's $n$ for the channel can also be varied by Limerinos' method using the bed gradation of each cross-section. Expansion and contraction losses are included in the determination of energy losses. The energy loss coefficients may be changed at any cross section.

For each discharge in a hydrograph, the downstream water surface elevation can be determined by either a user specified rating curve or a time dependent water surface elevation. Internal boundary condition can be imposed on the solution. The downstream rating curve can be changed at any time. Internal boundary condition can also be changed at any time. Split flow computations are not done and no special capabilities for computing energy losses through bridges is available. The supercritical flow is approximated by normal depth; therefore sediment phenomena occurring in supercritical reaches are simplified in HEC- 6.

HEC-6 can be executed in "fixed bed" mode, in which only water surface profiles are computed. Sediment information such as inflowing sediment load and bed gradations are not needed to run HEC-6 in fixed-bed mode.

## SEDIMENT

Sediment transport rates are calculated for grain sizes up to 2048 mm. Sediment sizes larger than 2048 mm, that may exist in the bed, are used for sorting computations but are not transported. For deposition and erosion of clay and silt sizes up to 0.0625 mm, Krone's method is used for deposition and Ariathurai and Krone's method is used for scour. The default procedure for clay and silt computations allows only depositions using a method based on settling velocity. The sediment transport function for bed material load is selected by the user. Transport functions available in the program are the following:

a. Toffaleti's (1966) transport function
b. Madden's (1963) modification of Laursen's (1958) relationship
c. Yang's (1973) stream power for sands
d. Duboys' transport function (Vanoni 1975)
e. Ackers-White (1973) transport function
f. Colby (1964) transport function
g. Toffaleti (1966) and Schoklitsch (1930) combination
h. Meyer-Peter and Muller (1948)
i. Toffaleti and Meyer-Peter and Muller combination
j. Madden's modification of Laursen's (1958) relationship
k. Modification by Ariathurai and Krone (1976) of Parthenaides' (1965) method for scour and Krone's (1962) method for deposition of cohesive sediments
l. Copeland's (1990) modification of Laursen's relationship (Copeland and Thomas 1989)

m. Users specification of transport coefficients based upon observed data

The above methods (except for method a.) utilise the Colby (1964) method for adjusting the sediment transport potential when the wash load concentration is high. Armoring and destruction of the armor layer are simulated based upon Gessler's (1970) approach. Deposition or scour is modeled by moving each cross-section point within the movable bed. The movable bed limits may extend beyond the channel bank limits. Deposition is allowed to occur in all wetted areas, even if the wetted areas are beyond the conveyance or movable bed limits. Scour occurs only within the movable bed limits. Sediment transport potential is based upon the hydraulic and sediment characteristics of the channel alone. Simulation of geological controls such as bedrock or a clay layer may be done by specifying a minimum elevation for the movable bed at any particular cross-section.

The sediment boundary conditions (inflowing sediment load as a function of water discharge) for the main river channel, its tributaries and local inflow/ outflow points can be changed with time. HEC-6 has the capability to simulate the diversion of water and sediment by grain size. A transmissive boundary condition is available at each downstream boundary: this boundary condition forces all sediment entering that section to pass it, resulting in no scour or deposition at that section.

### 3.2.4 THEORETICAL ASSUMPTIONS AND LIMITATIONS

HEC-6 is a one-dimensional continuous simulation model that uses a sequence of steady flows to represent discharge hydrographs. There is no provision for simulating the development of meanders or specifying a lateral distribution of sediment load across a cross-section. The cross-section is sub-divided into two parts with input data; that part which has a movable bed, and that which does not. The movable bed is constrained within the limits of the wetted perimeter. The entire wetted part of the cross section is normally moved uniformly up or down; an option is available, however, which causes the bed elevation to be adjusted in horizontal layers when deposition occurs. Bed forms are not simulated; however, $n$ values can be input as a function of discharge, which indirectly permits consideration of the effects of bed forms if the user can determine those effects from measured data. Limerinos' (1970) method is available as an option for computation of bed roughness. Density and secondary currents are not simulated.

There are three restrictions on the description of a network system within which sediment transport can be calculated with HEC-6:

a. Sediment transport in distributaries is not possible.
b. Flow around islands; i.e., closed loops, cannot be directly accommodated.
c. Only one junction or local inflow point is allowed between any two cross sections.

# ANALYSIS AND DESIGN

## 4.1 MORPHOLOGY OF BEAS RIVER

The study reach of the Beas River lies under the boulder reach with steep slope and coarse bed material. There is a total drop of 29.90 m in the bed elevation of the river within this reach of 3.27 km. Hence the average slope of the river is about 0.0091 or 1:110. However, the variation of slope along the river is significant and varies from 0.01476 to 0.00309. In the initial reach from chainage 0+000 to 1+015 the bed slope is relatively steeper with the slope of 1:100; hence the sediment carrying capacity of the river is higher. Then after from chainage 1+015 to 1+400 the bed slope becomes relatively flat with the slope of 1:192; hence the sediment carrying capacity gets reduced. Consequently, there is a heavy deposition of sediment and the river is braided in this reach. Similarly the slope of river becomes steeper in the reach from chainage 1+400 to 2+870 and flattens again then after. The variation of bed slope along the study reach of the river is as given below.

**Table-4.1, Variation of Bed Slope along the Study Reach in Beas River**

| Chainage | Reach Length | River Bed Elevation | Difference in Elevation | | Slope | |
|---|---|---|---|---|---|---|
| (km) | (m) | (ft) | (ft) | (m) | | |
| 0.000 | - | 3595.22 | | | | |
| 0.100 | 100.00 | 3591.62 | 3.60 | 1.098 | 0.01098 | 1:91 |
| 0.200 | 100.00 | 3588.18 | 3.44 | 1.049 | 0.01049 | 1:95 |
| 0.400 | 200.00 | 3581.29 | 6.89 | 2.101 | 0.01050 | 1:95 |
| 0.615 | 215.00 | 3576.30 | 4.99 | 1.521 | 0.00708 | 1:141 |
| 0.815 | 200.00 | 3568.07 | 8.23 | 2.509 | 0.01255 | 1:80 |
| 1.015 | 200.00 | 3562.09 | 5.98 | 1.823 | 0.00912 | 1:110 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 1.200 | 185.00 | 3558.81 | 3.28 | 1.000 | 0.00541 | 1:185 |
| 1.400 | 200.00 | 3555.53 | 3.28 | 1.000 | 0.00500 | 1:200 |
| 1.600 | 200.00 | 3548.02 | 7.51 | 2.290 | 0.01145 | 1:87 |
| 1.800 | 200.00 | 3541.14 | 6.88 | 2.098 | 0.01049 | 1:95 |
| 2.000 | 200.00 | 3535.84 | 5.30 | 1.616 | 0.00808 | 1:124 |
| 2.270 | 270.00 | 3525.51 | 10.33 | 3.149 | 0.01166 | 1:86 |
| 2.470 | 200.00 | 3517.80 | 7.71 | 2.351 | 0.01175 | 1:85 |
| 2.670 | 200.00 | 3509.60 | 8.20 | 2.500 | 0.01250 | 1:80 |
| 2.870 | 200.00 | 3499.92 | 9.68 | 2.951 | 0.01476 | 1:68 |
| 3.070 | 200.00 | 3497.20 | 2.72 | 0.829 | 0.00415 | 1:241 |
| 3.270 | 200.00 | 3495.17 | 2.03 | 0.619 | 0.00309 | 1:323 |

Regarding the plan form, the river is almost straight from chainage 0+000 to 2+370. Then it suddenly takes a right turn and again a left turn. Thus the river is curved from chainage 2+370 to 3+270 with its right bank concave. There are two major islands in the river in this study reach; one between chainage 1+015 to 1+400 and the other between chainage 2+350 to 2+750. The river width is varying from 40 m to 170 m. The river is very narrow from chainage 2+750 to 3+250 with the average width of about 50 m only. The outer (right) bank in this narrow reach is under attack of high current and thus unstable. The width of river is particularly wider at the location of islands.

## 4.2 HYDROLOGICAL ANALYSIS

The Beas River is a mountainous perennial river with significant variation of discharge with time and space. The discharge in the river is particularly very high during monsoon season due to high rainfall in its catchment. Normally the discharge in the river increases at night due to melting of snow over high Himalayas during the day. Every year the flood inundates a large area of floodplain mainly due to the low height of the right bank. The flood of 1995 was the highest flood ever recorded at the gauging site in this river. The magnitude of the flood was about 2500 cumecs, which inundated the entire runway and covered it with a large amount of sediments and tree trunks. The flood not only damaged the existing flood protection works but also badly damaged the airport runway interrupting the air services for a long period of time.

The annual maximum flood data of 1965 to 1995 for the Beas River at Bhunter gauging site, downstream of the confluence of Beas River with Parbati River, is given in table-4.2. The record shows the minimum annual discharge of 511.50 cumecs in the year 1979 and the maximum annual discharge of 2483.40 cumecs in the year 1995.

## FLOOD FREQUENCY ANALYSIS

The objective of flood frequency analysis is to relate the magnitude of extreme flood events to their frequency of occurrence through the use of probability distributions. The U.S. Water Resources Council recommends that adjustments be made for outliers before carrying out the flood frequency analysis.

## TESTING FOR OUTLIERS

Outliers are data points that depart significantly from the trend of the remaining data. The retention or deletion of these outliers can significantly affect the magnitude of statistical parameters computed from the data, especially for small samples. So the available maximum annual discharge is first checked for existence of any outliers before use in further analysis.

The following equations are used to detect the outliers:

$$Y_H = \overline{Y} + K_n S_y$$

$$Y_L = \overline{Y} - K_n S_y$$

Where $Y_H$ and $Y_L$ are respectively high outlier and low outlier threshold in log units, $\overline{Y}$ and $S_y$ are respectively the mean and the standard deviation of log transformed values of the sample data and $K_n$ is a factor depending on the sample size.

According to the Water Resources Council (1981), if information is available that indicates a high outlier is the maximum over an extended period of time, the outlier is treated as historic flood data and excluded from analysis, otherwise the outliers should be retained as part of systematic record.

Table –4.2, Maximum Annual Discharge

| Year | Discharge (X) cumecs | $(X-\overline{X})^2$ | Y= log X | $(Y-\overline{Y})^2$ | $(Y-\overline{Y})^3$ |
|---|---|---|---|---|---|
| 1965 | 711.06 | 39687.07 | 2.851906 | 0.005967 | -0.000461 |
| 1966 | 802.53 | 11609.23 | 2.904461 | 0.000610 | -0.000015 |
| 1967 | 823.17 | 7587.48 | 2.915490 | 0.000187 | -0.000003 |
| 1968 | 709.40 | 40351.22 | 2.850891 | 0.006125 | -0.000479 |
| 1969 | 768.70 | 20043.80 | 2.885757 | 0.001883 | -0.000082 |
| 1970 | 837.50 | 5296.36 | 2.922985 | 0.000038 | -0.000000 |
| 1971 | 689.30 | 48830.45 | 2.838408 | 0.008234 | -0.000747 |
| 1972 | 1161.00 | 62862.46 | 3.064832 | 0.018410 | 0.002498 |
| 1973 | 821.60 | 7863.46 | 2.914660 | 0.000210 | -0.000003 |
| 1974 | 677.50 | 54184.73 | 2.830909 | 0.009651 | -0.000948 |
| 1975 | 983.20 | 5317.89 | 2.992642 | 0.004031 | 0.000256 |
| 1976 | 879.00 | 978.20 | 2.943989 | 0.000220 | 0.000003 |
| 1977 | 918.60 | 69.29 | 2.963126 | 0.001154 | 0.000039 |
| 1978 | 728.30 | 33115.31 | 2.862310 | 0.004468 | -0.000299 |
| 1979 | 511.50 | 159022.40 | 2.708846 | 0.048534 | -0.010692 |
| 1980 | 991.70 | 6629.85 | 2.996380 | 0.004520 | 0.000304 |
| 1981 | 682.00 | 52109.99 | 2.833784 | 0.009095 | -0.000867 |
| 1982 | 665.40 | 59964.32 | 2.823083 | 0.011250 | -0.001193 |
| 1983 | 682.40 | 51927.53 | 2.834039 | 0.009046 | -0.000860 |
| 1984 | 580.50 | 108752.30 | 2.763802 | 0.027340 | -0.004521 |
| 1985 | 717.50 | 37162.64 | 2.855822 | 0.005377 | -0.000394 |
| 1986 | 770.20 | 19621.32 | 2.886604 | 0.001810 | -0.000077 |

| | | | | | |
|---|---|---|---|---|---|
| 1987 | 600.30 | 96085.20 | 2.778368 | 0.022735 | -0.003428 |
| 1988 | 1461.10 | 303406.94 | 3.164680 | 0.055474 | 0.013066 |
| 1989 | 1029.00 | 14095.36 | 3.012415 | 0.006933 | 0.000577 |
| 1990 | 810.40 | 9975.24 | 2.908699 | 0.000418 | -0.000009 |
| 1991 | 633.00 | 76882.05 | 2.801404 | 0.016319 | -0.002085 |
| 1992 | 850.10 | 3621.17 | 2.929470 | 0.000000 | 0.000000 |
| 1993 | 2153.50 | 1545605.59 | 3.333145 | 0.163211 | 0.065937 |
| 1994 | 1085.70 | 30773.53 | 3.035710 | 0.011355 | 0.001210 |
| 1995 | 2483.40 | 2474718.71 | 3.395047 | 0.217059 | 0.101127 |
| **Sum** | **28218.56** | **5388151.07** | **90.803666** | **0.671665** | **0.157853** |

Mean, $\overline{X}$ $= \frac{1}{n}\sum_{i=1}^{n} X_i$ = 910.28 cumecs

Mean, $\overline{Y}$ $= \frac{1}{n}\sum_{i=1}^{n} Y_i$ = 2.929151

Standard Deviation, $S_X = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(Xi - \overline{X})^2}$ = 423.80 cumecs

Standard Deviation, $S_y = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(Yi - \overline{Y})^2}$ = 0.149629

$K_n$= 2.577 (Taken from table 12.5.3 of Applied Hydrology by Ven Te Chow et. al. 1988)

## HIGH OUTLIERS

$Y_H = \overline{Y} + K_n S_y$ = 2.929151+ 2.577* 0.149629 =3.314744

The corresponding discharge, $Q_H = 10^{3.314744}$ = 2064.16 cumecs

Comparing the above value of $Q_H$ with the flood discharge of table-4.2, we find the discharge of 1993 and 1995, which are respectively 2153.50 and 2483.40 cumecs are greater than threshold value of 2064.16 cumecs. So these are high outliers. However, as there are no additional information available to confirm the high outliers, they are retained as part of the systematic record.

## LOW OUTLIERS

$Y_L = \overline{Y} - K_n S_y = 2.929151 - 2.577 * 0.149629$ $= 2.543557$

The corresponding discharge, $Q_H = 10^{2.543557}$ $= 349.59$ cumecs

Comparing the above value of $Q_L$ with the flood discharge of table-4.2, we find no discharge lower than the threshold value of 349.59 cumecs. So there are no low outliers.

Now the frequency analysis is carried out using frequency factors method, in which the magnitude of extreme hydrologic event is giver as:

$$X_T = \overline{X} + K_T\, Sx$$

Where $K_T$ is the frequency factor depending on the return period and the type of probability distribution to be used in the analysis.

Frequency analysis of the available maximum annual discharge shall be carried out for the following types of probability distribution.

## I) NORMAL DISTRIBUTION

For this distribution, the frequency factor, $K_T$, is equal to the standard normal variable, z. The value of z corresponding to an exceedence probability of p (p= 1/T) can be calculated by finding the value of an intermediate variable w:

$$W = \left[\ln\left(\frac{1}{p^2}\right)\right]^{\frac{1}{2}} \qquad (0 < p \le 0.5)$$

Then z can be calculated using the approximation

$$z = W - \frac{2.515517 + 0.802853W + 0.010328W^2}{1 + 1.432788W + 0.189269W^2 + 0.001308W^3}$$

Now, using the above formulae annual maximum discharge of various return period can be found as:

For T= 2 years,

p=1/2 = 0.5

$$W = \left[\ln\left(\frac{1}{p^2}\right)\right]^{\frac{1}{2}} \qquad = \left[\ln\left(\frac{1}{0.5^2}\right)\right]^{\frac{1}{2}} \qquad = 1.177410$$

$$z = W - \frac{2.515517 + 0.802853W + 0.010328W^2}{1 + 1.432788W + 0.189269W^2 + 0.001308W^3} \qquad = -1.341*10^{-7}$$

$$X_T = \overline{X} + K_T\,Sx \qquad = 910.28 - 1.341*10^{-7}*423.80 \qquad = 910.28 \text{ cumecs}$$

For T= 100 years,

p=1/100 = 0.01

$$W = \left[\ln\left(\frac{1}{p^2}\right)\right]^{\frac{1}{2}} \qquad = \left[\ln\left(\frac{1}{0.01^2}\right)\right]^{\frac{1}{2}} \qquad = 3.034854$$

$$z = W - \frac{2.515517 + 0.802853W + 0.010328W^2}{1 + 1.432788W + 0.189269W^2 + 0.001308W^3} \qquad = 2.326785$$

$$X_T = \overline{X} + K_T\,Sx \qquad = 910.28+2.326785*423.80 \qquad = 1896.37 \text{ cumecs}$$

For T= 500 years,

p=1/500 = 0.002

$$W = \left[\ln\left(\frac{1}{p^2}\right)\right]^{\frac{1}{2}} \qquad = \left[\ln\left(\frac{1}{0.002^2}\right)\right]^{\frac{1}{2}} \qquad = 3.525509$$

$$z = W - \frac{2.515517 + 0.802853W + 0.010328W^2}{1 + 1.432788W + 0.189269W^2 + 0.001308W^3} \qquad = 2.878506$$

$X_T = \overline{X} + K_T\,Sx \quad = 910.28+2.878506*423.80 \quad = 2130.19$ cumecs

For T= 1000 years,

p=1/1000 = 0.001

$$W = \left[\ln\left(\frac{1}{p^2}\right)\right]^{\frac{1}{2}} = \left[\ln\left(\frac{1}{0.001^2}\right)\right]^{\frac{1}{2}} = 3.716922$$

$$z = W - \frac{2.515517 + 0.802853W + 0.010328W^2}{1 + 1.432788W + 0.189269W^2 + 0.001308W^3} = 3.090522$$

$X_T = \overline{X} + K_T\,Sx \quad = 910.28+3.090522*423.80 \quad = 2220.04$ cumecs

## II) LOG NORMAL DISTRIBUTION

For log normal distribution, the frequency factor, $K_T$, is calculated in the same line as for the normal distribution. But the mean and the standard deviation are calculated for the logarithms of the data and using

$Y_T = \overline{Y} + K_T S_y$

Then the required value of $X_T$ is calculated by taking the antilog of $Y_T$.

For T= 2 years,

p=1/2 = 0.5

$$W = \left[\ln\left(\frac{1}{p^2}\right)\right]^{\frac{1}{2}} = \left[\ln\left(\frac{1}{0.5^2}\right)\right]^{\frac{1}{2}} = 1.177410$$

$$z = W - \frac{2.515517 + 0.802853W + 0.010328W^2}{1 + 1.432788W + 0.189269W^2 + 0.001308W^3} = -1.341*10^{-7}$$

$Y_T = \overline{Y} + K_T S_y \quad = 2.929151 - 1.341*10^{-7} * 0.149629 = 2.92915$

$X_T = 10^{Y_T} \quad = 10^{2.92915} \quad = 849.47$ cumecs

For T= 100 years,

p=1/100 = 0.01

$$W = \left[\ln\left(\frac{1}{p^2}\right)\right]^{\frac{1}{2}} \qquad = \left[\ln\left(\frac{1}{0.01^2}\right)\right]^{\frac{1}{2}} \qquad = 3.034854$$

$$z = W - \frac{2.515517 + 0.802853W + 0.010328W^2}{1 + 1.432788W + 0.189269W^2 + 0.001308W^3} \qquad = 2.326785$$

$$Y_T = \overline{Y} + K_T S_y \qquad = 2.929151 + 2.326785 * 0.149629 \qquad = 3.277305$$

$$X_T = 10^{Y_T} \qquad = 10^{3.277305} \qquad = 1893.67 \text{ cumecs}$$

For T= 500 years,

p=1/500 = 0.002

$$W = \left[\ln\left(\frac{1}{p^2}\right)\right]^{\frac{1}{2}} \qquad = \left[\ln\left(\frac{1}{0.002^2}\right)\right]^{\frac{1}{2}} \qquad = 3.525509$$

$$z = W - \frac{2.515517 + 0.802853W + 0.010328W^2}{1 + 1.432788W + 0.189269W^2 + 0.001308W^3} \qquad = 2.878506$$

$$Y_T = \overline{Y} + K_T S_y \qquad = 2.929151 + 2.878506 * 0.149629 \qquad = 3.359859$$

$$X_T = 10^{Y_T} \qquad = 10^{3.359859} \qquad = 2290.12 \text{ cumecs}$$

For T= 1000 years,

p=1/1000 = 0.001

$$W = \left[\ln\left(\frac{1}{p^2}\right)\right]^{\frac{1}{2}} \qquad = \left[\ln\left(\frac{1}{0.001^2}\right)\right]^{\frac{1}{2}} \qquad = 3.716922$$

$$z = W - \frac{2.515517 + 0.802853W + 0.010328W^2}{1 + 1.432788W + 0.189269W^2 + 0.001308W^3} \qquad = 3.090522$$

$$Y_T = \overline{Y} + K_T S_y \qquad = 2.929151 + 3.090522 * 0.149629 \qquad = 3.391583$$

$$X_T = 10^{Y_T} \qquad = 10^{3.391583} \qquad = 2463.67 \text{ cumecs}$$

## III) EXTREME VALUE TYPE I DISTRIBUTION (GUMBEL DISTRIBUTION)

For this distribution, the frequency factor, $K_T$, is given by the following expression as given by Chow (1953).

$$K_T = -\frac{\sqrt{6}}{\pi}\left\{0.5772 + \ln\left[\ln\left(\frac{T}{T-1}\right)\right]\right\}$$

For T= 2 years,

$$K_T = -\frac{\sqrt{6}}{\pi}\left\{0.5772 + \ln\left[\ln\left(\frac{2}{2-1}\right)\right]\right\} \qquad = -0.164272$$

$X_T = \overline{X} + K_T\, Sx$ = 910.28-0.164272*423.80 = 840.66 cumecs

For T= 100 years,

$$K_T = -\frac{\sqrt{6}}{\pi}\left\{0.5772 + \ln\left[\ln\left(\frac{100}{100-1}\right)\right]\right\} \qquad = 3.136681$$

$X_T = \overline{X} + K_T\, Sx$ = 910.28+3.136681*423.80 = 2239.61 cumecs

For T= 500 years,

$$K_T = -\frac{\sqrt{6}}{\pi}\left\{0.5772 + \ln\left[\ln\left(\frac{500}{500-1}\right)\right]\right\} \qquad = 4.394689$$

$X_T = \overline{X} + K_T\, Sx$ = 910.28+4.394689*423.80 = 2772.75 cumecs

For T= 1000 years,

$$K_T = -\frac{\sqrt{6}}{\pi}\left\{0.5772 + \ln\left[\ln\left(\frac{1000}{1000-1}\right)\right]\right\} \qquad = 4.935524$$

$X_T = \overline{X} + K_T\, Sx$ = 910.28+4.935524*423.80 = 3001.96 cumecs

## IV) LOG-PEARSON TYPE III DISTRIBUTION

For this distribution, the mean $\overline{Y}$, standard deviation $S_Y$ and the coefficient of skewness, $C_S$ are first calculated for the logarithms of the data. Then, the frequency factor, $K_T$, is computed by the following expression as given by Kite (1977).

$$K_T = z + (z^2 - 1)k + \frac{1}{3}(z^3 - 6z)k^2 - (z^2 - 1)k^3 + zk^4 + \frac{1}{3}k^5$$

Where $k = C_S / 6$ and z is as calculated in the normal distribution.

Now, $Cs = \dfrac{n\sum_{i=1}^{n}(Y_i - \overline{Y})^3}{(n-1)(n-2)S_Y^3} = \dfrac{31 * 0.157853}{30 * 29 * 0.149629^3} = 1.678989$

$k = C_S / 6 = 1.678989/6 = 0.279832$

For T= 2 years,

$p = 1/2 = 0.5$

$W = \left[\ln\left(\frac{1}{p^2}\right)\right]^{\frac{1}{2}} = \left[\ln\left(\frac{1}{0.5^2}\right)\right]^{\frac{1}{2}} = 1.177410$

$z = W - \dfrac{2.515517 + 0.802853W + 0.010328W^2}{1 + 1.432788W + 0.189269W^2 + 0.001308W^3} = -1.341 * 10^{-7}$

$K_T = z + (z^2 - 1)k + \frac{1}{3}(z^3 - 6z)k^2 - (z^2 - 1)k^3 + zk^4 + \frac{1}{3}k^5 = -0.257348$

$Y_T = \overline{Y} + K_T S_y = 2.929151 - 0.257348 * 0.149629 = 2.890644$

$X_T = 10^{Y_T} = 10^{2.890644} = 777.40$ cumecs

For T= 100 years,

$p = 1/100 = 0.01$

$W = \left[\ln\left(\frac{1}{p^2}\right)\right]^{\frac{1}{2}} = \left[\ln\left(\frac{1}{0.01^2}\right)\right]^{\frac{1}{2}} = 3.034854$

$z = W - \dfrac{2.515517 + 0.802853W + 0.010328W^2}{1 + 1.432788W + 0.189269W^2 + 0.001308W^3} = 2.326785$

$$K_T = z + (z^2-1)k + \frac{1}{3}(z^3-6z)k^2 - (z^2-1)k^3 + zk^4 + \frac{1}{3}k^5 \quad = 3.444468$$

$$Y_T = \overline{Y} + K_T S_y \quad = 2.929151+3.444468*0.149629 \quad = 3.444543$$

$$X_T = 10^{Y_T} \quad = 10^{3.444543} \quad = 2783.19 \text{ cumecs}$$

For T= 500 years,

p=1/500 = 0.002

$$W = \left[\ln\left(\frac{1}{p^2}\right)\right]^{\frac{1}{2}} \quad = \left[\ln\left(\frac{1}{0.002^2}\right)\right]^{\frac{1}{2}} \quad = 3.525509$$

$$z = W - \frac{2.515517 + 0.802853W + 0.010328W^2}{1 + 1.432788W + 0.189269W^2 + 0.001308W^3} \quad = 2.878506$$

$$K_T = z + (z^2-1)k + \frac{1}{3}(z^3-6z)k^2 - (z^2-1)k^3 + zk^4 + \frac{1}{3}k^5 \quad = 4.947620$$

$$Y_T = \overline{Y} + K_T S_y \quad = 2.929151+4.947620*0.149629 \quad = 3.669458$$

$$X_T = 10^{Y_T} \quad = 10^{3.669458} \quad = 4671.52 \text{ cumecs}$$

For T= 1000 years,

p=1/1000 = 0.001

$$W = \left[\ln\left(\frac{1}{p^2}\right)\right]^{\frac{1}{2}} \quad = \left[\ln\left(\frac{1}{0.001^2}\right)\right]^{\frac{1}{2}} \quad = 3.716922$$

$$z = W - \frac{2.515517 + 0.802853W + 0.010328W^2}{1 + 1.432788W + 0.189269W^2 + 0.001308W^3} \quad = 3.090522$$

$$K_T = z + (z^2-1)k + \frac{1}{3}(z^3-6z)k^2 - (z^2-1)k^3 + zk^4 + \frac{1}{3}k^5 \quad = 5.602079$$

$$Y_T = \overline{Y} + K_T S_y \quad = 2.929151+5.602079*0.149629 \quad = 3.767384$$

$$X_T = 10^{Y_T} \quad = 10^{3.767384} \quad = 5853.07 \text{ cumecs}$$

The results of the above computations has been summarised and presented in table-4.3.

**Table-4.3, Comparison of the Flood Discharge of Different Return Period for Different Distribution**

| Distribution | Discharge of different return period in cumecs | | | |
|---|---|---|---|---|
| | 2 Years | 100 Years | 500 Years | 1000 Years |
| Normal | 910.28 | 1896.37 | 2130.19 | 2220.04 |
| Log normal | 849.47 | 1893.67 | 2290.19 | 2463.67 |
| EV- Type 1 | 840.66 | 2239.61 | 2772.75 | 3001.96 |
| Log- Pearson Type III | 777.40 | 2783.19 | 4671.52 | 5853.07 |

## GOODNESS OF FIT

It can be seen from table-4.3 that the variation of discharge of different return period computed assuming different probability distribution is significant. So we have to check which of the theoretical distribution is closest to our sample data. The chi-square test can be used to determine how well the theoretical distribution function fit the empirical distributions (distributions obtained from sample data). The chi-square test statistic $\chi_c^2$ is given by

$$\chi_c^2 = \sum_{i=1}^{m}\left[\frac{(o_i - e_i)^2}{e_i}\right]$$

Where m is the number of intervals of the sample data and $o_i$ and $e_i$ are the observed and expected frequencies respectively.

The null hypothesis for the test is that the proposed probability distribution fits the data adequately. This hypothesis is rejected if the value of $\chi_c^2$ is larger than a limiting value, $\chi_{v,1-\alpha}^2$, determined from the $\chi^2$ distribution with $v$ degrees of freedom. Here, $v = m-p-1$, where m is the number of intervals as before, p is the number of parameters used in fitting the proposed distribution and $\alpha$ is the significance level. Now, let us check for the theoretical distribution that is closest to the observed sample data.

Table-4.4, Check for Normal Distribution

| Interval i | Range r | Observed Frequency $o_i$ | Relative Frequency fs(xi) | Zi | Cumm. Probability F(xi) | Probability Density f(xi) | Expected Frequency $e_i$ | $\chi_c^2$ |
|---|---|---|---|---|---|---|---|---|
| 1 | <550 | 1 | 0.0323 | -0.850 | 0.198 | 0.198 | 6.138 | 4.30 |
| 2 | 550-800 | 14 | 0.4516 | -0.260 | 0.397 | 0.199 | 6.169 | 9.94 |
| 3 | 800-1050 | 11 | 0.3548 | 0.330 | 0.629 | 0.232 | 7.192 | 2.02 |
| 4 | 1050-1300 | 2 | 0.0645 | 0.920 | 0.821 | 0.192 | 5.952 | 2.62 |
| 5 | >1300 | 3 | 0.0968 | 3.712 | 1.000 | 0.179 | 5.549 | 1.17 |
| Total: | | 31 | 1.0000 | | | 1.000 | 31.000 | 20.05 |

Mean= 910.28 cumecs

Standard deviation= 423.80 cumecs

Here,

m= 5, p= 2, $\nu = m - p - 1 = 2$

$\chi^2_{2,0.95} = 5.99$, from standard table

Since $\chi_c^2 > \chi^2_{2,0.95}$ the sample data does not follow the normal distribution.

Table-4.5, Check for Log-normal Distribution

| Interval i | Range r | Observed Frequency $o_i$ | Relative Frequency fs(xi) | Zi | Cumm. Probability F(xi) | Probability Density f(xi) | Expected Frequency $e_i$ | $\chi_c^2$ |
|---|---|---|---|---|---|---|---|---|
| 1 | <2.80 | 3 | 0.0968 | -0.863 | 0.194 | 0.194 | 6.014 | 1.511 |
| 2 | 2.80-2.88 | 10 | 0.3226 | -0.328 | 0.371 | 0.177 | 5.487 | 3.712 |
| 3 | 2.88-2.96 | 9 | 0.2903 | 0.206 | 0.582 | 0.211 | 6.541 | 0.924 |
| 4 | 2.96-3.04 | 5 | 0.1613 | 0.741 | 0.771 | 0.189 | 5.859 | 0.126 |
| 5 | >3.04 | 4 | 0.1290 | 3.147 | 1.000 | 0.229 | 7.099 | 1.353 |
| Total: | | 31 | 1.0000 | | | 1.000 | 31.000 | 7.626 |

Mean= 2.929151

Standard deviation= 0.149629

Here,

m= 5, p= 2, $\nu = m - p - 1 = 2$

$\chi^2_{2,0.95} = 5.99$, from standard table

Since $\chi^2_c > \chi^2_{2,0.95}$ the sample data does not follow the lognormal distribution.

**Table-4.6, Check for Extreme Value Type-1 (Gumble) Distribution**

| Interval i | Range r | Observed Frequency $o_i$ | Relative Frequency fs(xi) | Cummulative Probability F(xi) | Probability Density f(xi) | Expected Frequency $e_i$ | $\chi^2_c$ |
|---|---|---|---|---|---|---|---|
| 1 | <550 | 1 | 0.0323 | 0.188 | 0.188 | 5.828 | 4.00 |
| 2 | 550-750 | 12 | 0.3871 | 0.402 | 0.214 | 6.634 | 4.34 |
| 3 | 750-950 | 10 | 0.3226 | 0.608 | 0.206 | 6.386 | 2.05 |
| 4 | 950-1200 | 5 | 0.1613 | 0.792 | 0.184 | 5.704 | 0.09 |
| 5 | >1200 | 3 | 0.0968 | 1.000 | 0.208 | 6.448 | 1.84 |
| Total: | | 31 | 1.0000 | | 1.000 | 31.000 | 12.32 |

Mean= 910.28 cumecs

Standard deviation= 423.8 cumecs

Here,

m= 5, p= 2, $\nu = m - p - 1 = 2$

$\chi^2_{2,0.95} = 5.99$, from standard table

Since $\chi^2_c > \chi^2_{2,0.95}$ the sample data does not follow the extreme value type-1 distribution.

**Table-4.7, Check for Log-Pearson Type-3 Distribution**

| Interval i | Range r | Observed Frequency $o_i$ | Relative Frequency fs(xi) | Cumm. Probability F(xi) | Probability Density f(xi) | Expected Frequency $e_i$ | $\chi_c^2$ |
|---|---|---|---|---|---|---|---|
| 1 | <2.80 | 3 | 0.0968 | 0.166 | 0.166 | 5.145 | 0.89 |
| 2 | 2.80-2.88 | 10 | 0.3226 | 0.466 | 0.300 | 9.313 | 0.05 |
| 3 | 2.88-2.96 | 9 | 0.2903 | 0.653 | 0.187 | 5.794 | 1.77 |
| 4 | 2.96-3.04 | 5 | 0.1613 | 0.812 | 0.159 | 4.925 | 0.00 |
| 5 | >3.04 | 4 | 0.1290 | 1.000 | 0.188 | 5.823 | 0.57 |
| Total: | | 31 | 1.0000 | | 1.000 | 31.000 | 3.29 |

Mean= 2.929151

Standard deviation= 0.149629

Here,

m= 5, p= 3 $\nu = m - p - 1 = 1$

$\chi^2_{2,0.95} = 3.84$, from standard table

Since $\chi_c^2 < \chi^2_{2,0.95}$ the sample data can be assumed to be following the log-Pearson type-3 distribution.

## DESIGN FLOOD

It can be seen from table-4.3 that the variation of flood discharge is significantly high for different probability distribution. The 2-year return period flood, computed assuming log-Pearson distribution is the lowest among all the distributions. But the 100 year and 1000 year return period floods computed assuming log-person distribution is the highest among all the distributions. However, the above chi-square tests show that the sample data is closest to log-Pearson distribution. So, the following discharge shall be employed as the design discharge for further computation.

2-year return period flood, $Q_2$= 800 cumecs

100-year return period flood, $Q_{100}$= 2800 cumecs

500-year return period flood, $Q_{500}$= 4700 cumecs

1000-year return period flood, $Q_{1000}$= 5900 cumecs

## 4.3 GRAIN SIZE DISTRIBUTION OF BED MATERIAL

There is a wide variation of grain size of bed material in the Beas River ranging from 0.031mm to 2048 mm. The bed predominantly consists of sand, gravel and boulder. For representative sample of bed material, Wolman Sampling Method can be adopted in which samples are collected from numerous grid points and manual as well as sieve analysis are carried out to determine the gradation of the bed material. The following grain size distribution obtained from field measurements shall be used for this study.

**Table-4.8, Grain Size Distribution of Bed Material**

| Grain Size Class (mm) | Number of Stones | Percentage within the Subgroup | | Percentage by Weight of the Entire Size Range | Cumulative Percentage Finer than Upper Size Limit |
|---|---|---|---|---|---|
| | | Larger Stone | Sieve Analysis | | |
| 4096-2048 | - | - | | - | - |
| 2048-1024 | 4 | 2.76 | | 2.00 | 100.00 |
| 1024-512 | 5 | 3.45 | | 2.52 | 98.00 |
| 512-256 | 5 | 3.45 | | 2.50 | 95.48 |
| 256-128 | 12 | 8.28 | | 6.00 | 92.98 |
| 128-64 | 29 | 20.00 | | 14.50 | 86.98 |
| 64-32 | 48 | 33.10 | | 23.93 | 72.48 |
| 32-16 | 42 | 28.97 | | 21.00 | 48.55 |
| | **145** | **100.00** | | | |
| 16-8 | 452.00 | | 50.36 | 13.85 | 27.55 |
| 8-4 | 141.62 | | 15.78 | 4.35 | 13.70 |
| 4-2 | 43.54 | | 4.85 | 1.34 | 9.35 |

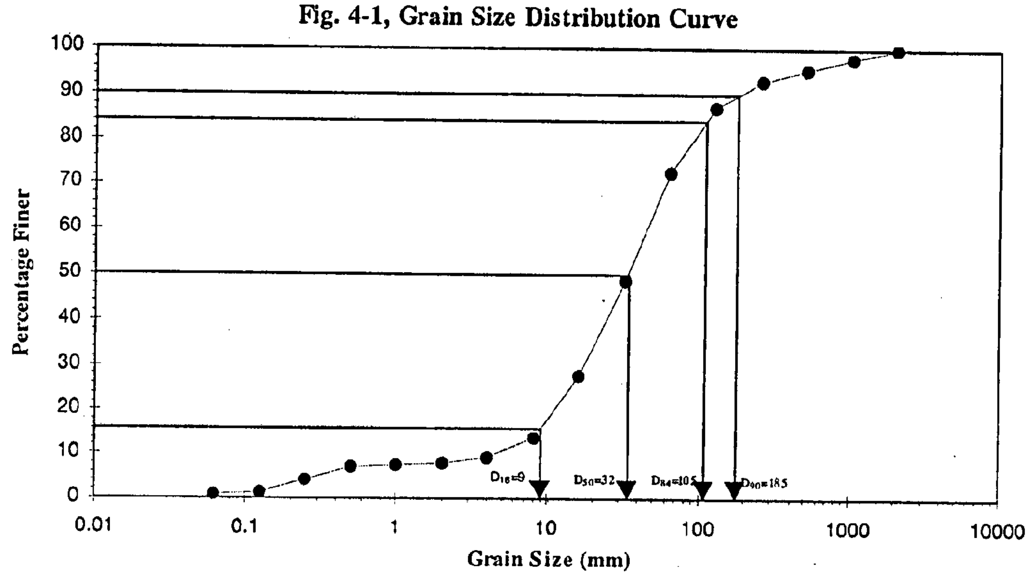
| | | | | | |
|---|---|---|---|---|---|
| 2-1 | 18.65 | | 2.08 | 0.57 | 8.01 |
| 1-0.50 | 8.63 | | 0.96 | 0.27 | 7.44 |
| 0.50-0.25 | 93.85 | | 10.46 | 2.88 | 7.17 |
| 0.25-0.125 | 93.35 | | 10.40 | 2.86 | 4.29 |
| 0.125-0.062 | 21.68 | | 2.42 | 0.68 | 1.43 |
| 0.062-0.031 | 24.25 | | 2.70 | 0.75 | 0.75 |
| | **897.57** | | **100.00** | **100.00** | |

The above grain size distribution of the bed material can be presented in a graphical form, popularly known as the grain size distribution curve, which is given in fig.-4.1. It shows the grain size in logarithmic scale as abscissa and the percentage finer as ordinate. This curve is utilised for determining different characteristic size of the bed material. The values of some of these characteristic size obtained from fig.-4.1 are given below:

$D_{16}$= 9 mm　　　　$D_{50}$= 32 mm

$D_{84}$= 105 mm　　　　$D_{90}$= 185 mm

**Fig. 4-1, Grain Size Distribution Curve**



## 4.4 ESTIMATION OF MANNING'S ROUGHNESS COEFFICIENT

The manning's roughness coefficient can be determined by the following empirical equations.

### I) STRICKLER'S EQUATION

$$n = \frac{(D_{50})^{1/6}}{21.1} \qquad = \frac{(32*10^{-3})^{1/6}}{21.1} \qquad =0.027$$

### II) MEYER'S EQUATION

$$n = \frac{(D_{90})^{1/6}}{26.0} \qquad = \frac{(185*10^{-3})^{1/6}}{26.0} \qquad =0.029$$

### III) LIMERINO'S EQUATION

$$n = \frac{0.113d^{1/6}}{1.16 + 2.0\log(d/D_{84})} \qquad = \frac{0.113(1.65)^{1/6}}{1.16 + 2.0\log(1.65/0.105)} \qquad =0.035$$

( for $D_{84}$= 105 mm and depth of flow, d= 1.65 m for low water level)

### IV) BRAY'S EQUATION

$n = 0.104 * S^{0.177}$, if $0.0002 < S < 0.01$

$= 0.104 * 0.0091^{0.177}$

$=0.045$

Thus the value of n computed from Bray's equation is the largest. Bray's equation is mainly developed for the gravel-bed river, which shall be used for computation of water surface profile by HEC-6.

## 4.5 GENERATION OF STAGE-DISCHARGE CURVE

The stage-discharge curve, at the downstream end of the study reach is required to compute the water surface profile for the given flow and river geometry. It can be generated by the following stepwise procedure.

i) The cross-section of the river, at which the stage- discharge curve is desired, is plotted at a suitable scale.

ii) The cross-sectional areas and the wetted perimeters are measured from the plot for various depths of flow, also known as the stages.

iii) The corresponding hydraulic mean radii are calculated for different stages of flow.

iv) The flow velocity is calculated using Manning's equation with the roughness coefficient, n= 0.045 and the bed slope, S= 0.0091.

v) The discharge is computed by multiplying the velocity and the flow area.

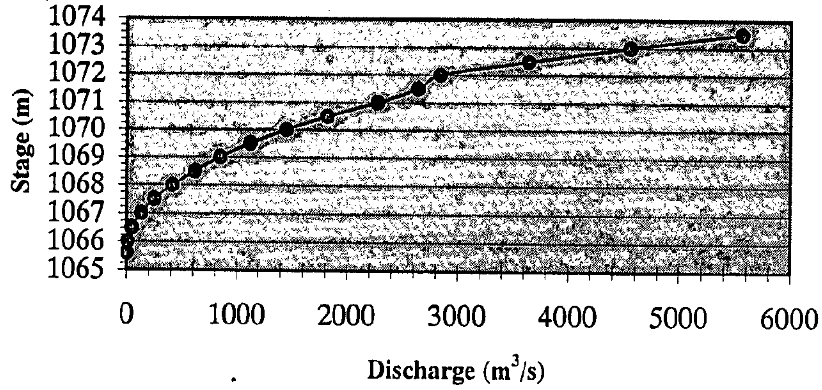
vi) Finally the stage-discharge curve is prepared with the stage as ordinate and the corresponding discharge as abscissa. The detail of the calculation is shown below in table-4.9 and the curve is given in fig.-4. 2.

**Table-4.9, Detail Calculation for Stage-Discharge Curve**

| Stage | Area | Wetted Perimeter | Hydraulic Radius | Velocity | Discharge |
|---|---|---|---|---|---|
| (m) | (Sq.m) | (m) | (m) | (m/s) | ($m^3$/s) |
| 1065.60 | 0.000 | 0.00 | 0.000 | 0.000 | 0.00 |
| 1066.00 | 8.475 | 34.50 | 0.246 | 0.831 | 7.05 |
| 1066.50 | 32.325 | 54.00 | 0.599 | 1.506 | 48.67 |
| 1067.00 | 63.225 | 64.70 | 0.977 | 2.088 | 131.98 |
| 1067.50 | 98.850 | 74.28 | 1.331 | 2.565 | 253.53 |
| 1068.00 | 138.675 | 82.24 | 1.686 | 3.003 | 416.47 |
| 1068.50 | 182.625 | 89.81 | 2.033 | 3.403 | 621.38 |
| 1069.00 | 231.075 | 101.20 | 2.283 | 3.676 | 849.39 |
| 1069.50 | 285.000 | 111.64 | 2.553 | 3.960 | 1128.50 |

| | | | | | |
|---|---|---|---|---|---|
| 1070.00 | 344.325 | 122.72 | 2.806 | 4.217 | 1452.04 |
| 1070.50 | 409.050 | 134.16 | 3.049 | 4.457 | 1823.28 |
| 1071.00 | 478.725 | 142.79 | 3.353 | 4.749 | 2273.28 |
| 1071.50 | 556.500 | 166.20 | 3.348 | 4.745 | 2640.36 |
| 1072.00 | 689.250 | 254.15 | 2.712 | 4.123 | 2841.47 |
| 1072.50 | 820.200 | 270.27 | 3.035 | 4.443 | 3644.54 |
| 1073.00 | 958.720 | 285.40 | 3.359 | 4.755 | 4558.53 |
| 1073.50 | 1106.240 | 302.53 | 3.657 | 5.031 | 5566.02 |

**Fig. 4-2, Stage-Discharge Curve**




## 4.6 GENERATION OF WATER SURFACE PROFILES

The water surface profile in a stream for a given geometry and flow condition can be determined by using softwares called Hec-Ras or Hec-6, developed by U.S. Hydrologic Engineering Center. In the present version of Hec-Ras only fix bed simulation is possible while in Hec-6 both fix bed and mobile bed simulation is possible. In the fixed bed model, the bed and the banks are assumed to be fixed i.e. there is neither erosion nor deposition of sediment; while in the mobile bed model it is assumed that the bed and the banks may be eroded or deposited with sediment. Thus to run hec-6 in mobile bed mode sediment data is required in addition to geometric and hydrologic data. In the present study the water surface profiles have been computed by using Hec-6 for both fixed bed and mobile bed. The water surface profiles have also been calculated by using Hec-Ras for fix bed. The various steps involve in the computations of water surface profiles are as follows:

- Cross-section points are marked in the available survey map (Fig.-1.1) and are numbered as 1 to 17 from downstream to upstream within the study reach of the river.

- Co-ordinates (elevation and station) of cross-section points are determined for all the 17 cross-sections with the help of contour lines in the map.

- The Manning's roughness coefficient, the expansion and the contraction coefficients along with the co-ordinates of the cross-section points constitute the geometric data. The roughness coefficient of 0.045 for the left and right overbank and 0.04 for the channel and the expansion and contraction coefficients of 0.3 and 0.1 respectively have been used in the calculation.

- The hydraulic computation starts from the downstream boundary toward the upstream boundary of the study reach. The stage-discharge curve generated at section 1 (as described in section 4.5) has been used as the downstream boundary condition.

- After feeding all the geometric and the flow data the program is executed, which finally produces the water surface profiles for the fix bed. In order to produce the water surface profile for mobile bed sediment data is required to be entered before the flow data.

As far as the requirement of input data is concerned, it is the same in both Hec-Ras and Hec-6. But there is a difference in the way the data is supplied to the program. In Hec-6 the input data are entered into the input file at specified fields, while in Hec-Ras the input data are entered into designated locations of the users' interface.

The input and the output data file of Hec-6 for simulation of Beas River in natural condition for 2 year and 500 year return period floods in fix bed mode is given in appendix-1 and 2 respectively. The output for the same condition as obtained by Hec-Ras is given in appendix-3. The input and the output data file of Hec-6 for simulation of Beas River in natural condition for 2 year and 500 year return period floods in mobile bed mode is given in appendix-4 and 5 respectively. A summary of outputs of Hec-6 (both fix bed and mobile bed) and Hec-Ras (fix bed) in natural condition for 2 year and 500 year floods are given in table-4.10 and table-4.11 respectively. Cross-sections of Beas River in natural condition with 500 year flood are shown in fig.-4.3.

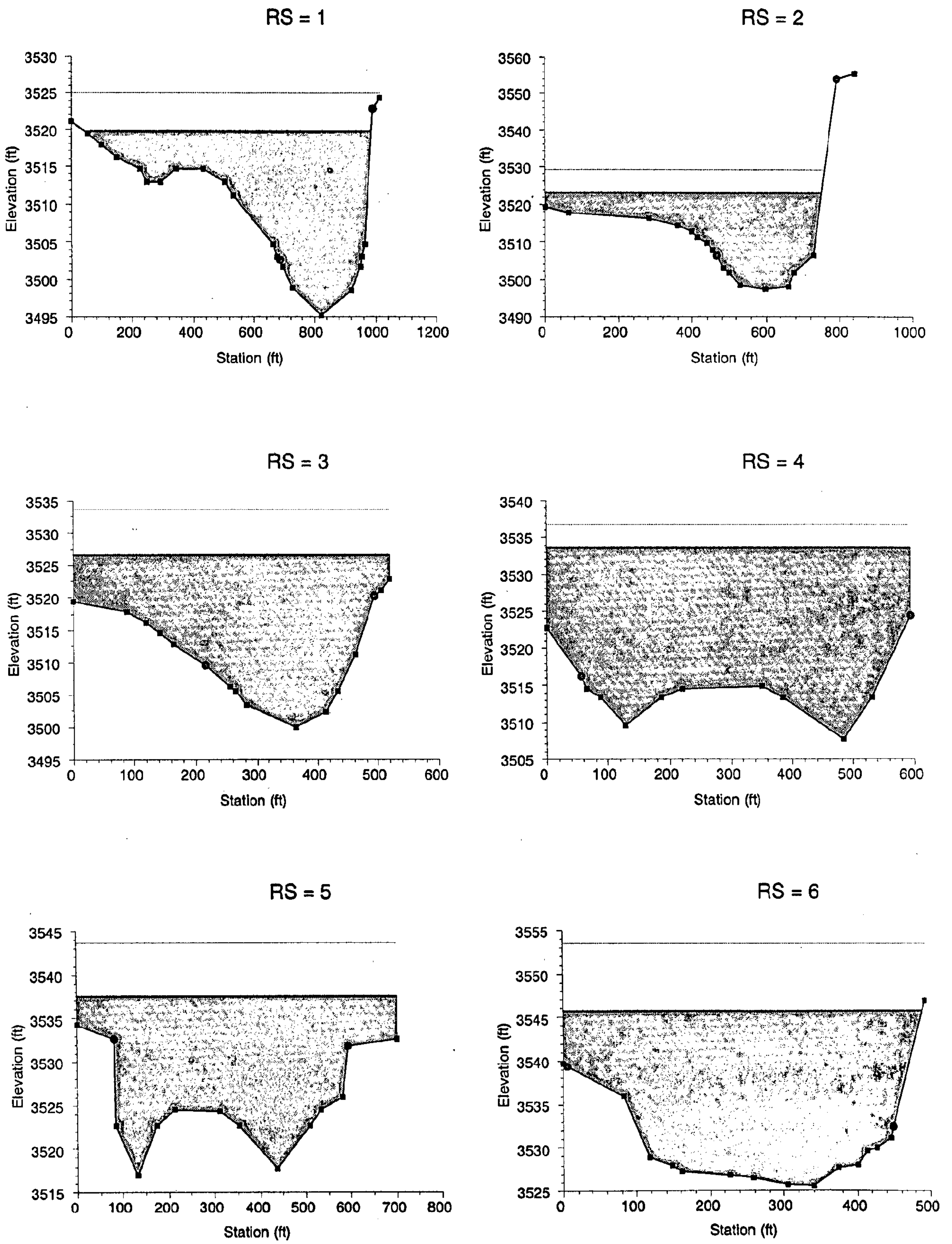
**Table-4.10, Summary of Output of Hec-6 (both fix bed and mobile bed) and Hec-Ras (fix bed) in Natural Condition for 2 Year Flood**

| Sec. No. | Water Surface Level | | | Velocity Head | | | Energy Line Level | | | Top Width | | | Hydraulic Depth | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hec-Ras | Hec-6 | | Hec-Ras | Hec-6 | | Hec-Ras | Hec-6 | | Hec-Ras | Hec-6 | | Hec-Ras | Hec-6 | |
| | | (fix) | (mobile) | | (fix) | (mobile) | | (fix) | (mobile) | | (fix) | (mobile) | | (fix) | (mobile) |
| | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) |
| 1 | 1068.881 | 1068.881 | 1068.881 | 0.765 | 0.767 | 0.767 | 1069.646 | 1069.648 | 1069.648 | 100.247 | 100.283 | 100.283 | 2.375 | 2.375 | 2.375 |
| 2 | 1070.210 | 1070.222 | 1070.222 | 0.512 | 0.508 | 0.508 | 1070.723 | 1070.730 | 1070.730 | 93.037 | 93.385 | 93.385 | 3.061 | 3.076 | 3.076 |
| 3 | 1071.085 | 1071.089 | 1071.089 | 0.698 | 0.698 | 0.698 | 1071.784 | 1071.788 | 1071.788 | 94.323 | 94.397 | 94.397 | 2.744 | 2.748 | 2.748 |
| 4 | 1072.655 | 1072.615 | 1072.615 | 0.488 | 0.509 | 0.509 | 1073.140 | 1073.123 | 1073.123 | 159.076 | 158.582 | 158.582 | 1.680 | 1.647 | 1.647 |
| 5 | 1075.244 | 1075.261 | 1075.261 | 0.713 | 0.696 | 0.696 | 1075.957 | 1075.958 | 1075.958 | 152.262 | 152.307 | 152.307 | 1.402 | 1.421 | 1.421 |
| 6 | 1077.524 | 1077.501 | 1077.501 | 0.662 | 0.679 | 0.679 | 1078.186 | 1078.180 | 1078.180 | 111.341 | 111.145 | 111.145 | 2.021 | 2.000 | 2.000 |
| 7 | 1080.771 | 1080.789 | 1080.789 | 1.009 | 0.991 | 0.991 | 1081.777 | 1081.780 | 1081.780 | 97.564 | 98.116 | 98.115 | 2.183 | 2.198 | 2.198 |
| 8 | 1082.881 | 1082.870 | 1082.874 | 0.671 | 0.671 | 0.676 | 1083.552 | 1083.541 | 1083.550 | 112.659 | 112.731 | 112.469 | 2.369 | 2.370 | 2.365 |
| 9 | 1085.015 | 1085.035 | 1085.045 | 0.921 | 0.899 | 0.890 | 1085.933 | 1085.934 | 1085.934 | 114.851 | 115.209 | 115.358 | 2.113 | 2.129 | 2.135 |
| 10 | 1086.905 | 1086.898 | 1086.895 | 0.451 | 0.448 | 0.452 | 1087.357 | 1087.347 | 1087.346 | 133.338 | 133.481 | 133.305 | 2.341 | 2.348 | 2.341 |
| 11 | 1088.027 | 1088.007 | 1088.012 | 0.366 | 0.374 | 0.373 | 1088.393 | 1088.382 | 1088.384 | 177.841 | 177.585 | 177.650 | 1.765 | 1.749 | 1.753 |
| 12 | 1088.899 | 1088.914 | 1088.913 | 0.354 | 0.350 | 0.350 | 1089.250 | 1089.264 | 1089.263 | 139.390 | 139.452 | 139.444 | 2.198 | 2.209 | 2.208 |
| 13 | 1090.409 | 1090.424 | 1090.420 | 0.896 | 0.882 | 0.885 | 1091.305 | 1091.306 | 1091.305 | 106.689 | 106.942 | 106.885 | 1.787 | 1.799 | 1.796 |
| 14 | 1093.174 | 1093.202 | 1093.202 | 1.012 | 0.983 | 0.984 | 1094.183 | 1094.185 | 1094.185 | 90.027 | 90.372 | 90.370 | 1.994 | 2.016 | 2.016 |
| 15 | 1095.241 | 1095.249 | 1095.250 | 0.421 | 0.417 | 0.417 | 1095.662 | 1095.666 | 1095.667 | 127.948 | 128.321 | 128.295 | 2.454 | 2.464 | 2.463 |
| 16 | 1096.405 | 1096.425 | 1096.426 | 0.915 | 0.896 | 0.895 | 1097.320 | 1097.321 | 1097.321 | 124.564 | 125.950 | 126.038 | 1.857 | 1.874 | 1.876 |
| 17 | 1097.966 | 1097.962 | 1097.961 | 0.613 | 0.629 | 0.630 | 1098.579 | 1098.591 | 1098.591 | 152.366 | 151.156 | 151.082 | 1.512 | 1.506 | 1.506 |

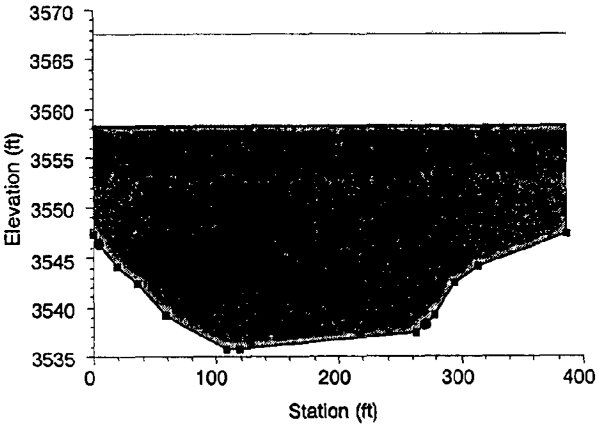
**Table-4.11, Summary of Output of Hec-6 (both fix bed and mobile bed) and Hec-Ras (fix bed) in Natural Condition for 500 Year Flood**

| Sec. | Water Surface Level | | | Velocity Head | | | Energy Line Level | | | Top Width | | | Hydraulic Depth | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Hec-Ras | Hec-6 | | Hec-Ras | Hec-6 | | Hec-Ras | Hec-6 | | Hec-Ras | Hec-6 | | Hec-Ras | Hec-6 | |
| | | (fix) | (mobile) | | (fix) | (mobile) | | (fix) | (mobile) | | (fix) | (mobile) | | (fix) | (mobile) |
| | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) |
| 1 | 1073.082 | 1073.081 | 1073.081 | 1.640 | 1.642 | 1.651 | 1074.723 | 1074.723 | 1074.731 | 288.082 | 288.046 | 288.038 | 6.244 | 6.242 | 6.213 |
| 2 | 1074.110 | 1074.097 | 1074.109 | 1.826 | 1.825 | 1.824 | 1075.933 | 1075.923 | 1075.933 | 229.037 | 229.036 | 229.044 | 6.649 | 6.647 | 6.656 |
| 3 | 1075.177 | 1075.150 | 1075.147 | 2.146 | 2.149 | 2.224 | 1077.320 | 1077.299 | 1077.371 | 157.991 | 157.991 | 157.991 | 6.482 | 6.456 | 6.313 |
| 4 | 1077.271 | 1077.222 | 1077.320 | 0.991 | 1.004 | 1.021 | 1078.265 | 1078.226 | 1078.341 | 180.991 | 180.991 | 180.991 | 6.131 | 6.074 | 6.016 |
| 5 | 1078.488 | 1078.521 | 1078.507 | 1.918 | 1.879 | 1.874 | 1080.405 | 1080.399 | 1080.382 | 213.991 | 213.991 | 213.991 | 4.595 | 4.629 | 4.640 |
| 6 | 1080.994 | 1081.035 | 1080.937 | 2.399 | 2.356 | 2.357 | 1083.396 | 1083.391 | 1083.294 | 148.970 | 149.086 | 148.800 | 4.930 | 4.971 | 4.979 |
| 7 | 1084.841 | 1084.866 | 1084.743 | 2.796 | 2.715 | 2.717 | 1087.637 | 1087.581 | 1087.460 | 118.030 | 118.030 | 118.030 | 6.168 | 6.192 | 6.266 |
| 8 | 1086.909 | 1086.798 | 1086.604 | 2.299 | 2.343 | 2.444 | 1089.207 | 1089.141 | 1089.048 | 124.034 | 124.034 | 124.034 | 6.226 | 6.114 | 6.022 |
| 9 | 1088.793 | 1088.823 | 1088.609 | 2.518 | 2.477 | 2.490 | 1091.308 | 1091.300 | 1091.099 | 139.168 | 139.258 | 138.627 | 5.591 | 5.623 | 5.708 |
| 10 | 1091.223 | 1091.209 | 1090.970 | 1.317 | 1.320 | 1.369 | 1092.540 | 1092.530 | 1092.338 | 179.152 | 179.019 | 177.254 | 6.439 | 6.420 | 6.405 |
| 11 | 1092.360 | 1092.352 | 1092.133 | 0.860 | 0.858 | 0.950 | 1093.223 | 1093.210 | 1093.083 | 214.576 | 214.602 | 213.575 | 5.970 | 5.976 | 5.690 |
| 12 | 1092.561 | 1092.561 | 1092.364 | 1.527 | 1.527 | 1.834 | 1094.088 | 1094.088 | 1094.197 | 170.043 | 170.043 | 169.124 | 5.494 | 5.489 | 5.007 |
| 13 | 1094.256 | 1094.293 | 1094.313 | 2.302 | 2.261 | 2.261 | 1096.558 | 1096.554 | 1096.575 | 157.192 | 157.312 | 157.380 | 5.137 | 5.173 | 5.166 |
| 14 | 1097.436 | 1097.485 | 1097.261 | 2.244 | 2.189 | 2.203 | 1099.683 | 1099.673 | 1099.464 | 170.043 | 170.043 | 170.043 | 5.662 | 5.709 | 5.804 |
| 15 | 1099.555 | 1099.545 | 1099.278 | 1.302 | 1.292 | 1.413 | 1100.854 | 1100.838 | 1100.691 | 166.043 | 166.043 | 166.043 | 6.655 | 6.640 | 6.404 |
| 16 | 1100.363 | 1100.364 | 1100.241 | 1.442 | 1.433 | 1.388 | 1101.805 | 1101.797 | 1101.629 | 196.049 | 196.049 | 196.049 | 5.195 | 5.195 | 5.507 |
| 17 | 1100.966 | 1100.970 | 1100.972 | 1.555 | 1.541 | 1.196 | 1102.521 | 1102.512 | 1102.168 | 230.058 | 230.058 | 230.058 | 4.046 | 4.054 | 4.662 |

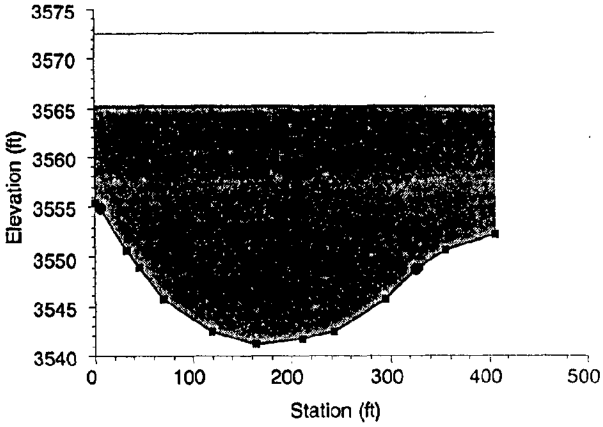
## Fig. 4-3, Cross-Sections of Beas River in Natural Condition during 500 Year Flood



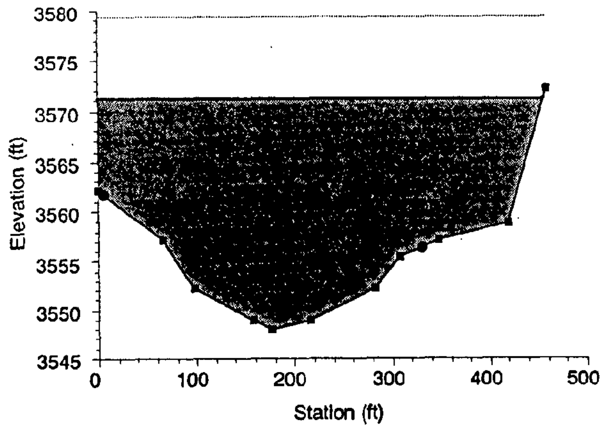
RS = 7



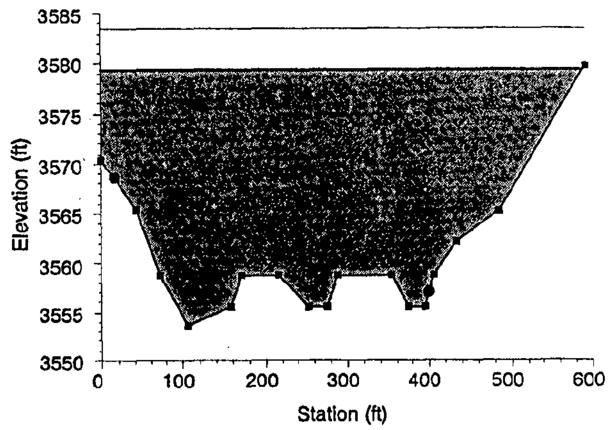

RS = 8



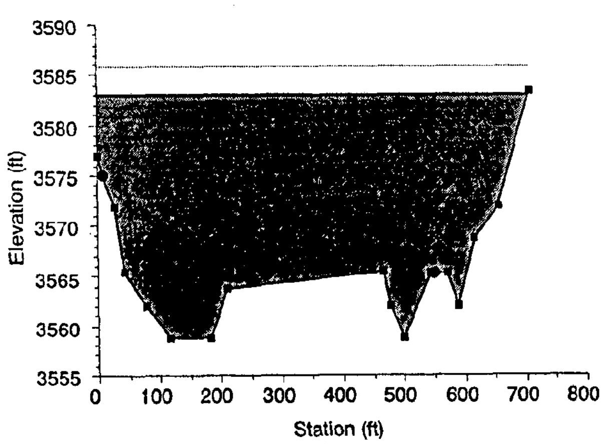

RS = 9



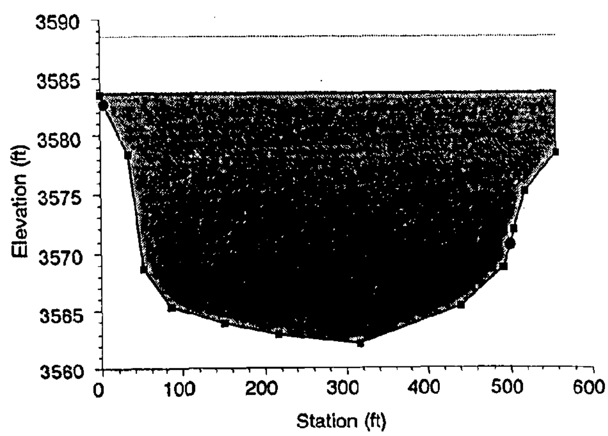

RS = 10



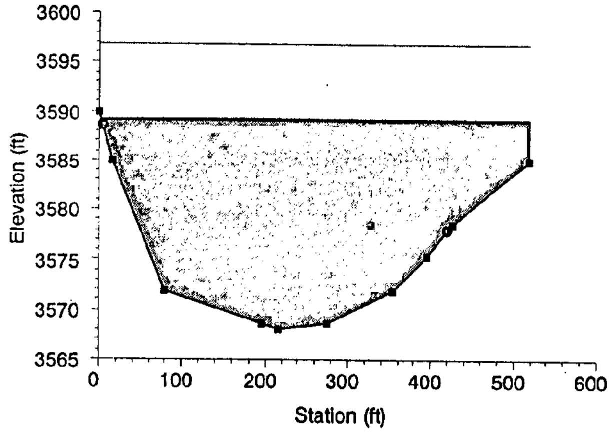

RS = 11



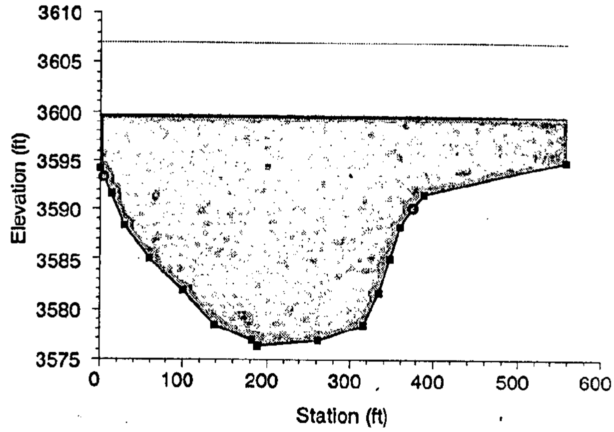

RS = 12



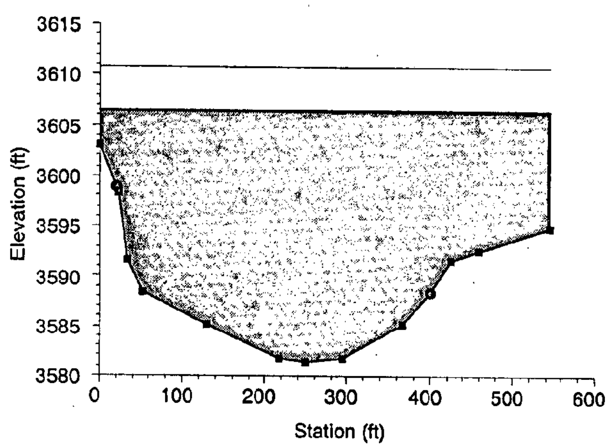
RS = 13



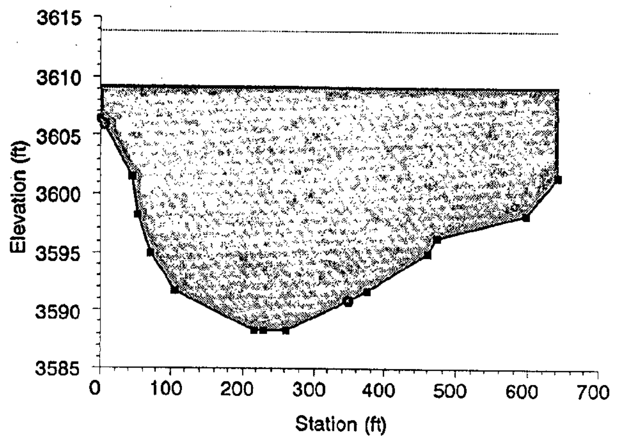

RS = 14



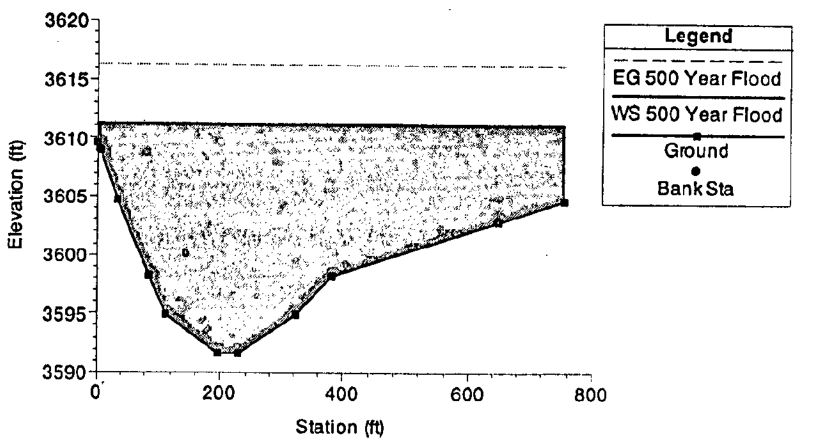

RS = 15




RS = 16




RS = 17



## 4.7 SEDIMENT LOAD COMPUTATION

The total sediment load in a stream consists of bed load and suspended load. The bed load is that part of sediment load, which is transported on or near the bed while the suspended load is the material moving is suspension in fluid, being kept in suspension by the turbulent fluctuations. The bed load and the suspended load are computed separately and the total sediment load is computed as the sum of the two.

### BED LOAD

As the field data for bed load is not available, the bed load transport rate is computed using the empirical relation given by Meyer, Peter and Muller, which is applicable for gravel-bed stream. The equation for bed load is given as:

$$q_b = 8(\tau_* - \tau_{*c})^{1.5}(D_{50})^{1.5}[g(G-1)]^{0.5}$$

where, $\tau_{*c} = \dfrac{\tau_c}{\gamma(G-1)D_{50}}$

$$\tau_* = \frac{\tau_o}{\gamma(G-1)D_{50}}$$

$$\tau_o = \gamma RS$$

Taking average width, B= 200 m and average depth of flow, d= 3.0 m for design discharge of 2834 $m^3/s$ (100000 $ft^3/s$) by fixed bed run in Hec-6,

B/d= 66.67

$\therefore R \cong d$

$D_{50}$= 32*$10^{-3}$ m (from grain size distribution curve)

G= 2.65

S= 0.0091

$\therefore$ Critical value of Shield's parameter for turbulent zone, $\tau_{*c} = 0.056$ (from River Training Techniques by Pilarczyk et. all.)

$\tau_o = 9810 * 3.0 * 0.0091$ $= 267.81$ N/m$^2$

$\tau_* = 267.81/(9810 * 1.65 * 32 * 10^{-3})$ $= 0.517$

$q_b = 8(0.517 - 0.056)^{1.5} * (32 * 10^{-3})^{1.5} * (9.81 * 1.65)^{0.5}$ $= 0.058$ m$^3$/m-s

Considering density of sediment, $\rho_s$= 2650 kg/m$^3$

$\therefore$ Bed load transport rate = 0.058*200*2650 = 30740 kg/s

= 30.74 t/s

## SUSPENDED LOAD

Suspended load data for Beas River at Bhuntar is available for eleven years from 1985 to 1995 and is given in appendix-12. Referring this data, it is assumed that the suspended load is equal to 150 ha-m/month for the discharge of 2834 m$^3$/s. Assuming the loose unit weight of sediment as 1650 kg/m$^3$ and sediment void ratio as 30 percent, we get:

Total weight of suspended sediment transported per month = 150* 10$^4$* 0.7* 1650

= 173.25*10$^7$ kg

$\therefore$ Suspended load transport rate = 173.25*10$^7$/(30*24*60*60)

= 668.40 kg/s

= 0.668 t/s

$\therefore$ Total sediment load transport rate = 30.74+0.668

= 31.408 t/s

$\therefore$ Total sediment concentration in ppm = 31.408*10$^3$*10$^6$/(2834*1000)

= 11083 ppm

## 4.8 DETERMINATION OF STABLE CHANNEL PARAMETERS

### I) BY RAUDKIVI'S METHOD

$$\tau_{*c} = \frac{d * S}{D(G-1)} \qquad = 0.056$$

for G= 2.65, we get D= 10.82 d S $\approx$ 11 d S

Hydraulic Radius, R= 0.59 d

$$\Rightarrow D = \frac{11RS}{0.59} = 19RS$$

Taking D= $D_{90}$ = 185 mm S= 0.0091

$$\therefore R = \frac{D}{19S} = \frac{185 * 10^{-3}}{19 * 0.0091} = 1.07 \text{ m}$$

Mean flow velocity, $U = 28R^{1/2}S^{1/3} = 28 * (1.07)^{1/2}(0.0091)^{1/3} = 6.05$ m/s

Area of flow, $A = \frac{Q_2}{U} = \frac{800}{6.05} = 132.23 \text{ m}^2$

Depth of flow, $d = \frac{R}{0.59} = \frac{1.07}{0.59} = 1.81$

Top width, $B = \frac{A}{R} = \frac{132.23}{1.07} = 123.58$ m

### II) BY HEY'S EMPIRICAL FORMULA

Using $Q_{bf}$ = 800 $m^3$/s $D_{16}$= 9 mm $D_{50}$= 32 mm $D_{84}$= 105 mm

$B = 4.33Q_{bf}^{0.50} = 4.33(800)^{0.5} = 119.64$ m

$d = 0.22Q_{bf}^{0.37}(D_{50})^{-0.11} = 0.22(800)^{0.37}(32 * 10^{-3})^{-0.11} = 3.81$ m

$d_{max} = 0.20^{0.37\sigma_D}(Q_{bf})^{0.36}(D_{50})^{-0.21} = 16.64$ m

Where $\sigma_D = 1/2\log(D_{84}/D_{16}) = 1/2\log(105/9) = 0.533$

Now, to calculate the regime slope, we first have to calculate the sediment transport at the bankful discharge.

Here, $Q_{bf}$ = 800 $m^3$/s B= 457.40 ft = 139.45 m

$d = 3571.638 - 3564.392 = 7.246$ ft $= 2.21$ m

$B/d = 139.45/2.21 = 63.10 \quad \therefore R = d = 2.21$

$D_{50} = 32*10^{-3}$ m $\qquad G = 2.65 \qquad S = 0.0091 \qquad \tau_{*c} = 0.056$

$\tau_o = \gamma RS = 9810 * 2.21 * 0.0091 = 197.29\ \text{N/m}^2$

$$\tau_* = \frac{\tau_o}{\gamma(G-1)D_{50}} = \frac{197.29}{9810*(2.65-1)*32*10^{-3}} = 0.38$$

$$q_b = 8(\tau_* - \tau_{*c})^{1.5}(D_{50})^{1.5}[g(G-1)]^{0.5} = 8(0.38-0.056)^{1.5}(32*10^{-3})^{1.5}[9.81(2.65-1)]^{0.5}$$

$= 0.034$ m3/m-s

$\therefore$ Bed load $= 0.034*139.45*2650/1000 = 12.56$ t/s

Suspended load assumed = 100 ha/m/month (based on field measurement of suspended load)

Total weight of suspended sediment transported per month

$= 100*10^4*1650*0.7 = 1.16*10^9$ kg

Rate of suspended sediment Transported $= 1.16*10^9/(30*24*60*60)$

$= 447$ kg/s $= 0.447$ t/s

Total sediment load transported $= 12.56+0.447 = 13$ t/s

$$S = 0.087^{0.84\sigma_D}(Q_{bf})^{-0.43}(D_{50})^{0.75}(Q_t)^{0.10}$$

$$= 0.087^{\,0.84*0.533}(800)^{-0.43}(32*10^{-3})^{0.75}(13000)^{0.10}$$

$$= 0.0037 \approx 1/270$$

## III) BY BRAY'S BEST FIT DIMENSIONLESS EXPRESSION

$B = 2.68*(Q_2^{0.496})*(D_{50}^{-0.241}) = 2.68*(800)^{.496}(32*10^{-3})^{-0.241} = 169.17$ m

$d = 0.20*(Q_2^{0.397})*(D_{50}^{0.008}) = 0.20*(800)^{0.397}*(32*10^{-3})^{0.008} = 2.76$ m

$U = 1.87*(Q_2^{0.107})*(D_{50}^{0.233}) = 1.87*(800)^{0.107}*(32*10^{-3})^{0.233} = 1.71$ m/s

$S = 0.063*(Q_2^{-0.375})*(D_{50}^{0.937}) = 0.063*(800)^{-0.375}*(32*10^{-3})^{0.937} = 0.000204$

$= 1/4900$

### IV) BY BRAY'S BEST FIT EXPRESSION

$B = 3.83Q_2^{0.528}D_{50}^{-0.07} = 3.83(800)^{0.528}(32*10^{-3})^{-0.07}$ $= 166.21$ m

$d = 0.246Q_2^{0.331}D_{50}^{-0.025} = 0.246(800)^{0.331}(32*10^{-3})^{-0.025}$ $= 2.45$ m

$U = 1.05Q_2^{0.140}D_{50}^{0.095} = 1.05(800)^{0.140}(32*10^{-3})^{0.095}$ $= 1.93$ m/s

$S = 0.018Q_2^{-0.334}D_{50}^{0.586} = 0.018(800)^{-0.334}(32*10^{-3})^{0.586}$ $= 0.00026$

$= 1/3846$

### V) BY KELLERHAL'S METHOD

$B = 3.26Q_2^{0.5} = 3.26(800)^{0.5}$ $= 92.21$ m

$d = 0.183Q_2^{0.4}D_{90}^{-0.12} = 0.183(800)^{0.4}(185*10^{-3})^{-0.12}$ $= 3.25$ m

$U = 1.67Q_2^{0.10}D_{90}^{0.12} = 1.67(800)^{0.10}(185*10^{-3})^{0.12}$ $= 2.66$ m/s

$S = 0.026Q_2^{-0.4}D_{90}^{0.92} = 0.026(800)^{-0.4}(185*10^{-3})^{0.92}$ $= 0.00038$

$= 1/2630$

### VI) BY HEY AND THORNE'S EMPIRICAL FORMULA

$B = 3.98Q_2^{0.52}Q_S^{-0.01} = 3.98(800)^{0.52}(13000)^{-0.01}$ $= 117.05$ m

$d = 0.16Q_2^{0.39}Q_S^{-0.02}D_{50}^{-0.15} = 0.16(800)^{0.39}(13000)^{-0.02}(32*10^{-3})^{-0.15}$ $= 3.00$ m

$S = 0.087Q_2^{-0.43}Q_S^{-0.10}D_{50}^{-0.09}D_{84}^{0.84} = 0.087(800)^{-0.43}(13000)^{-0.10}(32*10^{-3})^{-0.09}(105*10^{-3})^{0.84}$

$= 0.00039$ $= 1/2564$

The above calculations show that the values of stable channel parameters calculated by different methods vary significantly. Actually these empirical relations are based on some flume and field data. So they are applicable for a particular range of discharge and sediment size and gradation. Hey's empirical formulas are mainly developed for mobile gravel bed rivers, so it is considered most suitable for the Beas river. Thus the following channel parameters computed by Hey's relation is used for river channelization:

Channel width, B = 120.00 m flow depth, d = 3.80 m bed slope = 1/270

## 4.9 DIVERSION OF BEAS RIVER

As already mentioned, the runway length is required to be extended by 1000 m of 200 m width. But it is not possible to extend it from 16 side of the runway due to existence of heavy settlement and market at this side. So it is extended from 34 side only for the entire length of 1000 m. It can be observed from the survey map that the centerline of runway extended for the required length of 1000 m crosses the river twice. It requires diversion of existing channel along a new course so that the required space for the runway can be created.

The diversion channel shall be diverted from chainage 1+900 of the existing channel and is merged again with the existing channel at chainge 3+700. Thus the existing channel of 1800 m length shall be replaced by a new diversion channel of length 1700 m. In this case the reduction in channel length by diversion of the existing channel is not significant, so a pilot channel may not enlarge satisfactorily. Further, it is not possible to allow sufficient time for development of channel to ultimate section. So the full section of the channel will be excavated before diverting the flow into it.

The diversion channel shall be designed as a cosine curve since a straight channel is always unstable and try to meander. According to Chang (1984) most meanders tend to develop a radius of curvature to width ratio (r/B) between 2.2 and 4.0. Similarly according to Mamak (1956) and Grisin the optimum meander arc length is related with channel width (B) as $L/2 = 10$ to $15 * B$. Hey (1983) suggests the relation $L/2 = 2\pi B$. Assuming the trapezoidal cross-section for the diversion channel with bottom width of 120 m and side slope of 2H:1V, we get average width B of 130 m for average depth of flow of 5 m.

Hence, the range of $R_{min}$ and L can be as given below:

| | |
|---|---|
| $R_{min}$ = 286 m – 520 m | - by Chang |
| L = 2600 m – 3900 m | - by Mamak and Grisin |
| L = 1633 m | - by Hey |

A cosine curve for the given field situation is designed by trial assuming different values of $R_{min}$ and L. It is found that two cosine curves (length L/2 each) with $R_{min}$ equal to 400 m and L equal to 1750 m and $R_{min}$ equal to 500 m and L equal to 1600 m provided the required space for accommodation of the runway extension as shown in the survey map. A computer program has been developed in fortran to compute co-ordinates of points along the cosine curve for given $R_{min}$ and L. This program has been included here as appendix-6 in this thesis. The results of the program for $R_{min}$ equal to 400 m and L equal to 1750 m and $R_{min}$ equal to 500 m and L equal to 1600 m are given below in table-4.12 and 4.13 respectively.

**TABLE-4.12, RESULT OF COMPUTER PROGRAM OF COSINE CURVE FOR MINIMUM RADIUS OF 400 M AND CURVE LENGTH OF 1750 M**

RESULTS OF COSINE GENERATED CURVE: MNDR.OUT

| Radmin (m) | Curve Length (m) | N-division | |
|---|---|---|---|
| 400 | 1750 | 37 | |
| Angles in degrees | | | |
| 2.250 | 2.250 | 2.250 | 2.250 |
| 2.000 | 2.000 | 2.000 | 2.000 |
| 1.750 | 1.750 | 1.750 | 1.750 |
| 1.250 | 1.250 | 1.250 | 1.250 |
| 1.000 | 1.000 | 1.000 | 1.000 |
| 0.750 | 0.750 | 0.750 | 0.750 |
| 0.600 | 0.600 | 0.600 | 0.600 |
| 0.250 | 0.250 | 0.250 | 0.250 |
| 0.100 | 0.100 | 0.100 | 0.100 |
| 0.063 | | | |
| Cartesian coordinates and radii of the curve | | | |
| Angle | Abscissa, X (m) | Ordinate, Y (m) | Radius (m) |
| 2.250 | 399.691 | 15.719 | 400.639 |
| 4.500 | 398.762 | 31.463 | 402.573 |
| 6.750 | 397.205 | 47.261 | 405.861 |
| 9.000 | 395.007 | 63.140 | 410.602 |
| 11.000 | 392.496 | 77.369 | 416.166 |
| 13.000 | 389.444 | 91.715 | 423.152 |
| 15.000 | 385.848 | 106.128 | 431.713 |
| 17.000 | 381.637 | 120.806 | 442.223 |
| 18.750 | 377.425 | 133.857 | 453.296 |
| 20.500 | 372.722 | 147.036 | 466.379 |
| 22.250 | 367.426 | 160.559 | 482.107 |
| 24.000 | 361.550 | 174.309 | 500.926 |
| 25.250 | 356.927 | 184.389 | 516.854 |
| 26.500 | 351.876 | 194.797 | 535.524 |
| 27.750 | 346.445 | 205.390 | 557.241 |

| | | | |
|---|---|---|---|
| 29.000 | 340.539 | 216.316 | 583.046 |
| 30.000 | 335.415 | 225.365 | 607.535 |
| 31.000 | 329.898 | 234.723 | 636.407 |
| 32.000 | 324.000 | 244.342 | 670.591 |
| 33.000 | 317.509 | 254.525 | 712.868 |
| 33.750 | 312.212 | 262.561 | 751.661 |
| 34.500 | 306.494 | 270.992 | 798.702 |
| 35.250 | 300.369 | 279.775 | 856.269 |
| 36.000 | 293.532 | 289.310 | 931.422 |
| 36.600 | 287.564 | 297.429 | 1008.904 |
| 37.200 | 280.825 | 306.398 | 1113.802 |
| 37.800 | 273.339 | 316.146 | 1259.683 |
| 38.400 | 264.585 | 327.301 | 1488.219 |
| 38.650 | 260.205 | 332.799 | 1637.159 |
| 38.900 | 255.535 | 338.609 | 1833.102 |
| 39.150 | 250.196 | 345.191 | 2124.221 |
| 39.400 | 243.801 | 353.005 | 2624.736 |
| 39.500 | 240.694 | 356.780 | 2965.190 |
| 39.600 | 237.117 | 361.109 | 3487.141 |
| 39.700 | 232.766 | 366.355 | 4443.093 |
| 39.800 | 226.706 | 373.636 | 7255.691 |
| 39.860 | 220.459 | 381.120 | 27006.970 |
| Cartesian coordinates for XOIs and YOIs | | | |
| Angle | Abscissa, X (m) | Ordinate, Y (m) | Radius (m) |
| 2.250 | 600.181 | 23.599 | 400.639 |
| 4.500 | 600.723 | 47.364 | 402.573 |
| 6.750 | 601.658 | 71.469 | 405.861 |
| 9.000 | 603.041 | 96.103 | 410.602 |
| 11.000 | 604.720 | 118.648 | 416.166 |
| 13.000 | 606.910 | 141.962 | 423.152 |
| 15.000 | 609.715 | 166.122 | 431.713 |
| 17.000 | 613.331 | 191.667 | 442.223 |
| 18.750 | 617.336 | 215.349 | 453.296 |
| 20.500 | 622.308 | 240.381 | 466.379 |
| 22.250 | 628.608 | 267.472 | 482.107 |
| 24.000 | 636.568 | 296.789 | 500.926 |
| 25.250 | 643.635 | 319.641 | 516.854 |
| 26.500 | 652.268 | 344.670 | 535.524 |
| 27.750 | 662.743 | 371.908 | 557.241 |
| 29.000 | 675.734 | 402.226 | 583.046 |
| 30.000 | 688.552 | 429.379 | 607.535 |
| 31.000 | 704.207 | 459.785 | 636.407 |
| 32.000 | 723.411 | 493.998 | 670.591 |
| 33.000 | 748.033 | 534.212 | 712.868 |
| 33.750 | 771.355 | 569.509 | 751.661 |
| 34.500 | 800.436 | 610.693 | 798.702 |
| 35.250 | 837.035 | 659.199 | 856.269 |
| 36.000 | 886.195 | 720.135 | 931.422 |

| | | | |
|---|---|---|---|
| 36.600 | 938.206 | 780.831 | 1008.904 |
| 37.200 | 1010.321 | 860.491 | 1113.802 |
| 37.800 | 1113.111 | 967.898 | 1259.683 |
| 38.400 | 1278.354 | 1131.141 | 1488.219 |
| 38.650 | 1388.089 | 1235.453 | 1637.159 |
| 38.900 | 1534.337 | 1371.142 | 1833.102 |
| 39.150 | 1754.809 | 1570.828 | 2124.221 |
| 39.400 | 2141.037 | 1912.153 | 2624.736 |
| 39.500 | 2408.290 | 2144.539 | 2965.190 |
| 39.600 | 2824.782 | 2503.024 | 3487.141 |
| 39.700 | 3609.261 | 3171.290 | 4443.093 |
| 39.800 | 6100.363 | 5270.600 | 7255.691 |
| 39.860 | 30553.880 | 25721.130 | 27006.970 |

| TABLE-4.13, RESULT OF COMPUTER PROGRAM OF COSINE CURVE FOR MINIMUM RADIUS OF 500 M AND CURVE LENGTH OF 1600 M | | | |
|---|---|---|---|
| RESULTS OF COSINE GENERATED CURVE: MNDR.OUT | | | |
| Radmin (m) | Curve Length (m) | N-division | |
| 500 | 1600 | 41 | |
| Angles in degrees | | | |
| 1.750 | 1.750 | 1.750 | 1.750 |
| 1.500 | 1.500 | 1.500 | 1.500 |
| 1.250 | 1.250 | 1.250 | 1.250 |
| 1.000 | 1.000 | 1.000 | 1.000 |
| 0.750 | 0.750 | 0.750 | 0.750 |
| 0.500 | 0.500 | 0.500 | 0.500 |
| 0.250 | 0.250 | 0.250 | 0.250 |
| 0.150 | 0.150 | 0.150 | 0.150 |
| 0.100 | 0.100 | 0.100 | 0.100 |
| 0.030 | 0.030 | 0.030 | 0.030 |
| 0.037 | | | |
| Cartesian coordinates and radii of the curve | | | |
| Angle | Abscissa, X (m) | Ordinate, Y (m) | Radius (m) |
| 1.750 | 499.766 | 15.285 | 500.903 |
| 3.500 | 499.063 | 30.610 | 503.642 |
| 5.250 | 497.884 | 46.019 | 508.308 |
| 7.000 | 496.215 | 61.558 | 515.064 |
| 8.500 | 494.387 | 74.985 | 522.683 |
| 10.000 | 492.158 | 88.660 | 532.294 |
| 11.500 | 489.536 | 102.467 | 544.088 |
| 13.000 | 486.461 | 116.617 | 558.622 |
| 14.250 | 483.548 | 128.626 | 573.157 |
| 15.500 | 480.308 | 140.816 | 590.268 |
| 16.750 | 476.665 | 153.411 | 610.812 |
| 18.000 | 472.600 | 166.394 | 635.546 |
| 19.000 | 469.024 | 177.078 | 659.078 |
| 20.000 | 465.077 | 188.216 | 687.213 |
| 21.000 | 460.785 | 199.688 | 720.745 |
| 22.000 | 456.057 | 211.685 | 761.779 |
| 22.750 | 452.155 | 221.158 | 799.414 |

| | | | |
|---|---|---|---|
| 23.500 | 447.915 | 231.079 | 844.844 |
| 24.250 | 443.334 | 241.423 | 900.232 |
| 25.000 | 438.218 | 252.576 | 971.481 |
| 25.500 | 434.504 | 260.449 | 1030.832 |
| 26.000 | 430.471 | 268.806 | 1104.157 |
| 26.500 | 425.967 | 277.936 | 1199.630 |
| 27.000 | 421.032 | 287.717 | 1325.335 |
| 27.250 | 418.374 | 292.903 | 1404.733 |
| 27.500 | 415.416 | 298.613 | 1505.154 |
| 27.750 | 412.318 | 304.531 | 1627.106 |
| 28.000 | 408.789 | 311.200 | 1792.698 |
| 28.150 | 406.527 | 315.437 | 1917.894 |
| 28.300 | 404.084 | 319.988 | 2074.541 |
| 28.450 | 401.410 | 324.936 | 2278.367 |
| 28.600 | 398.243 | 330.760 | 2578.852 |
| 28.700 | 396.075 | 334.726 | 2835.081 |
| 28.800 | 393.661 | 339.124 | 3188.280 |
| 28.900 | 390.621 | 344.640 | 3783.142 |
| 29.000 | 387.219 | 350.787 | 4786.389 |
| 29.030 | 385.735 | 353.461 | 5415.814 |
| 29.060 | 384.483 | 355.714 | 6094.988 |
| 29.090 | 382.528 | 359.228 | 7593.616 |
| 29.120 | 380.693 | 362.525 | 9924.783 |
| 29.160 | 376.726 | 369.641 | 42432.240 |
| Cartesian coordinates for XOIs and YOIs | | | |
| Angle | Abscissa, X (m) | Ordinate, Y (m) | Radius (m) |
| 1.750 | 750.561 | 22.950 | 500.903 |
| 3.500 | 752.250 | 46.102 | 503.642 |
| 5.250 | 755.135 | 69.667 | 508.308 |
| 7.000 | 759.341 | 93.879 | 515.064 |
| 8.500 | 764.124 | 115.296 | 522.683 |
| 10.000 | 770.220 | 137.716 | 532.294 |
| 11.500 | 777.792 | 161.124 | 544.088 |
| 13.000 | 787.255 | 186.104 | 558.622 |
| 14.250 | 796.855 | 208.251 | 573.157 |
| 15.500 | 808.323 | 231.798 | 590.268 |
| 16.750 | 822.311 | 257.467 | 610.812 |
| 18.000 | 839.445 | 285.631 | 635.546 |
| 19.000 | 856.017 | 310.360 | 659.078 |
| 20.000 | 876.147 | 337.919 | 687.213 |
| 21.000 | 900.540 | 368.569 | 720.745 |
| 22.000 | 930.919 | 403.603 | 761.779 |
| 22.750 | 959.232 | 433.889 | 799.414 |
| 23.500 | 993.908 | 468.619 | 844.844 |
| 24.250 | 1036.825 | 508.846 | 900.232 |
| 25.000 | 1092.909 | 557.986 | 971.481 |
| 25.500 | 1140.261 | 597.196 | 1030.832 |
| 26.000 | 1199.431 | 643.964 | 1104.157 |
| 26.500 | 1277.398 | 702.711 | 1199.630 |
| 27.000 | 1381.348 | 777.304 | 1325.335 |
| 27.250 | 1447.628 | 823.196 | 1404.733 |
| 27.500 | 1532.037 | 880.195 | 1505.154 |
| 27.750 | 1635.291 | 948.170 | 1627.106 |
| 28.000 | 1776.598 | 1038.822 | 1792.698 |

| | | | |
|---|---|---|---|
| 28.150 | 1884.158 | 1106.411 | 1917.894 |
| 28.300 | 2019.505 | 1190.125 | 2074.541 |
| 28.450 | 2196.754 | 1298.012 | 2278.367 |
| 28.600 | 2460.160 | 1455.667 | 2578.852 |
| 28.700 | 2686.599 | 1589.351 | 2835.081 |
| 28.800 | 3001.368 | 1773.187 | 3188.280 |
| 28.900 | 3538.364 | 2083.211 | 3783.142 |
| 29.000 | 4464.458 | 2611.691 | 4786.389 |
| 29.030 | 5059.647 | 2948.966 | 5415.814 |
| 29.060 | 5715.163 | 3319.132 | 6094.988 |
| 29.090 | 7214.431 | 4162.669 | 7593.616 |
| 29.120 | 9703.556 | 5558.326 | 9924.783 |
| 29.160 | 58200.940 | 32642.460 | 42432.240 |

## 4.10 DESIGN OF LONGITUDINAL DIKES

The computation of water surface profiles (appendix-2, 3 and 5) shows that there is spillage of flow over the banks of the river for the design flood of 5oo year return period (4700 cumecs). Longitudinal dikes shall be provided to protect the flooding of nearby area including the airport. The river is carried along the existing course from chainage 0+000 to 1+900. There after it shall be channelised along the new course downstream of chainge1+900 to accommodate extension of the existing runway.

The top width of the dikes shall be kept 3.0 m wide to allow for vehicular movement during construction and subsequently for inspection and maintenance. Both the waterside slope and the outer slope of the dikes shall be sloping 2 H: 1 V. The top of the dikes shall be fixed 1.50 m above the design flood level. The main body of the dikes shall be constructed with riverbed material conforming certain specific gradation. In this case study, properties of embankment fill material will be considered as given below:

| | | |
|---|---|---|
| $D_{10}$ = 0.18 mm | $D_{15}$ = 0.20mm | $D_{50}$ = 1.20 mm |
| $D_{60}$ = 2.20 mm | $D_{90}$ = 15.00 mm | Solid density, $\rho_s$= 2650 kg/m3 |
| Porosity, n = 40 % | Angle of repose, $\phi$ = 40° | Cohesion, c = 0 |

The waterside slope of the dikes shall be protected by one of the following three alternative options of cover-layer:

- Stone rip-rap with graded filter
- Gabion mattress with geo-textile filter

- Cement concrete blocks with geo-textile filter

The final selection of the best alternative among the above alternatives depends upon the degree of protection required, durability, effectiveness, economy and ease of construction etc.

## 4.11 COPMUTATION OF WATER SURFACE PROFILE WITH DIKES AND THE DIVERSION CHANNEL

Water surface profile is again calculated for the study reach with the dikes and the diversion channel following the procedure given in section 4.6. The Manning's roughness coefficient is taken as 0.038 for the channel and 0.045 for the left and the right overbanks. The geometric data shall be fed assuming a trapezoidal channel section of bottom width 120 m, depth 6.5 m and side slope of 2:1. The longitudinal slope of the diversion channel is 0.01007 {Assuming the slope of the existing channel downstream of chainage 3+270 equal to 0.0091, we get the bed level at chainage 3+700 as 3482.34 ft (3495.17-3.28*(3700-3270)*0.0091). The bed level at chainage 1+900 is 3538.49 ft (averaging the bed level at chainage 1+800 and 2+000)}. The stage discharge curve shall again be prepared for the downstream end of the diversion channel following the procedure given is section 4.5 with $n = 0.038$ and $S = 0.01007$. This stage discharge curve shall be used as the downstream boundary condition for simulation in Hec-6 and Hec-Ras.

The input and the output data file of Hec-6 for simulation of Beas River with flood dike and diversion channel for 2 year and 500 year return period floods in fix bed mode is given in appendix-7 and 8 respectively. The output for the same condition as obtained by Hec-Ras is given in appendix-9. The input and the output data file of Hec-6 for simulation of Beas River with flood dike and diversion channel for 2 year and 500 year return period floods in mobile bed mode is given in appendix-10 and 11 respectively. A summary of outputs of Hec-6 (both fix bed and mobile bed) and Hec-Ras (fix bed) with dike and channelization for 2 year and 500 year floods are given in table-4.14 and table-4.15 respectively. Cross-sections and L-section of Beas River with dike and channelization for 500 year flood are shown in fig.-4.4 and fig.-4.5 respectively.

Table-4.14, Summary of Output of Hec-6 (both fix bed and mobile bed) and Hec-Ras (fix bed) with Dikes and Diversion Channel for 2 Year Flood

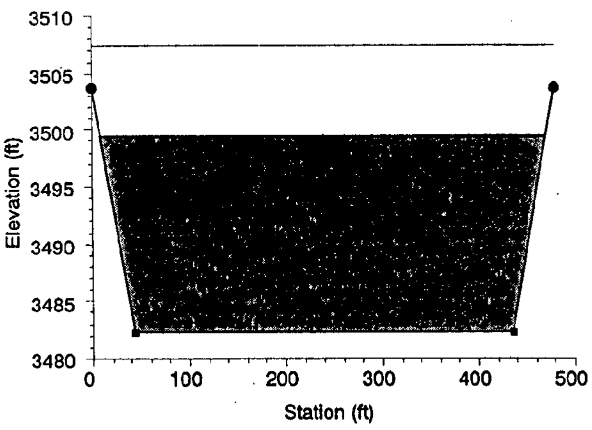
| Sec. No. | Water Surface Level | | | Velocity Head | | | Energy Line Level | | | Top Width | | | Hydraulic Depth | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hec-Ras | Hec-6 | | Hec-Ras | Hec-6 | | Hec-Ras | Hec-6 | | Hec-Ras | Hec-6 | | Hec-Ras | Hec-6 | |
| | | (fix) | (mobile) | | (fix) | (mobile) | | (fix) | (mobile) | | (fix) | (mobile) | | (fix) | (mobile) |
| | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) |
| 1 | 1063.415 | 1063.415 | 1063.415 | 0.720 | 0.719 | 0.719 | 1064.134 | 1064.134 | 1064.134 | 126.902 | 126.896 | 126.896 | 1.680 | 1.679 | 1.679 |
| 2 | 1065.451 | 1065.451 | 1065.451 | 0.701 | 0.701 | 0.701 | 1066.152 | 1066.152 | 1066.152 | 126.988 | 126.982 | 126.982 | 1.698 | 1.699 | 1.699 |
| 3 | 1067.448 | 1067.447 | 1067.447 | 0.713 | 0.714 | 0.714 | 1068.162 | 1068.161 | 1068.161 | 126.924 | 126.922 | 126.922 | 1.683 | 1.684 | 1.684 |
| 4 | 1069.473 | 1069.472 | 1069.472 | 0.704 | 0.706 | 0.706 | 1070.177 | 1070.177 | 1070.177 | 126.966 | 126.961 | 126.961 | 1.695 | 1.693 | 1.693 |
| 5 | 1071.482 | 1071.480 | 1071.480 | 0.710 | 0.713 | 0.713 | 1072.192 | 1072.192 | 1072.192 | 126.933 | 126.931 | 126.931 | 1.686 | 1.686 | 1.686 |
| 6 | 1073.500 | 1073.506 | 1073.506 | 0.704 | 0.710 | 0.710 | 1074.204 | 1074.216 | 1074.216 | 126.963 | 126.942 | 126.942 | 1.692 | 1.689 | 1.689 |
| 7 | 1075.509 | 1075.525 | 1075.525 | 0.710 | 0.711 | 0.711 | 1076.220 | 1076.235 | 1076.235 | 126.936 | 126.940 | 126.940 | 1.686 | 1.688 | 1.688 |
| 8 | 1077.527 | 1077.540 | 1077.540 | 0.704 | 0.706 | 0.706 | 1078.232 | 1078.246 | 1078.246 | 126.963 | 126.962 | 126.962 | 1.692 | 1.693 | 1.693 |
| 9 | 1079.537 | 1079.550 | 1079.550 | 0.710 | 0.712 | 0.712 | 1080.247 | 1080.262 | 1080.262 | 126.936 | 126.935 | 126.935 | 1.686 | 1.686 | 1.686 |
| 10 | 1080.549 | 1080.563 | 1080.563 | 0.707 | 0.699 | 0.699 | 1081.253 | 1081.262 | 1081.262 | 126.960 | 126.999 | 126.999 | 1.692 | 1.701 | 1.701 |
| 11 | 1081.534 | 1081.535 | 1081.535 | 0.579 | 0.575 | 0.575 | 1082.113 | 1082.110 | 1082.110 | 127.671 | 127.684 | 127.684 | 1.860 | 1.865 | 1.865 |
| 12 | 1083.348 | 1083.375 | 1083.375 | 0.802 | 0.777 | 0.777 | 1084.152 | 1084.152 | 1084.152 | 126.540 | 126.651 | 126.651 | 1.591 | 1.618 | 1.618 |
| 13 | 1085.713 | 1085.680 | 1085.680 | 0.732 | 0.753 | 0.753 | 1086.445 | 1086.433 | 1086.433 | 126.835 | 126.739 | 126.739 | 1.662 | 1.642 | 1.642 |
| 14 | 1087.302 | 1087.325 | 1087.325 | 0.399 | 0.389 | 0.389 | 1087.698 | 1087.715 | 1087.715 | 129.189 | 129.298 | 129.298 | 2.216 | 2.239 | 2.239 |
| 15 | 1088.091 | 1088.095 | 1088.095 | 0.485 | 0.484 | 0.484 | 1088.576 | 1088.579 | 1088.579 | 128.354 | 128.364 | 128.364 | 2.021 | 2.023 | 2.023 |
| 16 | 1089.460 | 1089.459 | 1089.459 | 0.802 | 0.795 | 0.795 | 1090.265 | 1090.254 | 1090.254 | 126.543 | 126.570 | 126.570 | 1.595 | 1.600 | 1.600 |
| 17 | 1091.970 | 1091.993 | 1091.993 | 0.802 | 0.781 | 0.781 | 1092.774 | 1092.774 | 1092.774 | 126.537 | 126.633 | 126.633 | 1.591 | 1.614 | 1.614 |
| 18 | 1093.976 | 1093.971 | 1093.971 | 0.470 | 0.471 | 0.471 | 1094.445 | 1094.441 | 1094.441 | 128.476 | 128.478 | 128.478 | 2.049 | 2.049 | 2.049 |
| 19 | 1095.591 | 1095.618 | 1095.618 | 0.802 | 0.778 | 0.778 | 1096.396 | 1096.396 | 1096.396 | 126.540 | 126.642 | 126.642 | 1.591 | 1.617 | 1.617 |
| 20 | 1096.796 | 1096.774 | 1096.774 | 0.665 | 0.686 | 0.686 | 1097.463 | 1097.460 | 1097.460 | 127.162 | 127.067 | 127.067 | 1.741 | 1.716 | 1.716 |

Table-4.15, Summary of Output of Hec-6 (both fix bed and mobile bed) and Hec-Ras (fix bed) with Dikes and Diversion Channel for 500 Year Flood

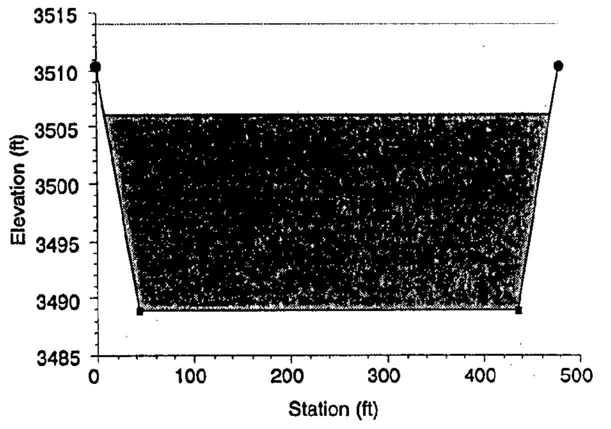
| Sec. No. | Water Surface Level | | | Velocity Head | | | Energy Line Level | | | Top Width | | | Hydraulic Depth | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hec-Ras | Hec-6 | | Hec-Ras | Hec-6 | | Hec-Ras | Hec-6 | | Hec-Ras | Hec-6 | | Hec-Ras | Hec-6 | |
| | | (fix) | (mobile) | | (fix) | (mobile) | | (fix) | (mobile) | | (fix) | (mobile) | | (fix) | (mobile) |
| | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) |
| 1 | 1066.905 | 1066.913 | 1066.880 | 2.430 | 2.438 | 2.438 | 1069.335 | 1069.352 | 1069.318 | 140.869 | 140.824 | 140.719 | 4.829 | 4.826 | 4.829 |
| 2 | 1068.921 | 1068.947 | 1068.887 | 2.430 | 2.406 | 2.412 | 1071.351 | 1071.353 | 1071.299 | 140.866 | 140.958 | 140.763 | 4.829 | 4.853 | 4.854 |
| 3 | 1070.936 | 1070.964 | 1070.900 | 2.427 | 2.401 | 2.412 | 1073.363 | 1073.366 | 1073.312 | 140.875 | 140.977 | 140.765 | 4.832 | 4.857 | 4.854 |
| 4 | 1072.948 | 1072.981 | 1072.925 | 2.430 | 2.399 | 2.402 | 1075.378 | 1075.381 | 1075.327 | 140.869 | 140.989 | 140.807 | 4.832 | 4.859 | 4.862 |
| 5 | 1074.963 | 1074.984 | 1074.933 | 2.430 | 2.412 | 2.408 | 1077.393 | 1077.396 | 1077.341 | 140.869 | 140.943 | 140.786 | 4.829 | 4.848 | 4.857 |
| 6 | 1076.976 | 1077.002 | 1076.942 | 2.430 | 2.406 | 2.406 | 1079.405 | 1079.408 | 1079.348 | 140.866 | 140.967 | 140.776 | 4.829 | 4.853 | 4.859 |
| 7 | 1078.994 | 1079.021 | 1078.957 | 2.427 | 2.402 | 2.405 | 1081.421 | 1081.423 | 1081.363 | 140.875 | 140.987 | 140.783 | 4.832 | 4.856 | 4.860 |
| 8 | 1081.003 | 1081.037 | 1080.952 | 2.430 | 2.399 | 2.413 | 1083.433 | 1083.435 | 1083.365 | 140.869 | 141.000 | 140.722 | 4.832 | 4.859 | 4.854 |
| 9 | 1083.018 | 1083.046 | 1082.877 | 2.430 | 2.404 | 2.409 | 1085.448 | 1085.450 | 1085.286 | 140.869 | 140.982 | 140.454 | 4.829 | 4.854 | 4.867 |
| 10 | 1084.024 | 1084.046 | 1083.907 | 2.430 | 2.411 | 2.415 | 1086.454 | 1086.456 | 1086.322 | 140.866 | 140.956 | 140.520 | 4.829 | 4.848 | 4.859 |
| 11 | 1085.067 | 1085.050 | 1084.971 | 2.207 | 2.224 | 2.397 | 1087.277 | 1087.274 | 1087.368 | 141.808 | 141.730 | 141.320 | 5.034 | 5.021 | 4.850 |
| 12 | 1086.930 | 1086.960 | 1086.743 | 2.430 | 2.402 | 2.416 | 1089.360 | 1089.362 | 1089.159 | 140.869 | 141.005 | 140.325 | 4.832 | 4.855 | 4.865 |
| 13 | 1089.220 | 1089.244 | 1088.895 | 2.430 | 2.409 | 2.422 | 1091.649 | 1091.652 | 1091.317 | 140.869 | 140.938 | 139.880 | 4.829 | 4.851 | 4.875 |
| 14 | 1091.354 | 1091.356 | 1090.862 | 1.585 | 1.588 | 1.930 | 1092.939 | 1092.944 | 1092.792 | 145.399 | 145.401 | 143.417 | 5.796 | 5.791 | 5.325 |
| 15 | 1092.134 | 1092.141 | 1091.942 | 1.710 | 1.709 | 2.085 | 1093.845 | 1093.850 | 1094.027 | 144.527 | 144.552 | 143.651 | 5.610 | 5.616 | 5.116 |
| 16 | 1093.043 | 1093.064 | 1093.293 | 2.430 | 2.411 | 2.145 | 1095.473 | 1095.475 | 1095.438 | 140.863 | 140.948 | 141.916 | 4.829 | 4.849 | 5.105 |
| 17 | 1095.552 | 1095.581 | 1095.290 | 2.430 | 2.403 | 2.409 | 1097.982 | 1097.984 | 1097.699 | 140.872 | 140.994 | 140.101 | 4.832 | 4.855 | 4.880 |
| 18 | 1097.631 | 1097.620 | 1097.146 | 1.951 | 1.949 | 2.341 | 1099.582 | 1099.570 | 1099.487 | 143.098 | 143.115 | 141.159 | 5.308 | 5.311 | 4.914 |
| 19 | 1099.177 | 1099.203 | 1098.820 | 2.427 | 2.403 | 2.233 | 1101.604 | 1101.606 | 1101.053 | 140.875 | 140.983 | 140.005 | 4.832 | 4.855 | 5.071 |
| 20 | 1100.223 | 1100.254 | 1099.908 | 2.433 | 2.401 | 1.815 | 1102.652 | 1102.655 | 1101.723 | 140.860 | 141.010 | 140.576 | 4.829 | 4.857 | 5.603 |

**Fig. 4-4, Cross-Sections of Beas River with Dikes and Diversion Channel during 500 Year Flood**

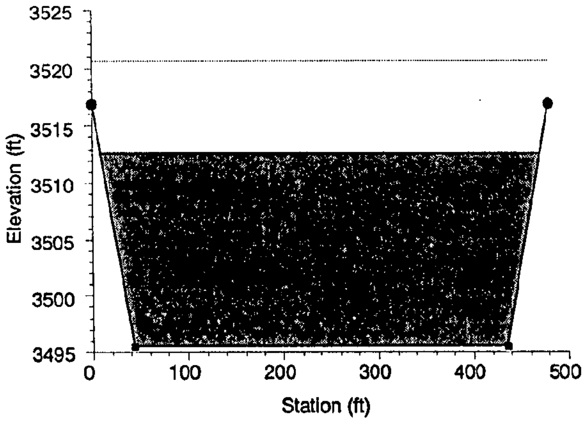
RS = 1



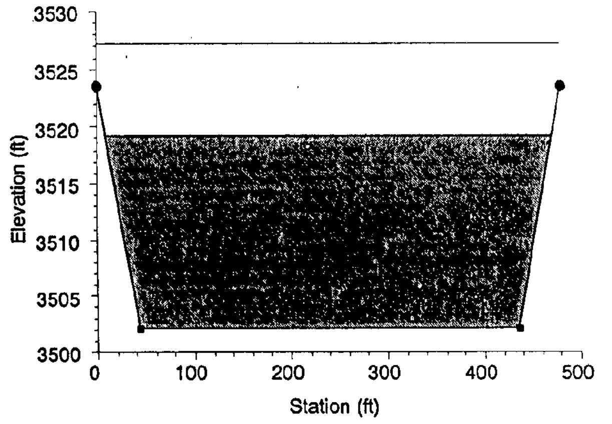

RS = 2



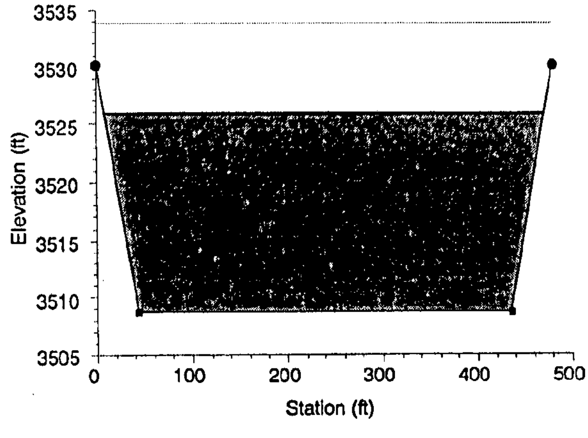

RS = 3



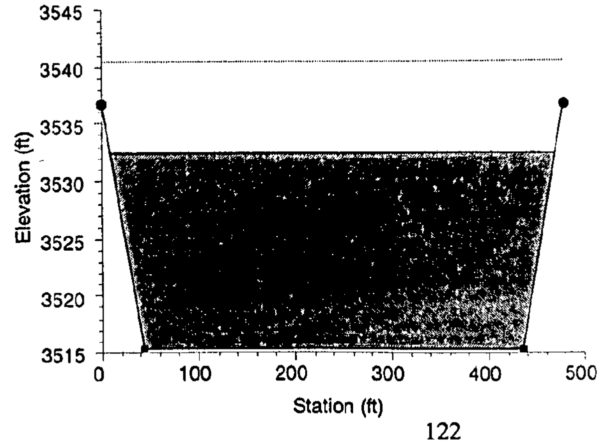

RS = 4




RS = 5




RS = 6



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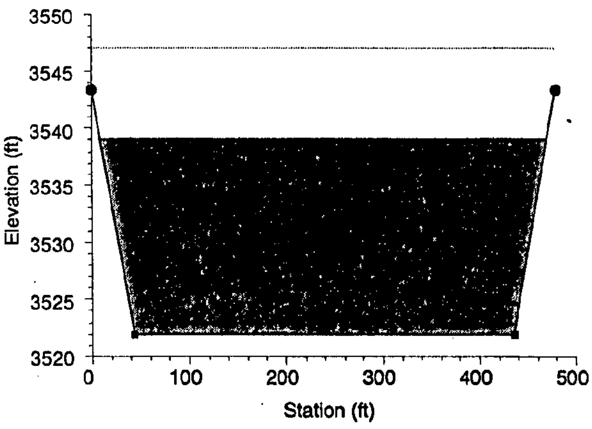


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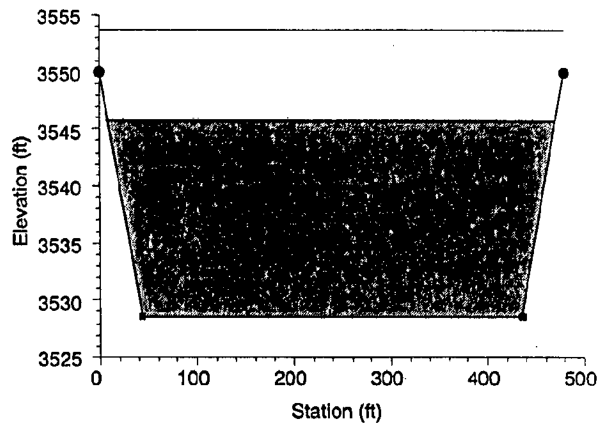


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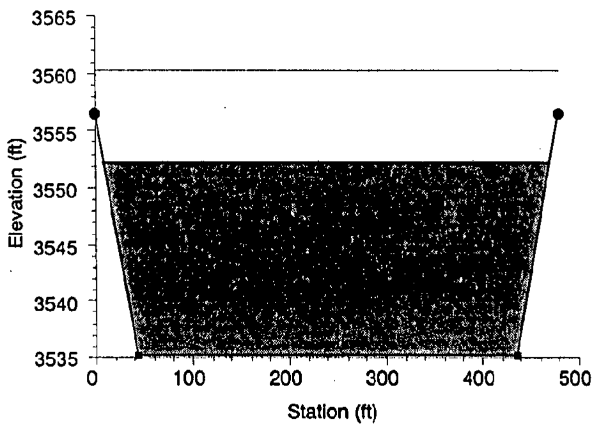


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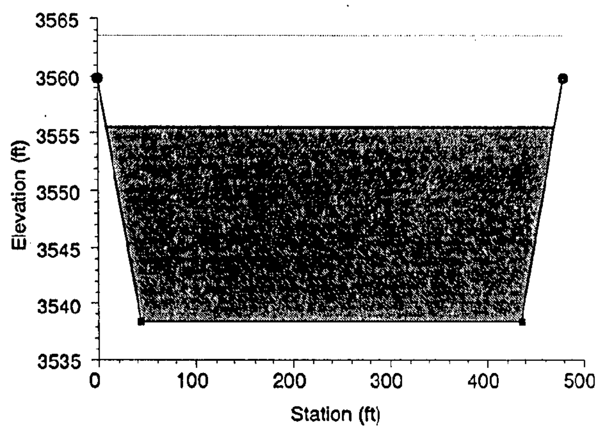


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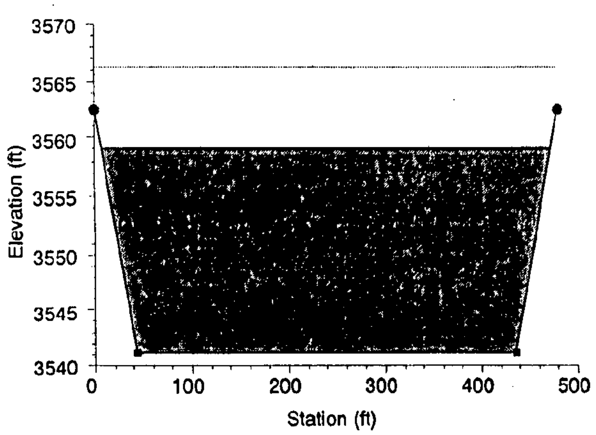


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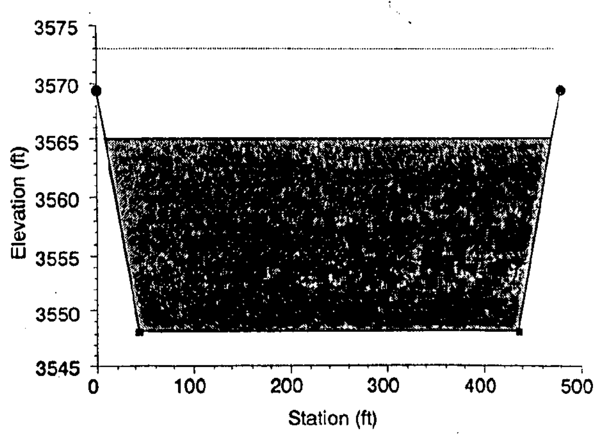

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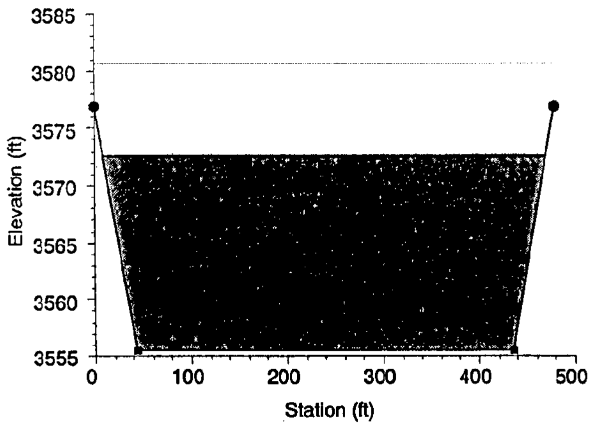


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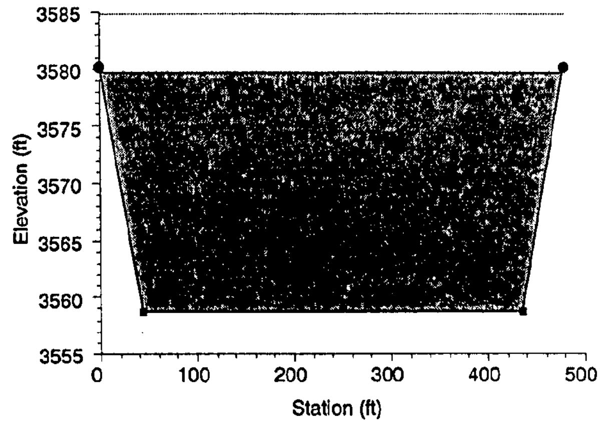


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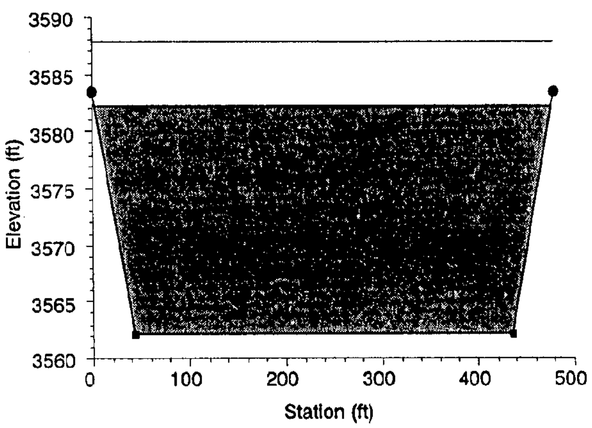


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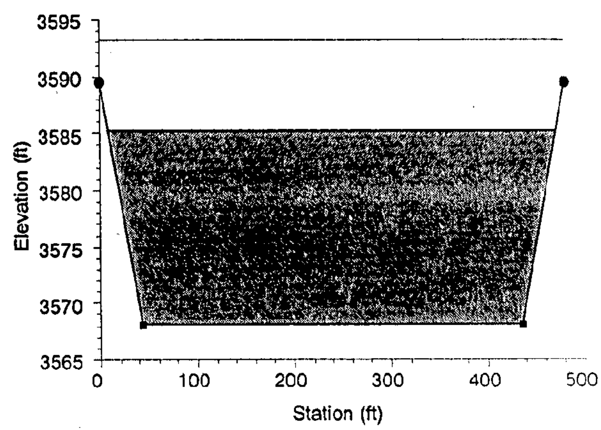


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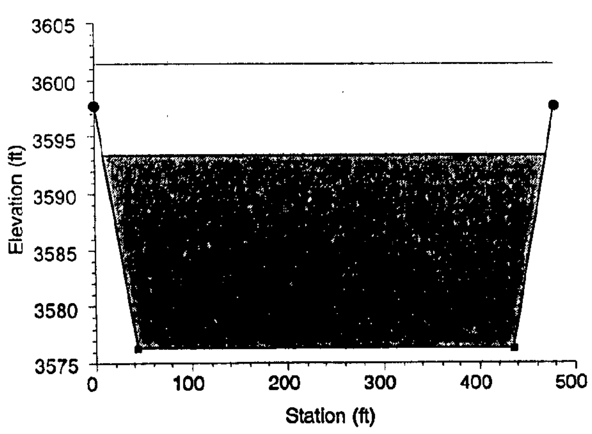


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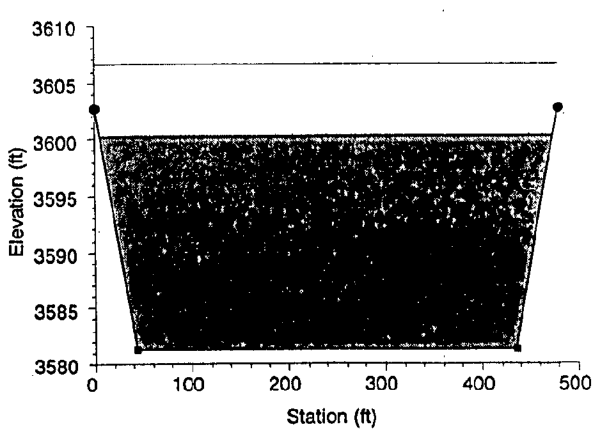
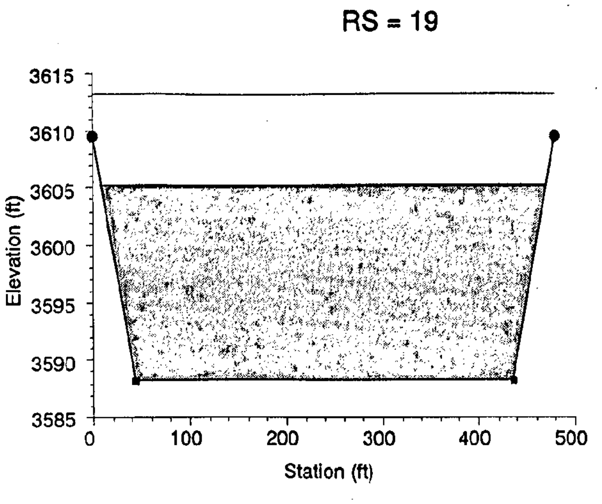
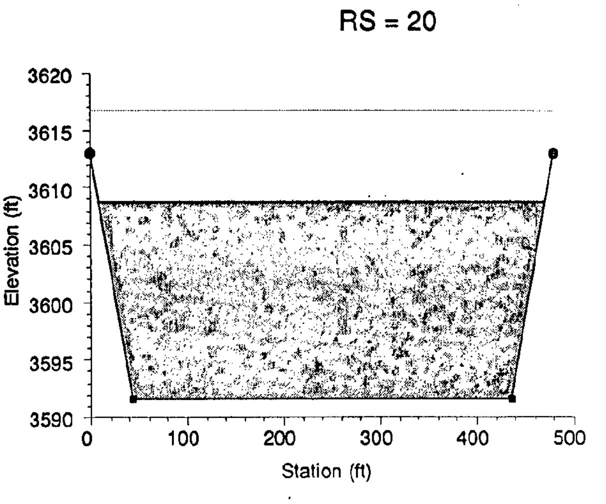



RS = 19
3615
3610
3605
3600
3595
3590
3585
Elevation (ft)
0
100
200
300
400
500
Station (ft)


RS = 20
3620
3615
3610
3605
3600
3595
3590
Elevation (ft)
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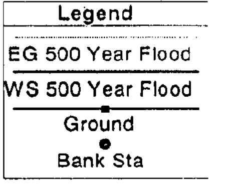
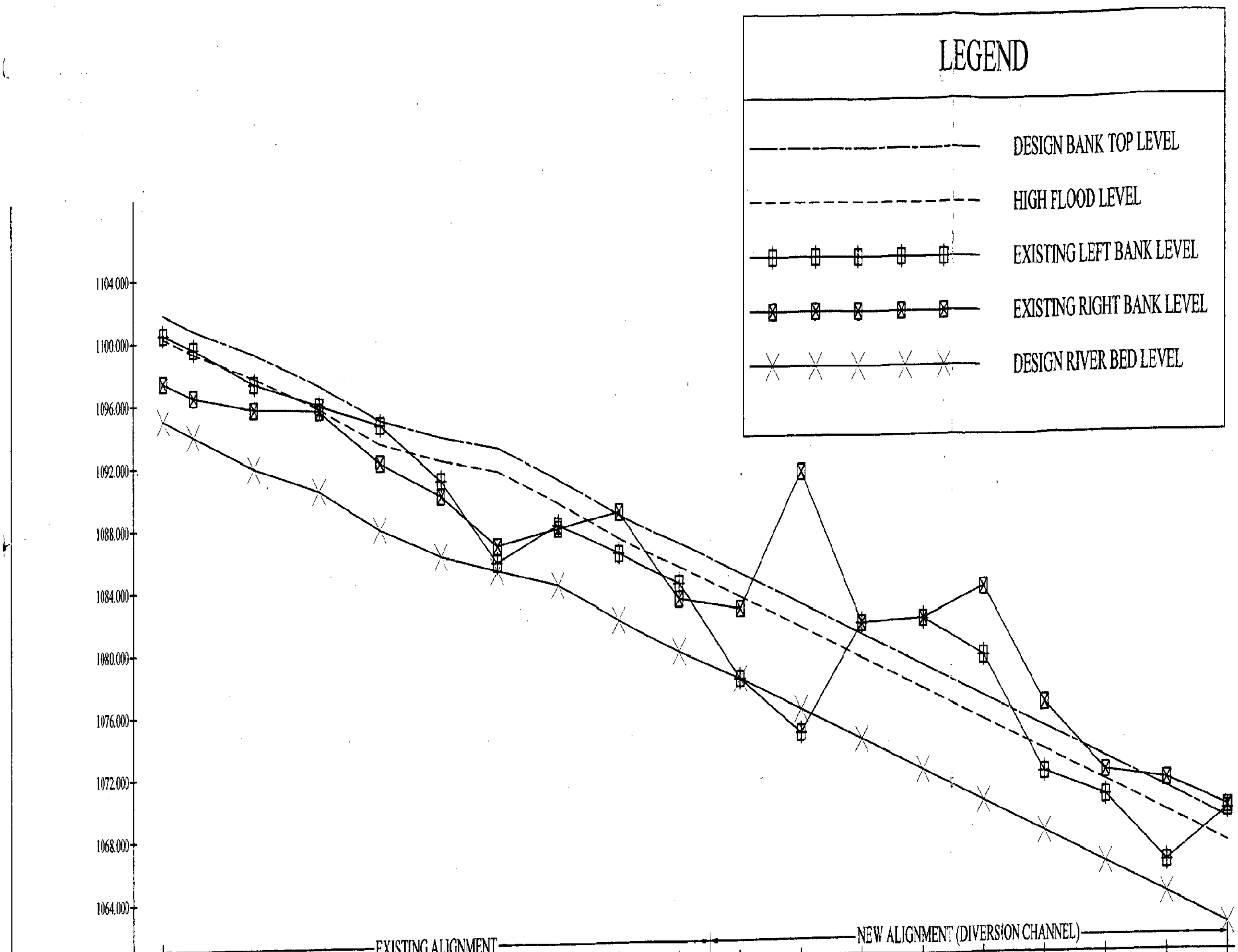
100
200
300
400
500
Station (ft)


Legend
EG 500 Year Flood
WS 500 Year Flood
Ground
Bank Sta




| CHAINAGE (Km) | 0+100 | 0+200 | 0+400 | 0+615 | 0+815 | 1+015 | 1+200 | 1+400 | 1+600 |
|---|---|---|---|---|---|---|---|---|---|
| DESIGN BANK TOP LEVEL (m) | 1101.754 | 1100.703 | 1099.131 | 1097.081 | 1094.793 | 1093.641 | 1092.856 | 1090.744 | 1088.460 |
| HIGH FLOOD LEVEL (m) | 1100.254 | 1099.203 | 1097.631 | 1095.581 | 1093.293 | 1092.141 | 1091.356 | 1089.244 | 1086.960 |
| EXISTING LEFT BANK LEVEL (m) | 1100.488 | 1099.512 | 1097.256 | 1095.793 | 1094.512 | 1090.854 | 1085.518 | 1087.835 | 1086.006 |
| EXISTING RIGHT BANK LEVEL (m) | 1097.409 | 1096.433 | 1095.610 | 1095.457 | 1092.073 | 1089.878 | 1086.585 | 1087.622 | 1088.659 |
| DESIGN RIVER BED LEVEL (m) | 1095.006 | 1093.957 | 1091.857 | 1090.335 | 1087.826 | 1086.003 | 1085.003 | 1084.003 | 1081.713 |

| CHAINAGE (Km) | 1+800 | 2+000 | 2+200 | 2+400 | 2+600 | 2+800 | 3+000 | 3+200 | 3+400 | 3+600 |
|---|---|---|---|---|---|---|---|---|---|---|
| DESIGN BANK TOP LEVEL (m) | 1086.567 | 1084.546 | 1082.537 | 1080.521 | 1078.502 | 1076.484 | 1074.481 | 1072.464 | 1070.447 | 1068.413 |
| HIGH FLOOD LEVEL (m) | 1085.067 | 1083.046 | 1081.037 | 1079.021 | 1077.002 | 1074.984 | 1072.981 | 1070.964 | 1068.947 | 1066.913 |
| EXISTING LEFT BANK LEVEL (m) | 1084.009 | 1077.800 | 1074.260 | 1081.250 | 1081.500 | 1079.100 | 1071.550 | 1070.000 | 1065.750 | 1069.000 |
| EXISTING RIGHT BANK LEVEL (m) | 1083.003 | 1082.287 | 1091.000 | 1081.250 | 1081.500 | 1083.500 | 1076.000 | 1071.585 | 1071.000 | 1069.207 |
| DESIGN RIVER BED LEVEL (m) | 1079.616 | 1077.802 | 1075.787 | 1073.774 | 1071.759 | 1069.747 | 1067.732 | 1065.716 | 1063.704 | 1061.689 |

Fig.-4.5, L-SECTION OF BEAS RIVER WITH DIKES AND DIVERSION CHANNEL FOR 500 YEAR FLOOD

## 4.12 DESIGN OF COVER LAYER FOR THE EMBANKMENT SLOPE

The nominal thickness of fully stable cover-layer with respect to current action can be calculated using the following general formula by Pilarczyk (1989):

$$D_n = \frac{\phi_c * K_T * K_h}{\Delta_m * K_s} * \frac{0.035}{\theta_c} * \frac{\bar{u}^2}{2g}$$

Where, $D_n$ is the nominal thickness of protection unit, $\phi_c$ is the stability factor, $K_T$ is the turbulence factor, $K_h$ is the depth and velocity distribution factor, $\Delta_m$ is the relative density of protection unit, $K_s$ is the slope factor, $\theta_c$ is the critical dimensionless shear stress, $\bar{u}$ is the mean velocity and g is the acceleration due to gravity.

### 4.12.1 DESIGN OF STONE RIP-RAP

### I) EMBANKMENT SLOPE PROTECTION

The thickness of stone rip-rap required for slope protection of an embankment can be computed by using the following formulae:

### A) PILARCZYK FORMULA

$$D_n = \frac{\phi_c * K_T * K_h}{\Delta_m * K_s} * \frac{0.035}{\theta_c} * \frac{\bar{u}^2}{2g}$$

Where, $\phi_c = 0.75$ for continuous protection of loose units

$K_T = 1.50$ for non-uniform flow with increased turbulence and bends ($R_c/B > 2$).

$$K_h = \left(\frac{h}{D_n} + 1\right)^{-0.2}$$

$$\Delta_m = G - 1 = 2.65 - 1 = 1.65 \text{ for rip-rap}$$

$$K_s = \sqrt{1 - \frac{\sin^2 \alpha}{\sin^2 \phi}} = \sqrt{1 - \frac{\sin^2 26.56}{\sin^2 40}} = 0.718$$

$\theta_c = 0.035$ for rip-rap

$$\therefore D_n = \frac{0.75 * 1.5}{1.65 * 0.718} * \left(\frac{5.0}{D_n} + 1\right)^{-0.2} * \frac{0.035}{0.035} * \frac{7^2}{2 * 9.81}$$

By trial $D_n = 1.82$ m

## B) INDIAN FORMULA

According to Indian formula thickness of stone cover is given by the following relationship:

$t = 0.06 * Q^{1/3} = 0.06(4700)^{1/3} = 1.01$ m

## C) USBR FORMULA

According to USBR, after Kinori and Hevorach (1984), the maximum stone size required for rip-rap is 1.60 m corresponding to flow velocity of 7.0m/s (referring the USBR curve).

## D) NEILL'S CURVE

According to Neill's curve, equivalent spherical diameter of rip-rap stone is 1.8 m corresponding to flow velocity of 7.0 m/s.

Provide the maximum of the above values of 1.80 m as the thickness of the stone rip-rap in sloping portion of the embankment.

## II) EMBANKMENT TOE PROTECTION

Launching apron is normally provided at the toe of an embankment to take care of the scour and to prevent the failure of the rip-rap provided in the sloping portion of the embankment. Hence the design of the launching apron first requires the prediction of scour depth. The following formulas can be used for prediction of scour due to long constriction:

## A) KOMURA (1971) FORMULA

Komura obtained the following equation for relative depth of scour along the constricted reach with the width of $B_1$ and the water depth $h_1$:

$$\frac{\Delta z}{h} = \left(1 + 1.2 * Fr^2\right)\left[\left(\frac{B}{B_1}\right)^{2/3} - 1\right]$$

Where, B is the upstream width of channel and Fr is the upstream Frounde Number and h is the upstream depth of flow.

Here, B = 215 m  B1 = 120 m

U = 5.50 m/s  h = 4.0 m

$\therefore \quad Fr = \dfrac{U}{\sqrt{gh}} = \dfrac{5.5}{\sqrt{9.81 * 4}} = 0.88$

$\therefore \quad \dfrac{\Delta z}{4.0} = \left[1 + 1.2(0.88)^2\right]\left[\left(\dfrac{215}{120}\right)^{2/3} - 1\right] = 0.92$

$\therefore$ Scour depth below the bed, $\Delta z = 0.92*4 = 3.68$ m

## B) MICHUE ET AL. (1984) FORMULA

$$\frac{\Delta z}{h} = \left[\left(\frac{B_1}{B}\right)^{-4/7} - 1\right] + \left(0.5 * Fr^2\right)\left[\left(\frac{B_1}{B}\right)^{-6/7} - 1\right]$$

$$\frac{\Delta z}{4.0} = \left[\left(\frac{120}{215}\right)^{-4/7} - 1\right] + 0.5 * (0.88)^2\left[\left(\frac{120}{215}\right)^{-6/7} - 1\right] = 0.65$$

$\therefore$ Scour depth below the bed, $\Delta z = 0.65*4 = 2.60$ m

## C) GILL (1972) FORMULA

$$\frac{\Delta z}{h} = \left(\frac{B_1}{B}\right)^{-6/7}\left[\left(\frac{B_1}{B}\right)^{-2/3}\left(1 - \frac{\tau_c}{\tau}\right) + \frac{\tau_c}{\tau}\right]^{-3/7} - 1$$

Here $\tau_c = 0.06(G-1)\,\gamma_f\,D_{50} = 0.06*(2.65-1)*9810*32*10^{-3} = 31.08\ N/m^2$

$\tau = \gamma_f R S = 9810 * 4 * 0.0091 = 357.08$ N/m$^2$

$$\therefore \quad \frac{\Delta z}{4} = \left(\frac{120}{215}\right)^{-6/7}\left[\left(\frac{120}{215}\right)^{-2/3}\left(1-\frac{31.08}{357.08}\right)+\frac{31.08}{357.08}\right]^{-3/7} - 1 = 0.41$$

$\therefore$ Scour depth below the bed, $\Delta z = 0.41*4 = 1.64$ m

The maximum of the above values is taken as the scour depth, $\Delta z = 3.68$ m

Anticipated scour depth below the deepest bed level = 1.25 * 3.68 = 4.60 m

Now, using Pilarczyk formula thickness of stone rip-rap at the launching is given as:

$$D_n = \frac{1.25*1.5}{(2.65-1)*0.718}\left(\frac{5}{D_n}+1\right)^{-0.2} * \frac{0.035}{0.035} * \frac{7^2}{2*9.81}$$

By trial thickness of launching apron $D_n = 3.28$ m

Provide thickness of launching apron = 3.6 m (In two layers of 1.8 m each, so that it can launch in the scour hole with the thickness of 1.8 m )

Quantity of stone required in the launching apron with anticipated scour depth of 4.60 m and thickness of cover layer of 1.80 (assuming the stable side slope of 1 V: 2 H after launching) = $\sqrt{5} * 4.6 * 1.8 = 18.51$ m$^3$/r.m.

This quantity of stone shall be placed in horizontal apron with 3.6 m thickness. So length of apron required = 18.51/3.60 = 5.14 m (Say 6.0 m).

Hence, provide 3.6 m thick stone launching apron for 6.0 m length at the toe of the embankment.

### 4.12.2 DESIGN OF GABION MATTRESSES

### I) EMBANKMENT SLOPE PROTECTION

The nominal thickness of gabion mattress is determined by using Pilarczyk formula as given below:

$$D_n = \frac{\phi_c * K_T * K_h}{\Delta_m * K_s} * \frac{0.035}{\theta_c} * \frac{\bar{u}^2}{2g}$$

Where, $\phi_c$ = 0.50 for continuous protection of gabion mattress

$K_T$= 1.50 for non-uniform flow with increased turbulence and bends ($R_c/B > 2$).

$$K_h = \left(\frac{h}{D_n} + 1\right)^{-0.2}$$

$\Delta_m = (G-1)(1-n) = (2.65-1) * (1-0.4) = 0.99$ (assuming porosity, n of gabion filing as 40%)

$$K_s = \sqrt{1 - \frac{\sin^2 \alpha}{\sin^2 \phi}} = \sqrt{1 - \frac{\sin^2 26.56}{\sin^2 40}} = 0.718$$

$\theta_c$ = 0.06 for gabion

$$\therefore D_n = \frac{0.5 * 1.5}{0.99 * 0.718} * \left(\frac{5.0}{D_n} + 1\right)^{-0.2} * \frac{0.035}{0.06} * \frac{7^2}{2 * 9.81}$$

By trial $D_n$ = 1.10 m

Hence provide 2.0 m * 1.5 m * 1.25 m size gabion mattress in the slope.

## II) EMBANKMENT TOE PROTECTION

The nominal thickness of gabion mattress as launching apron is calculated by Pillarczyk formula with $\phi c$ equal to 1.0 (for exposed edges of mattress) and all other variables as used in case (I).

$$\therefore D_n = \frac{1.0 * 1.5}{0.99 * 0.718} * \left(\frac{5.0}{D_n} + 1\right)^{-0.2} * \frac{0.035}{0.06} * \frac{7^2}{2 * 9.81}$$

By trial $D_n$ = 2.46 m, say 2.50 m

Quantity of gabion works required in the launching apron with anticipated scour depth of 4.60 m and thickness of cover layer of 1.25 m = √5*4.6*1.25 = 12.86 $m^3$/r.m.

Length of launching apron with 2.50 m thickness = 12.86/2.5 = 5.144 m, say 6.0 m

Hence provide 2.50 m thick (2 layers of 1.25 m thickness) gabion launching for 6.0 m length.

### 4.12.3 DESIGN OF LOOSE CONCRETE BLOCKS

#### I) EMBANKMENT SLOPE PROTECTION

The nominal thickness of loose concrete blocks is determined by using Pilarczyk formula as given below:

$$D_n = \frac{\phi_c * K_T * K_h}{\Delta_m * K_s} * \frac{0.035}{\theta_c} * \frac{\bar{u}^2}{2g}$$

Where, $\phi_c = 0.50$ for continuous protection of block mats

$K_T = 1.50$ for non-uniform flow with increased turbulence and bends ($R_c/B > 2$).

$$K_h = \left(\frac{h}{D_n} + 1\right)^{-0.2}$$

$\Delta_m = (G-1)(1-n) = (2.4-1)*(1-0.15) = 1.19$ (assuming G and n for loose concrete blocks as 2.4 and 0.15 respectively.)

$$K_s = \sqrt{1 - \frac{\sin^2 \alpha}{\sin^2 \phi}} = \sqrt{1 - \frac{\sin^2 26.56}{\sin^2 40}} = 0.718$$

$\theta_c = 0.075$ for block mats

$$\therefore D_n = \frac{0.5*1.5}{1.19*0.718} * \left(\frac{5.0}{D_n} + 1\right)^{-0.2} * \frac{0.035}{0.075} * \frac{7^2}{2*9.81}$$

By trial $D_n = 0.67$ m

Hence provide 1.0 m * 1.0 m * 0.8 m size 1:3:6 concrete blocks in the slope.

#### II) EMBANKMENT TOE PROTECTION

The nominal thickness of loose concrete blocks as launching apron is calculated by Pillarczyk formula with $\phi c$ equal to 1.0 (for exposed edges of block mats) and all other variables as used in case (I).

$$\therefore D_n = \frac{1.0*1.5}{1.19*0.718} * \left(\frac{5.0}{D_n} + 1\right)^{-0.2} * \frac{0.035}{0.075} * \frac{7^2}{2*9.81}$$

By trial $D_n = 1.53$ m, say 1.60 m

Quantity of concrete blocks required in the launching apron with anticipated scour depth of 4.60 m and thickness of cover layer of 0.8 m = $\sqrt{5}*4.6*0.8 = 8.23\ m^3/r.m.$ Length of launching apron with 1.60 m thickness = 8.23/1.60 = 5.144 m, say 6.0 m. Hence provide 1.60 m thick (2 layers of 0.80 m thickness) loose concrete blocks for 6.0 m length. A typical cross-section of embankment with P.C.C. block protection is shown in fig.-4.6.

## 4.13 DESIGN OF FILTER

A filter layer is normally required beneath the cover layer to prevent the water from removing bank material through the voids. The filter layer may be either a granular filter or geotextile filter. The designs of granular filter for rip-rap and geotextile filter for cement concrete blocks are presented below:

### 4.13.1 DESIGN OF GRANULAR FILTER

Let's say the gradations of bank material and the rip-rap are as given below:

| Bank Material | Rip-rap |
|---|---|
| $D_{10} = 0.18$ mm | |
| $D_{15} = 0.20$ mm | $D_{15} = 400.00$ mm |
| $D_{50} = 1.20$ mm | $D_{50} = 900.00$ mm |
| $D_{60} = 2.20$ mm | |
| $D_{85} = 14.00$ mm | $D_{85} = 1440.00$ mm |

Let's first determine whether the filter layer shall be required or not based on the retention criteria, uniformity criteria and the permeability criteria . .

i) Retention Criteria

$$\frac{D_{15} \text{ of rip-rap}}{D_{85} \text{ of base}} = \frac{400}{14} = 28.57 > 5, \text{ not ok.}$$

ii) Uniformity Criteria

$$\frac{D_{15} \text{ of rip-rap}}{D_{15} \text{ of base}} = \frac{400}{0.20} = 800 > 40, \text{ not ok.}$$

iii) Permeability Criteria

$$\frac{D_{50} \text{ of rip-rap}}{D_{50} \text{ of base}} = \frac{900}{1.2} = 750 > 25 \text{ not ok.}$$

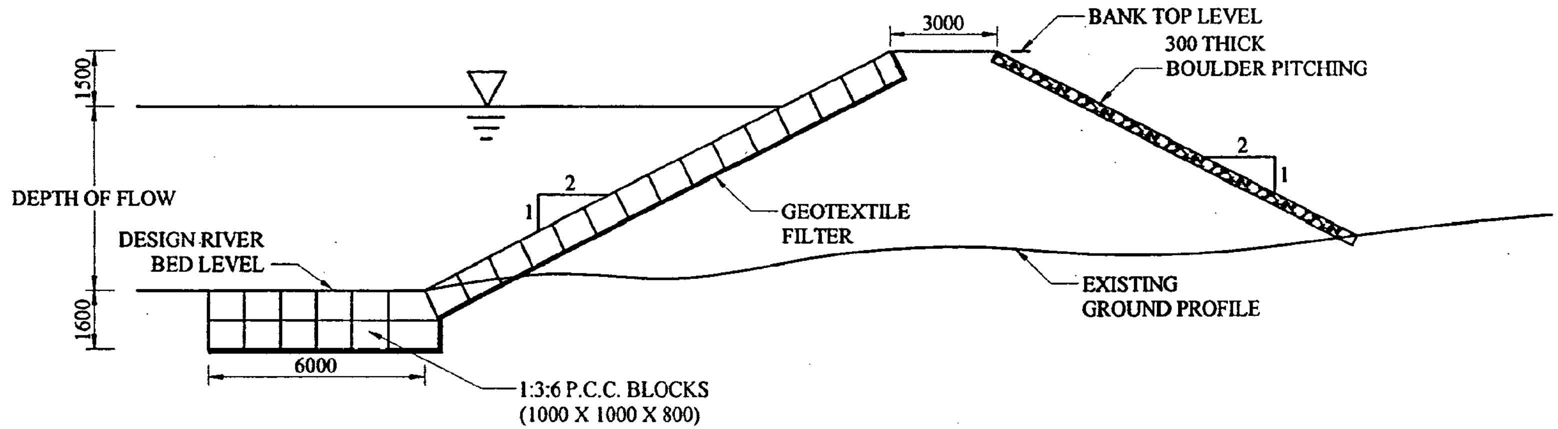



Fig.-4.6, TYPICAL X-SECTION OF EMBANKMENT
WITH P.C.C. BLOCK PROTECTION

The above values do not meet the recommended criteria, So a filter layer is required between the given base material and the rip-rap. The required size gradation of the filter with respect to the base material is determined from

$$\frac{D_{50}\text{ of filter}}{D_{50}\text{ of base}} < 25;\text{hence } D_{50}\text{ of filter} < 25 * 1.2 = 30\,\text{mm}$$

$$\frac{D_{15}\text{ of filter}}{D_{15}\text{ of base}} < 40;\text{hence } D_{15}\text{ of filter} < 40 * 0.2 = 8\,\text{mm}$$

$$\frac{D_{15}\text{ of filter}}{D_{85}\text{ of base}} < 5;\text{hence } D_{15}\text{ of filter} < 5 * 14 = 70\,\text{mm}$$

$$\frac{D_{15}\text{ of filter}}{D_{15}\text{ of base}} > 5;\text{hence } D_{15}\text{ of filter} > 5 * 0.2 = 1\,\text{mm}$$

From these results, the filter material adjacent to the base material should have the following dimension: $D_{50} < 30$ mm and 1 mm $< D_{15} <$ 8 mm.

In the next step, the required filter dimension with respect to the rip-rap is determined from

$$\frac{D_{50}\text{ of rip} - \text{rap}}{D_{50}\text{ of filter}} < 25;\text{hence } D_{50}\text{ of filter} > \frac{900}{25} = 36\,\text{mm}$$

$$\frac{D_{15}\text{ of rip} - \text{rap}}{D_{15}\text{ of filter}} < 40;\text{hence } D_{15}\text{ of filter} > \frac{400}{40} = 10\,\text{mm}$$

$$\frac{D_{15}\text{ of rip} - \text{rap}}{D_{85}\text{ of filter}} < 5;\text{hence } D_{85}\text{ of filter} > \frac{400}{5} = 80\,\text{mm}$$

$$\frac{D_{15}\text{ of rip} - \text{rap}}{D_{15}\text{ of filter}} > 5;\text{hence } D_{15}\text{ of filter} < \frac{400}{5} = 80\,\text{mm}$$

On the basis of these calculations, the filter layer adjacent to the rip-rap should have the following dimensions: 10 mm $< D_{15} <$ 80 mm, $D_{50} >$ 36 mm, $D_{85} >$ 80 mm

The two results obtained here are not compatible to each other, indicating that a single layer of granular material is not adequate. So two layers of filter shall be provided between the base material and the rip-rap. The filter 2 shall be provided in between the filter 1 and the rip-rap. Now let us assume the following gradation for the two filter layers:

Filter 1

$D_{15} = 2.00$ mm

$D_{50} = 15.00$ mm

$D_{85} = 40.00$ mm

Filter 2

$D_{15} = 15.00$ mm

$D_{50} = 50.00$ mm

$D_{85} = 85.00$ mm

The gradation of both the above filters need to be checked against the specified criteria. Let's first check the gradation of filter 1 with respect to the base material.

$$\frac{D_{50} \text{ of filter1}}{D_{50} \text{ of base}} < 25; \text{hence } D_{50} \text{ of filter1} < 25 * 1.2 = 30\,\text{mm}$$

$$\frac{D_{15} \text{ of filter1}}{D_{15} \text{ of base}} < 40; \text{hence } D_{15} \text{ of filter1} < 40 * 0.2 = 8\,\text{mm}$$

$$\frac{D_{15} \text{ of filter1}}{D_{85} \text{ of base}} < 5; \text{hence } D_{15} \text{ of filter1} < 5 * 14 = 70\,\text{mm}$$

$$\frac{D_{15} \text{ of filter1}}{D_{15} \text{ of base}} > 5; \text{hence } D_{15} \text{ of filter1} > 5 * 0.2 = 1\,\text{mm}$$

From these results, the filter 1 adjacent to the base material should have the following dimension $D_{50} < 30$ mm and 1 mm $< D_{15} <$ 8 mm.

In the next step, the required filter 1 dimension with respect to the filter 2 is determined from

$$\frac{D_{50} \text{ of filter 2}}{D_{50} \text{ of filter1}} < 25; \text{hence } D_{50} \text{ of filter1} > \frac{50}{25} = 2\,\text{mm}$$

$$\frac{D_{15} \text{ of filter 2}}{D_{15} \text{ of filter1}} < 40; \text{hence } D_{15} \text{ of filter1} > \frac{15}{40} = 0.375\,\text{mm}$$

$$\frac{D_{15} \text{ of filter 2}}{D_{85} \text{ of filter1}} < 5; \text{hence } D_{85} \text{ of filter1} > \frac{15}{5} = 3\,\text{mm}$$

$$\frac{D_{15} \text{ of filter 2}}{D_{15} \text{ of filter1}} > 5; \text{hence } D_{15} \text{ of filter1} < \frac{15}{5} = 3\,\text{mm}$$

Based on these calculations, the filter 1 adjacent to the filter 2 should have the following dimensions: 0.375 mm $< D_{15} <$ 3 mm, $D_{50} >$ 2 mm, $D_{85} >$ 3 mm. We thus can conclude that the filter 1 should have the following dimensions: 1 mm $< D_{15} <$ 3 mm, 2 mm $< D_{50}$ $<$ 30 mm, $D_{85} >$ 3 mm. It means the assumed gradation for filter 1 satisfies all the required criteria.

Similarly the gradation of filter 2 with respect to filter 1 is obtained from

$$\frac{D_{50}\text{ of filter 2}}{D_{50}\text{ of filter1}} < 25;\text{ hence } D_{50}\text{ of filter 2} < 25 * 15 = 375\,\text{mm}$$

$$\frac{D_{15}\text{ of filter 2}}{D_{15}\text{ of filter1}} < 40;\text{ hence } D_{15}\text{ of filter 2} < 40 * 2 = 80\,\text{mm}$$

$$\frac{D_{15}\text{ of filter 2}}{D_{85}\text{ of filter1}} < 5;\text{ hence } D_{15}\text{ of filter 2} < 5 * 40 = 200\,\text{mm}$$

$$\frac{D_{15}\text{ of filter 2}}{D_{15}\text{ of filter1}} > 5;\text{ hence } D_{15}\text{ of filter 2} > 5 * 2 = 10\,\text{mm}$$

From these results, the filter 2 adjacent to the filter 1 should have the following dimension: $D_{50}$ < 375 mm and 10 mm < $D_{15}$ < 80 mm.

In the next step, the required filter 2 dimension with respect to the rip-rap is determined from

$$\frac{D_{50}\text{ of rip-rap}}{D_{50}\text{ of filter 2}} < 25;\text{ hence } D_{50}\text{ of filter 2} > \frac{900}{25} = 36\,\text{mm}$$

$$\frac{D_{15}\text{ of rip-rap}}{D_{15}\text{ of filter 2}} < 40;\text{ hence } D_{15}\text{ of filter 2} > \frac{400}{40} = 10\,\text{mm}$$

$$\frac{D_{15}\text{ of rip-rap}}{D_{85}\text{ of filter 2}} < 5;\text{ hence } D_{85}\text{ of filter 2} > \frac{400}{5} = 80\,\text{mm}$$

$$\frac{D_{15}\text{ of rip-rap}}{D_{15}\text{ of filter 2}} > 5;\text{ hence } D_{15}\text{ of filter 2} < \frac{400}{5} = 80\,\text{mm}$$

Based on these calculations, the filter 2 adjacent to the rip-rap should have the following dimensions: 10 mm < $D_{15}$ < 80 mm, $D_{50}$ > 36 mm, $D_{85}$ > 80 mm. We thus can conclude that the filter 2 should have the following dimensions: 10 mm < $D_{15}$ < 80 mm, 36 mm < $D_{50}$ < 375 mm, $D_{85}$ > 80 mm. It means the assumed gradation for filter 2 satisfies all the required criteria.

### 4.13.2 DESIGN OF GEOTEXTILE FILTER

The cement concrete blocks shall be laid over the geotextile filter to retain the base material without building up of excessive water pressure. The required grade of the geotextile is fixed by the criteria of soil tightness and permeability as given below:

i) Sand Tightness

From fig.-6.136 of River Training Techniques by Pilarczyk et.al. for hydraulic loads without natural filter at unacceptable consequences $O_{98} < D_{15} = 0.2$ mm.

ii) Permeability

From fig.-6.137 of River Training Techniques by Pilarczyk et.al. for $D_{10} = 0.18$ mm and $k_s = 4*10^{-3}$ m/s, we get . = 0.06. Using equation 6.328 of River Training Techniques by Pilarczyk et.al., geotextile permeability $k_g > k_s/.$ $= 4*10^{-3}/0.06 = 0.067$ m/s.

## 4.14 DETERMINATION OF MAXIMUM SCOUR DEPTH AROUND BRIDGE PIERS

A large number of formulas have been developed for predicting local scour around bridge piers. Some of these have been given below.

### I) NEILL FORMULA

$$\frac{d_s}{b} = 1.5\left(\frac{D_0}{b}\right)^{0.3}$$

Where, $d_s$ is the depth of scour below mean bed elevation, b is the width of pier normal to flow and $D_0$ is the mean depth of flow upstream of pier.

Assuming the circular piers of 2 m diameter, b= 2.0 m $\quad$ $D_0$= 4.97 m

$$d_s = 1.5\left(\frac{4.97}{2.0}\right)^{0.3} * 2.0 \quad =3.94 \text{ m}$$

### II) SHEN ET AL. FORMULA

$$\frac{d_s}{b} = 3.4(F_0)^{2/3}\left(\frac{D_0}{b}\right)^{1/3}$$

Where $F_0 = U_0/(gD_0)^{1/2}$ is the Froude number based on the mean upstream velocity $U_0$ and depth $D_0$.

Using $U_0$= 6.85 m/s $\quad$ $D_0$= 4.97 m $\quad$ $F_0 = 6.85/(9.81*4.97)^{1/2} = 0.98$

$$d_s = 3.4(0.98)^{2/3}\left(\frac{4.97}{2.0}\right)^{1/3} * 2.0 \qquad = 9.10 \text{ m}$$

## III) COLORADO STATE UNIVERSITY FORMULA

$$\frac{d_s}{D_0} = 2.2\left(\frac{b}{D_0}\right)^{0.65}(F_0)^{0.43}$$

$$d_s = 2.2\left(\frac{2.0}{4.97}\right)^{0.65}(0.98)^{0.43} * 4.97 \qquad = 6.0 \text{ m}$$

## IV) MELVILLE AND SUTHERLAND FORMULA

$d_s = K_i K_y K_d K_\sigma K_s K_\alpha b$

Where the coefficients describe the influence of flow intensity ($K_i$), flow depth ($K_y$), sediment size ($K_d$), sediment gradation ($K_\sigma$), pier shape ($K_s$) and alignment ($K_\alpha$).

We have

| | | | |
|---|---|---|---|
| $d_{50}$= 32 mm | $d_{84}$= 105 mm | | |
| Depth of flow, y | = 3545.795-3529.490 | = 16.305 ft | = 4.97 m |
| Flow velocity, U | 22.468 ft/s | = 6.85 m/s | |

( y and U is given as calculated by Hec-6 at section 6, location of the bridge.)

***Calculation for $K_i$***

For $d_{50}$= 32 mm, the critical shear velocity, $u_{*c}$= 0.17 m/s from Shields' diagram.

Using the equation

$$\frac{U_c}{u_{*c}} = 5.75\log(5.53\frac{y}{d_{50}})$$

or, $\frac{U_c}{0.17} = 5.75\log(5.53 * \frac{4.97}{32 * 10^{-3}})$

$\therefore U_c$= 2.87 m/s

Geometric Standard deviation, $\sigma g = \frac{d_{84}}{d_{50}} = \frac{105}{32} = 3.28$

Equating $d_{max}$ with $d_{95}$, we have $d_{max} = \sigma g^{1.65} d_{50} = 3.28^{1.65} * 32 = 227.17$ mm

Median size of the coarsest possible armour, $d_{50a} = \frac{d_{max}}{1.8} = \frac{227.17}{1.8} = 126.21$ mm

The critical shear velocity of the armored bed is then given as:

$$u_{*ca} = 0.03(d_{50a})^{1/2} = 0.03(126.21)^{1/2} = 0.34 \text{ m/s}$$

$$\frac{U_{ca}}{u_{*ca}} = 5.75\log(5.53\frac{y}{d_{50a}})$$

$$\text{or, } \frac{U_{ca}}{0.34} = 5.75\log(5.53 * \frac{4.97}{126.21 * 10^{-3}})$$

$$\therefore U_{ca} = 4.57 \text{ m/s}$$

$U_a = 0.8*U_{ca} = 0.8*4.57 = 3.66$ m/s

(here $U_a > U_c$ so ok. Otherwise $U_a$ is taken equal to $U_c$.)

Now $\frac{U - (U_a - U_c)}{U_c} = \frac{6.85 - (3.66 - 2.87)}{2.87} = 2.11 > 1$ So live bed scour occurs.

$\therefore K_i = 2.4$

*Calculation for $K_y$*

Assuming circular piers of diameter, D = 2.0 m

$$\frac{y}{D} = \frac{4.97}{2.0} = 2.485$$

Since y/D < 2.6, $K_y$ is given by the following relation:

$$K_y = 0.78(y/D)^{0.255} = 0.78 * (4.97/2.00)^{0.255} = 0.98$$

*Calculation for $K_d$*

Since it is the case of live bed scour, we first determine $D/d_{50}$. (For clear bed scour we are required to determine $D/d_{50a}$)

$$\frac{D}{d_{50}} = \frac{2}{32 * 10^{-3}} = 62.50$$

$\therefore K_d = 1$ because $D/d_{50} > 25$

Here, $K_\sigma$= 1, also for group of circular piers both the $K_s$ and $K_\alpha$ are equal to 1.

$\therefore d_s$= 2.4 * 0.98 * 1 * 1 * 1 * 1 * 2 = 4.70 m

## V) SCOUR BASED ON RIVERBED ARMOR

Riverbed armoring refers to coarsening of the bed material as a result of degradation of well-graded sediment mixtures. The selective erosion of finer particles of the bed material leaves the coarser fractions of the mixture on the bed to induce coarsening of bed material. When the applied bed shear stress is sufficiently large to mobilise the larger bed particles, degradation continues; when the applied bed shear stress cannot mobilise the coarse bed particles, an armor layer forms on the bed surface. The armor layer becomes coarser and thicker as the bed degrades until it is sufficiently thick to prevent any further degradation. The armor layer is representative of stable bed condition and can be mobilised only during large floods.

The minimum grain diameter, $d_{sc}$ forming armor layer is given by the following relation:

$$d_{sc} = 10\ h\ S$$

Where h is the flow depth during floods and S the channel slope. Using h equal to 6.85 m (from hec-6 output) and S equal to 0.0091, we get:

$$d_{sc} = 10 * 6.85 * 0.0091 = 0.623 \text{ m}$$

Quantitatively, we can consider that an armor layer of approximately twice the grain size will stabilise the bed. The scour depth $\Delta z$ that will form an armor layer equal to 2 $d_{sc}$ can be estimated from the following equation:

$$\Delta z = 2 * d_{sc}(1/\Delta pc - 1)$$

Where $\Delta pc$ is fraction of material coarser than $d_{sc}$ available in the bed material. In our case $\Delta pc$ is equal to 0.05 from grain size distribution curve, fig. 4-1.

$$\therefore \Delta z = 2 * 0.623\left(\frac{1}{0.05} - 1\right) = 23.67 \text{ m}$$

Here, the fraction of material coarser than $d_{sc}$ is very low, so a large volume of bed material needs to be scoured before the armor layer can form. The effect of armor layer in this case will be limited.

The Melville and Sutherland formula consider a large number of variables affecting the scour. So adopt the scour depth, $d_s$ = 4.70 m below the average bed of the river for the present study.

## 4.15 COMPUTATION OF HORIZONTAL FORCE ON BRIDGE PIERS

The pier between the water level and the maximum scour is subjected to the horizontal force due to water current. The water current pressure is given by the equation:
$p = Kv^2$

Where, p is intensity of pressure in kg/m$^2$ due to water current, K is a constant having different values for different shapes of well and v is velocity of current in m/s at the point where pressure intensity is being calculated.

It is assumed that the velocity distribution in streams is such that $v^2$ is maximum at the free surface of water, zero at the deepest scour level and varies linearly in between them. Also the maximum velocity of flow is assumed to be equal to $\sqrt{2}$ times the mean velocity of the current.

Here, the average velocity U= 6.85 m/s.
So, the maximum velocity Umax= $\sqrt{2}$*6.85 = 9.69 m/s
For circular piers, K= 34.7 (from table 6.4 of Analysis and Design of Foundations and Retaining Structures by Shamsher Prakash, Gopal Ranjan and Swami Saran)
$p_{max}$= 34.7*9.69$^2$ = 3258.20 kg/m$^2$
Horizontal force H= ½ * $p_{max}$* h = ½* 3258.20* (4.97+6.50) = 18685.78 kg/m
= 183.31 KN/m

## 4.16 ESTIMATION OF FINANCIAL IMPLICATIONS

The estimation of quantity is based on the design and drawings included within the report. The cost estimate has been carried out with an approximate market rate. It includes the cost of excavation of the design section of the channel including the cost of 1700 meter long diversion channel. It also includes the cost of dikes and P.C.C. concrete block for slope protection works. It also includes the cost of earthworks in filling for construction of airport runway and also includes the cost of relocation of about 2.5 km of Garsa gravel road. It however does not include the cost of runway and the cost of land acquisition and compensation.

The detail of estimated quantity is given in table-4.17 and the abstract of cost of various items has been presented in table-4.16 below. The cost of channelization for extension of the runway comes out to be Rs. 608,140,074.77. The total project cost with 5 % contingencies and workcharge staff comes out to be Rs. 638,547,078.50.

**Table-4.16, Abstract of Cost for Channelization of Beas River for Extension of Airport Runway at Kullu**

| Item.No. | Item of Work | Unit | Quantity | Rate | Amount |
|---|---|---|---|---|---|
| 1 | Site clearance | L.S. | | | 500,000.00 |
| 2 | River diversion and care of water | | | | |
| | during construction | L.S. | | | 1,500,000.00 |
| 3 | Earthwork in excavation in riverbed | | | | |
| | with sand, gravel and boulder | | | | |
| | a) upto 1.5 m depth in wet condition | $m^3$ | 537988.63 | 95.00 | 51,108,919.38 |
| | b) above 1.5 m depth in wet | $m^3$ | 173763.03 | 110.00 | 19,113,932.75 |
| | condition | | | | |
| 4 | Earthwork in excavation by blasting | | | | |
| | of big boulders | $m^3$ | 39065.85 | 300.00 | 11,719,755.00 |
| 5 | Earthwork in excavation in gravel | | | | |
| | boulder mixed soil | $m^3$ | 1204375.00 | 60.00 | 72,262,500.00 |
| 6 | Earthwork in filling for embankment | | | | |
| | with river bed material in 30 cm thick | | | | |
| | horizontal layers with 98 % | | | | |
| | compaction | $m^3$ | 1523477.50 | 100.00 | 152,347,750.00 |
| 7 | Supply and placing of 1.0 m * 1.0 m * | | | | |
| | 0.8 m size 1:3:6 P.C.C. blocks in the | | | | |
| | waterface of the river | $m^3$ | 103680.00 | 2560.00 | 265,420,800.00 |
| 8 | Supply and packing of boulder in 30 | | | | |
| | cm thickness in land ward slope of | | | | |
| | the embankment | $m^3$ | 6417.66 | 454.00 | 2,913,617.64 |
| 9 | Supply and placing of geotextile filter | | | | |
| | as per the drawing | $m^2$ | 129600.00 | 218.00 | 28,252,800.00 |
| 10 | Construction of 5m wide gravel road | | | | |
| | including supply of construction | | | | |
| | materials | km | 2.50 | 1200000.00 | 3,000,000.00 |
| Total: | | | | | **608,140,074.77** |
| Contingencies and workcharge staff @ 5% | | | | | 30,407,003.74 |
| Grand Total: | | | | | **638,547,078.50** |

## Table-4.17, Estimate of Quantity for Channelization of Beas River for Extension of Airport Runway at Kullu

| a. Earthwork along the channel | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Chainage** | **Length** | **Cross-sectional Area** | | **Average Cross-sectional Area** | | **Quantity** | | **Item No.** | | | |
| | | **Excavation** | **Filling** | **Excavation** | **Filling** | **Excavation** | **Filling** | **3(a)** | **3(b)** | **4** | **5** |
| **(m)** | **(m)** | **($m^2$)** | **($m^2$)** | **($m^2$)** | **($m^2$)** | **($m^3$)** | **($m^3$)** | **($m^3$)** | **($m^3$)** | **($m^3$)** | **($m^3$)** |
| 0+000 | - | 194.00 | 46.00 | - | - | - | - | | | | |
| 0+100 | 100.00 | 194.00 | 46.00 | 194.00 | 46.00 | 19400.00 | 4600.00 | 16490.00 | 2522.00 | 388.00 | 0.00 |
| 0+200 | 100.00 | 120.00 | 46.00 | 157.00 | 46.00 | 15700.00 | 4600.00 | 13345.00 | 2041.00 | 314.00 | 0.00 |
| 0+400 | 200.00 | 147.00 | 27.00 | 133.50 | 36.50 | 26700.00 | 7300.00 | 22695.00 | 3471.00 | 534.00 | 0.00 |
| 0+615 | 215.00 | 241.00 | 13.00 | 194.00 | 20.00 | 41710.00 | 4300.00 | 35453.50 | 5422.30 | 834.20 | 0.00 |
| 0+815 | 200.00 | 155.00 | 13.00 | 198.00 | 13.00 | 39600.00 | 2600.00 | 33660.00 | 5148.00 | 792.00 | 0.00 |
| 1+015 | 200.00 | 67.00 | 40.00 | 111.00 | 26.50 | 22200.00 | 5300.00 | 18870.00 | 2886.00 | 444.00 | 0.00 |
| 1+200 | 185.00 | 162.00 | 123.00 | 114.50 | 81.50 | 21182.50 | 15077.50 | 18005.13 | 2753.73 | 423.65 | 0.00 |
| 1+400 | 200.00 | 169.00 | 25.00 | 165.50 | 74.00 | 33100.00 | 14800.00 | 28135.00 | 4303.00 | 662.00 | 0.00 |
| 1+600 | 200.00 | 242.00 | 17.00 | 205.50 | 21.00 | 41100.00 | 4200.00 | 34935.00 | 5343.00 | 822.00 | 0.00 |
| 1+800 | 200.00 | 206.00 | 42.00 | 224.00 | 29.50 | 44800.00 | 5900.00 | 38080.00 | 5824.00 | 896.00 | 0.00 |
| 2+000 | 200.00 | 336.00 | 97.00 | 271.00 | 69.50 | 54200.00 | 13900.00 | 46070.00 | 7046.00 | 1084.00 | 0.00 |
| 2+200 | 200.00 | 1535.00 | 151.00 | 935.50 | 124.00 | 187100.00 | 24800.00 | 28065.00 | 14968.00 | 3742.00 | 140325.00 |
| 2+400 | 200.00 | 995.00 | 0.00 | 1265.00 | 75.50 | 253000.00 | 15100.00 | 37950.00 | 20240.00 | 5060.00 | 189750.00 |
| 2+600 | 200.00 | 1210.00 | 0.00 | 1102.50 | 0.00 | 220500.00 | 0.00 | 33075.00 | 17640.00 | 4410.00 | 165375.00 |
| 2+800 | 200.00 | 1592.00 | 0.00 | 1401.00 | 0.00 | 280200.00 | 0.00 | 42030.00 | 22416.00 | 5604.00 | 210150.00 |
| 3+000 | 200.00 | 760.00 | 21.00 | 1176.00 | 10.50 | 235200.00 | 2100.00 | 35280.00 | 18816.00 | 4704.00 | 176400.00 |
| 3+200 | 200.00 | 726.00 | 14.00 | 743.00 | 17.50 | 148600.00 | 3500.00 | 22290.00 | 11888.00 | 2972.00 | 111450.00 |
| 3+400 | 200.00 | 683.00 | 52.00 | 704.50 | 33.00 | 140900.00 | 6600.00 | 21135.00 | 11272.00 | 2818.00 | 105675.00 |
| 3+600 | 200.00 | 695.00 | 0.00 | 689.00 | 26.00 | 137800.00 | 5200.00 | 20670.00 | 11024.00 | 2756.00 | 103350.00 |
| **Sub-total:** | | | | | | **1962992.50** | **139877.50** | **546233.63** | **175024.03** | **39259.85** | **1202475.00** |
| b. Earthwork along the runway extension | | | | | | | | | | | |
| Chainage | Length | Cross-sectional Area | | Average Cross-sectional Area | | Quantity | | Item No. | | | |
| | | Excavation | Filling | Excavation | Filling | Excavation | Filling | 3(a) | 3(b) | 4 | 5 |
| (m) | (m) | ($m^2$) | ($m^2$) | ($m^2$) | ($m^2$) | ($m^3$) | ($m^3$) | ($m^3$) | ($m^3$) | ($m^3$) | ($m^3$) |
| 0+000 | - | 0.00 | 310.00 | - | - | - | - | - | - | - | - |
| 0+200 | 200.00 | 0.00 | 1170.00 | 0.00 | 740.00 | 0.00 | 148000.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0+400 | 200.00 | 0.00 | 1032.00 | 0.00 | 1101.00 | 0.00 | 220200.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0+600 | 200.00 | 0.00 | 1455.00 | 0.00 | 1243.50 | 0.00 | 248700.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0+800 | 200.00 | 0.00 | 2140.00 | 0.00 | 1797.50 | 0.00 | 359500.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1+000 | 200.00 | 19.00 | 1955.00 | 9.50 | 2047.50 | 1900.00 | 409500.00 | 0.00 | 0.00 | 0.00 | 1900.00 |
| **Sub-total:** | | | | | | **1900.00** | **1385900.00** | **0.00** | **0.00** | **0.00** | **1900.00** |
| **Grand Total:** | | | | | | **1964892.50** | **1525777.50** | **546233.63** | **175024.03** | **39259.85** | **1204375.00** |

| c. Supply and placing of 1.0 m * 1.0 m * 0.8 m size 1:3:6 P.C.C. blocks in the waterface of the river | | | | | |
|---|---|---|---|---|---|
| **Chainage** | **No.** | **Length** | **Breadth** | **Height** | **Quantity** |
| **(m)** | | **(m)** | **(m)** | **(m)** | **(m3)** |
| 0+000 to 3+600 | 2.00 | 3600.00 | 18.00 | 0.80 | 103680.00 |

| d. Supply and placing of geotextile filter as per the drawing | | | | | |
|---|---|---|---|---|---|
| **Chainage** | **No.** | **Length** | **Breadth** | **Height** | **Quantity** |
| **(m)** | | **(m)** | **(m)** | **(m)** | **(m2)** |
| 0+000 to 3+600 | 2.00 | 3600.00 | 18.00 | - | 129600.00 |

| e. Supply and packing of boulder in 30 cm thickness in land ward slope of the embankment | | | | | | |
|---|---|---|---|---|---|---|
| **Chainage** | **No.** | **Length** | **Breadth** | **Average Breadth** | **Height** | **Quantity** |
| **(m)** | | **(m)** | **(m)** | **(m)** | **(m)** | **(m3)** |
| 0+000 | - | - | 5.52 | - | - | - |
| 0+100 | 2 | 100.00 | 5.52 | 5.52 | 0.30 | 331.20 |
| 0+200 | 2 | 100.00 | 5.39 | 5.46 | 0.30 | 327.30 |
| 0+400 | 2 | 200.00 | 2.97 | 4.18 | 0.30 | 501.60 |
| 0+615 | 2 | 215.00 | 2.59 | 2.78 | 0.30 | 358.62 |
| 0+815 | 1 | 200.00 | 4.09 | 3.34 | 0.30 | 200.40 |
| 1+015 | 2 | 200.00 | 3.20 | 3.65 | 0.30 | 437.40 |
| 1+200 | 2 | 185.00 | 9.48 | 6.34 | 0.30 | 703.74 |
| 1+400 | 2 | 200.00 | 3.27 | 6.38 | 0.30 | 765.00 |
| 1+600 | 1 | 200.00 | 4.98 | 4.13 | 0.30 | 247.50 |
| 1+800 | 2 | 200.00 | 5.79 | 5.39 | 0.30 | 646.20 |
| 2+000 | 1 | 200.00 | 10.02 | 7.91 | 0.30 | 474.30 |
| 2+200 | 1 | 200.00 | 9.00 | 9.51 | 0.30 | 570.60 |
| 2+400 | 0 | 200.00 | 0.00 | 4.50 | 0.30 | 0.00 |
| 2+600 | 0 | 200.00 | 0.00 | 0.00 | 0.30 | 0.00 |
| 2+800 | 0 | 200.00 | 0.00 | 0.00 | 0.30 | 0.00 |
| 3+000 | 1 | 200.00 | 3.00 | 1.50 | 0.30 | 90.00 |
| 3+200 | 2 | 200.00 | 3.17 | 3.09 | 0.30 | 370.20 |
| 3+400 | 1 | 200.00 | 9.95 | 6.56 | 0.30 | 393.60 |
| 3+600 | 0 | 200.00 | 0.00 | 4.98 | 0.30 | 0.00 |
| **Total** | | | | | | **6417.66** |

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 CONCLUSIONS

- The hydrological analysis of the available annual maximum discharge data shows that the discharge data is closest to the Log-Pearson Type-3 distribution. Accordingly, the 2-year, 100-year, 500-year and 1000-year return period floods are found to be 800 cumecs, 2800 cumecs, 4700 cumecs and 5900 cumecs respectively. The flood dikes and the diversion channel have been designed based on 500 year return period flood as the airport is an important installation and deserves for high safety factor.

- In the present study the water surface profiles have been computed by using two well-established software called HEC-RAS and HEC-6. The results obtained, from both the above software are quite matching for fixed bed application. However, the water surface profile obtained from HEC-6 for mobile bed application differs to some extent, as anticipated, with that calculated for fixed bed application. This is due to the change in bed level as a result of scour or deposition of the bed material.

- The computation of water surface profiles shows that the existing channel section is inadequate to carry the design flood of 4700 cumecs for the entire reach under investigation. Dikes are required to be provided to prevent spillage of water over the banks. The dike should be provided with a side slope of 2 horizontal in 1 vertical and it's top shall be kept 1.5 m above the design water surface profile.

- The computations of stable channel parameters show that the stable channel width, depth and longitudinal slope are respectively 120 m, 3.5 m and 1/270. So the channel has been designed with a trapezoidal section of 120 m bottom width with side slope of 2 horizontal in 1 vertical. The longitudinal slope of the channel has been provided with the existing slope of 1/110 from chainage 0+000 to 1+900 and then after the diversion channel has been designed with the available slope of 1/99 (=0.01007).

The existing channel of 1800 m length needs to be replaced by a new diversion channel of length 1700 m to accommodate the alignment of runway extension. The diversion channel has been designed as a smooth cosine curve instead of a straight channel because of the inherent instability of the later. In this case the reduction in channel length by diversion of the existing channel is not significant, so a pilot channel may not enlarge satisfactorily. Further, it is not possible to allow sufficient time for development of channel to ultimate section. So the full section of the channel needs to be excavated before diverting the flow into it.

Three different types of cover layer; namely the stone rip-rap, the gabion mattress and the cement concrete blocks have been designed as possible alternative solutions for protection of the embankment slope. The nominal thickness of stone rip-rap, gabion mattress and cement concrete blocks are found to be 1.80 m, 1.25 m and 0.80 m. However, the cement concrete blocks have been recommended for protection of the embankment slope as it requires less frequent maintenance in comparison to that for the stone rip-rap and the gabion mattress.

## 5.2 RECOMMENDATIONS

- Channelization of Beas River for extension of the runway may have certain environmental impact on the existing plants and animals. So environmental impact assessment of the channelization works is recommended prior to execution of the works in the field.

- Many assumptions have been made in the preceeding design and analysis of the channelization works, which may lead to some discrepancies in the computed and the observed results. Model study is recommended to simulate and verify the satisfactory functioning of the channnelization works.
- The proposed channelization works require land acquisition and resettlements, which must be properly assessed and the displaced people must be properly rehabilitated to minimise the disturbances during the construction phase.

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**APPENDIX-1, INPUT DATA FILE FOR HEC-6 FOR SIMULATION OF BEAS RIVER IN NATURAL CONDITION FOR 2 YEAR AND 500 YEAR RETURN PERIOD FLOODS (FIX BED APPLICATION).**

```
T1      FIXED BED APPLICATION IN NATURAL CONDITION.
T2      WITH A RATING CURVE AT THE DOWNSTREAM BOUNDARY.
T3      SIMULATION OF BEAS RIVER FOR 2 YEAR AND 500 YEAR RETURN PERIOD FLOODS
NC  .045     .045    .040      .1      .3
X1   1.0      23.  685.52  993.84      0.      0.      0.      0.      0.      0.
GR3521.1     0.03 3519.44   52.48 3517.80   98.40 3516.16  147.60 3514.52  226.32
GR3512.9   246.00 3512.88  295.20 3514.52  344.40 3514.52  432.96 3512.88  505.12
GR3511.2   531.36 3504.68  662.56 3503.04  677.32 3502.55  685.52 3501.73  695.36
GR3498.8   724.88 3495.17  823.28 3498.45  921.68 3501.73  951.20 3503.04  954.48
GR3504.7   964.32 3522.72  993.84 3524.20 1013.52
HD   1.0
X1   2.0      18.  465.76  793.76  665.84  672.40  669.12      0.      0.      0.
GR3519.4     0.03 3517.80   62.32 3516.16  282.08 3514.52  360.80 3512.88  396.88
GR3511.2   413.28 3509.60  439.52 3507.96  455.92 3506.32  465.76 3503.04  485.44
GR3501.8   498.56 3498.19  531.36 3497.20  596.96 3497.86  662.56 3501.79  675.68
GR3506.3   728.16 3553.88  793.76 3555.52  842.96
HD   2.0
X1   3.0      16.  216.48  495.28  623.20  672.40  721.60      0.      0.      0.
GR3519.4     0.03 3517.80   88.56 3516.16  118.08 3514.52  141.04 3512.88  164.00
GR3509.6   216.48 3506.32  255.84 3505.66  265.68 3503.37  282.08 3499.92  364.08
GR3502.4   413.28 3505.66  432.96 3511.24  462.48 3520.26  495.28 3521.08  505.12
GR3522.7   518.24
HD   3.0
X1   4.0      12.   55.76  593.68  580.56  787.20  656.00      0.      0.      0.
GR3522.7     0.03 3516.16   55.76 3514.52   65.60 3513.37   88.56 3509.60  127.92
GR3513.4   186.96 3514.52  219.76 3514.85  350.96 3513.37  383.76 3507.63  482.16
GR3513.4   531.36 3524.36  593.68
HD   4.0
X1   5.0      14.   82.00  593.68  596.96  754.40  672.40      0.      0.      0.
GR3534.2     0.03 3532.56   82.00 3522.72   83.64 3516.98  131.20 3522.72  173.84
GR3524.4   213.20 3524.36  311.60 3522.72  354.24 3517.80  436.24 3522.72  508.40
GR3524.4   534.64 3526.00  580.56 3531.74  593.68 3532.56  701.92
HD   5.0
X1   6.0      15.    6.00  450.00  682.24  688.80  685.52      0.      0.      0.
GR3539.6     0.03 3535.85   82.11 3528.96  118.14 3527.97  147.67 3527.32  160.79
GR3526.8   226.41 3526.50  259.22 3525.68  305.15 3525.51  341.24 3527.65  374.05
GR3527.9   400.29 3529.61  413.42 3529.94  426.54 3531.09  446.22 3546.87  492.16
HD   6.0
X1   7.0      11.    5.00  270.00  885.60  885.60  885.60      0.      0.      0.
GR3547.3     0.03 3544.05   19.72 3542.41   36.12 3539.13   59.09 3535.85  108.30
GR3535.8   118.15 3537.49  262.50 3539.13  278.91 3542.41  295.31 3544.05  315.00
GR3547.3   387.17
HD   7.0
X1   8.0      12.    5.00  325.00  656.00  656.00  656.00      0.      0.      0.
GR3555.5     0.03 3550.61   32.84 3548.97   45.96 3545.69   68.93 3542.41  118.14
GR3541.1   164.07 3541.62  210.01 3542.41  242.81 3545.69  295.01 3548.97  328.12
GR3550.6   354.36 3552.25  406.86
HD   8.0
X1   9.0      11.    5.00  330.00  656.00  656.00  656.00      0.      0.      0.
GR3562.1     0.03 3557.17   65.65 3552.25   98.46 3548.97  157.51 3548.02  177.20
GR3548.9   216.57 3552.25  282.18 3555.53  308.43 3557.17  347.80 3558.81  419.98
GR3572.2   459.32
HD   9.0
```

```
X1  10.0     17.   15.00  400.00  656.00  656.00  656.00      0.      0.      0.
GR3570.3     0.03 3565.38   42.68 3558.81   72.21 3553.56  105.02 3555.53  157.51
GR3558.8   170.63 3558.81  216.57 3555.53  252.65 3555.53  275.62 3558.81  288.74
GR3558.8   354.36 3555.53  374.05 3555.53  393.73 3558.81  406.85 3562.09  433.10
GR3565.3   485.59 3579.60  590.55
HD  10.0
X1  11.0     16.   10.00  550.00  656.00  656.00  656.00      0.      0.      0.
GR3576.8     0.03 3571.94   26.28 3565.38   42.68 3562.09   78.77 3558.81  118.14
GR3558.8   183.76 3563.74  210.00 3565.38  465.91 3562.09  479.03 3558.81  498.72
GR3565.3   544.65 3565.34  570.90 3562.09  590.58 3568.66  616.80 3571.94  656.20
GR3583.3   705.38
HD  11.0
X1  12.0     12.    5.00  500.00  606.80  606.80  606.80      0.      0.      0.
GR3583.4     0.03 3578.50   32.84 3568.66   52.52 3565.38   85.33 3563.93  150.95
GR3563.0   216.57 3562.09  314.99 3565.38  439.66 3568.66  492.16 3571.94  505.28
GR3575.2   518.40 3578.50  557.77
HD  12.0
X1  13.0     10.    5.00  420.00  656.00  656.00  656.00      0.      0.      0.
GR3590.0     0.03 3585.06   16.43 3571.94   78.77 3568.66  196.88 3568.07  216.57
GR3568.6   275.62 3571.94  354.36 3575.22  393.73 3578.50  426.54 3585.06  518.40
HD  13.0
X1  14.0     15.    5.00  375.00  656.00  656.00  656.00      0.      0.      0.
GR3594.2     0.03 3591.62   13.15 3588.34   29.55 3585.06   59.08 3581.78   98.45
GR3578.5   137.82 3576.86  183.83 3576.30  190.32 3576.86  262.49 3578.50  314.99
GR3581.7   334.67 3585.06  347.80 3588.34  357.64 3591.62  387.17 3594.90  557.77
HD  14.0
X1  15.0     13.   20.00  400.00  705.20  705.20  705.20      0.      0.      0.
GR3603.1     0.03 3598.18   23.00 3591.62   32.84 3588.34   52.52 3585.06  127.98
GR3581.7   216.57 3581.29  249.37 3581.78  295.31 3585.06  367.48 3588.34  400.29
GR3591.6   426.54 3592.64  459.35 3594.90  544.65
HD  15.0
X1  16.0     13.    5.00  350.00  656.00  656.00  656.00      0.      0.      0.
GR3606.4     0.03 3601.46   45.96 3598.18   52.52 3594.90   72.21 3591.62  105.02
GR3588.3   216.57 3588.18  229.69 3588.34  262.50 3591.62  374.05 3594.90  459.32
GR3596.2   472.47 3598.18  597.14 3601.46  643.07
HD  16.0
X1  17.0      9.    5.00  650.00  328.00  328.00  328.00      0.      0.      0.
GR3609.6     0.03 3604.75   32.84 3598.18   85.33 3594.90  111.58 3591.62  196.88
GR3591.6   229.69 3594.90  321.55 3598.18  380.61 3604.75  754.62
HD  17.0
EJ
$HYD
$RATING
RC             28 7057.51       0       0 3495.17 3500.78 3502.94 3504.52 3505.93
RC        3507.21 3508.29 3509.34 3510.26 3511.17 3511.90 3512.62 3513.34 3514.29
RC        3516.00 3516.55 3516.98 3517.24 3517.64 3518.03 3518.46 3518.82 3519.18
RC        3519.54 3519.87 3520.19 3520.46 3520.85
*   A   PROFILE 1 = 2 YEAR RETURN PERIOD FLOOD
Q 28230.
T    60.
W     1.
*   A   PROFILE 2 = 500 YEAR RETURN PERIOD FLOOD
Q165850.
T    60.
W     1.
$$END
```

**APPENDIX-2, OUTPUT OF HEC-6 FOR SIMULATION OF BEAS RIVER IN NATURAL CONDITION WITH 2 YEAR AND 500 YEAR RETURN PERIOD FLOODS (FIX BED APPLICATON).**

```
**************************************************     ****************************************
*  SCOUR AND DEPOSITION IN RIVERS AND RESERVOIRS *     *  U.S. ARMY CORPS OF ENGINEERS        *
*       Version: 4.1.00 -  OCTOBER 1993          *     *  HYDROLOGIC ENGINEERING CENTER       *
*  INPUT FILE:  FIXBED.DAT                       *     *  609 SECOND STREET                   *
*  OUTPUT FILE: FIXBED.OUT                       *     *  DAVIS, CALIFORNIA 95616-4687        *
*  RUN DATE: 27 FEB 04     RUN TIME: 14:43:35    *     *  (916) 756-1104                      *
**************************************************     ****************************************

                        X     X  XXXXXXX   XXXXX          XXXXX
                        X     X  X        X     X        X     X
                        X     X  X        X              X
                        XXXXXXX  XXXX     X        XXXXX XXXXXX
                        X     X  X        X              X     X
                        X     X  X        X     X        X     X
                        X     X  XXXXXXX   XXXXX          XXXXX

          ***********************************************************************
          *  MAXIMUM LIMITS FOR THIS VERSION ARE:                               *
          *       10  Stream Segments (Main Stem + Tributaries)                 *
          *      500  Cross Sections                                            *
          *      200  Elevation/Station Points per Cross Section                *
          *       20  Grain Sizes                                               *
          *       10  Control Points                                            *
          ***********************************************************************

T1      FIXED BED APPLICATION IN NATURAL CONDITION.
T2      WITH A RATING CURVE AT THE DOWNSTREAMBOUNDARY.
T3      SIMULATION OF BEAS RIVER FOR 2 YEAR AND 500 YEAR RETURN PERIOD FLOODS

N values...  Left    Channel   Right    Contraction    Expansion
            0.0450   0.0400   0.0450      1.1000        0.7000

SECTION NO.     1.000
...DEPTH of the Bed Sediment Control Volume =     0.00 ft.

SECTION NO.     2.000
...DEPTH of the Bed Sediment Control Volume =     0.00 ft.

SECTION NO.     3.000
...DEPTH of the Bed Sediment Control Volume =     0.00 ft.

SECTION NO.     4.000
...DEPTH of the Bed Sediment Control Volume =     0.00 ft.

SECTION NO.     5.000
...DEPTH of the Bed Sediment Control Volume =     0.00 ft.

SECTION NO.     6.000
...DEPTH of the Bed Sediment Control Volume =     0.00 ft.

SECTION NO.     7.000
...DEPTH of the Bed Sediment Control Volume =     0.00 ft.

SECTION NO.     8.000
...DEPTH of the Bed Sediment Control Volume =     0.00 ft.

SECTION NO.     9.000
...DEPTH of the Bed Sediment Control Volume =     0.00 ft.

SECTION NO.    10.000
...DEPTH of the Bed Sediment Control Volume =     0.00 ft.

SECTION NO.    11.000
...DEPTH of the Bed Sediment Control Volume =     0.00 ft.

SECTION NO.    12.000
...DEPTH of the Bed Sediment Control Volume =     0.00 ft.
```

```
SECTION NO.    13.000
...DEPTH of the Bed Sediment Control Volume =    0.00 ft.

SECTION NO.    14.000
...DEPTH of the Bed Sediment Control Volume =    0.00 ft.

SECTION NO.    15.000
...DEPTH of the Bed Sediment Control Volume =    0.00 ft.

SECTION NO.    16.000
...DEPTH of the Bed Sediment Control Volume =    0.00 ft.

SECTION NO.    17.000
...DEPTH of the Bed Sediment Control Volume =    0.00 ft.

NO. OF CROSS SECTIONS IN STREAM SEGMENT= 17
NO. OF INPUT DATA MESSAGES =    0

TOTAL NO. OF CROSS SECTIONS IN THE NETWORK =  17
TOTAL NO. OF STREAM SEGMENTS IN THE NETWORK=   1
END OF GEOMETRIC DATA

==========================================================================================

$HYD
FIXED BED MODEL

------------------------------------------------------------------------------------------
$RATING

Downstream Boundary Condition - Rating Curve
  Elevation       Stage      Discharge |  Elevation      Stage     Discharge
 -----------------------------------|-----------------------------------
   3495.170    3495.170        0.000 |   3516.000    3516.000    98805.140
   3500.780    3500.780     7057.510 |   3516.550    3516.550   105862.650
   3502.940    3502.940    14115.020 |   3516.980    3516.980   112920.160
   3504.520    3504.520    21172.530 |   3517.240    3517.240   119977.670
   3505.930    3505.930    28230.040 |   3517.640    3517.640   127035.180
   3507.210    3507.210    35287.550 |   3518.030    3518.030   134092.690
   3508.290    3508.290    42345.060 |   3518.460    3518.460   141150.200
   3509.340    3509.340    49402.570 |   3518.820    3518.820   148207.710
   3510.260    3510.260    56460.080 |   3519.180    3519.180   155265.220
   3511.170    3511.170    63517.590 |   3519.540    3519.540   162322.730
   3511.900    3511.900    70575.100 |   3519.870    3519.870   169380.240
   3512.620    3512.620    77632.610 |   3520.190    3520.190   176437.750
   3513.340    3513.340    84690.120 |   3520.460    3520.460   183495.260
   3514.290    3514.290    91747.630 |   3520.850    3520.850   190552.770

==========================================================================================
TIME STEP #       1
*   A   PROFILE 1 = 2 YEAR RETURN PERIOD FLOOD

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
FIXED BED APPLICATION IN NATURAL CONDITION.
ACCUMULATED TIME (yrs)..........       0.000

--- Downstream Boundary Condition Data for STREAM SEGMENT NO.  1 at Control Point #  1 ---
                           DISCHARGE   TEMPERATURE  WATER SURFACE
                             (cfs)       (deg F)        (ft)
                           28230.000      60.00       3505.930

****  DISCHARGE    WATER    ENERGY  VELOCITY   ALPHA     TOP      AVG       AVG VEL (by
subsection)
        (CFS)      SURFACE   LINE     HEAD               WIDTH     BED       1       2        3

SECTION NO.     1.000
****  28230.000  3505.930  3508.446   2.516    1.037   328.928  3498.140   3.785  12.780   0.000
                                              FLOW DISTRIBUTION (%) =     0.965  99.035   0.000
```

```
SECTION NO.       2.000
 ****  28230.000  3510.329  3511.995   1.665      1.028   306.302  3500.241    2.714  10.381    0.000
                                                  FLOW DISTRIBUTION (%) =      0.591  99.409    0.000
SECTION NO.       3.000
 ****  28230.000  3513.173  3515.463   2.289      1.049   309.622  3504.161    3.724  12.212    0.000
                                                  FLOW DISTRIBUTION (%) =      1.347  98.653    0.000
SECTION NO.       4.000
 ****  28230.000  3518.176  3519.844   1.669      1.007   520.149  3512.773    3.017  10.371    0.000
                                                  FLOW DISTRIBUTION (%) =      0.188  99.812    0.000
SECTION NO.       5.000
** SUPERCRITICAL **  Using Critical Water Surface +
SECTION NO.       5.000 TIME =      1.000 DAYS.
TRIAL    TRIAL        COMPUTED     CRITICAL
 NO.       WS            WS           WS
  0.   3526.763     3525.022
  1.   3526.857     3524.866     3526.807
 ****  28230.000  3526.857  3529.141   2.283      1.000   499.568  3522.195    0.000  12.122    0.000
                                                  FLOW DISTRIBUTION (%) =      0.000 100.000    0.000
SECTION NO.       6.000
 ****  28230.000  3534.203  3536.429   2.226      1.003   364.554  3527.642    0.000  11.970    2.746
                                                  FLOW DISTRIBUTION (%) =      0.000  99.953    0.047

SECTION NO.       7.000
** SUPERCRITICAL **  Using Critical Water Surface +
SECTION NO.       7.000 TIME =      1.000 DAYS.
TRIAL    TRIAL        COMPUTED     CRITICAL
 NO.       WS            WS           WS
  0.   3544.895     3542.209
  1.   3544.989     3542.102     3544.939
 ****  28230.000  3544.989  3548.238   3.249      1.065   321.822  3537.779    0.000  14.692    6.558
                                                  FLOW DISTRIBUTION (%) =      0.000  96.055    3.945
SECTION NO.       8.000
 ****  28230.000  3551.813  3554.015   2.202      1.046   369.759  3544.038    0.000  11.961    3.200
                                                  FLOW DISTRIBUTION (%) =      0.000  98.994    1.006
SECTION NO.       9.000
** SUPERCRITICAL **  Using Critical Water Surface +
SECTION NO.       9.000 TIME =      1.000 DAYS.
TRIAL    TRIAL        COMPUTED     CRITICAL
 NO.       WS            WS           WS
  0.   3558.822     3556.810
  1.   3558.916     3556.768     3558.866
 ****  28230.000  3558.916  3561.865   2.948      1.063   377.887  3551.933    0.000  13.863    3.726
                                                  FLOW DISTRIBUTION (%) =      0.000  98.620    1.380
SECTION NO.      10.000
 ****  28230.000  3565.026  3566.497   1.471      1.058   437.818  3557.323    0.000   9.884    4.653
                                                  FLOW DISTRIBUTION (%) =      0.000  95.997    4.003
SECTION NO.      11.000
 ****  28230.000  3568.664  3569.893   1.228      1.023   582.480  3562.928    0.000   9.026    6.045
                                                  FLOW DISTRIBUTION (%) =      0.000  94.563    5.437
SECTION NO.      12.000
 ****  28230.000  3571.638  3572.785   1.147      1.001   457.401  3564.392    0.000   8.593    1.262
                                                  FLOW DISTRIBUTION (%) =      0.000  99.991    0.009
SECTION NO.      13.000
** SUPERCRITICAL **  Using Critical Water Surface +
SECTION NO.      13.000 TIME =      1.000 DAYS.
TRIAL    TRIAL        COMPUTED     CRITICAL
 NO.       WS            WS           WS
  0.   3576.497     3574.742
  1.   3576.591     3574.724     3576.541
 ****  28230.000  3576.591  3579.483   2.892      1.000   350.769  3570.691    0.000  13.641    0.000
                                                  FLOW DISTRIBUTION (%) =      0.000 100.000    0.000
SECTION NO.      14.000
** SUPERCRITICAL **  Using Critical Water Surface +
SECTION NO.      14.000 TIME =      1.000 DAYS.
TRIAL    TRIAL        COMPUTED     CRITICAL
 NO.       WS            WS           WS
  0.   3585.608     3584.598
  1.   3585.702     3584.490     3585.652
 ****  28230.000  3585.702  3588.926   3.225      1.000   296.421  3579.090    0.000  14.405    0.000
                                                  FLOW DISTRIBUTION (%) =      0.000 100.000    0.000
```

```
SECTION NO.     15.000
 ****  28230.000  3592.416  3593.785   1.368    1.030   420.892  3584.335   0.000   9.415   2.663
                                                 FLOW DISTRIBUTION (%) =    0.000  99.280   0.720

SECTION NO.     16.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.     16.000 TIME =      1.000 DAYS.
 TRIAL    TRIAL        COMPUTED      CRITICAL
  NO.      WS            WS             WS
   1.    3596.179      3595.916
   2.    3596.273      3595.891      3596.223
 ****  28230.000  3596.273  3599.212   2.939    1.092   413.117  3590.125   0.000  14.300   7.959
                                                 FLOW DISTRIBUTION (%) =    0.000  89.089  10.911
 SECTION NO.     17.000
 ****  28230.000  3601.315  3603.379   2.064    1.000   495.793  3596.374   0.000  11.524   0.000
                                                 FLOW DISTRIBUTION (%) =    0.000 100.000   0.000

 ===================================================================================
 TIME STEP #       2
 *   AB  PROFILE 2 = 500 YEAR RETURN PERIOD FLOOD

 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
 FIXED BED APPLICATION IN NATURAL CONDITION.
 ACCUMULATED TIME (yrs)..........     0.003

 --- Downstream Boundary Condition Data for STREAM SEGMENT NO.  1 at Control Point #  1 ---
                               DISCHARGE   TEMPERATURE  WATER SURFACE
                                 (cfs)       (deg F)        (ft)
                               165850.000     60.00        3519.705

****  DISCHARGE     WATER    ENERGY  VELOCITY   ALPHA    TOP      AVG       AVG VEL  (by
subsection)
           (CFS)    SURFACE    LINE     HEAD             WIDTH     BED        1       2       3

 SECTION NO.      1.000
 **** 165850.000  3519.705  3525.092   5.387    1.389   944.792  3499.231   8.789  20.635   0.000
                                                 FLOW DISTRIBUTION (%) =   22.718  77.282   0.000
 SECTION NO.      2.000
 **** 165850.000  3523.038  3529.026   5.987    1.315   751.239  3501.237   9.427  21.399   0.000
                                                 FLOW DISTRIBUTION (%) =   19.687  80.313   0.000
 SECTION NO.      3.000
 **** 165850.000  3526.492  3533.541   7.049    1.150   518.210  3505.317  12.982  22.811   7.895
                                                 FLOW DISTRIBUTION (%) =   18.243  81.197   0.561
 SECTION NO.      4.000
 **** 165850.000  3533.289  3536.582   3.293    1.017   593.650  3513.367  10.252  14.739   7.599
                                                 FLOW DISTRIBUTION (%) =    4.765  95.235   0.000
 SECTION NO.      5.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.      5.000 TIME =      1.000 DAYS.
 TRIAL    TRIAL        COMPUTED      CRITICAL
  NO.      WS            WS             WS
   0.    3537.454      3534.404
   1.    3537.548      3534.439      3537.498
 **** 165850.000  3537.548  3543.710   6.162    1.090   701.890  3522.364   7.733  20.316   9.189
                                                 FLOW DISTRIBUTION (%) =    1.593  95.170   3.237
 SECTION NO.      6.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.      6.000 TIME =      1.000 DAYS.
 TRIAL    TRIAL        COMPUTED      CRITICAL
  NO.      WS            WS             WS
   0.    3545.701      3542.247
   1.    3545.795      3542.256      3545.745
 **** 165850.000  3545.795  3553.523   7.728    1.028   489.001  3529.490  10.642  22.468  10.658
                                                 FLOW DISTRIBUTION (%) =    0.243  98.076   1.681
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SECTION NO.      7.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.      7.000 TIME =      1.000 DAYS.
 TRIAL    TRIAL        COMPUTED     CRITICAL
  NO.       WS           WS           WS
   0.   3558.265     3552.623
   1.   3558.359     3552.626     3558.309
 **** 165850.000  3558.359  3567.265   8.906     1.055   387.140  3538.050  15.161  25.147  17.680
                                                   FLOW DISTRIBUTION (%) =    0.521  81.601  17.878

SECTION NO.      8.000
 **** 165850.000  3564.699  3572.383   7.684     1.039   406.830  3544.645  12.373  22.920  15.975
                                                   FLOW DISTRIBUTION (%) =    0.355  88.689  10.957
 SECTION NO.      9.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.      9.000 TIME =      1.000 DAYS.
 TRIAL    TRIAL        COMPUTED     CRITICAL
  NO.       WS           WS           WS
   0.   3571.247     3569.419
   1.   3571.341     3569.440     3571.291
 **** 165850.000  3571.341  3579.463   8.123     1.067   456.766  3552.899  13.558  23.855  15.303
                                                   FLOW DISTRIBUTION (%) =    0.383  86.208  13.409
 SECTION NO.     10.000
 **** 165850.000  3579.167  3583.499   4.331     1.097   587.183  3558.111   9.305  17.532  10.401
                                                   FLOW DISTRIBUTION (%) =    0.815  85.699  13.486
 SECTION NO.     11.000
 **** 165850.000  3582.915  3585.730   2.815     1.050   703.895  3563.314   6.229  13.906   9.246
                                                   FLOW DISTRIBUTION (%) =    0.265  88.748  10.986
 SECTION NO.     12.000
 **** 165850.000  3583.600  3588.607   5.008     1.030   557.740  3565.595   1.586  18.125   9.340
                                                   FLOW DISTRIBUTION (%) =    0.003  97.397   2.600
 SECTION NO.     13.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.     13.000 TIME =      1.000 DAYS.
 TRIAL    TRIAL        COMPUTED     CRITICAL
  NO.       WS           WS           WS
   0.   3589.187     3586.107
   1.   3589.281     3586.134     3589.231
 **** 165850.000  3589.281  3596.696   7.415     1.056   515.984  3572.314   1.559  22.282  11.759
                                                   FLOW DISTRIBUTION (%) =    0.001  94.598   5.401
 SECTION NO.     14.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.     14.000 TIME =      1.000 DAYS.
 TRIAL    TRIAL        COMPUTED     CRITICAL
  NO.       WS           WS           WS
   0.   3599.656     3594.550
   1.   3599.750     3594.605     3599.700
 **** 165850.000  3599.750  3606.929   7.179     1.122   557.740  3581.025   9.186  22.162   9.911
                                                   FLOW DISTRIBUTION (%) =    0.166  92.578   7.256
 SECTION NO.     15.000
 **** 165850.000  3606.509  3610.748   4.239     1.069   544.620  3584.729   6.072  17.227  11.331
                                                   FLOW DISTRIBUTION (%) =    0.404  85.970  13.626
 SECTION NO.     16.000
 **** 165850.000  3609.195  3613.894   4.700     1.054   643.040  3592.154   5.313  18.793  14.190
                                                   FLOW DISTRIBUTION (%) =    0.049  66.618  33.333
 SECTION NO.     17.000
 **** 165850.000  3611.183  3616.239   5.056     1.036   754.590  3597.886   4.535  18.342  11.013
                                                   FLOW DISTRIBUTION (%) =    0.027  94.853   5.120

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 $$END

       0   DATA ERRORS DETECTED.

 TOTAL NO. OF TIME STEPS READ =          2
 TOTAL NO. OF WS PROFILES =              2
 ITERATIONS IN EXNER EQ =                0

 COMPUTATIONS COMPLETED
 RUN TIME =  0 HOURS,  0 MINUTES &  0.00 SECONDS
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**APPENDIX-3, OUTPUT OF HEC-RAS FOR SIMULATION OF BEAS RIVER IN NATURAL CONDITION WITH 2 YEAR AND 500 YEAR RETURN PERIOD FLOODS (FIX BED APPLICATION)**

| Plan: Natural Beas River Study Reach RS: 1 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3508.44 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 2.51 | Wt. n-Val. | 0.045 | 0.04 | |
| W.S. Elev (ft) | 3505.93 | Reach Len. (ft) | | | |
| Crit W.S. (ft) | 3504.93 | Flow Area (sq ft) | 71.88 | 2189.06 | |
| E.G. Slope (ft/ft) | 0.007693 | Area (sq ft) | 71.88 | 2189.06 | |
| Q Total (cfs) | 28230 | Flow (cfs) | 272.14 | 27957.86 | |
| Top Width (ft) | 328.81 | Top Width (ft) | 47.96 | 280.85 | |
| Vel Total (ft/s) | 12.49 | Avg. Vel. (ft/s) | 3.79 | 12.77 | |
| Max Chl Dpth (ft) | 10.76 | Hydr. Depth (ft) | 1.5 | 7.79 | |
| Conv. Total (cfs) | 321861.5 | Conv. (cfs) | 3102.8 | 318758.7 | |
| Length Wtd. (ft) | | Wetted Per. (ft) | 48.1 | 282.07 | |
| Min Ch El (ft) | 3495.17 | Shear (lb/sq ft) | 0.72 | 3.73 | |
| Alpha | 1.04 | Stream Power (lb/ft s) | 2.72 | 47.6 | |
| Frctn Loss (ft) | | Cum Volume (acre-ft) | | | |
| C & E Loss (ft) | | Cum SA (acres) | | | |

| Plan: Natural Beas River Study Reach RS: 2 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3511.97 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 1.68 | Wt. n-Val. | 0.045 | 0.04 | |
| W.S. Elev (ft) | 3510.29 | Reach Len. (ft) | 665.84 | 669.12 | 672.4 |
| Crit W.S. (ft) | 3507.21 | Flow Area (sq ft) | 59.57 | 2690.24 | |
| E.G. Slope (ft/ft) | 0.003687 | Area (sq ft) | 59.57 | 2690.24 | |
| Q Total (cfs) | 28230 | Flow (cfs) | 162.56 | 28067.44 | |
| Top Width (ft) | 305.16 | Top Width (ft) | 37.28 | 267.88 | |
| Vel Total (ft/s) | 10.27 | Avg. Vel. (ft/s) | 2.73 | 10.43 | |
| Max Chl Dpth (ft) | 13.09 | Hydr. Depth (ft) | 1.6 | 10.04 | |
| Conv. Total (cfs) | 464885.6 | Conv. (cfs) | 2677 | 462208.6 | |
| Length Wtd. (ft) | 669.09 | Wetted Per. (ft) | 37.52 | 270.47 | |
| Min Ch El (ft) | 3497.2 | Shear (lb/sq ft) | 0.37 | 2.29 | |
| Alpha | 1.03 | Stream Power (lb/ft s) | 1 | 23.89 | |
| Frctn Loss (ft) | 3.45 | Cum Volume (acre-ft) | 1 | 37.48 | |
| C & E Loss (ft) | 0.08 | Cum SA (acres) | 0.65 | 4.21 | |

| Plan: Natural Beas River Study Reach RS: 3 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3515.45 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 2.29 | Wt. n-Val. | 0.045 | 0.04 | |
| W.S. Elev (ft) | 3513.16 | Reach Len. (ft) | 623.2 | 721.6 | 672.4 |
| Crit W.S. (ft) | | Flow Area (sq ft) | 101.29 | 2277.66 | |
| E.G. Slope (ft/ft) | 0.005832 | Area (sq ft) | 101.29 | 2277.66 | |
| Q Total (cfs) | 28230 | Flow (cfs) | 376.91 | 27853.09 | |
| Top Width (ft) | 309.38 | Top Width (ft) | 56.4 | 252.98 | |
| Vel Total (ft/s) | 11.87 | Avg. Vel. (ft/s) | 3.72 | 12.23 | |
| Max Chl Dpth (ft) | 13.24 | Hydr. Depth (ft) | 1.8 | 9 | |
| Conv. Total (cfs) | 369668.3 | Conv. (cfs) | 4935.5 | 364732.8 | |
| Length Wtd. (ft) | 720.66 | Wetted Per. (ft) | 56.51 | 254.49 | |
| Min Ch El (ft) | 3499.92 | Shear (lb/sq ft) | 0.65 | 3.26 | |
| Alpha | 1.05 | Stream Power (lb/ft s) | 2.43 | 39.85 | |
| Frctn Loss (ft) | 3.3 | Cum Volume (acre-ft) | 2.16 | 78.62 | |
| C & E Loss (ft) | 0.18 | Cum SA (acres) | 1.32 | 8.53 | |

| Plan: Natural Beas River Study Reach RS: 4 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3519.9 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 1.6 | Wt. n-Val. | 0.045 | 0.04 | |
| W.S. Elev (ft) | 3518.31 | Reach Len. (ft) | 580.56 | 656 | 787.2 |
| Crit W.S. (ft) | | Flow Area (sq ft) | 19.61 | 2774.3 | |
| E.G. Slope (ft/ft) | 0.007707 | Area (sq ft) | 19.61 | 2774.3 | |
| Q Total (cfs) | 28230 | Flow (cfs) | 59.29 | 28170.71 | |
| Top Width (ft) | 521.77 | Top Width (ft) | 18.28 | 503.49 | |
| Vel Total (ft/s) | 10.1 | Avg. Vel. (ft/s) | 3.02 | 10.15 | |
| Max Chl Dpth (ft) | 10.68 | Hydr. Depth (ft) | 1.07 | 5.51 | |
| Conv. Total (cfs) | 321569.9 | Conv. (cfs) | 675.4 | 320894.5 | |
| Length Wtd. (ft) | 655.42 | Wetted Per. (ft) | 18.41 | 504.94 | |
| Min Ch El (ft) | 3507.63 | Shear (lb/sq ft) | 0.51 | 2.64 | |
| Alpha | 1.01 | Stream Power (lb/ft s) | 1.55 | 26.84 | |
| Frctn Loss (ft) | 4.37 | Cum Volume (acre-ft) | 2.96 | 116.66 | |
| C & E Loss (ft) | 0.07 | Cum SA (acres) | 1.82 | 14.22 | |

| Plan: Natural Beas River Study Reach RS: 5 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3529.14 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 2.34 | Wt. n-Val. | | 0.04 | |
| W.S. Elev (ft) | 3526.8 | Reach Len. (ft) | 596.96 | 672.4 | 754.4 |
| Crit W.S. (ft) | 3526.8 | Flow Area (sq ft) | | 2298.32 | |
| E.G. Slope (ft/ft) | 0.014466 | Area (sq ft) | | 2298.32 | |
| Q Total (cfs) | 28230 | Flow (cfs) | | 28230 | |
| Top Width (ft) | 499.42 | Top Width (ft) | | 499.42 | |
| Vel Total (ft/s) | 12.28 | Avg. Vel. (ft/s) | | 12.28 | |
| Max Chl Dpth (ft) | 9.82 | Hydr. Depth (ft) | | 4.6 | |
| Conv. Total (cfs) | 234710.9 | Conv. (cfs) | | 234710.9 | |
| Length Wtd. (ft) | 672.32 | Wetted Per. (ft) | | 504.23 | |
| Min Ch El (ft) | 3516.98 | Shear (lb/sq ft) | | 4.12 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 50.56 | |
| Frctn Loss (ft) | 6.93 | Cum Volume (acre-ft) | 3.1 | 155.81 | |
| C & E Loss (ft) | 0.22 | Cum SA (acres) | 1.94 | 21.97 | |

| Plan: Natural Beas River Study Reach RS: 6 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3536.45 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 2.17 | Wt. n-Val. | | 0.04 | 0.045 |
| W.S. Elev (ft) | 3534.28 | Reach Len. (ft) | 682.24 | 685.52 | 688.8 |
| Crit W.S. (ft) | | Flow Area (sq ft) | | 2386.15 | 5.22 |
| E.G. Slope (ft/ft) | 0.008159 | Area (sq ft) | | 2386.15 | 5.22 |
| Q Total (cfs) | 28230 | Flow (cfs) | | 28215.55 | 14.45 |
| Top Width (ft) | 365.2 | Top Width (ft) | | 359.69 | 5.51 |
| Vel Total (ft/s) | 11.8 | Avg. Vel. (ft/s) | | 11.82 | 2.77 |
| Max Chl Dpth (ft) | 8.77 | Hydr. Depth (ft) | | 6.63 | 0.95 |
| Conv. Total (cfs) | 312539.9 | Conv. (cfs) | | 312379.9 | 160 |
| Length Wtd. (ft) | 685.52 | Wetted Per. (ft) | | 360.68 | 5.83 |
| Min Ch El (ft) | 3525.51 | Shear (lb/sq ft) | | 3.37 | 0.46 |
| Alpha | 1 | Stream Power (lb/ft s) | | 39.84 | 1.26 |
| Frctn Loss (ft) | 7.3 | Cum Volume (acre-ft) | 3.1 | 192.68 | 0.04 |
| C & E Loss (ft) | 0.02 | Cum SA (acres) | 1.94 | 28.73 | 0.04 |

| Plan: Natural Beas River Study Reach RS: 7 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3548.23 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 3.31 | Wt. n-Val. | | 0.04 | 0.045 |
| W.S. Elev (ft) | 3544.93 | Reach Len. (ft) | 885.6 | 885.6 | 885.6 |
| Crit W.S. (ft) | 3544.93 | Flow Area (sq ft) | | 1829.25 | 165.62 |
| E.G. Slope (ft/ft) | 0.01159 | Area (sq ft) | | 1829.25 | 165.62 |
| Q Total (cfs) | 28230 | Flow (cfs) | | 27130.4 | 1099.6 |
| Top Width (ft) | 320.01 | Top Width (ft) | | 255.58 | 64.43 |
| Vel Total (ft/s) | 14.15 | Avg. Vel. (ft/s) | | 14.83 | 6.64 |
| Max Chl Dpth (ft) | 9.13 | Hydr. Depth (ft) | | 7.16 | 2.57 |
| Conv. Total (cfs) | 262227.2 | Conv. (cfs) | | 252013.1 | 10214.1 |
| Length Wtd. (ft) | 885.6 | Wetted Per. (ft) | | 256.12 | 64.89 |
| Min Ch El (ft) | 3535.8 | Shear (lb/sq ft) | | 5.17 | 1.85 |
| Alpha | 1.06 | Stream Power (lb/ft s) | | 76.64 | 12.26 |
| Frctn Loss (ft) | 8.55 | Cum Volume (acre-ft) | 3.1 | 235.53 | 1.78 |
| C & E Loss (ft) | 0.34 | Cum SA (acres) | 1.94 | 34.98 | 0.75 |

| Plan: Natural Beas River Study Reach RS: 8 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3554.05 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 2.2 | Wt. n-Val. | | 0.04 | 0.045 |
| W.S. Elev (ft) | 3551.85 | Reach Len. (ft) | 656 | 656 | 656 |
| Crit W.S. (ft) | 3550.51 | Flow Area (sq ft) | | 2334.67 | 88.35 |
| E.G. Slope (ft/ft) | 0.006771 | Area (sq ft) | | 2334.67 | 88.35 |
| Q Total (cfs) | 28230 | Flow (cfs) | | 27947.33 | 282.67 |
| Top Width (ft) | 369.52 | Top Width (ft) | | 300.46 | 69.06 |
| Vel Total (ft/s) | 11.65 | Avg. Vel. (ft/s) | | 11.97 | 3.2 |
| Max Chl Dpth (ft) | 10.75 | Hydr. Depth (ft) | | 7.77 | 1.28 |
| Conv. Total (cfs) | 343059.6 | Conv. (cfs) | | 339624.4 | 3435.1 |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 301.28 | 69.14 |
| Min Ch El (ft) | 3541.1 | Shear (lb/sq ft) | | 3.28 | 0.54 |
| Alpha | 1.05 | Stream Power (lb/ft s) | | 39.21 | 1.73 |
| Frctn Loss (ft) | 5.71 | Cum Volume (acre-ft) | 3.1 | 266.88 | 3.69 |
| C & E Loss (ft) | 0.11 | Cum SA (acres) | 1.94 | 39.17 | 1.76 |

| Plan: Natural Beas River Study Reach RS: 9 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3561.86 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 3.02 | Wt. n-Val. | | 0.04 | 0.045 |
| W.S. Elev (ft) | 3558.85 | Reach Len. (ft) | 656 | 656 | 656 |
| Crit W.S. (ft) | 3558.85 | Flow Area (sq ft) | | 1987.72 | 98.12 |
| E.G. Slope (ft/ft) | 0.010818 | Area (sq ft) | | 1987.72 | 98.12 |
| Q Total (cfs) | 28230 | Flow (cfs) | | 27873.38 | 356.62 |
| Top Width (ft) | 376.71 | Top Width (ft) | | 286.63 | 90.08 |
| Vel Total (ft/s) | 13.53 | Avg. Vel. (ft/s) | | 14.02 | 3.63 |
| Max Chl Dpth (ft) | 10.82 | Hydr. Depth (ft) | | 6.93 | 1.09 |
| Conv. Total (cfs) | 271413.2 | Conv. (cfs) | | 267984.5 | 3428.7 |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 287.49 | 90.12 |
| Min Ch El (ft) | 3548.02 | Shear (lb/sq ft) | | 4.67 | 0.74 |
| Alpha | 1.06 | Stream Power (lb/ft s) | | 65.48 | 2.67 |
| Frctn Loss (ft) | 5.54 | Cum Volume (acre-ft) | 3.1 | 299.43 | 5.09 |
| C & E Loss (ft) | 0.24 | Cum SA (acres) | 1.94 | 43.59 | 2.96 |

| Plan: Natural Beas River Study Reach RS: 10 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3566.53 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 1.48 | Wt. n-Val. | | 0.04 | 0.045 |
| W.S. Elev (ft) | 3565.05 | Reach Len. (ft) | 656 | 656 | 656 |
| Crit W.S. (ft) | | Flow Area (sq ft) | | 2733.93 | 241.04 |
| E.G. Slope (ft/ft) | 0.004744 | Area (sq ft) | | 2733.93 | 241.04 |
| Q Total (cfs) | 28230 | Flow (cfs) | | 27105.26 | 1124.74 |
| Top Width (ft) | 437.35 | Top Width (ft) | | 355.84 | 81.51 |
| Vel Total (ft/s) | 9.49 | Avg. Vel. (ft/s) | | 9.91 | 4.67 |
| Max Chl Dpth (ft) | 11.49 | Hydr. Depth (ft) | | 7.68 | 2.96 |
| Conv. Total (cfs) | 409883.7 | Conv. (cfs) | | 393553.1 | 16330.5 |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 358.4 | 82.02 |
| Min Ch El (ft) | 3553.56 | Shear (lb/sq ft) | | 2.26 | 0.87 |
| Alpha | 1.06 | Stream Power (lb/ft s) | | 22.4 | 4.06 |
| Frctn Loss (ft) | 4.51 | Cum Volume (acre-ft) | 3.1 | 334.98 | 7.65 |
| C & E Loss (ft) | 0.15 | Cum SA (acres) | 1.94 | 48.43 | 4.25 |

| Plan: Natural Beas River Study Reach RS: 11 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3569.93 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 1.2 | Wt. n-Val. | | 0.04 | 0.045 |
| W.S. Elev (ft) | 3568.73 | Reach Len. (ft) | 656 | 656 | 656 |
| Crit W.S. (ft) | | Flow Area (sq ft) | | 2987.3 | 257.77 |
| E.G. Slope (ft/ft) | 0.005598 | Area (sq ft) | | 2987.3 | 257.77 |
| Q Total (cfs) | 28230 | Flow (cfs) | | 26692.42 | 1537.58 |
| Top Width (ft) | 583.32 | Top Width (ft) | | 515.69 | 67.63 |
| Vel Total (ft/s) | 8.7 | Avg. Vel. (ft/s) | | 8.94 | 5.96 |
| Max Chl Dpth (ft) | 9.93 | Hydr. Depth (ft) | | 5.79 | 3.81 |
| Conv. Total (cfs) | 377320.8 | Conv. (cfs) | | 356769.6 | 20551.2 |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 518.22 | 68.71 |
| Min Ch El (ft) | 3558.8 | Shear (lb/sq ft) | | 2.01 | 1.31 |
| Alpha | 1.02 | Stream Power (lb/ft s) | | 18 | 7.82 |
| Frctn Loss (ft) | 3.37 | Cum Volume (acre-ft) | 3.1 | 378.06 | 11.4 |
| C & E Loss (ft) | 0.03 | Cum SA (acres) | 1.94 | 54.99 | 5.37 |

| Plan: Natural Beas River Study Reach RS: 12 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3572.74 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 1.16 | Wt. n-Val. | | 0.04 | 0.045 |
| W.S. Elev (ft) | 3571.59 | Reach Len. (ft) | 606.8 | 606.8 | 606.8 |
| Crit W.S. (ft) | | Flow Area (sq ft) | | 3269.75 | 1.87 |
| E.G. Slope (ft/ft) | 0.00389 | Area (sq ft) | | 3269.75 | 1.87 |
| Q Total (cfs) | 28230 | Flow (cfs) | | 28227.68 | 2.32 |
| Top Width (ft) | 457.2 | Top Width (ft) | | 453.33 | 3.86 |
| Vel Total (ft/s) | 8.63 | Avg. Vel. (ft/s) | | 8.63 | 1.24 |
| Max Chl Dpth (ft) | 9.5 | Hydr. Depth (ft) | | 7.21 | 0.48 |
| Conv. Total (cfs) | 452628.9 | Conv. (cfs) | | 452591.7 | 37.2 |
| Length Wtd. (ft) | 606.8 | Wetted Per. (ft) | | 454.6 | 3.98 |
| Min Ch El (ft) | 3562.09 | Shear (lb/sq ft) | | 1.75 | 0.11 |
| Alpha | 1 | Stream Power (lb/ft s) | | 15.08 | 0.14 |
| Frctn Loss (ft) | 2.81 | Cum Volume (acre-ft) | 3.1 | 421.64 | 13.21 |
| C & E Loss (ft) | 0 | Cum SA (acres) | 1.94 | 61.74 | 5.87 |

| Plan: Natural Beas River Study Reach RS: 13 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3579.48 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 2.94 | Wt. n-Val. | | 0.04 | |
| W.S. Elev (ft) | 3576.54 | Reach Len. (ft) | 656 | 656 | 656 |
| Crit W.S. (ft) | 3576.54 | Flow Area (sq ft) | | 2050.17 | |
| E.G. Slope (ft/ft) | 0.013049 | Area (sq ft) | | 2050.17 | |
| Q Total (cfs) | 28230 | Flow (cfs) | | 28230 | |
| Top Width (ft) | 349.94 | Top Width (ft) | | 349.94 | |
| Vel Total (ft/s) | 13.77 | Avg. Vel. (ft/s) | | 13.77 | |
| Max Chl Dpth (ft) | 8.47 | Hydr. Depth (ft) | | 5.86 | |
| Conv. Total (cfs) | 247128.2 | Conv. (cfs) | | 247128.2 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 350.75 | |
| Min Ch El (ft) | 3568.07 | Shear (lb/sq ft) | | 4.76 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 65.57 | |
| Frctn Loss (ft) | 4.27 | Cum Volume (acre-ft) | 3.1 | 461.7 | 13.23 |
| C & E Loss (ft) | 0.54 | Cum SA (acres) | 1.94 | 67.79 | 5.9 |

| Plan: Natural Beas River Study Reach RS: 14 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3588.92 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 3.32 | Wt. n-Val. | | 0.04 | |
| W.S. Elev (ft) | 3585.61 | Reach Len. (ft) | 656 | 656 | 656 |
| Crit W.S. (ft) | 3585.61 | Flow Area (sq ft) | | 1931.89 | |
| E.G. Slope (ft/ft) | 0.012712 | Area (sq ft) | | 1931.89 | |
| Q Total (cfs) | 28230 | Flow (cfs) | | 28230 | |
| Top Width (ft) | 295.29 | Top Width (ft) | | 295.29 | |
| Vel Total (ft/s) | 14.61 | Avg. Vel. (ft/s) | | 14.61 | |
| Max Chl Dpth (ft) | 9.31 | Hydr. Depth (ft) | | 6.54 | |
| Conv. Total (cfs) | 250383.9 | Conv. (cfs) | | 250383.9 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 296.45 | |
| Min Ch El (ft) | 3576.3 | Shear (lb/sq ft) | | 5.17 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 75.57 | |
| Frctn Loss (ft) | 8.45 | Cum Volume (acre-ft) | 3.1 | 491.68 | 13.23 |
| C & E Loss (ft) | 0.11 | Cum SA (acres) | 1.94 | 72.64 | 5.9 |

| Plan: Natural Beas River Study Reach RS: 15 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3593.77 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 1.38 | Wt. n-Val. | | 0.04 | 0.045 |
| W.S. Elev (ft) | 3592.39 | Reach Len. (ft) | 705.2 | 705.2 | 705.2 |
| Crit W.S. (ft) | | Flow Area (sq ft) | | 2963.14 | 74.38 |
| E.G. Slope (ft/ft) | 0.004035 | Area (sq ft) | | 2963.14 | 74.38 |
| Q Total (cfs) | 28230 | Flow (cfs) | | 28030.86 | 199.14 |
| Top Width (ft) | 419.67 | Top Width (ft) | | 368.31 | 51.36 |
| Vel Total (ft/s) | 9.29 | Avg. Vel. (ft/s) | | 9.46 | 2.68 |
| Max Chl Dpth (ft) | 11.1 | Hydr. Depth (ft) | | 8.05 | 1.45 |
| Conv. Total (cfs) | 444388.8 | Conv. (cfs) | | 441254.1 | 3134.8 |
| Length Wtd. (ft) | 705.2 | Wetted Per. (ft) | | 369.19 | 51.58 |
| Min Ch El (ft) | 3581.29 | Shear (lb/sq ft) | | 2.02 | 0.36 |
| Alpha | 1.03 | Stream Power (lb/ft s) | | 19.13 | 0.97 |
| Frctn Loss (ft) | 4.66 | Cum Volume (acre-ft) | 3.1 | 531.31 | 13.83 |
| C & E Loss (ft) | 0.19 | Cum SA (acres) | 1.94 | 78.02 | 6.32 |

| Plan: Natural Beas River Study Reach RS: 16 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3599.21 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 3 | Wt. n-Val. | | 0.04 | 0.045 |
| W.S. Elev (ft) | 3596.21 | Reach Len. (ft) | 656 | 656 | 656 |
| Crit W.S. (ft) | 3596.21 | Flow Area (sq ft) | | 1739.93 | 378.82 |
| E.G. Slope (ft/ft) | 0.013623 | Area (sq ft) | | 1739.93 | 378.82 |
| Q Total (cfs) | 28230 | Flow (cfs) | | 25140.64 | 3089.36 |
| Top Width (ft) | 408.57 | Top Width (ft) | | 285.64 | 122.93 |
| Vel Total (ft/s) | 13.32 | Avg. Vel. (ft/s) | | 14.45 | 8.16 |
| Max Chl Dpth (ft) | 8.03 | Hydr. Depth (ft) | | 6.09 | 3.08 |
| Conv. Total (cfs) | 241870.2 | Conv. (cfs) | | 215401.1 | 26469.1 |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 286 | 123.07 |
| Min Ch El (ft) | 3588.18 | Shear (lb/sq ft) | | 5.17 | 2.62 |
| Alpha | 1.09 | Stream Power (lb/ft s) | | 74.76 | 21.35 |
| Frctn Loss (ft) | 4.44 | Cum Volume (acre-ft) | 3.1 | 566.72 | 17.24 |
| C & E Loss (ft) | 0.49 | Cum SA (acres) | 1.94 | 82.94 | 7.63 |

| Plan: Natural Beas River Study Reach RS: 17 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3603.34 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 2.01 | Wt. n-Val. | | 0.04 | |
| W.S. Elev (ft) | 3601.33 | Reach Len. (ft) | 328 | 328 | 328 |
| Crit W.S. (ft) | 3600.88 | Flow Area (sq ft) | | 2479.67 | |
| E.G. Slope (ft/ft) | 0.011117 | Area (sq ft) | | 2479.67 | |
| Q Total (cfs) | 28230 | Flow (cfs) | | 28230 | |
| Top Width (ft) | 499.76 | Top Width (ft) | | 499.76 | |
| Vel Total (ft/s) | 11.38 | Avg. Vel. (ft/s) | | 11.38 | |
| Max Chl Dpth (ft) | 9.73 | Hydr. Depth (ft) | | 4.96 | |
| Conv. Total (cfs) | 267737.9 | Conv. (cfs) | | 267737.9 | |
| Length Wtd. (ft) | 328 | Wetted Per. (ft) | | 500.41 | |
| Min Ch El (ft) | 3591.6 | Shear (lb/sq ft) | | 3.44 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 39.15 | |
| Frctn Loss (ft) | 4.03 | Cum Volume (acre-ft) | 3.1 | 582.61 | 18.67 |
| C & E Loss (ft) | 0.1 | Cum SA (acres) | 1.94 | 85.9 | 8.09 |

| Plan: Natural Beas River Study Reach RS: 1 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3525.09 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 5.38 | Wt. n-Val. | 0.045 | 0.04 | |
| W.S. Elev (ft) | 3519.71 | Reach Len. (ft) | | | |
| Crit W.S. (ft) | 3519.52 | Flow Area (sq ft) | 4284.7 | 6213 | |
| E.G. Slope (ft/ft) | 0.005632 | Area (sq ft) | 4284.7 | 6213 | |
| Q Total (cfs) | 165850 | Flow (cfs) | 37635.81 | 128214.2 | |
| Top Width (ft) | 944.91 | Top Width (ft) | 641.52 | 303.39 | |
| Vel Total (ft/s) | 15.8 | Avg. Vel. (ft/s) | 8.78 | 20.64 | |
| Max Chl Dpth (ft) | 24.54 | Hydr. Depth (ft) | 6.68 | 20.48 | |
| Conv. Total (cfs) | 2210008 | Conv. (cfs) | 501510.1 | 1708498 | |
| Length Wtd. (ft) | | Wetted Per. (ft) | 642.03 | 308.49 | |
| Min Ch El (ft) | 3495.17 | Shear (lb/sq ft) | 2.35 | 7.08 | |
| Alpha | 1.39 | Stream Power (lb/ft s) | 20.61 | 146.13 | |
| Frctn Loss (ft) | | Cum Volume (acre-ft) | | | |
| C & E Loss (ft) | | Cum SA (acres) | | | |

| Plan: Natural Beas River Study Reach RS: 2 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3529.06 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 5.99 | Wt. n-Val. | 0.045 | 0.04 | |
| W.S. Elev (ft) | 3523.08 | Reach Len. (ft) | 665.84 | 669.12 | 672.4 |
| Crit W.S. (ft) | 3523.08 | Flow Area (sq ft) | 3468.25 | 6227.88 | |
| E.G. Slope (ft/ft) | 0.005619 | Area (sq ft) | 3468.25 | 6227.88 | |
| Q Total (cfs) | 165850 | Flow (cfs) | 32548.71 | 133301.3 | |
| Top Width (ft) | 751.24 | Top Width (ft) | 465.73 | 285.51 | |
| Vel Total (ft/s) | 17.1 | Avg. Vel. (ft/s) | 9.38 | 21.4 | |
| Max Chl Dpth (ft) | 25.88 | Hydr. Depth (ft) | 7.45 | 21.81 | |
| Conv. Total (cfs) | 2212457 | Conv. (cfs) | 434203.3 | 1778253 | |
| Length Wtd. (ft) | 668.43 | Wetted Per. (ft) | 469.8 | 292.26 | |
| Min Ch El (ft) | 3497.2 | Shear (lb/sq ft) | 2.59 | 7.48 | |
| Alpha | 1.32 | Stream Power (lb/ft s) | 24.31 | 160.01 | |
| Frctn Loss (ft) | 3.76 | Cum Volume (acre-ft) | 59.25 | 95.55 | |
| C & E Loss (ft) | 0.18 | Cum SA (acres) | 8.46 | 4.52 | |

| Plan: Natural Beas River Study Reach RS: 3 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3533.61 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 7.04 | Wt. n-Val. | 0.045 | 0.04 | 0.045 |
| W.S. Elev (ft) | 3526.58 | Reach Len. (ft) | 623.2 | 721.6 | 672.4 |
| Crit W.S. (ft) | | Flow Area (sq ft) | 2345.79 | 5926.11 | 119.43 |
| E.G. Slope (ft/ft) | 0.006476 | Area (sq ft) | 2345.79 | 5926.11 | 119.43 |
| Q Total (cfs) | 165850 | Flow (cfs) | 29849 | 135144.8 | 856.25 |
| Top Width (ft) | 518.21 | Top Width (ft) | 216.45 | 278.8 | 22.96 |
| Vel Total (ft/s) | 19.76 | Avg. Vel. (ft/s) | 12.72 | 22.8 | 7.17 |
| Max Chl Dpth (ft) | 26.65 | Hydr. Depth (ft) | 10.84 | 21.26 | 5.2 |
| Conv. Total (cfs) | 2060909 | Conv. (cfs) | 370913.8 | 1679355 | 10640.1 |
| Length Wtd. (ft) | 702.96 | Wetted Per. (ft) | 223.86 | 281.26 | 26.95 |
| Min Ch El (ft) | 3499.92 | Shear (lb/sq ft) | 4.24 | 8.52 | 1.79 |
| Alpha | 1.16 | Stream Power (lb/ft s) | 53.91 | 194.26 | 12.85 |
| Frctn Loss (ft) | 4.24 | Cum Volume (acre-ft) | 100.84 | 196.22 | 0.92 |
| C & E Loss (ft) | 0.32 | Cum SA (acres) | 13.34 | 9.2 | 0.18 |

| Plan: Natural Beas River Study Reach RS: 4 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3536.71 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 3.25 | Wt. n-Val. | 0.045 | 0.04 | |
| W.S. Elev (ft) | 3533.45 | Reach Len. (ft) | 580.56 | 656 | 787.2 |
| Crit W.S. (ft) | | Flow Area (sq ft) | 781.58 | 10819.11 | |
| E.G. Slope (ft/ft) | 0.002928 | Area (sq ft) | 781.58 | 10819.11 | |
| Q Total (cfs) | 165850 | Flow (cfs) | 7192.03 | 158658 | |
| Top Width (ft) | 593.65 | Top Width (ft) | 55.73 | 537.92 | |
| Vel Total (ft/s) | 14.3 | Avg. Vel. (ft/s) | 9.2 | 14.66 | |
| Max Chl Dpth (ft) | 25.82 | Hydr. Depth (ft) | 14.02 | 20.11 | |
| Conv. Total (cfs) | 3065226 | Conv. (cfs) | 132922.5 | 2932304 | |
| Length Wtd. (ft) | 647.91 | Wetted Per. (ft) | 66.87 | 548.99 | |
| Min Ch El (ft) | 3507.63 | Shear (lb/sq ft) | 2.14 | 3.6 | |
| Alpha | 1.02 | Stream Power (lb/ft s) | 19.66 | 52.82 | |
| Frctn Loss (ft) | 2.71 | Cum Volume (acre-ft) | 121.68 | 322.31 | 2 |
| C & E Loss (ft) | 0.38 | Cum SA (acres) | 15.16 | 15.35 | 0.38 |

| Plan: Natural Beas River Study Reach RS: 5 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3543.73 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 6.29 | Wt. n-Val. | 0.045 | 0.04 | 0.045 |
| W.S. Elev (ft) | 3537.44 | Reach Len. (ft) | 596.96 | 672.4 | 754.4 |
| Crit W.S. (ft) | 3537.44 | Flow Area (sq ft) | 332.45 | 7711.84 | 572.13 |
| E.G. Slope (ft/ft) | 0.008426 | Area (sq ft) | 332.45 | 7711.84 | 572.13 |
| Q Total (cfs) | 165850 | Flow (cfs) | 2497.08 | 158243.3 | 5109.6 |
| Top Width (ft) | 701.89 | Top Width (ft) | 81.97 | 511.68 | 108.24 |
| Vel Total (ft/s) | 19.25 | Avg. Vel. (ft/s) | 7.51 | 20.52 | 8.93 |
| Max Chl Dpth (ft) | 20.46 | Hydr. Depth (ft) | 4.06 | 15.07 | 5.29 |
| Conv. Total (cfs) | 1806816 | Conv. (cfs) | 27203.9 | 1723947 | 55665.4 |
| Length Wtd. (ft) | 671.46 | Wetted Per. (ft) | 85.22 | 522.41 | 113.12 |
| Min Ch El (ft) | 3516.98 | Shear (lb/sq ft) | 2.05 | 7.77 | 2.66 |
| Alpha | 1.09 | Stream Power (lb/ft s) | 15.41 | 159.33 | 23.76 |
| Frctn Loss (ft) | 3.11 | Cum Volume (acre-ft) | 129.32 | 465.33 | 6.96 |
| C & E Loss (ft) | 0.91 | Cum SA (acres) | 16.1 | 23.45 | 1.32 |

| Plan: Natural Beas River Study Reach RS: 6 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3553.54 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 7.87 | Wt. n-Val. | 0.045 | 0.04 | 0.045 |
| W.S. Elev (ft) | 3545.66 | Reach Len. (ft) | 682.24 | 685.52 | 688.8 |
| Crit W.S. (ft) | 3545.66 | Flow Area (sq ft) | 37 | 7180.88 | 256.48 |
| E.G. Slope (ft/ft) | 0.009145 | Area (sq ft) | 37 | 7180.88 | 256.48 |
| Q Total (cfs) | 165850 | Flow (cfs) | 247 | 162847.2 | 2755.77 |
| Top Width (ft) | 488.62 | Top Width (ft) | 5.97 | 444 | 38.65 |
| Vel Total (ft/s) | 22.19 | Avg. Vel. (ft/s) | 6.68 | 22.68 | 10.74 |
| Max Chl Dpth (ft) | 20.15 | Hydr. Depth (ft) | 6.2 | 16.17 | 6.64 |
| Conv. Total (cfs) | 1734289 | Conv. (cfs) | 2582.8 | 1702890 | 28817.1 |
| Length Wtd. (ft) | 685.57 | Wetted Per. (ft) | 12.04 | 445.21 | 40.86 |
| Min Ch El (ft) | 3525.51 | Shear (lb/sq ft) | 1.75 | 9.21 | 3.58 |
| Alpha | 1.03 | Stream Power (lb/ft s) | 11.71 | 208.83 | 38.5 |
| Frctn Loss (ft) | 6.02 | Cum Volume (acre-ft) | 132.21 | 582.52 | 13.51 |
| C & E Loss (ft) | 0.47 | Cum SA (acres) | 16.79 | 30.97 | 2.48 |

| Plan: Natural Beas River Study Reach RS: 7 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3567.45 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 9.17 | Wt. n-Val. | 0.045 | 0.04 | 0.045 |
| W.S. Elev (ft) | 3558.28 | Reach Len. (ft) | 885.6 | 885.6 | 885.6 |
| Crit W.S. (ft) | 3558.28 | Flow Area (sq ft) | 56.63 | 5362.1 | 1668.28 |
| E.G. Slope (ft/ft) | 0.008633 | Area (sq ft) | 56.63 | 5362.1 | 1668.28 |
| Q Total (cfs) | 165850 | Flow (cfs) | 403.15 | 137197.5 | 28249.33 |
| Top Width (ft) | 387.14 | Top Width (ft) | 4.97 | 265 | 117.17 |
| Vel Total (ft/s) | 23.4 | Avg. Vel. (ft/s) | 7.12 | 25.59 | 16.93 |
| Max Chl Dpth (ft) | 22.48 | Hydr. Depth (ft) | 11.39 | 20.23 | 14.24 |
| Conv. Total (cfs) | 1784978 | Conv. (cfs) | 4338.9 | 1476603 | 304036.4 |
| Length Wtd. (ft) | 885.6 | Wetted Per. (ft) | 16.02 | 265.67 | 128.66 |
| Min Ch El (ft) | 3535.8 | Shear (lb/sq ft) | 1.91 | 10.88 | 6.99 |
| Alpha | 1.08 | Stream Power (lb/ft s) | 13.56 | 278.33 | 118.33 |
| Frctn Loss (ft) | 7.87 | Cum Volume (acre-ft) | 133.16 | 710.02 | 33.07 |
| C & E Loss (ft) | 0.39 | Cum SA (acres) | 16.9 | 38.17 | 4.07 |

| Plan: Natural Beas River Study Reach RS: 8 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3572.6 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 7.54 | Wt. n-Val. | 0.045 | 0.04 | 0.045 |
| W.S. Elev (ft) | 3565.06 | Reach Len. (ft) | 656 | 656 | 656 |
| Crit W.S. (ft) | 3563.58 | Flow Area (sq ft) | 49.35 | 6534.19 | 1167.34 |
| E.G. Slope (ft/ft) | 0.006749 | Area (sq ft) | 49.35 | 6534.19 | 1167.34 |
| Q Total (cfs) | 165850 | Flow (cfs) | 301.76 | 148657.3 | 16890.91 |
| Top Width (ft) | 406.83 | Top Width (ft) | 4.97 | 320 | 81.86 |
| Vel Total (ft/s) | 21.4 | Avg. Vel. (ft/s) | 6.11 | 22.75 | 14.47 |
| Max Chl Dpth (ft) | 23.96 | Hydr. Depth (ft) | 9.93 | 20.42 | 14.26 |
| Conv. Total (cfs) | 2018759 | Conv. (cfs) | 3673.1 | 1809486 | 205599.4 |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | 14.58 | 321.03 | 94.76 |
| Min Ch El (ft) | 3541.1 | Shear (lb/sq ft) | 1.43 | 8.58 | 5.19 |
| Alpha | 1.06 | Stream Power (lb/ft s) | 8.72 | 195.12 | 75.11 |
| Frctn Loss (ft) | 4.99 | Cum Volume (acre-ft) | 133.96 | 799.6 | 54.42 |
| C & E Loss (ft) | 0.16 | Cum SA (acres) | 16.97 | 42.58 | 5.57 |

| Plan: Natural Beas River Study Reach RS: 9 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3579.49 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 8.26 | Wt. n-Val. | 0.045 | 0.04 | 0.045 |
| W.S. Elev (ft) | 3571.24 | Reach Len. (ft) | 656 | 656 | 656 |
| Crit W.S. (ft) | 3571.24 | Flow Area (sq ft) | 46.34 | 5960.27 | 1440.2 |
| E.G. Slope (ft/ft) | 0.008699 | Area (sq ft) | 46.34 | 5960.27 | 1440.2 |
| Q Total (cfs) | 165850 | Flow (cfs) | 315.13 | 143330.6 | 22204.29 |
| Top Width (ft) | 456.47 | Top Width (ft) | 4.97 | 325 | 126.5 |
| Vel Total (ft/s) | 22.27 | Avg. Vel. (ft/s) | 6.8 | 24.05 | 15.42 |
| Max Chl Dpth (ft) | 23.22 | Hydr. Depth (ft) | 9.32 | 18.34 | 11.39 |
| Conv. Total (cfs) | 1778155 | Conv. (cfs) | 3378.6 | 1536714 | 238062.5 |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | 14.12 | 325.97 | 128.59 |
| Min Ch El (ft) | 3548.02 | Shear (lb/sq ft) | 1.78 | 9.93 | 6.08 |
| Alpha | 1.07 | Stream Power (lb/ft s) | 12.12 | 238.81 | 93.78 |
| Frctn Loss (ft) | 5.01 | Cum Volume (acre-ft) | 134.68 | 893.68 | 74.06 |
| C & E Loss (ft) | 0.22 | Cum SA (acres) | 17.05 | 47.44 | 7.13 |

| Plan: Natural Beas River Study Reach RS: 10 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3583.53 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 4.32 | Wt. n-Val. | 0.045 | 0.04 | 0.045 |
| W.S. Elev (ft) | 3579.21 | Reach Len. (ft) | 656 | 656 | 656 |
| Crit W.S. (ft) | | Flow Area (sq ft) | 146.26 | 8129.83 | 2161.58 |
| E.G. Slope (ft/ft) | 0.003845 | Area (sq ft) | 146.26 | 8129.83 | 2161.58 |
| Q Total (cfs) | 165850 | Flow (cfs) | 999.87 | 142390.8 | 22459.35 |
| Top Width (ft) | 587.62 | Top Width (ft) | 14.97 | 385 | 187.65 |
| Vel Total (ft/s) | 15.89 | Avg. Vel. (ft/s) | 6.84 | 17.51 | 10.39 |
| Max Chl Dpth (ft) | 25.65 | Hydr. Depth (ft) | 9.77 | 21.12 | 11.52 |
| Conv. Total (cfs) | 2674544 | Conv. (cfs) | 16124.1 | 2296234 | 362185.8 |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | 23.97 | 387.78 | 189.11 |
| Min Ch El (ft) | 3553.56 | Shear (lb/sq ft) | 1.46 | 5.03 | 2.74 |
| Alpha | 1.1 | Stream Power (lb/ft s) | 10.01 | 88.15 | 28.51 |
| Frctn Loss (ft) | 3.64 | Cum Volume (acre-ft) | 136.13 | 999.78 | 101.18 |
| C & E Loss (ft) | 0.39 | Cum SA (acres) | 17.2 | 52.78 | 9.5 |

| Plan: Natural Beas River Study Reach RS: 11 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3585.77 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 2.82 | Wt. n-Val. | 0.045 | 0.04 | 0.045 |
| W.S. Elev (ft) | 3582.94 | Reach Len. (ft) | 656 | 656 | 656 |
| Crit W.S. (ft) | | Flow Area (sq ft) | 70.48 | 10574.04 | 1967.66 |
| E.G. Slope (ft/ft) | 0.002687 | Area (sq ft) | 70.48 | 10574.04 | 1967.66 |
| Q Total (cfs) | 165850 | Flow (cfs) | 320.4 | 147304 | 18225.61 |
| Top Width (ft) | 703.81 | Top Width (ft) | 9.97 | 540 | 153.84 |
| Vel Total (ft/s) | 13.15 | Avg. Vel. (ft/s) | 4.55 | 13.93 | 9.26 |
| Max Chl Dpth (ft) | 24.14 | Hydr. Depth (ft) | 7.07 | 19.58 | 12.79 |
| Conv. Total (cfs) | 3199468 | Conv. (cfs) | 6181 | 2841691 | 351596.3 |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | 16.28 | 543.43 | 156.31 |
| Min Ch El (ft) | 3558.8 | Shear (lb/sq ft) | 0.73 | 3.26 | 2.11 |
| Alpha | 1.05 | Stream Power (lb/ft s) | 3.3 | 45.47 | 19.56 |
| Frctn Loss (ft) | 2.09 | Cum Volume (acre-ft) | 137.76 | 1140.61 | 132.27 |
| C & E Loss (ft) | 0.15 | Cum SA (acres) | 17.39 | 59.75 | 12.07 |

| Plan: Natural Beas River Study Reach RS: 12 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3588.61 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 5.01 | Wt. n-Val. | 0.045 | 0.04 | 0.045 |
| W.S. Elev (ft) | 3583.6 | Reach Len. (ft) | 606.8 | 606.8 | 606.8 |
| Crit W.S. (ft) | | Flow Area (sq ft) | 2.85 | 8920.02 | 462.58 |
| E.G. Slope (ft/ft) | 0.005088 | Area (sq ft) | 2.85 | 8920.02 | 462.58 |
| Q Total (cfs) | 165850 | Flow (cfs) | 4.48 | 161754.5 | 4091.05 |
| Top Width (ft) | 557.74 | Top Width (ft) | 4.97 | 495 | 57.77 |
| Vel Total (ft/s) | 17.67 | Avg. Vel. (ft/s) | 1.57 | 18.13 | 8.84 |
| Max Chl Dpth (ft) | 21.51 | Hydr. Depth (ft) | 0.57 | 18.02 | 8.01 |
| Conv. Total (cfs) | 2325215 | Conv. (cfs) | 62.8 | 2267796 | 57356.4 |
| Length Wtd. (ft) | 606.8 | Wetted Per. (ft) | 5.23 | 498.21 | 63.57 |
| Min Ch El (ft) | 3562.09 | Shear (lb/sq ft) | 0.17 | 5.69 | 2.31 |
| Alpha | 1.03 | Stream Power (lb/ft s) | 0.27 | 103.12 | 20.44 |
| Frctn Loss (ft) | 2.19 | Cum Volume (acre-ft) | 138.27 | 1276.39 | 149.2 |
| C & E Loss (ft) | 0.66 | Cum SA (acres) | 17.49 | 66.96 | 13.55 |

| Plan: Natural Beas River Study Reach RS: 13 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3596.71 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 7.55 | Wt. n-Val. | 0.045 | 0.04 | 0.045 |
| W.S. Elev (ft) | 3589.16 | Reach Len. (ft) | 656 | 656 | 656 |
| Crit W.S. (ft) | 3589.16 | Flow Area (sq ft) | 0.72 | 6991.49 | 749.9 |
| E.G. Slope (ft/ft) | 0.008548 | Area (sq ft) | 0.72 | 6991.49 | 749.9 |
| Q Total (cfs) | 165850 | Flow (cfs) | 1.03 | 157235.8 | 8613.15 |
| Top Width (ft) | 515.59 | Top Width (ft) | 2.19 | 415 | 98.4 |
| Vel Total (ft/s) | 21.42 | Avg. Vel. (ft/s) | 1.42 | 22.49 | 11.49 |
| Max Chl Dpth (ft) | 21.09 | Hydr. Depth (ft) | 0.33 | 16.85 | 7.62 |
| Conv. Total (cfs) | 1793793 | Conv. (cfs) | 11.1 | 1700624 | 93157.8 |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | 2.29 | 417.27 | 102.77 |
| Min Ch El (ft) | 3568.07 | Shear (lb/sq ft) | 0.17 | 8.94 | 3.89 |
| Alpha | 1.06 | Stream Power (lb/ft s) | 0.24 | 201.1 | 44.73 |
| Frctn Loss (ft) | 4.25 | Cum Volume (acre-ft) | 138.3 | 1396.2 | 158.33 |
| C & E Loss (ft) | 0.76 | Cum SA (acres) | 17.55 | 73.81 | 14.72 |

| Plan: Natural Beas River Study Reach RS: 14 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3606.96 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 7.36 | Wt. n-Val. | 0.045 | 0.04 | 0.045 |
| W.S. Elev (ft) | 3599.59 | Reach Len. (ft) | 656 | 656 | 656 |
| Crit W.S. (ft) | 3599.59 | Flow Area (sq ft) | 29.24 | 6870.24 | 1185.66 |
| E.G. Slope (ft/ft) | 0.007478 | Area (sq ft) | 29.24 | 6870.24 | 1185.66 |
| Q Total (cfs) | 165850 | Flow (cfs) | 165.69 | 154109.7 | 11574.57 |
| Top Width (ft) | 557.74 | Top Width (ft) | 4.97 | 370 | 182.77 |
| Vel Total (ft/s) | 20.51 | Avg. Vel. (ft/s) | 5.67 | 22.43 | 9.76 |
| Max Chl Dpth (ft) | 23.29 | Hydr. Depth (ft) | 5.88 | 18.57 | 6.49 |
| Conv. Total (cfs) | 1917861 | Conv. (cfs) | 1916 | 1782098 | 133846.3 |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | 10.46 | 372.34 | 187.57 |
| Min Ch El (ft) | 3576.3 | Shear (lb/sq ft) | 1.31 | 8.61 | 2.95 |
| Alpha | 1.13 | Stream Power (lb/ft s) | 7.4 | 193.23 | 28.81 |
| Frctn Loss (ft) | 5.24 | Cum Volume (acre-ft) | 138.53 | 1500.58 | 172.9 |
| C & E Loss (ft) | 0.02 | Cum SA (acres) | 17.6 | 79.72 | 16.84 |

| Plan: Natural Beas River Study Reach RS: 15 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3610.8 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 4.27 | Wt. n-Val. | 0.045 | 0.04 | 0.045 |
| W.S. Elev (ft) | 3606.54 | Reach Len. (ft) | 705.2 | 705.2 | 705.2 |
| Crit W.S. (ft) | | Flow Area (sq ft) | 111.32 | 8295.85 | 2001.88 |
| E.G. Slope (ft/ft) | 0.003591 | Area (sq ft) | 111.32 | 8295.85 | 2001.88 |
| Q Total (cfs) | 165850 | Flow (cfs) | 615.11 | 143572.1 | 21662.77 |
| Top Width (ft) | 544.62 | Top Width (ft) | 19.97 | 380 | 144.65 |
| Vel Total (ft/s) | 15.93 | Avg. Vel. (ft/s) | 5.53 | 17.31 | 10.82 |
| Max Chl Dpth (ft) | 25.24 | Hydr. Depth (ft) | 5.57 | 21.83 | 13.84 |
| Conv. Total (cfs) | 2767632 | Conv. (cfs) | 10264.6 | 2395868 | 361498.7 |
| Length Wtd. (ft) | 705.2 | Wetted Per. (ft) | 23.86 | 382.7 | 156.53 |
| Min Ch El (ft) | 3581.29 | Shear (lb/sq ft) | 1.05 | 4.86 | 2.87 |
| Alpha | 1.08 | Stream Power (lb/ft s) | 5.78 | 84.1 | 31.03 |
| Frctn Loss (ft) | 3.53 | Cum Volume (acre-ft) | 139.67 | 1623.34 | 198.7 |
| C & E Loss (ft) | 0.31 | Cum SA (acres) | 17.8 | 85.79 | 19.49 |

| Plan: Natural Beas River Study Reach RS: 16 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3613.92 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 4.73 | Wt. n-Val. | 0.045 | 0.04 | 0.045 |
| W.S. Elev (ft) | 3609.19 | Reach Len. (ft) | 656 | 656 | 656 |
| Crit W.S. (ft) | | Flow Area (sq ft) | 15.19 | 5877.38 | 3894.42 |
| E.G. Slope (ft/ft) | 0.005947 | Area (sq ft) | 15.19 | 5877.38 | 3894.42 |
| Q Total (cfs) | 165850 | Flow (cfs) | 60.42 | 111144.2 | 54645.34 |
| Top Width (ft) | 643.04 | Top Width (ft) | 4.97 | 345 | 293.07 |
| Vel Total (ft/s) | 16.95 | Avg. Vel. (ft/s) | 3.98 | 18.91 | 14.03 |
| Max Chl Dpth (ft) | 21.01 | Hydr. Depth (ft) | 3.06 | 17.04 | 13.29 |
| Conv. Total (cfs) | 2150672 | Conv. (cfs) | 783.5 | 1441271 | 708617.3 |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | 7.79 | 346.53 | 301.07 |
| Min Ch El (ft) | 3588.18 | Shear (lb/sq ft) | 0.72 | 6.3 | 4.8 |
| Alpha | 1.06 | Stream Power (lb/ft s) | 2.88 | 119.07 | 67.39 |
| Frctn Loss (ft) | 2.98 | Cum Volume (acre-ft) | 140.62 | 1730.07 | 243.1 |
| C & E Loss (ft) | 0.14 | Cum SA (acres) | 17.99 | 91.25 | 22.78 |

| Plan: Natural Beas River Study Reach RS: 17 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3616.27 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 5.1 | Wt. n-Val. | 0.045 | 0.04 | 0.045 |
| W.S. Elev (ft) | 3611.17 | Reach Len. (ft) | 328 | 328 | 328 |
| Crit W.S. (ft) | | Flow Area (sq ft) | 9.63 | 8555.94 | 767.75 |
| E.G. Slope (ft/ft) | 0.007855 | Area (sq ft) | 9.63 | 8555.94 | 767.75 |
| Q Total (cfs) | 165850 | Flow (cfs) | 36.3 | 157659.8 | 8153.91 |
| Top Width (ft) | 754.59 | Top Width (ft) | 4.97 | 645 | 104.62 |
| Vel Total (ft/s) | 17.77 | Avg. Vel. (ft/s) | 3.77 | 18.43 | 10.62 |
| Max Chl Dpth (ft) | 19.57 | Hydr. Depth (ft) | 1.94 | 13.27 | 7.34 |
| Conv. Total (cfs) | 1871304 | Conv. (cfs) | 409.6 | 1778893 | 92001.5 |
| Length Wtd. (ft) | 328 | Wetted Per. (ft) | 6.59 | 646.17 | 111.05 |
| Min Ch El (ft) | 3591.6 | Shear (lb/sq ft) | 0.72 | 6.49 | 3.39 |
| Alpha | 1.04 | Stream Power (lb/ft s) | 2.7 | 119.65 | 36.01 |
| Frctn Loss (ft) | 2.23 | Cum Volume (acre-ft) | 140.71 | 1784.41 | 260.66 |
| C & E Loss (ft) | 0.11 | Cum SA (acres) | 18.03 | 94.98 | 24.28 |

**APPENDIX-4, INPUT DATA FILE FOR HEC-6 FOR SIMULATION OF BEAS RIVER IN NATURAL CONDITION FOR 2 YEAR AND 500 YEAR TETURN PERIOD FLOODS (MOBILE BED APPLICATION).**

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T1       MOBILE BED APPLICATION IN NATURAL CONDITION.
T2       WITH A RATING CURVE AT THE DOWNSTREAM BOUNDARY.
T3       SIMULATION OF BEAS RIVER FOR 2 YEAR AND 500 YEAR RETURN PERIOD FLOODS
NC  .045    .045    .040      .1      .3
X1   1.0     23.  685.52  993.84      0.      0.      0.      0.      0.      0.
GR3521.1    0.03 3519.44   52.48 3517.80   98.40 3516.16  147.60 3514.52  226.32
GR3512.9  246.00 3512.88  295.20 3514.52  344.40 3514.52  432.96 3512.88  505.12
GR3511.2  531.36 3504.68  662.56 3503.04  677.32 3502.55  685.52 3501.73  695.36
GR3498.8  724.88 3495.17  823.28 3498.45  921.68 3501.73  951.20 3503.04  954.48
GR3504.7  964.32 3522.72  993.84 3524.20 1013.52
HD   1.0     10.  685.52  993.84
X1   2.0     18.  465.76  793.76  665.84  672.40  669.12      0.      0.      0.
GR3519.4    0.03 3517.80   62.32 3516.16  282.08 3514.52  360.80 3512.88  396.88
GR3511.2  413.28 3509.60  439.52 3507.96  455.92 3506.32  465.76 3503.04  485.44
GR3501.8  498.56 3498.19  531.36 3497.20  596.96 3497.86  662.56 3501.79  675.68
GR3506.3  728.16 3553.88  793.76 3555.52  842.96
HD   2.0     10.  465.76  793.76
X1   3.0     16.  216.48  495.28  623.20  672.40  721.60      0.      0.      0.
GR3519.4    0.03 3517.80   88.56 3516.16  118.08 3514.52  141.04 3512.88  164.00
GR3509.6  216.48 3506.32  255.84 3505.66  265.68 3503.37  282.08 3499.92  364.08
GR3502.4  413.28 3505.66  432.96 3511.24  462.48 3520.26  495.28 3521.08  505.12
GR3522.7  518.24
HD   3.0     10.  216.48  495.28
X1   4.0     12.   55.76  593.68  580.56  787.20  656.00      0.      0.      0.
GR3522.7    0.03 3516.16   55.76 3514.52   65.60 3513.37   88.56 3509.60  127.92
GR3513.4  186.96 3514.52  219.76 3514.85  350.96 3513.37  383.76 3507.63  482.16
GR3513.4  531.36 3524.36  593.68
HD   4.0     10.   55.76  593.68
X1   5.0     14.   82.00  593.68  596.96  754.40  672.40      0.      0.      0.
GR3534.2    0.03 3532.56   82.00 3522.72   83.64 3516.98  131.20 3522.72  173.84
GR3524.4  213.20 3524.36  311.60 3522.72  354.24 3517.80  436.24 3522.72  508.40
GR3524.4  534.64 3526.00  580.56 3531.74  593.68 3532.56  701.92
HD   5.0     10.   82.00  593.68
X1   6.0     15.    6.00  450.00  682.24  688.80  685.52      0.      0.      0.
GR3539.6    0.03 3535.85   82.11 3528.96  118.14 3527.97  147.67 3527.32  160.79
GR3526.8  226.41 3526.50  259.22 3525.68  305.15 3525.51  341.24 3527.65  374.05
GR3527.9  400.29 3529.61  413.42 3529.94  426.54 3531.09  446.22 3546.87  492.16
HD   6.0     10.    6.00  450.00
X1   7.0     11.    5.00  270.00  885.60  885.60  885.60      0.      0.      0.
GR3547.3    0.03 3544.05   19.72 3542.41   36.12 3539.13   59.09 3535.85  108.30
GR3535.8  118.15 3537.49  262.50 3539.13  278.91 3542.41  295.31 3544.05  315.00
GR3547.3  387.17
HD   7.0     10.    5.00  270.00
X1   8.0     12.    5.00  325.00  656.00  656.00  656.00      0.      0.      0.
GR3555.5    0.03 3550.61   32.84 3548.97   45.96 3545.69   68.93 3542.41  118.14
GR3541.1  164.07 3541.62  210.01 3542.41  242.81 3545.69  295.01 3548.97  328.12
GR3550.6  354.36 3552.25  406.86
HD   8.0     10.    5.00  325.00
X1   9.0     11.    5.00  330.00  656.00  656.00  656.00      0.      0.      0.
GR3562.1    0.03 3557.17   65.65 3552.25   98.46 3548.97  157.51 3548.02  177.20
GR3548.9  216.57 3552.25  282.18 3555.53  308.43 3557.17  347.80 3558.81  419.98
GR3572.2  459.32
HD   9.0     10.    5.00  330.00
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X1  10.0      17.    15.00   400.00  656.00   656.00  656.00      0.        0.        0.
GR3570.3    0.03 3565.38    42.68 3558.81    72.21 3553.56   105.02 3555.53   157.51
GR3558.8  170.63 3558.81   216.57 3555.53   252.65 3555.53   275.62 3558.81   288.74
GR3558.8  354.36 3555.53   374.05 3555.53   393.73 3558.81   406.85 3562.09   433.10
GR3565.3  485.59 3579.60   590.55
HD  10.0      10.    15.00   400.00
X1  11.0      16.    10.00   550.00  656.00   656.00  656.00      0.        0.        0.
GR3576.8    0.03 3571.94    26.28 3565.38    42.68 3562.09    78.77 3558.81   118.14
GR3558.8  183.76 3563.74   210.00 3565.38   465.91 3562.09   479.03 3558.81   498.72
GR3565.3  544.65 3565.34   570.90 3562.09   590.58 3568.66   616.80 3571.94   656.20
GR3583.3  705.38
HD  11.0      10.    10.00   550.00
X1  12.0      12.     5.00   500.00  606.80   606.80  606.80      0.        0.        0.
GR3583.4    0.03 3578.50    32.84 3568.66    52.52 3565.38    85.33 3563.93   150.95
GR3563.0  216.57 3562.09   314.99 3565.38   439.66 3568.66   492.16 3571.94   505.28
GR3575.2  518.40 3578.50   557.77
HD  12.0      10.     5.00   500.00
X1  13.0      10.     5.00   420.00  656.00   656.00  656.00      0.        0.        0.
GR3590.0    0.03 3585.06    16.43 3571.94    78.77 3568.66   196.88 3568.07   216.57
GR3568.6  275.62 3571.94   354.36 3575.22   393.73 3578.50   426.54 3585.06   518.40
HD  13.0      10.     5.00   420.00
X1  14.0      15.     5.00   375.00  656.00   656.00  656.00      0.        0.        0.
GR3594.2    0.03 3591.62    13.15 3588.34    29.55 3585.06    59.08 3581.78    98.45
GR3578.5  137.82 3576.86   183.83 3576.30   190.32 3576.86   262.49 3578.50   314.99
GR3581.7  334.67 3585.06   347.80 3588.34   357.64 3591.62   387.17 3594.90   557.77
HD  14.0      10.     5.00   375.00
X1  15.0      13.    20.00   400.00  705.20   705.20  705.20      0.        0.        0.
GR3603.1    0.03 3598.18    23.00 3591.62    32.84 3588.34    52.52 3585.06   127.98
GR3581.7  216.57 3581.29   249.37 3581.78   295.31 3585.06   367.48 3588.34   400.29
GR3591.6  426.54 3592.64   459.35 3594.90   544.65
HD  15.0      10.    20.00   400.00
X1  16.0      13.     5.00   350.00  656.00   656.00  656.00      0.        0.        0.
GR3606.4    0.03 3601.46    45.96 3598.18    52.52 3594.90    72.21 3591.62   105.02
GR3588.3  216.57 3588.18   229.69 3588.34   262.50 3591.62   374.05 3594.90   459.32
GR3596.2  472.47 3598.18   597.14 3601.46   643.07
HD  16.0      10.     5.00   350.00
X1  17.0       9.     5.00   650.00  328.00   328.00  328.00      0.        0.        0.
GR3609.6    0.03 3604.75    32.84 3598.18    85.33 3594.90   111.58 3591.62   196.88
GR3591.6  229.69 3594.90   321.55 3598.18   380.61 3604.75   754.62
HD  17.0      10.     5.00   650.00
EJ
T4       BEAS RIVER FROM CHAINAGE 0+000 TO 3+270
T5       LOAD CURVE FROM GAGE DATA.
T6       BED GRADATIONS FROM FIELD SAMPLES.
T7       Use Full Range of Sands, Gravels, Cobbles and Boulders
T8       SEDIMENT TRANSPORT BY Yang's STREAM POWER [ref ASCE JOURNAL (YANG 1971)]
I1             10
I2  CLAY        2
I2              1    .0585    .1170     .264    6.860    93.30
I2              2    .0585    .1170     .264    6.860    93.30
I3  SILT        2        4        4
I4  SAND        4        1       15
I5             .5       .5      .25       .5      .25        0      1.0
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LQ              200       1000      10000     50000    100000    200000
LT TOTAL        115        780      10200     72500    182000    432000
LF   CLAY      .000       .000       .000      .000      .000      .000
LF   SILT      .280       .250       .150      .100      .150      .150
LF    VFS      .450       .350       .350      .250      .220      .080
LF     FS      .150       .250       .220      .200      .180      .120
LF     MS      .100       .080       .100      .150      .130      .150
LF     CS      .020       .050       .080      .150      .120      .180
LF    VCS      .000       .020       .060      .100      .100      .120
LF    VFG      .000       .000       .030      .030      .050      .100
LF     FG      .000       .000       .010      .020      .040      .060
LF     MG      .000       .000       .000      .000      .010      .030
LF     CG      .000       .000       .000      .000      .000      .010
LF    VCG      .000       .000       .000      .000      .000      .000
LF     SC      .000       .000       .000      .000      .000      .000
LF     LC      .000       .000       .000      .000      .000      .000
LF     SB      .000       .000       .000      .000      .000      .000
LF     MB      .000       .000       .000      .000      .000      .000
LF     LB      .000       .000       .000      .000      .000      .000
PF EXAMP        1.0        1.0     2048.0    1024.0     97.98     512.0     95.48     256.0     92.98
PFC128.0      86.98       64.0      72.48      32.0     48.55      16.0     27.55       8.0     13.70
PFC   4.0      9.35        2.0       8.01       1.0      7.44       0.5      7.17      0.25      4.29
PFC0.125       1.43      0.062       0.75
$HYD
$RATING
RC               28 7057.51          0         0 3495.17 3500.78 3502.94 3504.52 3505.93
RC          3507.21 3508.29 3509.34 3510.26 3511.17 3511.90 3512.62 3513.34 3514.29
RC          3516.00 3516.55 3516.98 3517.24 3517.64 3518.03 3518.46 3518.82 3519.18
RC          3519.54 3519.87 3520.19 3520.46 3520.85
*    AB     PROFILE 1 = 2 YEAR RETURN PERIOD FLOOD
Q 28230.
T     60.
W      1.
*    AB     PROFILE 2 = 500 YEAR RETURN PERIOD FLOOD
Q165850.
T     60.
W      1.
$$END
```

**APPENDIX-5, OUTPUT OF HEC-6 FOR SIMULATION OF BEAS RIVER IN NATURA CONDITION WITH 2 YEAR AND 500 YEAR RETURN PERIOD FLOODS (MOBILE BI APPLICATION).**

```
***************************************************      **********************************
*  SCOUR AND DEPOSITION IN RIVERS AND RESERVOIRS   *      *  U.S. ARMY CORPS OF ENGINEERS
*       Version: 4.1.00 -  OCTOBER 1993            *      *  HYDROLOGIC ENGINEERING CENTER
*  INPUT FILE:  MOBILE.DAT                         *      *  609 SECOND STREET
*  OUTPUT FILE: MOBILE.OUT                         *      *  DAVIS, CALIFORNIA 95616-4687
*  RUN DATE: 27 FEB 04     RUN TIME: 14:38:19      *      *  (916) 756-1104
***************************************************      **********************************

                       X     X  XXXXXXX   XXXXX           XXXXX
                       X     X  X        X     X         X     X
                       X     X  X        X               X
                       XXXXXXX  XXXX     X        XXXXX  XXXXXX
                       X     X  X        X               X     X
                       X     X  X        X     X         X     X
                       X     X  XXXXXXX   XXXXX           XXXXX

         ***********************************************************************
         *  MAXIMUM LIMITS FOR THIS VERSION ARE:                               *
         *       10  Stream Segments (Main Stem + Tributaries)                 *
         *      500  Cross Sections                                            *
         *      200  Elevation/Station Points per Cross Section                *
         *       20  Grain Sizes                                               *
         *       10  Control Points                                            *
         ***********************************************************************

T1       MOBILE BED APPLICATION IN NATURAL CONDITION.
T2       WITH A RATING CURVE AT THE DOWNSTREAM BOUNDARY.
T3       SIMULATION OF BEAS RIVER FOR 2 YEAR AND 500 YEAR RETURN PERIOD FLOODS

N values...  Left    Channel   Right    Contraction   Expansion
            0.0450   0.0400   0.0450      1.1000       0.7000

SECTION NO.      1.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

SECTION NO.      2.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

SECTION NO.      3.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

SECTION NO.      4.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

SECTION NO.      5.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

SECTION NO.      6.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

SECTION NO.      7.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

SECTION NO.      8.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

SECTION NO.      9.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.
```

```
SECTION NO.    10.000
 ...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

 SECTION NO.    11.000
 ...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

 SECTION NO.    12.000
 ...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

 SECTION NO.    13.000
 ...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

 SECTION NO.    14.000
 ...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

 SECTION NO.    15.000
 ...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

 SECTION NO.    16.000
 ...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

 SECTION NO.    17.000
 ...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

 NO. OF CROSS SECTIONS IN STREAM SEGMENT= 17
 NO. OF INPUT DATA MESSAGES =   0

 TOTAL NO. OF CROSS SECTIONS IN THE NETWORK =  17
 TOTAL NO. OF STREAM SEGMENTS IN THE NETWORK=   1
 END OF GEOMETRIC DATA


==========================================================================================

 T4       BEAS RIVER FROM CHAINAGE 0+000 TO 3+270
 T5       LOAD CURVE FROM GAGE DATA.
 T6       BED GRADATIONS FROM FIELD SAMPLES.
 T7       Use Full Range of Sands, Gravels, Cobbles and Boulders
 T8       SEDIMENT TRANSPORT BY Yang's STREAM POWER [ref ASCE JOURNAL (YANG 1971)]

          MOBILE BED APPLICATION IN NATURAL CONDITION.
          WITH A RATING CURVE AT THE DOWNSTREAM BOUNDARY.
          SIMULATION OF BEAS RIVER FOR 2 YEAR AND 500 YEAR RETURN PERIOD FLOODS

 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
 SEDIMENT PROPERITES AND PARAMETERS

        SPI      IBG    MNQ      SPGF      ACGR     NFALL    IBSHER
 I1     10.        0      1     1.000    32.174        2          1
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
 CLAY IS PRESENT.

        MTCL     SPGC      PUCD       UWCL      CCCD
 I2      2      2.650    78.000     30.000    16.000
```

DEPOSITION COEFFICIENTS BY LAYER

| LAYER NO. | DEPOSITION THRESHOLD SHEAR STRESS lb/sq.ft |
|---|---|
| ACTIVE LAYER 1 | 0.0585 |
| INACTIVE LAYER 2 | 0.0585 |

EROSION COEFFICIENTS BY LAYER

| LAYER NO | PARTICLE EROSION SHEAR STRESS lb/sq.ft | MASS EROSION SHEAR STRESS lb/sq.ft. | MASS EROSION RATE lb/sf/hr | SLOPE OF PARTICLE EROSION LINE=ER1 1/hr | SLOPE OF MASS EROSION LINE=ER2 1/hr |
|---|---|---|---|---|---|
| ACTIVE LAYER 1 | 0.1170 | 0.2640 | 6.8600 | 46.6667 | 93.3000 |
| INACTIVE LAYER 2 | 0.1170 | 0.2640 | 6.8600 | 46.6667 | 93.3000 |

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

SILT IS PRESENT

| | MTCL | IASL | LASL | SGSL | PUSDLB | UWSDLB | CCSDLB |
|---|---|---|---|---|---|---|---|
| I3 | 2 | 4 | 4 | 2.650 | 82.000 | 65.000 | 5.700 |

DEPOSITION COEFFICIENTS BY LAYER

| LAYER NO. | DEPOSITION THRESHOLD SHEAR STRESS lb/sq.ft |
|---|---|
| ACTIVE LAYER 1 | 0.0200 |
| INACTIVE LAYER 2 | 0.0200 |

EROSION COEFFICIENTS BY LAYER

| LAYER NO | PARTICLE EROSION SHEAR STRESS lb/sq.ft | MASS EROSION SHEAR STRESS lb/sq.ft. | MASS EROSION RATE lb/sf/hr | SLOPE OF PARTICLE EROSION LINE=ER1 1/hr | SLOPE OF MASS EROSION LINE=ER2 1/hr |
|---|---|---|---|---|---|
| ACTIVE LAYER 1 | 0.1170 | 0.2640 | 6.8600 | 46.6667 | 93.3000 |
| INACTIVE LAYER 2 | 0.1170 | 0.2640 | 6.8600 | 46.6667 | 93.3000 |

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

SANDS - BOULDERS ARE PRESENT

| | MTC | IASA | LASA | SPGS | GSF | BSAE | PSI | UWDLB |
|---|---|---|---|---|---|---|---|---|
| I4 | 4 | 1 | 15 | 2.650 | 0.667 | 0.500 | 30.000 | 93.000 |

USING TRANSPORT CAPACITY RELATIONSHIP # 4, YANG
GRAIN SIZES UTILIZED (mean diameter - mm)

| | | | |
|---|---|---|---|
| CLAY.............. | 0.003 | MEDIUM GRAVEL..... | 11.314 |
| COARSE SILT....... | 0.045 | COARSE GRAVEL..... | 22.627 |
| VERY FINE SAND.... | 0.088 | VERY COARSE GRAVEL | 45.255 |
| FINE SAND......... | 0.177 | SMALL COBBLES..... | 90.510 |
| MEDIUM SAND....... | 0.354 | LARGE COBBLES..... | 181.019 |
| COARSE SAND....... | 0.707 | SMALL BOULDERS.... | 362.039 |
| VERY COARSE SAND.. | 1.414 | MEDIUM BOULDERS... | 724.077 |
| VERY FINE GRAVEL.. | 2.828 | LARGE BOULDERS.... | 1448.150 |
| FINE GRAVEL....... | 5.657 | | |

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

COEFFICIENTS FOR COMPUTATION SCHEME WERE SPECIFIED

| | DBI | DBN | XID | XIN | XIU | UBI | UBN | JSL |
|---|---|---|---|---|---|---|---|---|
| I5 | 0.500 | 0.500 | 0.250 | 0.500 | 0.250 | 0.000 | 1.000 | 1 |

SEDIMENT LOAD TABLE FOR STREAM SEGMENT # 1

LOAD BY GRAIN SIZE CLASS (tons/day)

| LQ | | 200.000 | 1000.00 | 10000.0 | 50000.0 | 100000. | 200000. |
|---|---|---|---|---|---|---|---|
| LF | CLAY | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 |
| LF | SILT | 32.2000 | 195.000 | 1530.00 | 7250.00 | 27300.0 | 64800.0 |
| LF | VFS | 51.7500 | 273.000 | 3570.00 | 18125.0 | 40040.0 | 34560.0 |
| LF | FS | 17.2500 | 195.000 | 2244.00 | 14500.0 | 32760.0 | 51840.0 |
| LF | MS | 11.5000 | 62.4000 | 1020.00 | 10875.0 | 23660.0 | 64800.0 |
| LF | CS | 2.30000 | 39.0000 | 816.000 | 10875.0 | 21840.0 | 77760.0 |
| LF | VCS | 0.100000E-19 | 15.6000 | 612.000 | 7250.00 | 18200.0 | 51840.0 |
| LF | VFG | 0.100000E-19 | 0.100000E-19 | 306.000 | 2175.00 | 9100.00 | 43200.0 |
| LF | FG | 0.100000E-19 | 0.100000E-19 | 102.000 | 1450.00 | 7280.00 | 25920.0 |
| LF | MG | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 1820.00 | 12960.0 |
| LF | CG | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 4320.00 |
| LF | VCG | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 |
| LF | SC | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 |
| LF | LC | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 |
| LF | SB | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 |
| LF | MB | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 |
| LF | LB | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 |
| | TOTAL | 115.000 | 780.000 | 10200.0 | 72500.0 | 182000. | 432000. |

REACH GEOMETRY FOR STREAM SEGMENT 1

| CROSS SECTION NO. | REACH LENGTH (ft) | MOVABLE BED WIDTH | INITIAL BED-ELEVATIONS LEFT SIDE (ft) | THALWEG (ft) | RIGHT SIDE (ft) | ACCUMULATED CHANNEL DISTANCE FROM DOWNSTREAM (ft) | (miles) |
|---|---|---|---|---|---|---|---|
| | 0.000 | | | | | | |
| 1.000 | | 322.260 | 3502.550 | 3495.170 | 3522.720 | 0.000 | 0.000 |
| | 669.120 | | | | | | |
| 2.000 | | 357.520 | 3506.320 | 3497.200 | 3553.880 | 669.120 | 0.127 |
| | 721.600 | | | | | | |
| 3.000 | | 309.960 | 3509.600 | 3499.920 | 3520.260 | 1390.720 | 0.263 |
| | 656.000 | | | | | | |
| 4.000 | | 565.785 | 3516.160 | 3507.630 | 3524.360 | 2046.720 | 0.388 |
| | 672.400 | | | | | | |
| 5.000 | | 606.785 | 3532.560 | 3516.980 | 3531.740 | 2719.120 | 0.515 |
| | 685.520 | | | | | | |
| 6.000 | | 468.065 | 3539.327 | 3525.510 | 3532.388 | 3404.640 | 0.645 |
| | 885.600 | | | | | | |
| 7.000 | | 271.940 | 3546.480 | 3535.800 | 3538.240 | 4290.240 | 0.813 |
| | 656.000 | | | | | | |
| 8.000 | | 324.045 | 3554.759 | 3541.100 | 3548.661 | 4946.240 | 0.937 |
| | 656.000 | | | | | | |
| 9.000 | | 336.385 | 3561.727 | 3548.020 | 3556.429 | 5602.240 | 1.061 |
| | 656.000 | | | | | | |
| 10.000 | | 395.910 | 3568.573 | 3553.560 | 3557.097 | 6258.240 | 1.185 |
| | 656.000 | | | | | | |
| 11.000 | | 555.435 | 3574.954 | 3558.800 | 3565.308 | 6914.240 | 1.310 |
| | 606.800 | | | | | | |
| 12.000 | | 500.125 | 3582.658 | 3562.090 | 3570.620 | 7521.040 | 1.424 |
| | 656.000 | | | | | | |
| 13.000 | | 420.755 | 3588.503 | 3568.070 | 3577.846 | 8177.040 | 1.549 |
| | 656.000 | | | | | | |
| 14.000 | | 378.570 | 3593.223 | 3576.300 | 3590.268 | 8833.040 | 1.673 |
| | 705.200 | | | | | | |
| 15.000 | | 390.130 | 3598.823 | 3581.290 | 3588.311 | 9538.240 | 1.806 |
| | 656.000 | | | | | | |
| 16.000 | | 359.510 | 3605.865 | 3588.180 | 3590.913 | 10194.240 | 1.931 |
| | 328.000 | | | | | | |
| 17.000 | | 699.795 | 3608.865 | 3591.600 | 3602.912 | 10522.240 | 1.993 |

BED MATERIAL GRADATION

| SECNO | SAE | DMAX (ft) | DXPI (ft) | XPI | TOTAL BED | BED MATERIAL FRACTIONS per grain size | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 2.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 3.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 4.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 6.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 7.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 8.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 9.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 10.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 11.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 12.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VCGRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 13.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 14.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 15.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 16.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.200 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 17.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |

BED SEDIMENT CONTROL VOLUMES

STREAM SEGMENT # 1: MOBILE BED APPLICATION IN NATURAL CONDITION.

| SECTION NUMBER | LENGTH (ft) | WIDTH (ft) | DEPTH (ft) | VOLUME (cu.ft) | VOLUME (cu.yd) |
|---|---|---|---|---|---|
| 1.000 | 334.560 | 334.013 | 10.000 | 0.111748E+07 | 41388.0 |
| 2.000 | 695.360 | 343.639 | 10.000 | 0.238953E+07 | 88501.1 |
| 3.000 | 688.800 | 358.871 | 10.000 | 0.247191E+07 | 91552.0 |
| 4.000 | 664.200 | 530.592 | 10.000 | 0.352419E+07 | 130526. |
| 5.000 | 678.960 | 576.674 | 10.000 | 0.391539E+07 | 145014. |
| 6.000 | 785.560 | 451.390 | 10.000 | 0.354594E+07 | 131331. |
| 7.000 | 770.800 | 316.887 | 10.000 | 0.244256E+07 | 90465.3 |
| 8.000 | 656.000 | 317.418 | 10.000 | 0.208226E+07 | 77120.7 |
| 9.000 | 656.000 | 344.249 | 10.000 | 0.225827E+07 | 83639.8 |
| 10.000 | 656.000 | 412.577 | 10.000 | 0.270650E+07 | 100241. |
| 11.000 | 631.400 | 518.952 | 10.000 | 0.327667E+07 | 121358. |
| 12.000 | 631.400 | 495.240 | 10.000 | 0.312695E+07 | 115813. |
| 13.000 | 656.000 | 426.952 | 10.000 | 0.280081E+07 | 103734. |
| 14.000 | 680.600 | 387.343 | 10.000 | 0.263626E+07 | 97639.1 |
| 15.000 | 680.600 | 383.215 | 10.000 | 0.260816E+07 | 96598.5 |
| 16.000 | 492.000 | 404.124 | 10.000 | 0.198829E+07 | 73640.4 |
| 17.000 | 164.000 | 586.367 | 10.000 | 961641. | 35616.3 |

NO. OF INPUT DATA MESSAGES= 0
END OF SEDIMENT DATA

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$HYD
BEGIN COMPUTATIONS.

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$RATING

Downstream Boundary Condition - Rating Curve

| Elevation | Stage | Discharge | Elevation | Stage | Discharge |
|---|---|---|---|---|---|
| 3495.170 | 3495.170 | 0.000 | 3516.000 | 3516.000 | 98805.140 |
| 3500.780 | 3500.780 | 7057.510 | 3516.550 | 3516.550 | 105862.650 |
| 3502.940 | 3502.940 | 14115.020 | 3516.980 | 3516.980 | 112920.160 |
| 3504.520 | 3504.520 | 21172.530 | 3517.240 | 3517.240 | 119977.670 |
| 3505.930 | 3505.930 | 28230.040 | 3517.640 | 3517.640 | 127035.180 |
| 3507.210 | 3507.210 | 35287.550 | 3518.030 | 3518.030 | 134092.690 |
| 3508.290 | 3508.290 | 42345.060 | 3518.460 | 3518.460 | 141150.200 |
| 3509.340 | 3509.340 | 49402.570 | 3518.820 | 3518.820 | 148207.710 |
| 3510.260 | 3510.260 | 56460.080 | 3519.180 | 3519.180 | 155265.220 |
| 3511.170 | 3511.170 | 63517.590 | 3519.540 | 3519.540 | 162322.730 |
| 3511.900 | 3511.900 | 70575.100 | 3519.870 | 3519.870 | 169380.240 |
| 3512.620 | 3512.620 | 77632.610 | 3520.190 | 3520.190 | 176437.750 |
| 3513.340 | 3513.340 | 84690.120 | 3520.460 | 3520.460 | 183495.260 |
| 3514.290 | 3514.290 | 91747.630 | 3520.850 | 3520.850 | 190552.770 |

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TIME STEP # 1
* AB PROFILE 1 = 2 YEAR RETURN PERIOD FLOOD

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MOBILE BED APPLICATION IN NATURAL CONDITION.
ACCUMULATED TIME (yrs).......... 0.000

--- Downstream Boundary Condition Data for STREAM SEGMENT NO. 1 at Control Point # 1 ---

| DISCHARGE (cfs) | TEMPERATURE (deg F) | WATER SURFACE (ft) |
|---|---|---|
| 28230.000 | 60.00 | 3505.930 |

```
**** DISCHARGE     WATER    ENERGY  VELOCITY   ALPHA     TOP      AVG      AVG VEL (by subsection)
       (CFS)       SURFACE   LINE     HEAD               WIDTH     BED         1        2        3

SECTION NO.       1.000
****  28230.000  3505.930  3508.446   2.516     1.037   328.928  3498.140   3.785   12.780    0.000
                                                FLOW DISTRIBUTION (%) =     0.965   99.035    0.000
SECTION NO.       2.000
****  28230.000  3510.329  3511.995   1.665     1.028   306.302  3500.241   2.714   10.381    0.000
                                                FLOW DISTRIBUTION (%) =     0.591   99.409    0.000
SECTION NO.       3.000
****  28230.000  3513.173  3515.463   2.289     1.049   309.622  3504.161   3.724   12.212    0.000
                                                FLOW DISTRIBUTION (%) =     1.347   98.653    0.000
SECTION NO.       4.000
****  28230.000  3518.176  3519.844   1.669     1.007   520.149  3512.773   3.017   10.371    0.000
                                                FLOW DISTRIBUTION (%) =     0.188   99.812    0.000
SECTION NO.       5.000
** SUPERCRITICAL **  Using Critical Water Surface +
SECTION NO.       5.000 TIME =      1.000 DAYS.
TRIAL    TRIAL        COMPUTED     CRITICAL
 NO.       WS            WS           WS
  0.    3526.763      3525.022
  1.    3526.857      3524.866     3526.807
****  28230.000  3526.857  3529.141   2.283     1.000   499.568  3522.195   0.000   12.122    0.000
                                                FLOW DISTRIBUTION (%) =     0.000  100.000    0.000
SECTION NO.       6.000
****  28230.000  3534.203  3536.429   2.226     1.003   364.555  3527.642   0.000   11.970    2.746
                                                FLOW DISTRIBUTION (%) =     0.000   99.953    0.047
SECTION NO.       7.000
** SUPERCRITICAL **  Using Critical Water Surface +
SECTION NO.       7.000 TIME =      1.000 DAYS.
TRIAL    TRIAL        COMPUTED     CRITICAL
 NO.       WS            WS           WS
  0.    3544.895      3542.209
  1.    3544.989      3542.102     3544.939
****  28230.000  3544.989  3548.238   3.249     1.065   321.817  3537.779   0.000   14.693    6.559
                                                FLOW DISTRIBUTION (%) =     0.000   96.056    3.944
SECTION NO.       8.000
****  28230.000  3551.827  3554.043   2.216     1.045   368.897  3544.070   0.000   11.997    3.199
                                                FLOW DISTRIBUTION (%) =     0.000   99.011    0.989
SECTION NO.       9.000
** SUPERCRITICAL **  Using Critical Water Surface +
SECTION NO.       9.000 TIME =      1.000 DAYS.
TRIAL    TRIAL        COMPUTED     CRITICAL
 NO.       WS            WS           WS
  0.    3558.852      3556.848
  1.    3558.946      3556.805     3558.896
****  28230.000  3558.946  3561.865   2.919     1.063   378.374  3551.943   0.000   13.797    3.762
                                                FLOW DISTRIBUTION (%) =     0.000   98.571    1.429
SECTION NO.      10.000
****  28230.000  3565.014  3566.496   1.482     1.058   437.242  3557.336   0.000    9.922    4.669
                                                FLOW DISTRIBUTION (%) =     0.000   96.020    3.980
SECTION NO.      11.000
****  28230.000  3568.679  3569.901   1.222     1.023   582.693  3562.928   0.000    9.003    6.024
                                                FLOW DISTRIBUTION (%) =     0.000   94.560    5.440
SECTION NO.      12.000
****  28230.000  3571.635  3572.784   1.149     1.001   457.376  3564.394   0.000    8.597    1.259
                                                FLOW DISTRIBUTION (%) =     0.000   99.991    0.009
SECTION NO.      13.000
** SUPERCRITICAL **  Using Critical Water Surface +
SECTION NO.      13.000 TIME =      1.000 DAYS.
TRIAL    TRIAL        COMPUTED     CRITICAL
 NO.       WS            WS           WS
  0.    3576.484      3574.748
  1.    3576.578      3574.729     3576.528
****  28230.000  3576.578  3579.482   2.904     1.000   350.584  3570.688   0.000   13.670    0.000
                                                FLOW DISTRIBUTION (%) =     0.000  100.000    0.000
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SECTION NO.      14.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.     14.000 TIME =      1.000 DAYS.
 TRIAL    TRIAL         COMPUTED      CRITICAL
  NO.       WS             WS            WS
   0.    3585.607      3584.622
   1.    3585.701      3584.513      3585.651
 ****  28230.000  3585.701  3588.926   3.226     1.000   296.413  3579.090    0.000  14.407    0.000
                                                   FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
 SECTION NO.     15.000
 ****  28230.000  3592.419  3593.788   1.369     1.030   420.808  3584.340    0.000   9.418    2.664
                                                   FLOW DISTRIBUTION (%) =     0.000  99.281    0.719
 SECTION NO.     16.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.     16.000 TIME =      1.000 DAYS.
 TRIAL    TRIAL         COMPUTED      CRITICAL
  NO.       WS             WS            WS
   1.    3596.184      3595.921
   2.    3596.277      3595.896      3596.227
 ****  28230.000  3596.277  3599.212   2.935     1.093   413.405  3590.125    0.000  14.291    7.947
                                                   FLOW DISTRIBUTION (%) =     0.000  89.090   10.910
 SECTION NO.     17.000
 ****  28230.000  3601.311  3603.378   2.067     1.000   495.550  3596.372    0.000  11.532    0.000
                                                   FLOW DISTRIBUTION (%) =     0.000 100.000    0.000

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 MOBILE BED APPLICATION IN NATURAL CONDITION.
       ACCUMULATED TIME (yrs)....       0.003
       FLOW DURATION (days)......       1.000

 UPSTREAM BOUNDARY CONDITIONS
 ----------------------------------------------------------------------
 Stream Segment # 1      |   DISCHARGE    | SEDIMENT LOAD | TEMPERATURE
 Section No.      17.000 |     (cfs)      |  (tons/day)   |   (deg F)
 ----------------------------------------------------------------------
                 INFLOW |     28230.00 |       35512.55 |       60.00

TABLE SA-1. TRAP EFFICIENCY ON STREAM SEGMENT #  1
          MOBILE BED APPLICATION IN NATURAL CONDITION.
          ACCUMULATED AC-FT ENTERING AND LEAVING THIS STREAM SEGMENT
****************************************************************************************************
   TIME       ENTRY *               CLAY               *                SILT              *                SAND             *
   DAYS       POINT *     INFLOW   OUTFLOW  TRAP EFF *     INFLOW   OUTFLOW  TRAP EFF *     INFLOW   OUTFLOW  TRAP EFF *
   1.00      17.000 *       0.00                      *       2.95                     *      15.47                      *
  TOTAL=      1.000 *       0.00      3.97********** *       2.95      3.44     -0.17 *      15.47     35.14     -1.27 *
****************************************************************************************************

 TABLE SB-1:  SEDIMENT LOAD PASSING THE  BOUNDARIES OF STREAM SEGMENT #  1
 ------------------------------------------------------------------------------
   SEDIMENT INFLOW at the Upstream Boundary:
       GRAIN SIZE       LOAD (tons/day) |    GRAIN SIZE       LOAD (tons/day)
   ------------------------------------------------------------------------
     CLAY.............          0.00  |  MEDIUM GRAVEL.....          0.00
     COARSE SILT.......      4172.18  |  COARSE GRAVEL.....          0.00
     VERY FINE SAND....     10177.96  |  VERY COARSE GRAVEL          0.00
     FINE SAND.........      7473.96  |  SMALL COBBLES.....          0.00
     MEDIUM SAND.......      4692.09  |  LARGE COBBLES.....          0.00
     COARSE SAND.......      4334.57  |  SMALL BOULDERS....          0.00
     VERY COARSE SAND..      3013.17  |  MEDIUM BOULDERS...       4172.18
     VERY FINE GRAVEL..      1083.78  |  LARGE BOULDERS....      31340.37
     FINE GRAVEL.......       564.85  |
                        -------------                       -------------
                                              TOTAL =        35512.55
```

SEDIMENT OUTFLOW from the Downstream Boundary

| GRAIN SIZE | LOAD (tons/day) | GRAIN SIZE | LOAD (tons/day) |
|---|---|---|---|
| CLAY............. | 2592.78 | MEDIUM GRAVEL..... | 1045.96 |
| COARSE SILT....... | 4876.70 | COARSE GRAVEL..... | 2692.88 |
| VERY FINE SAND.... | 13102.88 | VERY COARSE GRAVEL | 4842.58 |
| FINE SAND......... | 19918.41 | SMALL COBBLES..... | 3279.76 |
| MEDIUM SAND....... | 17223.57 | LARGE COBBLES..... | 0.00 |
| COARSE SAND....... | 4820.55 | SMALL BOULDERS.... | 0.00 |
| VERY COARSE SAND.. | 4023.13 | MEDIUM BOULDERS... | 0.00 |
| VERY FINE GRAVEL.. | 34.02 | LARGE BOULDERS.... | 0.00 |
| FINE GRAVEL....... | 192.16 | | |
| | | TOTAL = | 78645.38 |

TABLE SB-2: STATUS OF THE BED PROFILE AT TIME = 1.000 DAYS

| SECTION NUMBER | BED CHANGE (ft) | WS ELEV (ft) | THALWEG (ft) | Q (cfs) | TRANSPORT RATE (tons/day) CLAY | SILT | SAND |
|---|---|---|---|---|---|---|---|
| 17.000 | -2.84 | 3601.31 | 3588.76 | 28230. | 41. | 4183. | 39938. |
| 16.000 | -1.96 | 3596.28 | 3586.22 | 28230. | 235. | 4236. | 54193. |
| 15.000 | -0.11 | 3592.42 | 3581.18 | 28230. | 298. | 4253. | 55283. |
| 14.000 | -1.25 | 3585.70 | 3575.05 | 28230. | 559. | 4324. | 67893. |
| 13.000 | 0.10 | 3576.58 | 3568.17 | 28230. | 774. | 4382. | 66421. |
| 12.000 | 1.03 | 3571.64 | 3563.12 | 28230. | 816. | 4394. | 52731. |
| 11.000 | 0.17 | 3568.68 | 3558.97 | 28230. | 907. | 4419. | 50256. |
| 10.000 | -0.84 | 3565.01 | 3552.72 | 28230. | 1011. | 4447. | 59424. |
| 9.000 | -1.13 | 3558.95 | 3546.89 | 28230. | 1248. | 4511. | 69539. |
| 8.000 | -0.34 | 3551.83 | 3540.76 | 28230. | 1383. | 4548. | 72407. |
| 7.000 | -0.68 | 3544.99 | 3535.12 | 28230. | 1644. | 4619. | 78844. |
| 6.000 | -0.44 | 3534.20 | 3525.07 | 28230. | 1839. | 4672. | 84301. |
| 5.000 | -0.08 | 3526.86 | 3516.90 | 28230. | 2112. | 4746. | 85115. |
| 4.000 | 0.55 | 3518.18 | 3508.18 | 28230. | 2259. | 4786. | 76594. |
| 3.000 | 0.46 | 3513.17 | 3500.38 | 28230. | 2420. | 4830. | 71464. |
| 2.000 | -0.05 | 3510.33 | 3497.15 | 28230. | 2510. | 4854. | 71767. |
| 1.000 | 0.10 | 3505.93 | 3495.27 | 28230. | 2593. | 4877. | 71176. |

TIME STEP # 2
* AB PROFILE 2 = 500 YEAR RETURN PERIOD FLOOD

MOBILE BED APPLICATION IN NATURAL CONDITION.
ACCUMULATED TIME (yrs).......... 0.003

--- Downstream Boundary Condition Data for STREAM SEGMENT NO. 1 at Control Point # 1 ---

| DISCHARGE (cfs) | TEMPERATURE (deg F) | WATER SURFACE (ft) |
|---|---|---|
| 165850.000 | 60.00 | 3519.705 |

| **** DISCHARGE (CFS) | WATER SURFACE | ENERGY LINE | VELOCITY HEAD | ALPHA | TOP WIDTH | AVG BED | AVG VEL (by subsection 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|---|---|
| SECTION NO. | 1.000 | | | | | | | | |
| **** 165850.000 | 3519.705 | 3525.119 | 5.414 | 1.388 | 944.764 | 3499.327 | 8.842 | 20.698 | 0.000 |
| | | | | FLOW DISTRIBUTION (%) = | | | 22.852 | 77.148 | 0.000 |
| SECTION NO. | 2.000 | | | | | | | | |
| **** 165850.000 | 3523.077 | 3529.061 | 5.984 | 1.315 | 751.264 | 3501.244 | 9.403 | 21.387 | 0.000 |
| | | | | FLOW DISTRIBUTION (%) = | | | 19.610 | 80.390 | 0.000 |
| SECTION NO. | 3.000 | | | | | | | | |
| **** 165850.000 | 3526.483 | 3533.778 | 7.295 | 1.148 | 518.210 | 3505.776 | 13.339 | 23.223 | 8.121 |
| | | | | FLOW DISTRIBUTION (%) = | | | 18.590 | 80.837 | 0.573 |
| SECTION NO. | 4.000 | | | | | | | | |
| **** 165850.000 | 3533.611 | 3536.960 | 3.349 | 1.016 | 593.650 | 3513.880 | 10.439 | 14.865 | 7.901 |
| | | | | FLOW DISTRIBUTION (%) = | | | 4.870 | 95.130 | 0.000 |

```
SECTION NO.       5.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.       5.000 TIME =      2.000 DAYS.
 TRIAL     TRIAL         COMPUTED      CRITICAL
  NO.        WS             WS            WS
   0.    3537.410      3534.821
   1.    3537.504      3534.856      3537.454
 **** 165850.000  3537.504  3543.652   6.148     1.090    701.890  3522.285    7.657  20.288    9.113
                                                  FLOW DISTRIBUTION (%) =     1.561  95.255    3.184
 SECTION NO.       6.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.       6.000 TIME =      2.000 DAYS.
 TRIAL     TRIAL         COMPUTED      CRITICAL
  NO.        WS             WS            WS
   0.    3545.380      3542.172
   1.    3545.474      3542.181      3545.424
 **** 165850.000  3545.474  3553.204   7.730     1.027    488.065  3529.142   10.268  22.461   10.477
                                                  FLOW DISTRIBUTION (%) =     0.222  98.203    1.574
 SECTION NO.       7.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.       7.000 TIME =      2.000 DAYS.
 TRIAL     TRIAL         COMPUTED      CRITICAL
  NO.        WS             WS            WS
   0.    3557.863      3552.217
   1.    3557.957      3552.221      3557.907
 **** 165850.000  3557.957  3566.870   8.913     1.061    387.140  3537.403   14.695  25.147   17.220
                                                  FLOW DISTRIBUTION (%) =     0.487  82.589   16.924
 SECTION NO.       8.000
 **** 165850.000  3564.062  3572.078   8.016     1.041    406.830  3544.311   12.214  23.404   15.994
                                                  FLOW DISTRIBUTION (%) =     0.328  89.187   10.485
 SECTION NO.       9.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.       9.000 TIME =      2.000 DAYS.
 TRIAL     TRIAL         COMPUTED      CRITICAL
  NO.        WS             WS            WS
   0.    3570.543      3569.102
   1.    3570.637      3569.122      3570.587
 **** 165850.000  3570.637  3578.804   8.167     1.073    454.698  3551.914   12.756  23.867   14.707
                                                  FLOW DISTRIBUTION (%) =     0.333  87.565   12.101
 SECTION NO.      10.000
 **** 165850.000  3578.381  3582.870   4.489     1.098    581.393  3557.371    8.948  17.800   10.315
                                                  FLOW DISTRIBUTION (%) =     0.720  86.810   12.470
 SECTION NO.      11.000
 **** 165850.000  3582.197  3585.312   3.115     1.048    700.525  3563.533    6.261  14.619    9.781
                                                  FLOW DISTRIBUTION (%) =     0.237  88.840   10.923
 SECTION NO.      12.000
 **** 165850.000  3582.953  3588.967   6.014     1.029    554.728  3566.531    0.756  19.865   10.289
                                                  FLOW DISTRIBUTION (%) =     0.000  97.364    2.636
 SECTION NO.      13.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.      13.000 TIME =      2.000 DAYS.
 TRIAL     TRIAL         COMPUTED      CRITICAL
  NO.        WS             WS            WS
   0.    3589.254      3586.909
   1.    3589.348      3586.928      3589.298
 **** 165850.000  3589.348  3596.766   7.417     1.056    516.207  3572.403    1.649  22.290   11.841
                                                  FLOW DISTRIBUTION (%) =     0.001  94.513    5.486
 SECTION NO.      14.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.      14.000 TIME =      2.000 DAYS.
 TRIAL     TRIAL         COMPUTED      CRITICAL
  NO.        WS             WS            WS
   0.    3598.922      3594.513
   1.    3599.016      3594.568      3598.966
 **** 165850.000  3599.016  3606.241   7.226     1.123    557.740  3579.979    8.329  22.126    9.062
                                                  FLOW DISTRIBUTION (%) =     0.132  93.966    5.902
 SECTION NO.      15.000
 **** 165850.000  3605.632  3610.265   4.634     1.072    544.620  3584.627    5.792  17.995   11.607
                                                  FLOW DISTRIBUTION (%) =     0.324  86.604   13.072
 SECTION NO.      16.000
 **** 165850.000  3608.791  3613.343   4.552     1.072    643.040  3590.728    4.645  18.550   13.240
                                                  FLOW DISTRIBUTION (%) =     0.038  69.701   30.261
```

SECTION NO. 17.000

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **** | 165850.000 | 3611.189 | 3615.112 | 3.923 | 1.040 | 754.590 | 3595.896 | 3.619 | 16.122 | 8.814 |
| | | | | | FLOW DISTRIBUTION (%) = | | | 0.021 | 95.888 | 4.091 |

MOBILE BED APPLICATION IN NATURAL CONDITION.
ACCUMULATED TIME (yrs).... 0.005
FLOW DURATION (days)...... 1.000

UPSTREAM BOUNDARY CONDITIONS

| Stream Segment # 1 / Section No. 17.000 | DISCHARGE (cfs) | SEDIMENT LOAD (tons/day) | TEMPERATURE (deg F) |
|---|---|---|---|
| INFLOW | 165850.00 | 331060.03 | 60.00 |

TABLE SA-1. TRAP EFFICIENCY ON STREAM SEGMENT # 1
MOBILE BED APPLICATION IN NATURAL CONDITION.
ACCUMULATED AC-FT ENTERING AND LEAVING THIS STREAM SEGMENT

| TIME DAYS | ENTRY POINT | CLAY INFLOW | CLAY OUTFLOW | CLAY TRAP EFF | SILT INFLOW | SILT OUTFLOW | SILT TRAP EFF | SAND INFLOW | SAND OUTFLOW | SAND TRAP EFF |
|---|---|---|---|---|---|---|---|---|---|---|
| 2.00 | 17.000 | 0.00 | | | 39.19 | | | 153.59 | | |
| TOTAL= | 1.000 | 0.00 | 3.97 | ********* | 39.19 | 39.69 | -0.01 | 153.59 | 180.73 | -0.18 |

TABLE SB-1: SEDIMENT LOAD PASSING THE BOUNDARIES OF STREAM SEGMENT # 1

SEDIMENT INFLOW at the Upstream Boundary:

| GRAIN SIZE | LOAD (tons/day) | GRAIN SIZE | LOAD (tons/day) |
|---|---|---|---|
| CLAY............. | 0.00 | MEDIUM GRAVEL..... | 7626.37 |
| COARSE SILT....... | 51306.01 | COARSE GRAVEL..... | 0.00 |
| VERY FINE SAND.... | 35961.68 | VERY COARSE GRAVEL | 0.00 |
| FINE SAND......... | 45795.65 | SMALL COBBLES..... | 0.00 |
| MEDIUM SAND....... | 49360.64 | LARGE COBBLES..... | 0.00 |
| COARSE SAND....... | 55180.24 | SMALL BOULDERS.... | 0.00 |
| VERY COARSE SAND.. | 39072.37 | MEDIUM BOULDERS... | 51306.01 |
| VERY FINE GRAVEL.. | 28363.67 | LARGE BOULDERS.... | 279754.02 |
| FINE GRAVEL....... | 18393.41 | | |
| | | TOTAL = | 331060.03 |

SEDIMENT OUTFLOW from the Downstream Boundary

| GRAIN SIZE | LOAD (tons/day) | GRAIN SIZE | LOAD (tons/day) |
|---|---|---|---|
| CLAY............. | 0.00 | MEDIUM GRAVEL..... | 3128.39 |
| COARSE SILT....... | 51306.01 | COARSE GRAVEL..... | 9495.11 |
| VERY FINE SAND.... | 35874.74 | VERY COARSE GRAVEL | 22428.54 |
| FINE SAND......... | 45222.54 | SMALL COBBLES..... | 26276.89 |
| MEDIUM SAND....... | 48731.64 | LARGE COBBLES..... | 15993.97 |
| COARSE SAND....... | 55932.19 | SMALL BOULDERS.... | 5529.00 |
| VERY COARSE SAND.. | 25683.04 | MEDIUM BOULDERS... | 0.00 |
| VERY FINE GRAVEL.. | 88.22 | LARGE BOULDERS.... | 0.00 |
| FINE GRAVEL....... | 524.26 | | |
| | | TOTAL = | 346214.54 |

TABLE SB-2: STATUS OF THE BED PROFILE AT TIME = 2.000 DAYS

| SECTION NUMBER | BED CHANGE (ft) | WS ELEV (ft) | THALWEG (ft) | Q (cfs) | TRANSPORT RATE (tons/day) CLAY | SILT | SAND |
|---|---|---|---|---|---|---|---|
| 17.000 | 7.44 | 3611.19 | 3599.04 | 165850. | 0. | 51306. | 236859. |
| 16.000 | -3.21 | 3608.79 | 3584.97 | 165850. | 0. | 51306. | 248073. |
| 15.000 | -0.24 | 3605.63 | 3581.05 | 165850. | 0. | 51306. | 249654. |
| 14.000 | -3.38 | 3599.02 | 3572.92 | 165850. | 0. | 51306. | 275408. |
| 13.000 | -1.59 | 3589.35 | 3566.48 | 165850. | 0. | 51306. | 297245. |
| 12.000 | -0.17 | 3582.95 | 3561.92 | 165850. | 0. | 51306. | 314652. |
| 11.000 | 1.62 | 3582.20 | 3560.42 | 165850. | 0. | 51306. | 292903. |
| 10.000 | -0.47 | 3578.38 | 3553.09 | 165850. | 0. | 51306. | 288294. |
| 9.000 | -2.58 | 3570.64 | 3545.44 | 165850. | 0. | 51306. | 303233. |
| 8.000 | -0.68 | 3564.06 | 3540.42 | 165850. | 0. | 51306. | 306449. |
| 7.000 | -1.85 | 3557.96 | 3533.95 | 165850. | 0. | 51306. | 319510. |
| 6.000 | -0.43 | 3545.47 | 3525.08 | 165850. | 0. | 51306. | 319252. |
| 5.000 | 0.35 | 3537.50 | 3517.33 | 165850. | 0. | 51306. | 312003. |
| 4.000 | 1.39 | 3533.61 | 3509.02 | 165850. | 0. | 51306. | 298486. |
| 3.000 | -0.64 | 3526.48 | 3499.28 | 165850. | 0. | 51306. | 310639. |
| 2.000 | 1.08 | 3523.08 | 3498.28 | 165850. | 0. | 51306. | 299676. |
| 1.000 | 1.13 | 3519.70 | 3496.30 | 165850. | 0. | 51306. | 294909. |

$$END

0 DATA ERRORS DETECTED.

TOTAL NO. OF TIME STEPS READ = 2
TOTAL NO. OF WS PROFILES = 2
ITERATIONS IN EXNER EQ = 340

COMPUTATIONS COMPLETED
RUN TIME = 0 HOURS, 0 MINUTES & 0.00 SECONDS

## APPENDIX-6, COMPUTER PROGRAM FOR GENERATION OF COSINE CURVE FOR RIVER CHANNELS

```
************************************************************************
*                              MAIN PROGRAM MNDR.FOR                   *
************************************************************************
c       Program for Generation of Cosine Curve for River Channel
c       Main Program
        common /blockA/ delsai(50),cumang(50),icount(10000),rad(10000),
      1 xdash(10000),ydash(10000),rmin,crvlen,nangle,
      1 xodash(10000),yodash(10000)
        dimension x(10000),y(10000),xo(10000),yo(10000)
        open(1,file='input.dat',status='old')
        open(2,file='result.out')
c       Enter the value of Rmin in metre in the input file.
        read(1,*) rmin
c       Enter the length of the curve L in meter in the input file.
        read(1,*) crvlen
        pi=22./7.
        saimax=180.*crvlen/(2.*pi**2*rmin)
        write(*,*)'saimax= ',saimax
        write(*,*)'Break saimax into suitable number of divisions.'
        pause
c       Enter the numbers of divisions of saimax desired
c       in the input file.
        read(1,*) nangle
c       Enter the angles in degrees.
        read(1,*) (delsai(i),i=1,nangle)
        write(*,*) (delsai(i),i=1,nangle)
        m=200
        do 10 i=1,nangle
              delsai(i)=delsai(i)*pi/180.
10      continue
        alo=2.*pi/crvlen
        saimax=crvlen/(2.0*pi*rmin)
        sdelsi=delsai(1)/float(m)
        cumang(1)=delsai(1)
        do 20 i=2,nangle
              cumang(i)=cumang(i-1)+delsai(i)
20      continue
        do 30 i=1,nangle
              t=cumang(i)/sdelsi
              it=ifix(t)
              tt=t-it
              if(tt.ge.0.5)then
                    it=it+1
              endif
              icount(i)=it
```

```
30      continue
        rad(1)=rmin
        xdash(1)=0.0
        ydash(1)=0.0
        xodash(1)=0.0
        yodash(1)=0.0
        x(1)=rmin
        y(1)=0.0
        do 60 k=1,nangle
                if(k.eq.1)then
                        nn=2
                        go to 40
                else
                        nn=icount(k-1)+2
                endif
40              do 50 j=nn,icount(k)+1
                        chkang=float(j-1)*sdelsi
                        tempo=(1.-(alo*rmin*chkang)**2)**0.5
                        if(chkang.gt.saimax) go to 70
                        if(tempo.lt.0)go to 70
                        rad(j)=rmin/(1.0-(rmin*alo*float(j-1)*sdelsi)**2)**0.5
c                       write(*,*)'radius for line no= 'j,rad(j)
                        xdash(j)=(rad(j-1)-rad(j))*cos(float(j-1)*sdelsi)
     1                  +xdash(j-1)
                        ydash(j)=(rad(j-1)-rad(j))*sin(float(j-1)*sdelsi)
     1                  +ydash(j-1)
                        xodash(j)=(rad(j)-0.5*rmin)*cos(chkang)+xdash(j-1)
                        yodash(j)=(rad(j)-0.5*rmin)*sin(chkang)+ydash(j-1)
                        x(j)=rad(j)*cos(chkang)+xdash(j)
                        y(j)=rad(j)*sin(chkang)+ydash(j)
                        xo(j)=rad(j)*cos(chkang)+xodash(j)
                        yo(j)=rad(j)*sin(chkang)+yodash(j)
50              continue
60      continue
        call pout(x,y,pi,xo,yo)
70      write(*,*)'Design another curve.'
        stop
        end
```

```
***********************************************************************
*                         SUBROUTINE POUT                             *
***********************************************************************
      subroutine pout(x,y,pi,xo,yo)
      common /block A/delsai(50),cumang(50),icount(10000),rad(10000),
     1 xdash(10000),ydash(10000),rmin,crvlen,nangle,
     1 xodash(10000),yodash(10000)
      dimension x(10000),y(10000),xo(10000),yo(10000)
      write(2,*)'RESULTS OF COSINE GENERATED CURVE: MNDR.OUT'
      write(2,*)
      write(2,*)
      write(2,*)'Radmin (m)      Curve Length (m)            N-division   '
      write(2,11)rmin,crvlen,nangle
11    format(f9.2,12x,f7.2,20x,i3,//)
      do 10 i=1,nangle
      cumang(i)=cumang(i)*180./pi
      delsai(i)=delsai(i)*180./pi
10    continue
      write(2,*)'Angles in degrees'
      write(2,*)(delsai(i),i=1,nangle)
      write(2,*)
      write(2,*)'Cartesian coordinates and radii of the curve'
      write(2,*)'Angle  Abscissa, X (m)  Ordinate, Y (m)  Radius (m)'
      do 20 i=1,nangle
            ii=icount(i)+1
c           write(*,*)'ii= ',ii,'for division= ',i
      write(2,12)cumang(i),x(ii),y(ii),rad(ii)
12    format(f5.2,3x,f10.3,8x,f10.3,8x,f10.3)
20    continue
      write(2,*)
      write(2,*)'Cartesian coordinates for XOIs and YOIs'
      write(2,*)'Angle  Abscissa, X (m)  Ordinate, Y (m)  Radius (m)'
      do 30 i=1,nangle
            ii=icount(i)+1
c           write(*,*)'ii= ',ii,'for division= ',i
            write(2,12)cumang(i),xo(ii),yo(ii),rad(ii)
30    continue
      return
      end
```

**APPENDIX-7, INPUT DATA FOR HEC-6 FOR SIMULATION OF BEAS RIVER WITH DIKES AND DIVERSION CHANNEL FOR 2 YEAR AND 500 YEAR FLOODS (FIX BED APPLICATION)**

```
T1       FIXED BED APPLICATION IN RIVER WITH DIKES AND DIVERSION CHANNEL.
T2       WITH A RATING CURVE AT THE DOWNSTREAM BOUNDARY.
T3       SIMULATION OF BEAS RIVER FOR 2 YEAR AND 500 YEAR RETURN PERIOD FLOODS
NC   .045     .045     .038       .1        .3
X1    1.0       4.        0.  478.88        0.        0.        0.        0.        0.        0.
GR3503.7    0.00 3482.34   42.64 3482.34  436.24 3503.66  478.88
HD    1.0
X1    2.0       4.        0.  478.88  665.00  645.00  656.00        0.        0.        0.
GR3510.3    0.00 3488.95   42.64 3488.95  436.24 3510.27  478.88
HD    2.0
X1    3.0       4.        0.  478.88  675.00  635.00  656.00        0.        0.        0.
GR3516.9    0.00 3495.55   42.64 3495.55  436.24 3516.87  478.88
HD    3.0
X1    4.0       4.        0.  478.88  635.00  675.00  656.00        0.        0.        0.
GR3523.5    0.00 3502.16   42.64 3502.16  436.24 3523.48  478.88
HD    4.0
X1    5.0       4.        0.  478.88  645.00  665.00  656.00        0.        0.        0.
GR3530.1    0.00 3508.77   42.64 3508.77  436.24 3530.09  478.88
HD    5.0
X1    6.0       4.        0.  478.88  670.00  642.00  656.00        0.        0.        0.
GR3536.7    0.00 3515.37   42.64 3515.37  436.24 3536.69  478.88
HD    6.0
X1    7.0       4.        0.  478.88  673.00  635.00  656.00        0.        0.        0.
GR3543.3    0.00 3521.98   42.64 3521.98  436.24 3543.30  478.88
HD    7.0
X1    8.0       4.        0.  478.88  647.00  665.00  656.00        0.        0.        0.
GR3549.9    0.00 3528.58   42.64 3528.58  436.24 3549.90  478.88
HD    8.0
X1    9.0       4.        0.  478.88  637.00  675.00  656.00        0.        0.        0.
GR3556.5    0.00 3535.19   42.64 3535.19  436.24 3556.51  478.88
HD    9.0
X1   10.0       4.        0.  478.88  323.00  333.00  328.00        0.        0.        0.
GR3559.8    0.00 3538.49   42.64 3538.49  436.24 3559.81  478.88
HD   10.0
X1   11.0       4.        0.  478.88  328.00  328.00  328.00        0.        0.        0.
GR3562.5    0.00 3541.14   42.64 3541.14  436.24 3562.46  478.88
HD   11.0
X1   12.0       4.        0.  478.88  656.00  656.00  656.00        0.        0.        0.
GR3569.3    0.00 3548.02   42.64 3548.02  436.24 3569.34  478.88
HD   12.0
X1   13.0       4.        0.  478.88  656.00  656.00  656.00        0.        0.        0.
GR3576.9    0.00 3555.53   42.64 3555.53  436.24 3576.85  478.88
HD   13.0
X1   14.0       4.        0.  478.88  656.00  656.00  656.00        0.        0.        0.
GR3580.1    0.00 3558.81   42.64 3558.81  436.24 3580.13  478.88
HD   14.0
X1   15.0       4.        0.  478.88  606.80  606.80  606.80        0.        0.        0.
GR3583.4    0.00 3562.09   42.64 3562.09  436.24 3583.41  478.88
HD   15.0
X1   16.0       4.        0.  478.88  656.00  656.00  656.00        0.        0.        0.
GR3589.4    0.00 3568.07   42.64 3568.07  436.24 3589.39  478.88
HD   16.0
```

```
X1  17.0       4.      0.  478.88  656.00  656.00  656.00      0.      0.      0.
GR3597.6    0.00 3576.30   42.64 3576.30  436.24 3597.62  478.88
HD  17.0
X1  18.0       4.      0.  478.88  705.20  705.20  705.20      0.      0.      0.
GR3602.6    0.00 3581.29   42.64 3581.29  436.24 3602.61  478.88
HD  18.0
X1  19.0       4.      0.  478.88  656.00  656.00  656.00      0.      0.      0.
GR3609.5    0.00 3588.18   42.64 3588.18  436.24 3609.50  478.88
HD  19.0
X1  20.0       4.      0.  478.88  328.00  328.00  328.00      0.      0.      0.
GR3612.9    0.00 3591.62   42.64 3591.62  436.24 3612.94  478.88
HD  20.0
EJ
$HYD
$RATING
RC            25 7057.51       0       0 3482.34 3484.85 3486.10 3487.25 3488.00
RC       3488.80 3489.58 3490.30 3490.96 3491.58 3492.18 3492.80 3493.30 3493.82
RC       3494.36 3494.82 3495.38 3495.80 3496.30 3496.75 3497.20 3497.60 3498.08
RC       3498.50 3498.90
*   A   PROFILE 1 = 2 YEAR RETURN PERIOD FLOOD
Q 28230.
T    60.
W     1.
*   A   PROFILE 2 = 500 YEAR RETURN PERIOD FLOOD
Q165850.
T    60.
W     1.
$$END
```

**APPENDIX-8, OUTPUT OF HEC-6 FOR SIMULATION OF BEAS RIVER WITH DIKES AND DIVERSION CHANNEL FOR 2 YEAR AND 500 YEAR FLOODS (FIX BED APPLICATION)**

```
**************************************************      **********************************
*  SCOUR AND DEPOSITION IN RIVERS AND RESERVOIRS  *      *  U.S. ARMY CORPS OF ENGINEERS  *
*       Version: 4.1.00 - OCTOBER 1993            *      *  HYDROLOGIC ENGINEERING CENTER *
*  INPUT FILE:  FIXBED1.DAT                       *      *  609 SECOND STREET             *
*  OUTPUT FILE: FIXBED1.OUT                       *      *  DAVIS, CALIFORNIA 95616-4687  *
*  RUN DATE: 31 MAY 04     RUN TIME: 16:59:21     *      *  (916) 756-1104                *
**************************************************      **********************************

                 X     X  XXXXXXX   XXXXX         XXXXX
                 X     X  X        X     X       X     X
                 X     X  X        X             X
                 XXXXXXX  XXXX     X       XXXXX XXXXXX
                 X     X  X        X             X     X
                 X     X  X        X     X       X     X
                 X     X  XXXXXXX   XXXXX         XXXXX

     ***********************************************************************
     *  MAXIMUM LIMITS FOR THIS VERSION ARE:                               *
     *      10  Stream Segments (Main Stem + Tributaries)                  *
     *     500  Cross Sections                                             *
     *     200  Elevation/Station Points per Cross Section                 *
     *      20  Grain Sizes                                                *
     *      10  Control Points                                             *
     ***********************************************************************

T1       FIXED BED APPLICATION IN RIVER WITH DIKES AND DIVERSION CHANNEL.
T2       WITH A RATING CURVE AT THE DOWNSTREAM BOUNDARY.
T3       SIMULATION OF BEAS RIVER FOR 2 YEAR AND 500 YEAR RETURN PERIOD FLOODS

N values...  Left    Channel   Right    Contraction   Expansion
           0.0450    0.0380   0.0450       1.1000       0.7000

SECTION NO.     1.000
...DEPTH of the Bed Sediment Control Volume =    0.00 ft.

SECTION NO.     2.000
...DEPTH of the Bed Sediment Control Volume =    0.00 ft.

SECTION NO.     3.000
...DEPTH of the Bed Sediment Control Volume =    0.00 ft.

SECTION NO.     4.000
...DEPTH of the Bed Sediment Control Volume =    0.00 ft.

SECTION NO.     5.000
...DEPTH of the Bed Sediment Control Volume =    0.00 ft.

SECTION NO.     6.000
...DEPTH of the Bed Sediment Control Volume =    0.00 ft.

SECTION NO.     7.000
...DEPTH of the Bed Sediment Control Volume =    0.00 ft.

SECTION NO.     8.000
...DEPTH of the Bed Sediment Control Volume =    0.00 ft.

SECTION NO.     9.000
...DEPTH of the Bed Sediment Control Volume =    0.00 ft.
```

```
SECTION NO.     10.000
...DEPTH of the Bed Sediment Control Volume =     0.00 ft.

SECTION NO.     11.000
...DEPTH of the Bed Sediment Control Volume =     0.00 ft.

SECTION NO.     12.000
...DEPTH of the Bed Sediment Control Volume =     0.00 ft.

SECTION NO.     13.000
...DEPTH of the Bed Sediment Control Volume =     0.00 ft.

SECTION NO.     14.000
...DEPTH of the Bed Sediment Control Volume =     0.00 ft.

SECTION NO.     15.000
...DEPTH of the Bed Sediment Control Volume =     0.00 ft.

SECTION NO.     16.000
...DEPTH of the Bed Sediment Control Volume =     0.00 ft.

SECTION NO.     17.000
...DEPTH of the Bed Sediment Control Volume =     0.00 ft.

SECTION NO.     18.000
...DEPTH of the Bed Sediment Control Volume =     0.00 ft.

SECTION NO.     19.000
...DEPTH of the Bed Sediment Control Volume =     0.00 ft.

SECTION NO.     20.000
...DEPTH of the Bed Sediment Control Volume =     0.00 ft.

NO. OF CROSS SECTIONS IN STREAM SEGMENT= 20
NO. OF INPUT DATA MESSAGES =    0

TOTAL NO. OF CROSS SECTIONS IN THE NETWORK =  20
TOTAL NO. OF STREAM SEGMENTS IN THE NETWORK=   1
END OF GEOMETRIC DATA

================================================================================

$HYD
FIXED BED MODEL

--------------------------------------------------------------------------------
```

$RATING

Downstream Boundary Condition - Rating Curve

| Elevation | Stage | Discharge | Elevation | Stage | Discharge |
|---|---|---|---|---|---|
| 3482.340 | 3482.340 | 0.000 | 3493.820 | 3493.820 | 91747.630 |
| 3484.850 | 3484.850 | 7057.510 | 3494.360 | 3494.360 | 98805.140 |
| 3486.100 | 3486.100 | 14115.020 | 3494.820 | 3494.820 | 105862.650 |
| 3487.250 | 3487.250 | 21172.530 | 3495.380 | 3495.380 | 112920.160 |
| 3488.000 | 3488.000 | 28230.040 | 3495.800 | 3495.800 | 119977.670 |
| 3488.800 | 3488.800 | 35287.550 | 3496.300 | 3496.300 | 127035.180 |
| 3489.580 | 3489.580 | 42345.060 | 3496.750 | 3496.750 | 134092.690 |
| 3490.300 | 3490.300 | 49402.570 | 3497.200 | 3497.200 | 141150.200 |
| 3490.960 | 3490.960 | 56460.080 | 3497.600 | 3497.600 | 148207.710 |
| 3491.580 | 3491.580 | 63517.590 | 3498.080 | 3498.080 | 155265.220 |
| 3492.180 | 3492.180 | 70575.100 | 3498.500 | 3498.500 | 162322.730 |
| 3492.800 | 3492.800 | 77632.610 | 3498.900 | 3498.900 | 169380.240 |
| 3493.300 | 3493.300 | 84690.120 | | | |

================================================================================

TIME STEP # 1

* A PROFILE 1 = 2 YEAR RETURN PERIOD FLOOD

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

FIXED BED APPLICATION IN RIVER WITH DIKES AND DIVERSION CHANNEL.

ACCUMULATED TIME (yrs).......... 0.000

--- Downstream Boundary Condition Data for STREAM SEGMENT NO. 1 at Contrd Point # 1 ---

| DISCHARGE (cfs) | TEMPERATURE (deg F) | WATER SURFACE (ft) |
|---|---|---|
| 28230.000 | 60.00 | 3488.000 |

| **** | DISCHARGE (CFS) | WATER SURFACE | ENERGY LINE | VEDCITY HEAD | ALPHA | TOP WIDTH | AVG BED | AVG VEL (by subsection) 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|---|---|---|
| SECTION NO. | | 1.000 | | | | | | | | |
| **** | 28230.000 | 3488.000 | 3490.358 | 2.358 | 1.000 | 416.219 | 3482.494 | 0.000 | 12.318 | 0.000 |
| | | | | | FLOW DISTRIBUTION (%) = | | | 0.000 | 100.000 | 0.000 |
| SECTION NO. | | 2.000 | | | | | | | | |
| **** | 28230.000 | 3494.679 | 3496.979 | 2.299 | 1.000 | 416.502 | 3489.107 | 0.000 | 12.164 | 0.000 |
| | | | | | FLOW DISTRIBUTION (%) = | | | 0.000 | 100.000 | 0.000 |
| SECTION NO. | | 3.000 | | | | | | | | |
| **** | 28230.000 | 3501.226 | 3503.567 | 2.341 | 1.000 | 416.304 | 3495.701 | 0.000 | 12.273 | 0.000 |
| | | | | | FLOW DISTRIBUTION (%) = | | | 0.000 | 100.000 | 0.000 |
| SECTION NO. | | 4.000 | | | | | | | | |
| **** | 28230.000 | 3507.867 | 3510.182 | 2.315 | 1.000 | 416.432 | 3502.313 | 0.000 | 12.205 | 0.000 |
| | | | | | FLOW DISTRIBUTION (%) = | | | 0.000 | 00000 | 0.000 |
| SECTION NO. | | 5.000 | | | | | | | | |
| **** | 28230.000 | 3514.455 | 3516.791 | 2.337 | 1.000 | 416.334 | 3508.925 | 0.000 | 12.262 | 0.000 |
| | | | | | FLOW DISTRIBUTION (%) = | | | 0.000 | 100.000 | 0.000 |
| SECTION NO. | | 6.000 | | | | | | | | |
| **** | 28230.000 | 3521.099 | 3523.428 | 2.329 | 1.000 | 416.370 | 3515.560 | 0.000 | 12.242 | 0.000 |
| | | | | | FLOW DISTRIBUTION (%) = | | | 0.000 | 100.000 | 0.000 |
| SECTION NO. | | 7.000 | | | | | | | | |
| **** | 28230.000 | 3527.721 | 3530.62 | 2.332 | 1.000 | 416.364 | 3522.185 | 0.000 | 12.249 | 0.000 |
| | | | | | FLOW DISTRIBUTION (%) = | | | 0.000 | 100.000 | 0.000 |
| SECTION NO. | | 8.000 | | | | | | | | |
| **** | 28230.000 | 3534.332 | 3536.648 | 2.316 | 1.000 | 416.436 | 3528739 | 0.000 | 12.209 | 0.000 |
| | | | | | FLOW DISTRIBUTION (%) = | | | 0.000 | 100.000 | 0.000 |
| SECTION NO. | | 9.000 | | | | | | | | |
| **** | 28230.000 | 3540.923 | 3543.259 | 2.336 | 1.000 | 416.348 | 3535.393 | 0.000 | 12.261 | 0.000 |
| | | | | | FLOW DISTRIBUTION (%) = | | | 0.000 | 100.000 | 0.000 |
| SECTION NO. | | 10.000 | | | | | | | | |
| **** | 28230.000 | 3544.245 | 3546.538 | 2.292 | 1.000 | 416.558 | 3538.665 | 0.000 | 12.145 | 0.000 |
| | | | | | FLOW DISTRIBUTION (%) = | | | 0.000 | 100.000 | 0.000 |
| SECTION NO. | | 11.000 | | | | | | | | |
| **** | 28230.000 | 3547.434 | 3549.321 | 1.887 | 1.000 | 418.802 | 3541.317 | 0.000 | 11.020 | 0.000 |
| | | | | | FLOW DISTRIBUTION (%) = | | | 0.00100.000 | | 0.000 |

```
SECTION NO.    12.000
** SUPERCRITICAL **  Using Critical Water Surface +
SECTION NO.     12.000 TIME =      1.000 DAYS.
TRIAL    TRIAL        COMPUTED     CRITICAL
 NO.       WS            WS            WS
  0.   3553.375     3553.018
  1.   3553.469     3552.921     3553.419
****  28230.000  3553.469  3556.018   2.550     1.000   415.415  3548.163    0.000  12.809    0.000
                                                 FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
SECTION NO.     13.000
****  28230.000  3561.029  3563.500   2.471     1.000   415.705  3555.643    0.000  12.609    0.000
                                                 FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
SECTION NO.     14.000
****  28230.000  3566.427  3567.704   1.276     1.000   424.098  3559.082    0.000   9.062    0.000
                                                 FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
SECTION NO.     15.000
****  28230.000  3568.951  3570.538   1.588     1.000   412.033  3562.317    0.000  10.108    0.000
                                                 FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
SECTION NO.     16.000
****  28230.000  3573.426  3576.034   2.609     1.000   415.148  3568.177    0.000  12.956    0.000
                                                 FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
SECTION NO.     17.000
** SUPERCRITICAL **  Using Critical Water Surface +
SECTION NO.     17.000 TIME =      1.000 DAYS.
TRIAL    TRIAL        COMPUTED     CRITICAL
 NO.       WS            WS            WS
  0.   3581.643     3581.467
  1.   3581.736     3581.320     3581.686
****  28230.000  3581.736  3584.298   2.561     1.000   415.356  3576.442    0.000  12.838    0.000
                                                 FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
SECTION NO.     18.000
****  28230.000  3588.224  3589.768   1.544     1.000   421.407  3581.503    0.000   9.967    0.000
                                                 FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
SECTION NO.     19.000
** SUPERCRITICAL **  Using Critical Water Surface +
SECTION NO.     19.000 TIME =      1.000 DAYS.
TRIAL    TRIAL        COMPUTED     CRITICAL
 NO.       WS            WS            WS
  0.   3593.533     3592.561
  1.   3593.627     3592.498     3593.577
****  28230.000  3593.627  3596.178   2.551     1.000   415.387  3588.323    0.000  12.813    0.000
                                                 FLOW DISTRIBUTION (%) =     0.000 100.000 0.000
SECTION NO.     20.000
****  28230.000  3597.418  3599.669   2.251     1.000   416.779  3591.790    0.000  12.034    0.000
                                                 FLOW DISTRIBUTION (%) =     0.000 100.000    0.000

=================================================================================================
TIME STEP #        2
*   AB  PROFILE 2 = 500 YEAR RETURN PERIOD FLOOD

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
FIXED BED APPLICATION IN RIVER WITH DIKES AND DIVERSION CHANNEL.
ACCUMULATED TIME (yrs)..........        0.003

--- Downstream Boundary Condition Data for STREAM SEGMENT NO.  1 at Control Point #  1---
                                   DISCHARGE    TEMPERATURE   WATER SURFACE
                                     (cfs)        (deg F)         (ft)
                                   165850.000      60.00        3498.700

****  DISCHARGE    WATER    ENERGY  VELOCITY  ALPHA     TOP      AVG       AVG VEL (by subsection)
        (CFS)     SURFACE    LINE     HEAD             WIDTH     BED          1        2        3

SECTION NO.     1.000
** CRITICAL WATER SURFACE USED AT SECTION NO.      1.000 AT TIME =      1.000 DAYS.****ELOEQ**
**** 165850.000  3499.476  3507.473   7.997     1.000   461.903  3483.648    0.000  22.685    0.000
                                                 FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
SECTION NO.     2.000
** SUPERCRITICAL **  Using Critical Water Surface +
SECTION NO.     2.000 TIME =      1.00 DAYS.
TRIAL    TRIAL        COMPUTED     CRITICAL
 NO.       WS            WS            WS
  0.   3506.054     3505.167
  1.   3506.147     3505.218     3506.097
**** 165850.000  3506.147  3514.039   7.891     1.000   462.342  3490.228    0.000  2235    0.000
                                                 FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
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SECTION NO.       3.000
** SUPERCRITICAL **  Using Critical Water Surface +
SECTION NO.       3.000 TIME =      1.000 DAYS.
TRIAL    TRIAL        COMPUTED      CRITICAL
 NO.       WS            WS            WS
  0.    3512.669      3511.703
  1.    3512.763      3511.723      3512.713
**** 165850.000  3512.763  3520.639   7.876     1.000    462.404  3496.831    0.000  22.512    0.000
                                                 FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
SECTION NO.       4.000
** SUPERCRITICAL **  Using Critical Water Surface +
SECTION NO.       4.000 TIME =      1.000 DAYS.
TRIAL    TRIAL        COMPUTED      CRITICAL
 NO.       WS            WS            WS
  0.    3519.285      3518.300
  1.    3519.379      3518.317      3519.329
**** 165850.000  3519.379  3527.249   7.869     1.000    462.445  3503.442    0.000  22.503    0.000
                                                 FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
SECTION NO.       5.000
** SUPERCRITICAL **  Using Critical Water Surface +
SECTION NO.       5.000 TIME =      1.000 DAYS.
TRIAL    TRIAL        COMPUTED      CRITICAL
 NO.       WS            WS            WS
  0.    3525.854      3524.902
  1.    3525.948      3524.917      3525.898
**** 165850.000  3525.948  3533.858   7.910     1.000    462.294  3510.046    0.000  22.561    0.000
                                                 FLOW DISTRIBUTION (%) =     000 100.000    0.000
SECTION NO.       6.000
** SUPERCRITICAL **  Using Critical Water Surface +
SECTION NO.       6.000 TIME =      1.000 DAYS.
TRIAL    TRIAL        COMPUTED      CRITICAL
 NO.       WS            WS            WS
  0.    3532.473      3531.525
  1.    3532.567      3531.547      3532.517
**** 165850.000  3532.567  3540.458   7.891     1.000    462.372  3516.649    0.000  22.534    0.000
                                                 FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
SECTION NO.       7.000
** SUPERCRITICAL **  Using Critical Water Surface +
SECTION NO.       7.000 TIME =      1.000 DAYS.
TRIAL    TRIAL        COMPUTED      CRITICAL
 NO.       WS            WS            WS
  0.    3539.095      3538.123
  1.    3539.189      3538.141      3539.139
**** 165850.000  3539.189  3547.068   7.879     1.000    462.437  3523.261    0.000  22.516    0.000
                                                 FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
SECTION NO.       8.000
** SUPERCRITICAL **  Using Critical Water Surface +
SECTION NO.       8.000 TIME =      1.000 DAYS.
TRIAL    TRIAL        COMPUTED      CRITICAL
 NO.       WS            WS            WS
  0.    3545.706      3544.731
  1.    3545.800      3544.749      3545.750
**** 165850.000  3545.800  3553.668   7.868     1.000    462.481  3529.862    0.000  22.500    0.000
                                                 FLOW DISTRIBUTION (%) =     0.000 100.000    0.000

SECTION NO.       9.000
** SUPERCRITICAL **  Using Critical Water Suface +
SECTION NO.       9.000 TIME =      1.000 DAYS.
TRIAL    TRIAL        COMPUTED      CRITICAL
 NO.       WS            WS            WS
  0.    3552.297      3551.325
  1.    3552.391      3551.340      3552.341
**** 165850.000  3552.391  3560.277   7886     1.000    462.421  3536.470    0.000  22.527    0.000
                                                 FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
SECTION NO.      10.000
** SUPERCRITICAL **  Using Critical Water Surface +
SECTION NO.      10.000 TIME =      1.000 DAYS.
TRIAL    TRIAL        COMPUTED      CRITICAL
 NO.       WS            WS            WS
  0.    3555.576      3555.124
  1.    3555.670      3555.164      3555.620
**** 165850.000  3555.670  3563.577   7.907     1.000    462.335  3539.767    0.000  22.557    0.000
                                                 FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
SECTION NO.      11.000
**** 165850.000  3558.965  3566.259   7.294     1.000    464.873  3542.497    0.000  21.664    0.000
                                                 FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
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SECTION NO.     12.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.      12.000 TIME =       1.000 DAYS.
 TRIAL    TRIAL         COMPUTED      CRITCAL
  NO.       WS             WS           WS
   0.    3565.134      3563.764
   1.    3565.228      3563.782      3565.178
 **** 165850.000  3565.228  3573.107   7.879     1.000    462.496  3549.302   0.000  22.516    0.000
                                                  FLOW DISTRIBUTION (%) =      0.000 100.000    0.000
 SECTION NO.      13.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.      13.000 TIME =       1.000 DAYS.
 TRIAL    TRIAL         COMPUTED      CRITICAL
  NO.       WS             WS           WS
   0.    3572.626      3570.765
   1.    3572.719      3570.779      3572.669
 **** 165850.000  3572.719  3580.619   7.900     1.000    462.278  3556.807   0.000  22.546    0.000
                                                  FLOW DISTRIBUTION(%) =     0.000 100.000    0.000
 SECTION NO.      14.000
 **** 165850.000  3579.648  3584.856   5.208     1.000    476.916  3560.652   0.000  18.306    0.000
                                                  FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
 SECTION NO.      15.000
 **** 165850.000  3582.223  3587.828   5.605     1.000    474.129  3563.804   0.000  18.992    0.000
                                                  FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
 SECTION NO.      16.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.      16.000 TIME =       1.000 DAYS.
 TRIAL    TRIAL         COMPUTED      CRITICAL
  NO.       WS             WS           WS
   0.    3585.157      3584.807
   1.    3585.251      3584.837      3585.201
 **** 165850.000  3585.251  3593.158   7.907     1.000    462.309  3569.347   0.000  22.556    0.000
                                                  FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
 SECTION NO.      17.000
 ** SUPERCRITICAL **  Using Critical Water Suface +
 SECTION NO.      17.000 TIME =       1.000 DAYS.
 TRIAL    TRIAL         COMPUTED      CRITICAL
  NO.       WS             WS           WS
   0.    3593.413      3590.826
   1.    3593.507      3590.851      3593.457
 **** 165850.000  3593.507  3601.387   7881     1.000    462.459  3577.581   0.000  22.519    0.000
                                                  FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
 SECTION NO.      18.000
 **** 165850.000  3600.195  3606.589   6.393     1.000    469.416  3582.776 0.000  20.283    0.000
                                                  FLOW DISTRIBUTION (%) =     0.000 100.000    0.000

SECTION NO.     19.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.      19.000 TIME =       1.000 DAYS.
 TRIAL    TRIAL         COMPUTED      CRITICAL
  NO.       WS             WS           WS
   0.    3605.292      3603.830
   1.    3605.386      3603.854      3605.336
 **** 165850.000  3605.386  3613.268   7.882     1.000    462.424  3589.460   0.000  22.521    0.000
                                                  FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
 SECTION NO.      20.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.      20.000 TIME =       1.000 DAYS.
 TRIAL    TRIAL         COMPUTED      CRITCAL
  NO.       WS             WS           WS
   0.    3608.738      3608.128
   1.    3608.832      3608.171      3608.782
 **** 165850.000  3608.832  3616.707   7.875     1.000    462.512  3592.902   0.000  22.511    0.000
                                                  FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
-----------------------------------------------------------------------------------------------
 $$END

        0    DATA ERRORS DETECTED.

 TOTAL NO. OF TIME STEPS READ =          2
 TOTAL NO. OF WS PROFILES =              2
 ITERATIONS IN EXNER EQ =                0

 COMPUTATIONS COMPLETED
 RUN TIME =  0 HOURS,  0 MINUTES &  0.00 SECONDS
```

**APPENDIX-9, OUTPUT OF HEC-RAS FOR SIMULATION OF BEAS RIVER WITH DIKES AND DIVERSION CHANNEL WITH 2 YEAR AND 500 YEAR RETURN PERIOD FLOODS (FIX BED APPLICATION)**

| Plan: Diversion Beas River Bhuntar Reach RS: 1 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3490.36 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 2.36 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3488 | Reach Len. (ft) | | | |
| Crit W.S. (ft) | 3487.7 | Flow Area (sq ft) | | 2291.81 | |
| E.G. Slope (ft/ft) | 0.010294 | Area (sq ft) | | 2291.81 | |
| Q Total (cfs) | 28230 | Flow (cfs) | | 28230 | |
| Top Width (ft) | 416.24 | Top Width (ft) | | 416.24 | |
| Vel Total (ft/s) | 12.32 | Avg. Vel. (ft/s) | | 12.32 | |
| Max Chl Dpth (ft) | 5.66 | Hydr. Depth (ft) | | 5.51 | |
| Conv. Total (cfs) | 278245.2 | Conv. (cfs) | | 278245.2 | |
| Length Wtd. (ft) | | Wetted Per. (ft) | | 418.91 | |
| Min Ch El (ft) | 3482.34 | Shear (lb/sq ft) | | 3.52 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 43.31 | |
| Frctn Loss (ft) | | Cum Volume (acre-ft) | | | |
| C & E Loss (ft) | | Cum SA (acres) | | | |

| Plan: Diversion Beas River Bhuntar Reach RS: 2 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3496.98 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 2.3 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3494.68 | Reach Len. (ft) | 665 | 656 | 645 |
| Crit W.S. (ft) | 3494.31 | Flow Area (sq ft) | | 2320.78 | |
| E.G. Slope (ft/ft) | 0.009881 | Area (sq ft) | | 2320.78 | |
| Q Total (cfs) | 28230 | Flow (cfs) | | 28230 | |
| Top Width (ft) | 416.52 | Top Width (ft) | | 416.52 | |
| Vel Total (ft/s) | 12.16 | Avg. Vel. (ft/s) | | 12.16 | |
| Max Chl Dpth (ft) | 5.73 | Hydr. Depth (ft) | | 5.57 | |
| Conv. Total (cfs) | 283991.5 | Conv. (cfs) | | 283991.5 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 419.22 | |
| Min Ch El (ft) | 3488.95 | Shear (lb/sq ft) | | 3.42 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 41.54 | |
| Frctn Loss (ft) | 6.62 | Cum Volume (acre-ft) | | 34.73 | |
| C & E Loss (ft) | 0.01 | Cum SA (acres) | | 6.27 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 3 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3503.57 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 2.34 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3501.23 | Reach Len. (ft) | 675 | 656 | 635 |
| Crit W.S. (ft) | 3500.91 | Flow Area (sq ft) | | 2299.64 | |
| E.G. Slope (ft/ft) | 0.01018 | Area (sq ft) | | 2299.64 | |
| Q Total (cfs) | 28230 | Flow (cfs) | | 28230 | |
| Top Width (ft) | 416.31 | Top Width (ft) | | 416.31 | |
| Vel Total (ft/s) | 12.28 | Avg. Vel. (ft/s) | | 12.28 | |
| Max Chl Dpth (ft) | 5.68 | Hydr. Depth (ft) | | 5.52 | |
| Conv. Total (cfs) | 279793 | Conv. (cfs) | | 279793 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 419 | |
| Min Ch El (ft) | 3495.55 | Shear (lb/sq ft) | | 3.49 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 42.82 | |
| Frctn Loss (ft) | 6.58 | Cum Volume (acre-ft) | | 69.52 | |
| C & E Loss (ft) | 0.01 | Cum SA (acres) | | 12.54 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 4 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3510.18 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 2.31 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3507.87 | Reach Len. (ft) | 635 | 656 | 675 |
| Crit W.S. (ft) | 3507.52 | Flow Area (sq ft) | | 2313.56 | |
| E.G. Slope (ft/ft) | 0.009982 | Area (sq ft) | | 2313.56 | |
| Q Total (cfs) | 28230 | Flow (cfs) | | 28230 | |
| Top Width (ft) | 416.45 | Top Width (ft) | | 416.45 | |
| Vel Total (ft/s) | 12.2 | Avg. Vel. (ft/s) | | 12.2 | |
| Max Chl Dpth (ft) | 5.71 | Hydr. Depth (ft) | | 5.56 | |
| Conv. Total (cfs) | 282555.6 | Conv. (cfs) | | 282555.6 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 419.15 | |
| Min Ch El (ft) | 3502.16 | Shear (lb/sq ft) | | 3.44 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 41.97 | |
| Frctn Loss (ft) | 6.61 | Cum Volume (acre-ft) | | 104.26 | |
| C & E Loss (ft) | 0 | Cum SA (acres) | | 18.81 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 5 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3516.79 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 2.33 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3514.46 | Reach Len. (ft) | 645 | 656 | 665 |
| Crit W.S. (ft) | 3514.13 | Flow Area (sq ft) | | 2302.58 | |
| E.G. Slope (ft/ft) | 0.010138 | Area (sq ft) | | 2302.58 | |
| Q Total (cfs) | 28230 | Flow (cfs) | | 28230 | |
| Top Width (ft) | 416.34 | Top Width (ft) | | 416.34 | |
| Vel Total (ft/s) | 12.26 | Avg. Vel. (ft/s) | | 12.26 | |
| Max Chl Dpth (ft) | 5.69 | Hydr. Depth (ft) | | 5.53 | |
| Conv. Total (cfs) | 280376.8 | Conv. (cfs) | | 280376.8 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 419.03 | |
| Min Ch El (ft) | 3508.77 | Shear (lb/sq ft) | | 3.48 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 42.64 | |
| Frctn Loss (ft) | 6.6 | Cum Volume (acre-ft) | | 139.02 | |
| C & E Loss (ft) | 0.01 | Cum SA (acres) | | 25.08 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 6 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3523.39 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 2.31 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3521.08 | Reach Len. (ft) | 670 | 656 | 642 |
| Crit W.S. (ft) | 3520.73 | Flow Area (sq ft) | | 2312.95 | |
| E.G. Slope (ft/ft) | 0.00999 | Area (sq ft) | | 2312.95 | |
| Q Total (cfs) | 28230 | Flow (cfs) | | 28230 | |
| Top Width (ft) | 416.44 | Top Width (ft) | | 416.44 | |
| Vel Total (ft/s) | 12.21 | Avg. Vel. (ft/s) | | 12.21 | |
| Max Chl Dpth (ft) | 5.71 | Hydr. Depth (ft) | | 5.55 | |
| Conv. Total (cfs) | 282434.4 | Conv. (cfs) | | 282434.4 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 419.14 | |
| Min Ch El (ft) | 3515.37 | Shear (lb/sq ft) | | 3.44 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 42.01 | |
| Frctn Loss (ft) | 6.6 | Cum Volume (acre-ft) | | 173.77 | |
| C & E Loss (ft) | 0 | Cum SA (acres) | | 31.35 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 7 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3530 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 2.33 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3527.67 | Reach Len. (ft) | 673 | 656 | 635 |
| Crit W.S. (ft) | 3527.34 | Flow Area (sq ft) | | 2302.99 | |
| E.G. Slope (ft/ft) | 0.010132 | Area (sq ft) | | 2302.99 | |
| Q Total (cfs) | 28230 | Flow (cfs) | | 28230 | |
| Top Width (ft) | 416.35 | Top Width (ft) | | 416.35 | |
| Vel Total (ft/s) | 12.26 | Avg. Vel. (ft/s) | | 12.26 | |
| Max Chl Dpth (ft) | 5.69 | Hydr. Depth (ft) | | 5.53 | |
| Conv. Total (cfs) | 280457.5 | Conv. (cfs) | | 280457.5 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 419.03 | |
| Min Ch El (ft) | 3521.98 | Shear (lb/sq ft) | | 3.48 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 42.61 | |
| Frctn Loss (ft) | 6.6 | Cum Volume (acre-ft) | | 208.53 | |
| C & E Loss (ft) | 0.01 | Cum SA (acres) | | 37.62 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 8 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3536.6 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 2.31 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3534.29 | Reach Len. (ft) | 647 | 656 | 665 |
| Crit W.S. (ft) | 3533.94 | Flow Area (sq ft) | | 2312.55 | |
| E.G. Slope (ft/ft) | 0.009996 | Area (sq ft) | | 2312.55 | |
| Q Total (cfs) | 28230 | Flow (cfs) | | 28230 | |
| Top Width (ft) | 416.44 | Top Width (ft) | | 416.44 | |
| Vel Total (ft/s) | 12.21 | Avg. Vel. (ft/s) | | 12.21 | |
| Max Chl Dpth (ft) | 5.71 | Hydr. Depth (ft) | | 5.55 | |
| Conv. Total (cfs) | 282353.6 | Conv. (cfs) | | 282353.6 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 419.13 | |
| Min Ch El (ft) | 3528.58 | Shear (lb/sq ft) | | 3.44 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 42.03 | |
| Frctn Loss (ft) | 6.6 | Cum Volume (acre-ft) | | 243.28 | |
| C & E Loss (ft) | 0 | Cum SA (acres) | | 43.9 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 9 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3543.21 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 2.33 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3540.88 | Reach Len. (ft) | 637 | 656 | 675 |
| Crit W.S. (ft) | 3540.55 | Flow Area (sq ft) | | 2303.3 | |
| E.G. Slope (ft/ft) | 0.010127 | Area (sq ft) | | 2303.3 | |
| Q Total (cfs) | 28230 | Flow (cfs) | | 28230 | |
| Top Width (ft) | 416.35 | Top Width (ft) | | 416.35 | |
| Vel Total (ft/s) | 12.26 | Avg. Vel. (ft/s) | | 12.26 | |
| Max Chl Dpth (ft) | 5.69 | Hydr. Depth (ft) | | 5.53 | |
| Conv. Total (cfs) | 280517.9 | Conv. (cfs) | | 280517.9 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 419.04 | |
| Min Ch El (ft) | 3535.19 | Shear (lb/sq ft) | | 3.48 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 42.59 | |
| Frctn Loss (ft) | 6.6 | Cum Volume (acre-ft) | | 278.04 | |
| C & E Loss (ft) | 0.01 | Cum SA (acres) | | 50.17 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 10 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3546.51 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 2.32 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3544.2 | Reach Len. (ft) | 323 | 328 | 333 |
| Crit W.S. (ft) | | Flow Area (sq ft) | | 2311.94 | |
| E.G. Slope (ft/ft) | 0.010005 | Area (sq ft) | | 2311.94 | |
| Q Total (cfs) | 28230 | Flow (cfs) | | 28230 | |
| Top Width (ft) | 416.43 | Top Width (ft) | | 416.43 | |
| Vel Total (ft/s) | 12.21 | Avg. Vel. (ft/s) | | 12.21 | |
| Max Chl Dpth (ft) | 5.71 | Hydr. Depth (ft) | | 5.55 | |
| Conv. Total (cfs) | 282232.4 | Conv. (cfs) | | 282232.4 | |
| Length Wtd. (ft) | 328 | Wetted Per. (ft) | | 419.13 | |
| Min Ch El (ft) | 3538.49 | Shear (lb/sq ft) | | 3.45 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 42.07 | |
| Frctn Loss (ft) | 3.3 | Cum Volume (acre-ft) | | 295.42 | |
| C & E Loss (ft) | 0 | Cum SA (acres) | | 53.3 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 11 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3549.33 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 1.9 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3547.43 | Reach Len. (ft) | 328 | 328 | 328 |
| Crit W.S. (ft) | | Flow Area (sq ft) | | 2555.2 | |
| E.G. Slope (ft/ft) | 0.007227 | Area (sq ft) | | 2555.2 | |
| Q Total (cfs) | 28230 | Flow (cfs) | | 28230 | |
| Top Width (ft) | 418.76 | Top Width (ft) | | 418.76 | |
| Vel Total (ft/s) | 11.05 | Avg. Vel. (ft/s) | | 11.05 | |
| Max Chl Dpth (ft) | 6.29 | Hydr. Depth (ft) | | 6.1 | |
| Conv. Total (cfs) | 332067.6 | Conv. (cfs) | | 332067.6 | |
| Length Wtd. (ft) | 328 | Wetted Per. (ft) | | 421.73 | |
| Min Ch El (ft) | 3541.14 | Shear (lb/sq ft) | | 2.73 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 30.2 | |
| Frctn Loss (ft) | 2.77 | Cum Volume (acre-ft) | | 313.74 | |
| C & E Loss (ft) | 0.04 | Cum SA (acres) | | 56.45 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 12 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3556.02 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 2.63 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3553.38 | Reach Len. (ft) | 656 | 656 | 656 |
| Crit W.S. (ft) | 3553.38 | Flow Area (sq ft) | | 2168.52 | |
| E.G. Slope (ft/ft) | 0.012325 | Area (sq ft) | | 2168.52 | |
| Q Total (cfs) | 28230 | Flow (cfs) | | 28230 | |
| Top Width (ft) | 415.05 | Top Width (ft) | | 415.05 | |
| Vel Total (ft/s) | 13.02 | Avg. Vel. (ft/s) | | 13.02 | |
| Max Chl Dpth (ft) | 5.36 | Hydr. Depth (ft) | | 5.22 | |
| Conv. Total (cfs) | 254284.3 | Conv. (cfs) | | 254284.3 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 417.59 | |
| Min Ch El (ft) | 3548.02 | Shear (lb/sq ft) | | 4 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 52.02 | |
| Frctn Loss (ft) | 6.08 | Cum Volume (acre-ft) | | 349.31 | |
| C & E Loss (ft) | 0.22 | Cum SA (acres) | | 62.72 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 13 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3563.54 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 2.4 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3561.14 | Reach Len. (ft) | 656 | 656 | 656 |
| Crit W.S. (ft) | 3560.89 | Flow Area (sq ft) | | 2268.85 | |
| E.G. Slope (ft/ft) | 0.010637 | Area (sq ft) | | 2268.85 | |
| Q Total (cfs) | 28230 | Flow (cfs) | | 28230 | |
| Top Width (ft) | 416.02 | Top Width (ft) | | 416.02 | |
| Vel Total (ft/s) | 12.44 | Avg. Vel. (ft/s) | | 12.44 | |
| Max Chl Dpth (ft) | 5.6 | Hydr. Depth (ft) | | 5.45 | |
| Conv. Total (cfs) | 273722.3 | Conv. (cfs) | | 273722.3 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 418.67 | |
| Min Ch El (ft) | 3555.53 | Shear (lb/sq ft) | | 3.6 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 44.78 | |
| Frctn Loss (ft) | 7.5 | Cum Volume (acre-ft) | | 382.72 | |
| C & E Loss (ft) | 0.02 | Cum SA (acres) | | 68.98 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 14 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3567.65 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 1.31 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3566.35 | Reach Len. (ft) | 656 | 656 | 656 |
| Crit W.S. (ft) | | Flow Area (sq ft) | | 3079.19 | |
| E.G. Slope (ft/ft) | 0.003949 | Area (sq ft) | | 3079.19 | |
| Q Total (cfs) | 28230 | Flow (cfs) | | 28230 | |
| Top Width (ft) | 423.74 | Top Width (ft) | | 423.74 | |
| Vel Total (ft/s) | 9.17 | Avg. Vel. (ft/s) | | 9.17 | |
| Max Chl Dpth (ft) | 7.53 | Hydr. Depth (ft) | | 7.27 | |
| Conv. Total (cfs) | 449213.4 | Conv. (cfs) | | 449213.4 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 427.3 | |
| Min Ch El (ft) | 3558.81 | Shear (lb/sq ft) | | 1.78 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 16.29 | |
| Frctn Loss (ft) | 4 | Cum Volume (acre-ft) | | 422.99 | |
| C & E Loss (ft) | 0.11 | Cum SA (acres) | | 75.31 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 15 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3570.53 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 1.59 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3568.94 | Reach Len. (ft) | 606.8 | 606.8 | 606.8 |
| Crit W.S. (ft) | | Flow Area (sq ft) | | 2789.53 | |
| E.G. Slope (ft/ft) | 0.005437 | Area (sq ft) | | 2789.53 | |
| Q Total (cfs) | 28230 | Flow (cfs) | | 28230 | |
| Top Width (ft) | 421 | Top Width (ft) | | 421 | |
| Vel Total (ft/s) | 10.12 | Avg. Vel. (ft/s) | | 10.12 | |
| Max Chl Dpth (ft) | 6.85 | Hydr. Depth (ft) | | 6.63 | |
| Conv. Total (cfs) | 382851.4 | Conv. (cfs) | | 382851.4 | |
| Length Wtd. (ft) | 606.8 | Wetted Per. (ft) | | 424.23 | |
| Min Ch El (ft) | 3562.09 | Shear (lb/sq ft) | | 2.23 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 22.59 | |
| Frctn Loss (ft) | 2.79 | Cum Volume (acre-ft) | | 463.87 | |
| C & E Loss (ft) | 0.09 | Cum SA (acres) | | 81.19 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 16 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3576.07 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 3 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3573.43 | Reach Len. (ft) | 656 | 656 | 656 |
| Crit W.S. (ft) | 3573.43 | Flow Area (sq ft) | | 2168.72 | |
| E.G. Slope (ft/ft) | 0.012321 | Area (sq ft) | | 2168.72 | |
| Q Total (cfs) | 28230 | Flow (cfs) | | 28230 | |
| Top Width (ft) | 415.06 | Top Width (ft) | | 415.06 | |
| Vel Total (ft/s) | 13.02 | Avg. Vel. (ft/s) | | 13.02 | |
| Max Chl Dpth (ft) | 5.36 | Hydr. Depth (ft) | | 5.23 | |
| Conv. Total (cfs) | 254323 | Conv. (cfs) | | 254323 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 417.59 | |
| Min Ch El (ft) | 3568.07 | Shear (lb/sq ft) | | 3.99 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 52 | |
| Frctn Loss (ft) | 5.15 | Cum Volume (acre-ft) | | 501.2 | |
| C & E Loss (ft) | 0.31 | Cum SA (acres) | | 87.48 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 17 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3584.3 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 2.63 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3581.66 | Reach Len. (ft) | 656 | 656 | 656 |
| Crit W.S. (ft) | 3581.66 | Flow Area (sq ft) | | 2167.2 | |
| E.G. Slope (ft/ft) | 0.012349 | Area (sq ft) | | 2167.2 | |
| Q Total (cfs) | 28230 | Flow (cfs) | | 28230 | |
| Top Width (ft) | 415.04 | Top Width (ft) | | 415.04 | |
| Vel Total (ft/s) | 13.03 | Avg. Vel. (ft/s) | | 13.03 | |
| Max Chl Dpth (ft) | 5.36 | Hydr. Depth (ft) | | 5.22 | |
| Conv. Total (cfs) | 254032.7 | Conv. (cfs) | | 254032.7 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 417.57 | |
| Min Ch El (ft) | 3576.3 | Shear (lb/sq ft) | | 4 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 52.12 | |
| Frctn Loss (ft) | 8.09 | Cum Volume (acre-ft) | | 533.85 | |
| C & E Loss (ft) | 0 | Cum SA (acres) | | 93.73 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 18 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3589.78 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 1.54 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3588.24 | Reach Len. (ft) | 705.2 | 705.2 | 705.2 |
| Crit W.S. (ft) | 3586.65 | Flow Area (sq ft) | | 2832.52 | |
| E.G. Slope (ft/ft) | 0.005174 | Area (sq ft) | | 2832.52 | |
| Q Total (cfs) | 28230 | Flow (cfs) | | 28230 | |
| Top Width (ft) | 421.4 | Top Width (ft) | | 421.4 | |
| Vel Total (ft/s) | 9.97 | Avg. Vel. (ft/s) | | 9.97 | |
| Max Chl Dpth (ft) | 6.95 | Hydr. Depth (ft) | | 6.72 | |
| Conv. Total (cfs) | 392452.6 | Conv. (cfs) | | 392452.6 | |
| Length Wtd. (ft) | 705.2 | Wetted Per. (ft) | | 424.69 | |
| Min Ch El (ft) | 3581.29 | Shear (lb/sq ft) | | 2.15 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 21.47 | |
| Frctn Loss (ft) | 5.38 | Cum Volume (acre-ft) | | 574.32 | |
| C & E Loss (ft) | 0.11 | Cum SA (acres) | | 100.51 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 19 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3596.18 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 2.63 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3593.54 | Reach Len. (ft) | 656 | 656 | 656 |
| Crit W.S. (ft) | 3593.54 | Flow Area (sq ft) | | 2168.62 | |
| E.G. Slope (ft/ft) | 0.012323 | Area (sq ft) | | 2168.62 | |
| Q Total (cfs) | 28230 | Flow (cfs) | | 28230 | |
| Top Width (ft) | 415.05 | Top Width (ft) | | 415.05 | |
| Vel Total (ft/s) | 13.02 | Avg. Vel. (ft/s) | | 13.02 | |
| Max Chl Dpth (ft) | 5.36 | Hydr. Depth (ft) | | 5.22 | |
| Conv. Total (cfs) | 254303.6 | Conv. (cfs) | | 254303.6 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 417.59 | |
| Min Ch El (ft) | 3588.18 | Shear (lb/sq ft) | | 4 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 52.01 | |
| Frctn Loss (ft) | 5 | Cum Volume (acre-ft) | | 611.98 | |
| C & E Loss (ft) | 0.33 | Cum SA (acres) | | 106.8 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 20 Profile: 2 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3599.68 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 2.18 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3597.49 | Reach Len. (ft) | 328 | 328 | 328 |
| Crit W.S. (ft) | 3596.98 | Flow Area (sq ft) | | 2379.9 | |
| E.G. Slope (ft/ft) | 0.009105 | Area (sq ft) | | 2379.9 | |
| Q Total (cfs) | 28230 | Flow (cfs) | | 28230 | |
| Top Width (ft) | 417.09 | Top Width (ft) | | 417.09 | |
| Vel Total (ft/s) | 11.86 | Avg. Vel. (ft/s) | | 11.86 | |
| Max Chl Dpth (ft) | 5.87 | Hydr. Depth (ft) | | 5.71 | |
| Conv. Total (cfs) | 295853.1 | Conv. (cfs) | | 295853.1 | |
| Length Wtd. (ft) | 328 | Wetted Per. (ft) | | 419.86 | |
| Min Ch El (ft) | 3591.62 | Shear (lb/sq ft) | | 3.22 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 38.22 | |
| Frctn Loss (ft) | 3.45 | Cum Volume (acre-ft) | | 629.11 | |
| C & E Loss (ft) | 0.04 | Cum SA (acres) | | 109.94 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 1 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3507.42 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 7.97 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3499.45 | Reach Len. (ft) | | | |
| Crit W.S. (ft) | 3499.45 | Flow Area (sq ft) | | 7320.73 | |
| E.G. Slope (ft/ft) | 0.008632 | Area (sq ft) | | 7320.73 | |
| Q Total (cfs) | 165850 | Flow (cfs) | | 165850 | |
| Top Width (ft) | 462.05 | Top Width (ft) | | 462.05 | |
| Vel Total (ft/s) | 22.65 | Avg. Vel. (ft/s) | | 22.65 | |
| Max Chl Dpth (ft) | 17.11 | Hydr. Depth (ft) | | 15.84 | |
| Conv. Total (cfs) | 1785088 | Conv. (cfs) | | 1785088 | |
| Length Wtd. (ft) | | Wetted Per. (ft) | | 470.13 | |
| Min Ch El (ft) | 3482.34 | Shear (lb/sq ft) | | 8.39 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 190.11 | |
| Frctn Loss (ft) | | Cum Volume (acre-ft) | | | |
| C & E Loss (ft) | | Cum SA (acres) | | | |

| Plan: Diversion Beas River Bhuntar Reach RS: 2 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3514.03 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 7.97 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3506.06 | Reach Len. (ft) | 665 | 656 | 645 |
| Crit W.S. (ft) | 3506.06 | Flow Area (sq ft) | | 7320.16 | |
| E.G. Slope (ft/ft) | 0.008634 | Area (sq ft) | | 7320.16 | |
| Q Total (cfs) | 165850 | Flow (cfs) | | 165850 | |
| Top Width (ft) | 462.04 | Top Width (ft) | | 462.04 | |
| Vel Total (ft/s) | 22.66 | Avg. Vel. (ft/s) | | 22.66 | |
| Max Chl Dpth (ft) | 17.11 | Hydr. Depth (ft) | | 15.84 | |
| Conv. Total (cfs) | 1784872 | Conv. (cfs) | | 1784872 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 470.12 | |
| Min Ch El (ft) | 3488.95 | Shear (lb/sq ft) | | 8.39 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 190.16 | |
| Frctn Loss (ft) | 5.66 | Cum Volume (acre-ft) | | 110.24 | |
| C & E Loss (ft) | 0 | Cum SA (acres) | | 6.96 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 3 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3520.63 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 7.96 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3512.67 | Reach Len. (ft) | 675 | 656 | 635 |
| Crit W.S. (ft) | 3512.67 | Flow Area (sq ft) | | 7323.55 | |
| E.G. Slope (ft/ft) | 0.008622 | Area (sq ft) | | 7323.55 | |
| Q Total (cfs) | 165850 | Flow (cfs) | | 165850 | |
| Top Width (ft) | 462.07 | Top Width (ft) | | 462.07 | |
| Vel Total (ft/s) | 22.65 | Avg. Vel. (ft/s) | | 22.65 | |
| Max Chl Dpth (ft) | 17.12 | Hydr. Depth (ft) | | 15.85 | |
| Conv. Total (cfs) | 1786164 | Conv. (cfs) | | 1786164 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 470.15 | |
| Min Ch El (ft) | 3495.55 | Shear (lb/sq ft) | | 8.38 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 189.87 | |
| Frctn Loss (ft) | 5.66 | Cum Volume (acre-ft) | | 220.51 | |
| C & E Loss (ft) | 0 | Cum SA (acres) | | 13.92 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 4 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3527.24 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 7.97 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3519.27 | Reach Len. (ft) | 635 | 656 | 675 |
| Crit W.S. (ft) | 3519.27 | Flow Area (sq ft) | | 7321.63 | |
| E.G. Slope (ft/ft) | 0.008629 | Area (sq ft) | | 7321.63 | |
| Q Total (cfs) | 165850 | Flow (cfs) | | 165850 | |
| Top Width (ft) | 462.05 | Top Width (ft) | | 462.05 | |
| Vel Total (ft/s) | 22.65 | Avg. Vel. (ft/s) | | 22.65 | |
| Max Chl Dpth (ft) | 17.11 | Hydr. Depth (ft) | | 15.85 | |
| Conv. Total (cfs) | 1785432 | Conv. (cfs) | | 1785432 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 470.13 | |
| Min Ch El (ft) | 3502.16 | Shear (lb/sq ft) | | 8.39 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 190.03 | |
| Frctn Loss (ft) | 5.66 | Cum Volume (acre-ft) | | 330.78 | |
| C & E Loss (ft) | 0 | Cum SA (acres) | | 20.88 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 5 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3533.85 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 7.97 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3525.88 | Reach Len. (ft) | 645 | 656 | 665 |
| Crit W.S. (ft) | 3525.88 | Flow Area (sq ft) | | 7320.73 | |
| E.G. Slope (ft/ft) | 0.008632 | Area (sq ft) | | 7320.73 | |
| Q Total (cfs) | 165850 | Flow (cfs) | | 165850 | |
| Top Width (ft) | 462.05 | Top Width (ft) | | 462.05 | |
| Vel Total (ft/s) | 22.65 | Avg. Vel. (ft/s) | | 22.65 | |
| Max Chl Dpth (ft) | 17.11 | Hydr. Depth (ft) | | 15.84 | |
| Conv. Total (cfs) | 1785087 | Conv. (cfs) | | 1785087 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 470.13 | |
| Min Ch El (ft) | 3508.77 | Shear (lb/sq ft) | | 8.39 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 190.11 | |
| Frctn Loss (ft) | 5.66 | Cum Volume (acre-ft) | | 441.04 | |
| C & E Loss (ft) | 0 | Cum SA (acres) | | 27.83 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 6 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3540.45 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 7.97 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3532.48 | Reach Len. (ft) | 670 | 656 | 642 |
| Crit W.S. (ft) | 3532.48 | Flow Area (sq ft) | | 7320.17 | |
| E.G. Slope (ft/ft) | 0.008634 | Area (sq ft) | | 7320.17 | |
| Q Total (cfs) | 165850 | Flow (cfs) | | 165850 | |
| Top Width (ft) | 462.04 | Top Width (ft) | | 462.04 | |
| Vel Total (ft/s) | 22.66 | Avg. Vel. (ft/s) | | 22.66 | |
| Max Chl Dpth (ft) | 17.11 | Hydr. Depth (ft) | | 15.84 | |
| Conv. Total (cfs) | 1784873 | Conv. (cfs) | | 1784873 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 470.12 | |
| Min Ch El (ft) | 3515.37 | Shear (lb/sq ft) | | 8.39 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 190.16 | |
| Frctn Loss (ft) | 5.66 | Cum Volume (acre-ft) | | 551.28 | |
| C & E Loss (ft) | 0 | Cum SA (acres) | | 34.79 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 7 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3547.06 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 7.96 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3539.1 | Reach Len. (ft) | 673 | 656 | 635 |
| Crit W.S. (ft) | 3539.1 | Flow Area (sq ft) | | 7323.55 | |
| E.G. Slope (ft/ft) | 0.008622 | Area (sq ft) | | 7323.55 | |
| Q Total (cfs) | 165850 | Flow (cfs) | | 165850 | |
| Top Width (ft) | 462.07 | Top Width (ft) | | 462.07 | |
| Vel Total (ft/s) | 22.65 | Avg. Vel. (ft/s) | | 22.65 | |
| Max Chl Dpth (ft) | 17.12 | Hydr. Depth (ft) | | 15.85 | |
| Conv. Total (cfs) | 1786164 | Conv. (cfs) | | 1786164 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 470.15 | |
| Min Ch El (ft) | 3521.98 | Shear (lb/sq ft) | | 8.38 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 189.87 | |
| Frctn Loss (ft) | 5.66 | Cum Volume (acre-ft) | | 661.55 | |
| C & E Loss (ft) | 0 | Cum SA (acres) | | 41.75 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 8 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3553.66 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 7.97 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3545.69 | Reach Len. (ft) | 647 | 656 | 665 |
| Crit W.S. (ft) | 3545.69 | Flow Area (sq ft) | | 7321.63 | |
| E.G. Slope (ft/ft) | 0.008629 | Area (sq ft) | | 7321.63 | |
| Q Total (cfs) | 165850 | Flow (cfs) | | 165850 | |
| Top Width (ft) | 462.05 | Top Width (ft) | | 462.05 | |
| Vel Total (ft/s) | 22.65 | Avg. Vel. (ft/s) | | 22.65 | |
| Max Chl Dpth (ft) | 17.11 | Hydr. Depth (ft) | | 15.85 | |
| Conv. Total (cfs) | 1785433 | Conv. (cfs) | | 1785433 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 470.13 | |
| Min Ch El (ft) | 3528.58 | Shear (lb/sq ft) | | 8.39 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 190.03 | |
| Frctn Loss (ft) | 5.66 | Cum Volume (acre-ft) | | 771.82 | |
| C & E Loss (ft) | 0 | Cum SA (acres) | | 48.71 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 9 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3560.27 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 7.97 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3552.3 | Reach Len. (ft) | 637 | 656 | 675 |
| Crit W.S. (ft) | 3552.3 | Flow Area (sq ft) | | 7320.73 | |
| E.G. Slope (ft/ft) | 0.008632 | Area (sq ft) | | 7320.73 | |
| Q Total (cfs) | 165850 | Flow (cfs) | | 165850 | |
| Top Width (ft) | 462.05 | Top Width (ft) | | 462.05 | |
| Vel Total (ft/s) | 22.65 | Avg. Vel. (ft/s) | | 22.65 | |
| Max Chl Dpth (ft) | 17.11 | Hydr. Depth (ft) | | 15.84 | |
| Conv. Total (cfs) | 1785087 | Conv. (cfs) | | 1785087 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 470.13 | |
| Min Ch El (ft) | 3535.19 | Shear (lb/sq ft) | | 8.39 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 190.11 | |
| Frctn Loss (ft) | 5.66 | Cum Volume (acre-ft) | | 882.08 | |
| C & E Loss (ft) | 0 | Cum SA (acres) | | 55.67 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 10 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3563.57 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 7.97 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3555.6 | Reach Len. (ft) | 323 | 328 | 333 |
| Crit W.S. (ft) | 3555.6 | Flow Area (sq ft) | | 7320.16 | |
| E.G. Slope (ft/ft) | 0.008634 | Area (sq ft) | | 7320.16 | |
| Q Total (cfs) | 165850 | Flow (cfs) | | 165850 | |
| Top Width (ft) | 462.04 | Top Width (ft) | | 462.04 | |
| Vel Total (ft/s) | 22.66 | Avg. Vel. (ft/s) | | 22.66 | |
| Max Chl Dpth (ft) | 17.11 | Hydr. Depth (ft) | | 15.84 | |
| Conv. Total (cfs) | 1784872 | Conv. (cfs) | | 1784872 | |
| Length Wtd. (ft) | 328 | Wetted Per. (ft) | | 470.12 | |
| Min Ch El (ft) | 3538.49 | Shear (lb/sq ft) | | 8.39 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 190.16 | |
| Frctn Loss (ft) | 2.83 | Cum Volume (acre-ft) | | 937.2 | |
| C & E Loss (ft) | 0 | Cum SA (acres) | | 59.15 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 11 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3566.27 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 7.24 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3559.02 | Reach Len. (ft) | 328 | 328 | 328 |
| Crit W.S. (ft) | 3558.26 | Flow Area (sq ft) | | 7678.6 | |
| E.G. Slope (ft/ft) | 0.007435 | Area (sq ft) | | 7678.6 | |
| Q Total (cfs) | 165850 | Flow (cfs) | | 165850 | |
| Top Width (ft) | 465.13 | Top Width (ft) | | 465.13 | |
| Vel Total (ft/s) | 21.6 | Avg. Vel. (ft/s) | | 21.6 | |
| Max Chl Dpth (ft) | 17.88 | Hydr. Depth (ft) | | 16.51 | |
| Conv. Total (cfs) | 1923481 | Conv. (cfs) | | 1923481 | |
| Length Wtd. (ft) | 328 | Wetted Per. (ft) | | 473.58 | |
| Min Ch El (ft) | 3541.14 | Shear (lb/sq ft) | | 7.53 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 162.54 | |
| Frctn Loss (ft) | 2.62 | Cum Volume (acre-ft) | | 993.67 | |
| C & E Loss (ft) | 0.07 | Cum SA (acres) | | 62.64 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 12 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3573.1 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 7.97 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3565.13 | Reach Len. (ft) | 656 | 656 | 656 |
| Crit W.S. (ft) | 3565.13 | Flow Area (sq ft) | | 7321.63 | |
| E.G. Slope (ft/ft) | 0.008629 | Area (sq ft) | | 7321.63 | |
| Q Total (cfs) | 165850 | Flow (cfs) | | 165850 | |
| Top Width (ft) | 462.05 | Top Width (ft) | | 462.05 | |
| Vel Total (ft/s) | 22.65 | Avg. Vel. (ft/s) | | 22.65 | |
| Max Chl Dpth (ft) | 17.11 | Hydr. Depth (ft) | | 15.85 | |
| Conv. Total (cfs) | 1785432 | Conv. (cfs) | | 1785432 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 470.13 | |
| Min Ch El (ft) | 3548.02 | Shear (lb/sq ft) | | 8.39 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 190.03 | |
| Frctn Loss (ft) | 5.25 | Cum Volume (acre-ft) | | 1106.62 | |
| C & E Loss (ft) | 0.22 | Cum SA (acres) | | 69.62 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 13 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3580.61 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 7.97 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3572.64 | Reach Len. (ft) | 656 | 656 | 656 |
| Crit W.S. (ft) | 3572.64 | Flow Area (sq ft) | | 7320.73 | |
| E.G. Slope (ft/ft) | 0.008632 | Area (sq ft) | | 7320.73 | |
| Q Total (cfs) | 165850 | Flow (cfs) | | 165850 | |
| Top Width (ft) | 462.05 | Top Width (ft) | | 462.05 | |
| Vel Total (ft/s) | 22.65 | Avg. Vel. (ft/s) | | 22.65 | |
| Max Chl Dpth (ft) | 17.11 | Hydr. Depth (ft) | | 15.84 | |
| Conv. Total (cfs) | 1785087 | Conv. (cfs) | | 1785087 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 470.13 | |
| Min Ch El (ft) | 3555.53 | Shear (lb/sq ft) | | 8.39 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 190.11 | |
| Frctn Loss (ft) | 5.66 | Cum Volume (acre-ft) | | 1216.87 | |
| C & E Loss (ft) | 0 | Cum SA (acres) | | 76.58 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 14 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3584.84 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 5.2 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3579.64 | Reach Len. (ft) | 656 | 656 | 656 |
| Crit W.S. (ft) | 3575.92 | Flow Area (sq ft) | | 9065.7 | |
| E.G. Slope (ft/ft) | 0.004433 | Area (sq ft) | | 9065.7 | |
| Q Total (cfs) | 165850 | Flow (cfs) | | 165850 | |
| Top Width (ft) | 476.91 | Top Width (ft) | | 476.91 | |
| Vel Total (ft/s) | 18.29 | Avg. Vel. (ft/s) | | 18.29 | |
| Max Chl Dpth (ft) | 20.83 | Hydr. Depth (ft) | | 19.01 | |
| Conv. Total (cfs) | 2490830 | Conv. (cfs) | | 2490830 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 486.75 | |
| Min Ch El (ft) | 3558.81 | Shear (lb/sq ft) | | 5.16 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 94.31 | |
| Frctn Loss (ft) | 3.95 | Cum Volume (acre-ft) | | 1340.26 | |
| C & E Loss (ft) | 0.28 | Cum SA (acres) | | 83.65 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 15 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3587.81 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 5.61 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3582.2 | Reach Len. (ft) | 606.8 | 606.8 | 606.8 |
| Crit W.S. (ft) | | Flow Area (sq ft) | | 8724.64 | |
| E.G. Slope (ft/ft) | 0.004994 | Area (sq ft) | | 8724.64 | |
| Q Total (cfs) | 165850 | Flow (cfs) | | 165850 | |
| Top Width (ft) | 474.05 | Top Width (ft) | | 474.05 | |
| Vel Total (ft/s) | 19.01 | Avg. Vel. (ft/s) | | 19.01 | |
| Max Chl Dpth (ft) | 20.11 | Hydr. Depth (ft) | | 18.4 | |
| Conv. Total (cfs) | 2346943 | Conv. (cfs) | | 2346943 | |
| Length Wtd. (ft) | 606.8 | Wetted Per. (ft) | | 483.54 | |
| Min Ch El (ft) | 3562.09 | Shear (lb/sq ft) | | 5.63 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 106.93 | |
| Frctn Loss (ft) | 2.85 | Cum Volume (acre-ft) | | 1464.17 | |
| C & E Loss (ft) | 0.12 | Cum SA (acres) | | 90.27 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 16 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3593.15 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 7.97 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3585.18 | Reach Len. (ft) | 656 | 656 | 656 |
| Crit W.S. (ft) | 3585.18 | Flow Area (sq ft) | | 7318.25 | |
| E.G. Slope (ft/ft) | 0.008641 | Area (sq ft) | | 7318.25 | |
| Q Total (cfs) | 165850 | Flow (cfs) | | 165850 | |
| Top Width (ft) | 462.03 | Top Width (ft) | | 462.03 | |
| Vel Total (ft/s) | 22.66 | Avg. Vel. (ft/s) | | 22.66 | |
| Max Chl Dpth (ft) | 17.11 | Hydr. Depth (ft) | | 15.84 | |
| Conv. Total (cfs) | 1784140 | Conv. (cfs) | | 1784140 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 470.1 | |
| Min Ch El (ft) | 3568.07 | Shear (lb/sq ft) | | 8.4 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 190.32 | |
| Frctn Loss (ft) | 4.23 | Cum Volume (acre-ft) | | 1584.97 | |
| C & E Loss (ft) | 0.71 | Cum SA (acres) | | 97.32 | |

| Plan: Diversion   Beas River   Bhuntar Reach   RS: 17   Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3601.38 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 7.97 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3593.41 | Reach Len. (ft) | 656 | 656 | 656 |
| Crit W.S. (ft) | 3593.41 | Flow Area (sq ft) | | 7321.85 | |
| E.G. Slope (ft/ft) | 0.008628 | Area (sq ft) | | 7321.85 | |
| Q Total (cfs) | 165850 | Flow (cfs) | | 165850 | |
| Top Width (ft) | 462.06 | Top Width (ft) | | 462.06 | |
| Vel Total (ft/s) | 22.65 | Avg. Vel. (ft/s) | | 22.65 | |
| Max Chl Dpth (ft) | 17.11 | Hydr. Depth (ft) | | 15.85 | |
| Conv. Total (cfs) | 1785518 | Conv. (cfs) | | 1785518 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 470.14 | |
| Min Ch El (ft) | 3576.3 | Shear (lb/sq ft) | | 8.39 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 190.01 | |
| Frctn Loss (ft) | 5.66 | Cum Volume (acre-ft) | | 1695.21 | |
| C & E Loss (ft) | 0 | Cum SA (acres) | | 104.28 | |

| Plan: Diversion   Beas River   Bhuntar Reach   RS: 18   Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3606.63 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 6.4 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3600.23 | Reach Len. (ft) | 705.2 | 705.2 | 705.2 |
| Crit W.S. (ft) | 3598.4 | Flow Area (sq ft) | | 8172.2 | |
| E.G. Slope (ft/ft) | 0.006121 | Area (sq ft) | | 8172.2 | |
| Q Total (cfs) | 165850 | Flow (cfs) | | 165850 | |
| Top Width (ft) | 469.36 | Top Width (ft) | | 469.36 | |
| Vel Total (ft/s) | 20.29 | Avg. Vel. (ft/s) | | 20.29 | |
| Max Chl Dpth (ft) | 18.94 | Hydr. Depth (ft) | | 17.41 | |
| Conv. Total (cfs) | 2119867 | Conv. (cfs) | | 2119867 | |
| Length Wtd. (ft) | 705.2 | Wetted Per. (ft) | | 478.3 | |
| Min Ch El (ft) | 3581.29 | Shear (lb/sq ft) | | 6.53 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 132.5 | |
| Frctn Loss (ft) | 5.09 | Cum Volume (acre-ft) | | 1820.63 | |
| C & E Loss (ft) | 0.16 | Cum SA (acres) | | 111.82 | |

| Plan: Diversion   Beas River   Bhuntar Reach   RS: 19   Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3613.26 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 7.96 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3605.3 | Reach Len. (ft) | 656 | 656 | 656 |
| Crit W.S. (ft) | 3605.3 | Flow Area (sq ft) | | 7323.88 | |
| E.G. Slope (ft/ft) | 0.00862 | Area (sq ft) | | 7323.88 | |
| Q Total (cfs) | 165850 | Flow (cfs) | | 165850 | |
| Top Width (ft) | 462.07 | Top Width (ft) | | 462.07 | |
| Vel Total (ft/s) | 22.65 | Avg. Vel. (ft/s) | | 22.65 | |
| Max Chl Dpth (ft) | 17.12 | Hydr. Depth (ft) | | 15.85 | |
| Conv. Total (cfs) | 1786294 | Conv. (cfs) | | 1786294 | |
| Length Wtd. (ft) | 656 | Wetted Per. (ft) | | 470.16 | |
| Min Ch El (ft) | 3588.18 | Shear (lb/sq ft) | | 8.38 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 189.84 | |
| Frctn Loss (ft) | 4.73 | Cum Volume (acre-ft) | | 1937.31 | |
| C & E Loss (ft) | 0.47 | Cum SA (acres) | | 118.83 | |

| Plan: Diversion Beas River Bhuntar Reach RS: 20 Profile: 500 Year Flood | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (ft) | 3616.7 | Element | Left OB | Channel | Right OB |
| Vel Head (ft) | 7.98 | Wt. n-Val. | | 0.038 | |
| W.S. Elev (ft) | 3608.73 | Reach Len. (ft) | 328 | 328 | 328 |
| Crit W.S. (ft) | 3608.73 | Flow Area (sq ft) | | 7317.57 | |
| E.G. Slope (ft/ft) | 0.008644 | Area (sq ft) | | 7317.57 | |
| Q Total (cfs) | 165850 | Flow (cfs) | | 165850 | |
| Top Width (ft) | 462.02 | Top Width (ft) | | 462.02 | |
| Vel Total (ft/s) | 22.66 | Avg. Vel. (ft/s) | | 22.66 | |
| Max Chl Dpth (ft) | 17.1 | Hydr. Depth (ft) | | 15.84 | |
| Conv. Total (cfs) | 1783882 | Conv. (cfs) | | 1783882 | |
| Length Wtd. (ft) | 328 | Wetted Per. (ft) | | 470.1 | |
| Min Ch El (ft) | 3591.62 | Shear (lb/sq ft) | | 8.4 | |
| Alpha | 1 | Stream Power (lb/ft s) | | 190.38 | |
| Frctn Loss (ft) | 2.83 | Cum Volume (acre-ft) | | 1992.44 | |
| C & E Loss (ft) | 0 | Cum SA (acres) | | 122.31 | |

**APPENDIX-10, INPUT DATA FOR HEC-6 FOR SIMULATION OF BEAS RIVER WITH DIKES AND DIVERSION CHANNEL FOR 2 YEAR AND 500 YEAR FLOODS (MOBILE BED APPLICATION)**

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T1      MOBILE BED APPLICATION IN RIVER WITH DIKES AND DIVERSION CHANNEL.
T2      WITH A RATING CURVE AT THE DOWNSTREAM BOUNDARY.
T3      SIMULATION OF BEAS RIVER FOR 2 YEAR AND 500 YEAR RETURN PERIOD FLOODS
NC  .045    .045    .038      .1      .3
X1   1.0      4.      0.  478.88      0.      0.      0.      0.      0.      0.
GR3503.7    0.00 3482.34   42.64 3482.34  436.24 3503.66  478.88
HD   1.0     10.      0.  478.88
X1   2.0      4.      0.  478.88  665.00  645.00  656.00      0.      0.      0.
GR3510.3    0.00 3488.95   42.64 3488.95  436.24 3510.27  478.88
HD   2.0     10.      0.  478.88
X1   3.0      4.      0.  478.88  675.00  635.00  656.00      0.      0.      0.
GR3516.9    0.00 3495.55   42.64 3495.55  436.24 3516.87  478.88
HD   3.0     10.      0.  478.88
X1   4.0      4.      0.  478.88  635.00  675.00  656.00      0.      0.      0.
GR3523.5    0.00 3502.16   42.64 3502.16  436.24 3523.48  478.88
HD   4.0     10.      0.  478.88
X1   5.0      4.      0.  478.88  645.00  665.00  656.00      0.      0.      0.
GR3530.1    0.00 3508.77   42.64 3508.77  436.24 3530.09  478.88
HD   5.0     10.      0.  478.88
X1   6.0      4.      0.  478.88  670.00  642.00  656.00      0.      0.      0.
GR3536.7    0.00 3515.37   42.64 3515.37  436.24 3536.69  478.88
HD   6.0     10.      0.  478.88
X1   7.0      4.      0.  478.88  673.00  635.00  656.00      0.      0.      0.
GR3543.3    0.00 3521.98   42.64 3521.98  436.24 3543.30  478.88
HD   7.0     10.      0.  478.88
X1   8.0      4.      0.  478.88  647.00  665.00  656.00      0.      0.      0.
GR3549.9    0.00 3528.58   42.64 3528.58  436.24 3549.90  478.88
HD   8.0     10.      0.  478.88
X1   9.0      4.      0.  478.88  637.00  675.00  656.00      0.      0.      0.
GR3556.5    0.00 3535.19   42.64 3535.19  436.24 3556.51  478.88
HD   9.0     10.      0.  478.88
X1  10.0      4.      0.  478.88  323.00  333.00  328.00      0.      0.      0.
GR3559.8    0.00 3538.49   42.64 3538.49  436.24 3559.81  478.88
HD  10.0     10.      0.  478.88
X1  11.0      4.      0.  478.88  328.00  328.00  328.00      0.      0.      0.
GR3562.5    0.00 3541.14   42.64 3541.14  436.24 3562.46  478.88
HD  11.0     10.      0.  478.88
X1  12.0      4.      0.  478.88  656.00  656.00  656.00      0.      0.      0.
GR3569.3    0.00 3548.02   42.64 3548.02  436.24 3569.34  478.88
HD  12.0     10.      0.  478.88
X1  13.0      4.      0.  478.88  656.00  656.00  656.00      0.      0.      0.
GR3576.9    0.00 3555.53   42.64 3555.53  436.24 3576.85  478.88
HD  13.0     10.      0.  478.88
X1  14.0      4.      0.  478.88  656.00  656.00  656.00      0.      0.      0.
GR3580.1    0.00 3558.81   42.64 3558.81  436.24 3580.13  478.88
HD  14.0     10.      0.  478.88
X1  15.0      4.      0.  478.88  606.80  606.80  606.80      0.      0.      0.
GR3583.4    0.00 3562.09   42.64 3562.09  436.24 3583.41  478.88
HD  15.0     10.      0.  478.88
X1  16.0      4.      0.  478.88  656.00  656.00  656.00      0.      0.      0.
GR3589.4    0.00 3568.07   42.64 3568.07  436.24 3589.39  478.88
HD  16.0     10.      0.  478.88
X1  17.0      4.      0.  478.88  656.00  656.00  656.00      0.      0.      0.
GR3597.6    0.00 3576.30   42.64 3576.30  436.24 3597.62  478.88
HD  17.0     10.      0.  478.88
X1  18.0      4.      0.  478.88  705.20  705.20  705.20      0.      0.      0.
GR3602.6    0.00 3581.29   42.64 3581.29  436.24 3602.61  478.88
HD  18.0     10.      0.  478.88
```

```
X1  19.0      4.       0.  478.88  656.00  656.00  656.00       0.        0.        0.
GR3609.5   0.00 3588.18   42.64 3588.18  436.24 3609.50  478.88
HD  19.0     10.       0.  478.88
X1  20.0      4.       0.  478.88  328.00  328.00  328.00       0.        0.        0.
GR3612.9   0.00 3591.62   42.64 3591.62  436.24 3612.94  478.88
HD  20.0     10.       0.  478.88
EJ
T4       BEAS RIVER FROM CHAINAGE 0+000 TO 3+600 ALONG DIVERSION CHANNEL.
T5       LOAD CURVE FROM GAGE DATA.
T6       BED GRADATIONS FROM FIELD SAMPLES.
T7       USE FULL RANGE OF SAND, GRAVEL, COBBLE AND BOULDER.
T8       SEDIMENT TRANSPORT BY Yang's STREAM POWER [ref ASCE JOURNAL (YANG 1971)]
I1            10
I2  CLAY       2
I2             1   .0585   .1170    .264   6.860   93.30
I2             2   .0585   .1170    .264   6.860   93.30
I3  SILT       2       4       4
I4  SAND       4       1      15
I5            .5      .5     .25      .5     .25       0     1.0
LQ           200    1000   10000   50000  100000  200000
LT TOTAL     115     780   10200   72500  182000  432000
LF  CLAY    .000    .000    .000    .000    .000    .000
LF  SILT    .280    .250    .150    .100    .150    .150
LF   VFS    .450    .350    .350    .250    .220    .080
LF    FS    .150    .250    .220    .200    .180    .120
LF    MS    .100    .080    .100    .150    .130    .150
LF    CS    .020    .050    .080    .150    .120    .180
LF   VCS    .000    .020    .060    .100    .100    .120
LF   VFG    .000    .000    .030    .030    .050    .100
LF    FG    .000    .000    .010    .020    .040    .060
LF    MG    .000    .000    .000    .000    .010    .030
LF    CG    .000    .000    .000    .000    .000    .010
LF   VCG    .000    .000    .000    .000    .000    .000
LF    SC    .000    .000    .000    .000    .000    .000
LF    LC    .000    .000    .000    .000    .000    .000
LF    SB    .000    .000    .000    .000    .000    .000
LF    MB    .000    .000    .000    .000    .000    .000
LF    LB    .000    .000    .000    .000    .000    .000
PF EXAMP     1.0     1.0  2048.0  1024.0   97.98   512.0   95.48   256.0   92.98
PFC128.0   86.98    64.0   72.48    32.0   48.55    16.0   27.55     8.0   13.70
PFC  4.0    9.35     2.0    8.01     1.0    7.44     0.5    7.17    0.25    4.29
PFC0.125    1.43   0.062    0.75
$HYD
$RATING
RC            25 7057.51       0       0 3482.34 3484.85 3486.10 3487.25 3488.00
RC       3488.80 3489.58 3490.30 3490.96 3491.58 3492.18 3492.80 3493.30 3493.82
RC       3494.36 3494.82 3495.38 3495.80 3496.30 3496.75 3497.20 3497.60 3498.08
RC       3498.50 3498.90
*   AB   PROFILE 1 = 2 YEAR RETURN PERIOD FLOOD
Q 28230.
T    60.
W     1.
*   AB   PROFILE 2 = 500 YEAR RETURN PERIOD FLOOD
Q165850.
T    60.
W     1.
$$END
```

## APPENDIX-11 OUTPUT OF HEC-6 FOR SIMULATION OF BEAS RIVER WITH DIKES AND DIVERSION CHANNEL FOR 2 YEAR AND 500 YEAR FLOODS (MOBILE BED APPLICATION)

```
*****************************************************        **************************************
*  SCOUR AND DEPOSITION IN RIVERS AND RESERVOIRS    *        *  U.S. ARMY CORPS OF ENGINEERS      *
*       Version: 4.1.00 -  OCTOBER 1993             *        *  HYDROLOGIC ENGINEERING CENTER     *
*  INPUT FILE:  MOBILE1.DAT                         *        *  609 SECOND STREET                 *
*  OUTPUT FILE: MOBILE1.OUT                         *        *  DAVIS, CALIFORNIA 95616-4687      *
*  RUN DATE: 31 MAY 04     RUN TIME: 17:03:47       *        *  (916) 756-1104                    *
*****************************************************        **************************************

              X       X  XXXXXXX   XXXXX              XXXXX
              X       X  X        X     X            X     X
              X       X  X        X                  X
              XXXXXXX    XXXX     X          XXXXX   XXXXXX
              X       X  X        X                  X     X
              X       X  X        X     X            X     X
              X       X  XXXXXXX   XXXXX              XXXXX

     *****************************************************************
     *  MAXIMUM LIMITS FOR THIS VERSION ARE:                          *
     *        10  Stream Segments (Main Stem + Tributaries)           *
     *       500  Cross Sections                                      *
     *       200  Elevation/Station Points per Cross Section          *
     *        20  Grain Sizes                                         *
     *        10  Control Points                                      *
     *****************************************************************
```

```
T1      MOBILE BED APPLICATION IN RIVER WITH DIKES AND DIVERSION CHANNEL.
T2      WITH A RATING CURVE AT THE DOWNSTREAM BOUNDARY.
T3      SIMULATION OF BEAS RIVER FOR 2 YEAR AND 500 YEAR RETURN PERIOD FLOODS

N values...  Left    Channel   Right    Contraction    Expansion
            0.0450   0.0380   0.0450      1.1000        0.7000

SECTION NO.     1.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

SECTION NO.     2.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

SECTION NO.     3.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

SECTION NO.     4.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

SECTION NO.     5.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

SECTION NO.     6.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

SECTION NO.     7.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

SECTION NO.     8.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

SECTION NO.     9.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.
```

```
SECTION NO.    10.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

SECTION NO.    11.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

SECTION NO.    12.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

SECTION NO.    13.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

SECTION NO.    14.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

SECTION NO.    15.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

SECTION NO.    16.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

SECTION NO.    17.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

SECTION NO.    18.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

SECTION NO.    19.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

SECTION NO.    20.000
...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

NO. OF CROSS SECTIONS IN STREAM SEGMENT= 20
NO. OF INPUT DATA MESSAGES =    0

TOTAL NO. OF CROSS SECTIONS IN THE NETWORK =  20
TOTAL NO. OF STREAM SEGMENTS IN THE NETWORK=   1
END OF GEOMETRIC DATA

==========================================================================================

T4      BEAS RIVER FROM CHAINAGE 0+000 TO 3+600 ALONG DIVERSION CHANNEL.
T5      LOAD CURVE FROM GAGE DATA.
T6      BED GRADATIONS FROM FIELD SAMPLES.
T7      USE FULL RANGE OF SAND, GRAVEL, COBBLE AND BOULDER.
T8      SEDIMENT TRANSPORT BY Yang's STREAM POWER [ref ASCE JOURNAL (YANG 1971)]

        MOBILE BED APPLICATION IN RIVER WITH DIKES AND DIVERSION CHANNEL.
        WITH A RATING CURVE AT THE DOWNSTREAM BOUNDARY.
        SIMULATION OF BEAS RIVER FOR 2 YEAR AND 500 YEAR RETURN PERIOD FLOODS
```

SEDIMENT PROPERITES AND PARAMETERS

| | SPI | IBG | MNQ | SPGF | ACGR | NFALL | IBSHER |
|---|---|---|---|---|---|---|---|
| I1 | 10. | 0 | 1 | 1.000 | 32.174 | 2 | 1 |

CLAY IS PRESENT.

| | MTCL | SPGC | PUCD | UWCL | CCCD |
|---|---|---|---|---|---|
| I2 | 2 | 2.650 | 78.000 | 30.000 | 16.000 |

DEPOSITION COEFFICIENTS BY LAYER

| | LAYER NO. | DEPOSITION THRESHOLD SHEAR STRESS lb/sq.ft |
|---|---|---|
| ACTIVE LAYER | 1 | 0.0585 |
| INACTIVE LAYER | 2 | 0.0585 |

EROSION COEFFICIENTS BY LAYER

| | LAYER NO | PARTICLE EROSION SHEAR STRESS lb/sq.ft | MASS EROSION SHEAR STRESS lb/sq.ft. | MASS EROSION RATE lb/sf/hr | SLOPE OF PARTICLE EROSION LINE=ER1 1/hr | SLOPE OF MASS EROSION LINE=ER2 1/hr |
|---|---|---|---|---|---|---|
| ACTIVE LAYER | 1 | 0.1170 | 0.2640 | 6.8600 | 46.6667 | 93.3000 |
| INACTIVE LAYER | 2 | 0.1170 | 0.2640 | 6.8600 | 46.6667 | 93.3000 |

SILT IS PRESENT

| | MTCL | IASL | LASL | SGSL | PUSDLB | UWSDLB | CCSDLB |
|---|---|---|---|---|---|---|---|
| I3 | 2 | 4 | 4 | 2.650 | 82.000 | 65.000 | 5.700 |

DEPOSITION COEFFICIENTS BY LAYER

| | LAYER NO. | DEPOSITION THRESHOLD SHEAR STRESS lb/sq.ft |
|---|---|---|
| ACTIVE LAYER | 1 | 0.0200 |
| INACTIVE LAYER | 2 | 0.0200 |

EROSION COEFFICIENTS BY LAYER

| | LAYER NO | PARTICLE EROSION SHEAR STRESS lb/sq.ft | MASS EROSION SHEAR STRESS lb/sq.ft. | MASS EROSION RATE lb/sf/hr | SLOPE OF PARTICLE EROSION LINE=ER1 1/hr | SLOPE OF MASS EROSION LINE=ER2 1/hr |
|---|---|---|---|---|---|---|
| ACTIVE LAYER | 1 | 0.1170 | 0.2640 | 6.8600 | 46.6667 | 93.3000 |
| INACTIVE LAYER | 2 | 0.1170 | 0.2640 | 6.8600 | 46.6667 | 93.3000 |

SANDS - BOULDERS ARE PRESENT

| | MTC | IASA | LASA | SPGS | GSF | BSAE | PSI | UWDLB |
|---|---|---|---|---|---|---|---|---|
| I4 | 4 | 1 | 15 | 2.650 | 0.667 | 0.500 | 30.000 | 93.000 |

USING TRANSPORT CAPACITY RELATIONSHIP # 4, YANG
GRAIN SIZES UTILIZED (mean diameter - mm)

| | | | |
|---|---|---|---|
| CLAY.............. | 0.003 | MEDIUM GRAVEL..... | 11.314 |
| COARSE SILT....... | 0.045 | COARSE GRAVEL..... | 22.627 |
| VERY FINE SAND.... | 0.088 | VERY COARSE GRAVEL | 45.255 |
| FINE SAND......... | 0.177 | SMALL COBBLES..... | 90.510 |
| MEDIUM SAND....... | 0.354 | LARGE COBBLES..... | 181.019 |
| COARSE SAND....... | 0.707 | SMALL BOULDERS.... | 362.039 |
| VERY COARSE SAND.. | 1.414 | MEDIUM BOULDERS... | 724.077 |
| VERY FINE GRAVEL.. | 2.828 | LARGE BOULDERS.... | 1448.150 |
| FINE GRAVEL....... | 5.657 | | |

COEFFICIENTS FOR COMPUTATION SCHEME WERE SPECIFIED

| | DBI | DBN | XID | XIN | XIU | UBI | UBN | JSL |
|---|---|---|---|---|---|---|---|---|
| I5 | 0.500 | 0.500 | 0.250 | 0.500 | 0.250 | 0.000 | 1.000 | 1 |

SEDIMENT LOAD TABLE FOR STREAM SEGMENT # 1
LOAD BY GRAIN SIZE CLASS (tons/day)

| LQ | | 200.000 | 1000.00 | 10000.0 | 50000.0 | 100000. | 200000. |
|---|---|---|---|---|---|---|---|
| LF | CLAY | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 |
| LF | SILT | 32.2000 | 195.000 | 1530.00 | 7250.00 | 27300.0 | 64800.0 |
| LF | VFS | 51.7500 | 273.000 | 3570.00 | 18125.0 | 40040.0 | 34560.0 |
| LF | FS | 17.2500 | 195.000 | 2244.00 | 14500.0 | 32760.0 | 51840.0 |
| LF | MS | 11.5000 | 62.4000 | 1020.00 | 10875.0 | 23660.0 | 64800.0 |
| LF | CS | 2.30000 | 39.0000 | 816.000 | 10875.0 | 21840.0 | 77760.0 |
| LF | VCS | 0.100000E-19 | 15.6000 | 612.000 | 7250.00 | 18200.0 | 51840.0 |
| LF | VFG | 0.100000E-19 | 0.100000E-19 | 306.000 | 2175.00 | 9100.00 | 43200.0 |
| LF | FG | 0.100000E-19 | 0.100000E-19 | 102.000 | 1450.00 | 7280.00 | 25920.0 |
| LF | MG | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 1820.00 | 12960.0 |
| LF | CG | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 4320.00 |
| LF | VCG | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 |
| LF | SC | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 |
| LF | LC | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 |
| LF | SB | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 |
| LF | MB | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 |
| LF | LB | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 | 0.100000E-19 |
| | TOTAL | 115.000 | 780.000 | 10200.0 | 72500.0 | 182000. | 432000. |

REACH GEOMETRY FOR STREAM SEGMENT 1

| CROSS SECTION NO. | REACH LENGTH (ft) | MOVABLE BED WIDTH | INITIAL BEDELEVATIONS LEFT SIDE (ft) | THALWEG (ft) | RIGHT SIDE (ft) | ACCUMULATED CHANNEL DISTANCE FROM DOWNSTREAM (ft) | (miles) |
|---|---|---|---|---|---|---|---|
| 1.000 | 0.000 | 478.880 | 3503.700 | 3482.340 | 3503.660 | 0.000 | 0.000 |
| 2.000 | 656.000 | 478.880 | 3510.300 | 3488.950 | 3510.270 | 656.000 | 0.124 |
| 3.000 | 656.000 | 478.880 | 3516.900 | 3495.550 | 3516.870 | 1312.000 | 0.248 |
| 4.000 | 656.000 | 478.880 | 3523.500 | 3502.160 | 3523.480 | 1968.000 | 0.373 |
| 5.000 | 656.000 | 478.880 | 3530.100 | 3508.770 | 3530.090 | 2624.000 | 0.497 |
| 6.000 | 656.000 | 478.880 | 3536.700 | 3515.370 | 3536.690 | 3280.000 | 0.621 |
| 7.000 | 656.000 | 478.880 | 3543.300 | 3521.980 | 3543.300 | 3936.000 | 0.745 |
| 8.000 | 656.000 | 478.880 | 3549.900 | 3528.580 | 3549.900 | 4592.000 | 0.870 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 656.000 | | | | | | |
| 9.000 | | 478.880 | 3556.500 | 3535.190 | 3556.510 | 5248.000 | 0.994 |
| | 328.000 | | | | | | |
| 10.000 | | 478.880 | 3559.800 | 3538.490 | 3559.810 | 5576.000 | 1.056 |
| | 328.000 | | | | | | |
| 11.000 | | 478.880 | 3562.500 | 3541.140 | 3562.460 | 5904.000 | 1.118 |
| | 656.000 | | | | | | |
| 12.000 | | 478.880 | 3569.300 | 3548.020 | 3569.340 | 6560.000 | 1.242 |
| | 656.000 | | | | | | |
| 13.000 | | 478.880 | 3576.900 | 3555.530 | 3576.850 | 7216.000 | 1.367 |
| | 656.000 | | | | | | |
| 14.000 | | 478.880 | 3580.100 | 3558.810 | 3580.130 | 7872.000 | 1.491 |
| | 606.800 | | | | | | |
| 15.000 | | 478.880 | 3583.400 | 3562.090 | 3583.410 | 8478.800 | 1.606 |
| | 656.000 | | | | | | |
| 16.000 | | 478.880 | 3589.400 | 3568.070 | 3589.390 | 9134.800 | 1.730 |
| | 656.000 | | | | | | |
| 17.000 | | 478.880 | 3597.600 | 3576.300 | 3597.620 | 9790.800 | 1.854 |
| | 705.200 | | | | | | |
| 18.000 | | 478.880 | 3602.600 | 3581.290 | 3602.610 | 10496.000 | 1.988 |
| | 656.000 | | | | | | |
| 19.000 | | 478.880 | 3609.500 | 3588.180 | 3609.500 | 11152.000 | 2.112 |
| | 328.000 | | | | | | |
| 20.000 | | 478.880 | 3612.900 | 3591.620 | 3612.940 | 11480.000 | 2.174 |

## BED MATERIAL GRADATION

| SECNO | SAE | DMAX (ft) | DXPI (ft) | XPI | TOTAL BED | BED MATERIAL FRACTIONS per grain size | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 2.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 3.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 4.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 5.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 6.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 7.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 8.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 10.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 11.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 12.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 13.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 14.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 15.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 16.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 17.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 18.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 19.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |
| 20.000 | 1.000 | 6.719 | 6.719 | 1.000 | 1.000 | CLAY | 0.006 | C SAND | 0.003 | M GRVL | 0.138 | L COBL | 0.060 |
| | | | | | | C SILT | 0.002 | VC SAND | 0.006 | C GRVL | 0.210 | S BLDR | 0.025 |
| | | | | | | VF SAND | 0.007 | VF GRVL | 0.013 | VC GRVL | 0.239 | M BLDR | 0.025 |
| | | | | | | F SAND | 0.029 | F GRVL | 0.043 | S COBL | 0.145 | L BLDR | 0.020 |
| | | | | | | M SAND | 0.029 | | | | | | |

BED SEDIMENT CONTROL VOLUMES

STREAM SEGMENT # 1: MOBILE BED APPLICATION IN RIVER WITH DIKES AND DIVERSION CHANNEL.

| SECTION NUMBER | LENGTH (ft) | WIDTH (ft) | DEPTH (ft) | VOLUME (cu.ft) | (cu.yd) |
|---|---|---|---|---|---|
| 1.000 | 328.000 | 478.880 | 10.000 | 0.157073E+07 | 58175.1 |
| 2.000 | 656.000 | 478.880 | 10.000 | 0.314145E+07 | 116350. |
| 3.000 | 656.000 | 478.880 | 10.000 | 0.314145E+07 | 116350. |
| 4.000 | 656.000 | 478.880 | 10.000 | 0.314145E+07 | 116350. |
| 5.000 | 656.000 | 478.880 | 10.000 | 0.314145E+07 | 116350. |
| 6.000 | 656.000 | 478.880 | 10.000 | 0.314145E+07 | 116350. |
| 7.000 | 656.000 | 478.880 | 10.000 | 0.314145E+07 | 116350. |
| 8.000 | 656.000 | 478.880 | 10.000 | 0.314145E+07 | 116350. |
| 9.000 | 492.000 | 478.880 | 10.000 | 0.235609E+07 | 87262.6 |
| 10.000 | 328.000 | 478.880 | 10.000 | 0.157073E+07 | 58175.1 |
| 11.000 | 492.000 | 478.880 | 10.000 | 0.235609E+07 | 87262.6 |
| 12.000 | 656.000 | 478.880 | 10.000 | 0.314145E+07 | 116350. |
| 13.000 | 656.000 | 478.880 | 10.000 | 0.314145E+07 | 116350. |
| 14.000 | 631.400 | 478.880 | 10.000 | 0.302365E+07 | 111987. |
| 15.000 | 631.400 | 478.880 | 10.000 | 0.302365E+07 | 111987. |
| 16.000 | 656.000 | 478.880 | 10.000 | 0.314145E+07 | 116350. |
| 17.000 | 680.600 | 478.880 | 10.000 | 0.325926E+07 | 120713. |
| 18.000 | 680.600 | 478.880 | 10.000 | 0.325926E+07 | 120713. |
| 19.000 | 492.000 | 478.880 | 10.000 | 0.235609E+07 | 87262.6 |
| 20.000 | 164.000 | 478.880 | 10.000 | 785363. | 29087.5 |

NO. OF INPUT DATA MESSAGES= 0
END OF SEDIMENT DATA

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$HYD
BEGIN COMPUTATIONS.

--------------------------------------------------------------------------

$RATING

Downstream Boundary Condition - Rating Curve

| Elevation | Stage | Discharge | Elevation | Stage | Discharge |
|---|---|---|---|---|---|
| 3482.340 | 3482.340 | 0.000 | 3493.820 | 3493.820 | 91747.630 |
| 3484.850 | 3484.850 | 7057.510 | 3494.360 | 3494.360 | 98805.140 |
| 3486.100 | 3486.100 | 14115.020 | 3494.820 | 3494.820 | 105862.650 |
| 3487.250 | 3487.250 | 21172.530 | 3495.380 | 3495.380 | 112920.160 |
| 3488.000 | 3488.000 | 28230.040 | 3495.800 | 3495.800 | 119977.670 |
| 3488.800 | 3488.800 | 35287.550 | 3496.300 | 3496.300 | 127035.180 |
| 3489.580 | 3489.580 | 42345.060 | 3496.750 | 3496.750 | 134092.690 |
| 3490.300 | 3490.300 | 49402.570 | 3497.200 | 3497.200 | 141150.200 |
| 3490.960 | 3490.960 | 56460.080 | 3497.600 | 3497.600 | 148207.710 |
| 3491.580 | 3491.580 | 63517.590 | 3498.080 | 3498.080 | 155265.220 |
| 3492.180 | 3492.180 | 70575.100 | 3498.500 | 3498.500 | 162322.730 |
| 3492.800 | 3492.800 | 77632.610 | 3498.900 | 3498.900 | 169380.240 |
| 3493.300 | 3493.300 | 84690.120 | | | |

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===========================================================================================
TIME STEP #        1
*   AB   PROFILE 1 = 2 YEAR RETURN PERIOD FLOOD

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MOBILE BED APPLICATION IN RIVER WITH DIKES AND DIVERSION CHANNEL.
ACCUMULATED TIME (yrs)..........        0.000

--- Downstream Boundary Condition Data for STREM SEGMENT NO.  1 at Control Point #  1---
                                DISCHARGE   TEMPERATURE  WATER SURFACE
                                  (cfs)       (deg F)       (ft)
                                28230.000      60.00       3488.000

****  DISCHARGE    WATER    ENERGY  VELOCITY   ALPHA    TOP      AVG      AVG VEL (by subsection)
        (CFS)     SURFACE    LINE     HEAD              WIDTH    BED        1        2        3

SECTION NO.      1.000
****  28230.000  3488.000  3490.358   2.358    1.000   416.219  3482.494   0.000   12.318   0.000
                                                   FLOW DISTRIBUTION (%) =  0.000  100.000   0.000

SECTION NO.      2.000
****  28230.000  3494.679  3496.979   2.299    1.000   416.502  3489.107   0.000    2.164   0.000
                                                   FLOW DISTRIBUTION (%) =  0.000  100.000   0.000

SECTION NO.      3.000
****  28230.000  3501.226  3503.567   2.341    1.000   416.304  3495.701   0.000   12.273   0.000
                                                   FLOW DISTRIBUTION (%) =  0.000  100.000   0.000

SECTION NO.      4.000
****  28230.000  3507.867  3510.182   2.315    1.000   416.432  3502.313   0.000   12.205   0.000
                                                   FLOW DISTRIBUTION (%) =  0.000  100.000   0.000

SECTION NO.      5.000
****  28230.000  3514.455  3516.791   2.337    1.000   416.334  3508.925   0.000   12.262   0.000
                                                   FLOW DISTRIBUTION (%) =  0.000  100.000   0000

SECTION NO.      6.000
****  28230.000  3521.099  3523.428   2.329    1.000   416.370  3515.560   0.000   12.242   0.000
                                                   FLOW DISTRIBUTION (%) =  0.000  100.000   0.000

SECTION NO.      7.000
****  28230.000  3527.721  3530.052   2.332    1.000   416.364  3522.185   0.000   12.249   0.000
                                                   FLOW DISTRIBUTION (%) =  0.000  100.000   0.000

SECTION NO.      8.000
****  28230.000  3534.332  3536.648   2.316    1.000   416.436  3528.779   0.000   12.209   0.000
                                                   FLOW DISTRIBUTION (%) =  0.000  100.000   0.000

SECTION NO.      9.000
****  28230.000  3540.923  3543.259   2.336    1.000   416.348  3535.393   0.00    12.261   0.000
                                                   FLOW DISTRIBUTION (%) =  0.000  100.000   0.000

SECTION NO.     10.000
****  28230.000  3544.245  3546.538   2.292    1.000   416.558  3538.665   0.000   12.145   0.000
                                                   FLOW DISTRIBUTION (%) =  0.000  100.000   0.000

SECTION NO.     11.000
****  28230.000  3547.434  3549.321   1.887    1.000   418.802  3541.317   0.000   11.020   0.000
                                                   FLOW DISTRIBUTION (%) =  0.000  100.000   0.000

SECTION NO.     12.000
** SUPERCRITICAL **  Using Critical Water Surface +
SECTION NO.     12.000 TIME =     1.000 DAYS.
TRIAL    TRIAL       COMPUTED     CRITICAL
 NO.      WS           WS            WS
  0.    3553.375    3553.018
  1.    3553.469    3552.921     3553.419
****  28230.000  3553.469  3556.018   2.550    1.000   415.415  3548.163   0.000   12.809   0.000
                                                   FLOW DISTRIBUTION (%) =  0.000   10.000   0.000

SECTION NO.     13.000
****  28230.000  3561.029  3563.500   2.471    1.000   415.705  3555.643   0.000   12.609   0.000
                                                   FLOW DISTRIBUTION (%) =  0.000  100.000   0.000

SECTION NO.     14.000
****  28230.000  3566.427  3567.704   1.276    1.000   424.098  3559.082   0.000    9.062   0.000
                                                   FLOW DISTRIBUTION (%) =  0.000  100.000   0.000

SECTION NO.     15.000
****  28230.000  3568.951  3570.538   1.588    1.000   421.033  3562.317   0.000   10.108   0.000
                                                   FLOW DISTRIBUTION (%) =  0.000  100.000   0.000

SECTION NO.     16.000
****  28230.000  3573.426  3576.034   2.609    1.000   415.148  3568177    0.000   12.956   0.000
                                                   FLOW DISTRIBUTION (%) =  0.000  100.000   0.000
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SECTION NO.     17.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.     17.000 TIME =     1.000 DAYS.

 TRIAL    TRIAL        COMPUTED     CRITICAL
  NO.       WS            WS           WS
   0.    3581.643     3581.467
   1.    3581.736     3581.320     3581.686
 ****  28230.000  3581.736  3584.298   2.561    1.000   415.356  3576.442   0.000  12.838   0.00
                                                  FLOW DISTRIBUTION (%) =   0.000 100.000   0.000
 SECTION NO.     18.000
 ****  28230.000  3588.224  3589.768   1.544    1.000   421.407  3581.503   0.000   9.967   0.000
                                                  FLOW DISTRIBUTION (%) =   0.000 100.000   0.000
 SECTION NO.     19.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.     19.000 TIME =     1.000 DAYS.
 TRIAL    TRIAL        COMPUTED     CRITICAL
  NO.       WS            WS           WS
   0.    3593.533     3592.561
   1.    3593.627     3592.498     3593.577
 ****  28230.000  3593.627  3596.178   2.551    1.000   415.387  3588.323   0.000  12.813   0.000
                                                  FLOW DISTRIBUTION (%) =   0.000 100.000   0.000
 SECTION NO.     20.000
 ****  28230.000  3597.418  3599.669   2.251    1.000   416.779  3591.790   0.000  12.034   0.000
                                                  FLOW DISTRIBUTION (%) =   0.000 100.000   0.000

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 MOBILE BED APPLICATION IN RIVER WITH DIKES AND DIVERSION CHANNEL.
        ACCUMULATED TIME (yrs)....       0.003
        FLOW DURATION (days)......       1.000

 UPSTREAM BOUNDARY CONDITIONS
 ----------------------------------------------------------------------
 Stream Segment # 1     |  DISCHARGE    | SEDIMENT LOAD | TEMPERATURE
 Section No.    20.000  |    (cfs)      |  (tons/day)   |   (deg F)
 ----------------------------------------------------------------------
                 INFLOW |    28230.00   |    35512.55   |     60.00

 TABLE SA-1. TRAP EFFICIENCY ON STREAM SEGMENT #  1
             MOBILE BED APPLICATION IN RIVER WITH DIKES AND DIVERSION CHANNEL.
             ACCUMULATED AC-FT ENTERING AND LEAVING THIS STREAM SEGMENT
*****************************************************************************************************
   TIME      ENTRY *             CLAY                *              SILT              *              SAND            *
   DAYS      POINT *   INFLOW  OUTFLOW  TRAP EFF *   INFLOW  OUTFLOW  TRAP EFF *   INFLOW  OUTFLOW  TRAP EFF *
   1.00     20.000 *     0.00                    *     2.95                    *    15.47                    *
  TOTAL=     1.000 *     0.00     4.88********** *     2.95     3.56     -0.21 *    15.47    53.38     -2.45 *
*****************************************************************************************************

 TABLE SB-1:  SEDIMENT LOAD PASSING THE  BOUNDARIES OF STREAM SEGMENT #  1
 ------------------------------------------------------------------------------------
   SEDIMENT INFLOW at the Upstream Boundary:
       GRAIN SIZE       LOAD (tons/day) |    GRAIN SIZE       LOAD (tons/day)
   ----------------------------------------------------------------------------
     CLAY.............           0.00   |  MEDIUM GRAVEL.....            0.00
     COARSE SILT.......       4172.18   |  COARSE GRAVEL.....            0.00
     VERY FINE SAND....      10177.96   |  VERY COARSE GRAVEL            0.00
     FINE SAND.........       7473.96   |  SMALL COBBLES.....            0.00
     MEDIUM SAND.......       4692.09   |  LARGE COBBLES.....            0.00
     COARSE SAND.......       4334.57   |  SMALL BOULDERS....            0.00
     VERY COARSE SAND..       3013.17   |  MEDIUM BOULDERS...         4172.18
     VERY FINE GRAVEL..       1083.78   |  LARGE BOULDERS....        31340.37
     FINE GRAVEL.......        564.85   |
                         -------------                          -------------
                                                     TOTAL =        35512.55
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SEDIMENT OUTFLOW from the Downstream Boundary

| GRAIN SIZE | LOAD (tons/day) | GRAIN SIZE | LOAD (tons/day) |
|---|---|---|---|
| CLAY............. | 3190.93 | MEDIUM GRAVEL..... | 3636.87 |
| COARSE SILT....... | 5039.23 | COARSE GRAVEL..... | 9052.23 |
| VERY FINE SAND.... | 13777.66 | VERY COARSE GRAVEL | 15908.87 |
| FINE SAND......... | 22789.33 | SMALL COBBLES..... | 11482.34 |
| MEDIUM SAND....... | 20114.56 | LARGE COBBLES..... | 223.19 |
| COARSE SAND....... | 5689.75 | SMALL BOULDERS.... | 0.00 |
| VERY COARSE SAND.. | 4634.60 | MEDIUM BOULDERS... | 0.00 |
| VERY FINE GRAVEL.. | 126.90 | LARGE BOULDERS.... | 0.00 |
| FINE GRAVEL....... | 691.89 | | |
| | | TOTAL = | 116358.33 |

TABLE SB-2: STATUS OF THE BED PROFILE AT TIME = 1.000 DAYS

| SECTION NUMBER | BED CHANGE (ft) | WS ELEV (ft) | THALWEG (ft) | Q (cfs) | TRANSPORT RATE (tons/day) CLAY | SILT | SAND |
|---|---|---|---|---|---|---|---|
| 20.000 | -3.76 | 3597.42 | 3587.86 | 28230. | 47. | 4185. | 43763. |
| 19.000 | -1.96 | 3593.63 | 3586.22 | 28230. | 207. | 4228. | 63108. |
| 18.000 | -0.09 | 3588.22 | 3581.20 | 28230. | 319. | 4259. | 64230. |
| 17.000 | -0.99 | 3581.74 | 3575.31 | 28230. | 554. | 4323. | 77566. |
| 16.000 | -0.20 | 3573.43 | 3567.87 | 28230. | 772. | 4382. | 79936. |
| 15.000 | 1.21 | 3568.95 | 3563.30 | 28230. | 883. | 4412. | 64211. |
| 14.000 | 0.19 | 3566.43 | 3559.00 | 28230. | 944. | 4429. | 61708. |
| 13.000 | -1.16 | 3561.03 | 3554.37 | 28230. | 1153. | 4486. | 76893. |
| 12.000 | -0.71 | 3553.47 | 3547.31 | 28230. | 1366. | 4543. | 85973. |
| 11.000 | 0.36 | 3547.43 | 3541.50 | 28230. | 1477. | 4574. | 82230. |
| 10.000 | -0.47 | 3544.25 | 3538.02 | 28230. | 1574. | 4600. | 85209. |
| 9.000 | -0.57 | 3540.92 | 3534.62 | 28230. | 1721. | 4640. | 90696. |
| 8.000 | -0.24 | 3534.33 | 3528.34 | 28230. | 1916. | 4693. | 93660. |
| 7.000 | -0.21 | 3527.72 | 3521.77 | 28230. | 2113. | 4746. | 96159. |
| 6.000 | -0.21 | 3521.10 | 3515.16 | 28230 | 2309. | 4800. | 98635. |
| 5.000 | -0.19 | 3514.45 | 3508.58 | 28230. | 2506. | 4853. | 100875. |
| 4.000 | -0.19 | 3507.87 | 3501.97 | 28230. | 2701. | 4906. | 103065. |
| 3.000 | -0.19 | 3501.23 | 3495.36 | 28230. | 2898. | 4960. | 105257. |
| 2.000 | -0.19 | 3494.68 | 3488.76 | 28230. | 3091. | 5012. | 107496. |
| 1.000 | -0.12 | 3488.00 | 3482.22 | 28230. | 3191. | 5039. | 108128. |

TIME STEP # 2

* AB PROFILE 2 = 500 YEAR RETURN PERIOD FLOOD

MOBILE BED APPLICATION IN RIVER WITH DIKES AND DIVERSION CHANNEL.

ACCUMULATED TIME (yrs).......... 0.003

--- Downstream Boundary Condition Data for STREAM SEGMENT NO. 1 at Control Point # 1--

| DISCHARGE (cfs) | TEMPERATURE (deg F) | WATER SURFACE (ft) |
|---|---|---|
| 165850.000 | 60.00 | 3498.700 |

| **** | DISCHARGE (CFS) | WATER SURFACE | ENERGY LINE | VELOCITY HEAD | ALPHA | TOP WIDTH | AVG BED | AVG VEL (by subsection) 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|---|---|---|
| **** | 165850.000 | 3499.365 | 3507.362 | 7.997 | 1.000 | 461.557 | 3483.525 | 0.000 | 22.685 | 0.000 |

SECTION NO. 1.000

** CRITICAL WATER SURFACE USED AT SECTION NO. 1.000 AT TIME = 2.000 DAYS.****ELOEQ**

FLOW DISTRIBUTION (%) = 0.000 100.000 0.000

```
SECTION NO.      2.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.      2.000 TIME =      2.000 DAYS.
 TRIAL    TRIAL        COMPUTED     CRITICAL
  NO.       WS            WS           WS
   0.   3505.855      3505.042
   1.   3505.949      3505.091     3505.899
 **** 165850.000  3505.949  3513.860   7.910     1.000    461.702  3490.028    0.000  22.562    0.000
                                                          FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
 SECTION NO.      3.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.      3.000 TIME =      2.000 DAYS.
 TRIAL    TRIAL        COMPUTED     CRITICAL
  NO.       WS            WS           WS
   0.   3512.458      3511.516
   1.   3512.552      3511.530     3512.502
 **** 165850.000  3512.552  3520.463   7.911     1.000    461.710  3496.631    0.000  22.562  0.000
                                                          FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
 SECTION NO.      4.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.      4.000 TIME =      2.000 DAYS.
 TRIAL    TRIAL        COMPUTED     CRITICAL
  NO.       WS            WS           WS
   0.   3519.099      3518.124
   1.   3519.193      3518.150     3519.143
 **** 165850.000  3519.193  3527.073   7.880     1.000    461.848  3503.246    0.000  22.518    0.000
                                                          FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
 SECTION NO.      5.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.      5.000 TIME =      2.000 DAYS.
 TRIAL    TRIAL        COMPUTED     CRITICAL
  NO.       WS            WS           WS
   0.   3525.686      3524.724
   1.   3525.780      3524.738     3525.730
 **** 165850.000  3525.780  3533.679   7.898     1.000    461.778  3509.849    0.000  22.544    0.000
                                                          FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
 SECTION NO.      6.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.      6.000 TIME =      2.000 DAYS.
 TRIAL    TRIAL        COMPUTED     CRITICAL
  NO.       WS            WS           WS
   0.   3532.275      3531.335
   1.   3532.369      3531.351     3532.319
 **** 165850.000  3532.369  3540.262   7.893     1.000    461.746  3516.432    0.000  22.537    0.000
                                                          FLOW DISTRIBUTION (%) =     0.000100.000    0.000
 SECTION NO.      7.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.      7.000 TIME =      2.000 DAYS.
 TRIAL    TRIAL        COMPUTED     CRITICAL
  NO.       WS            WS           WS
   0.   3538.886      3537.917
   1.   3538.980      3537.932     3538.930
 **** 165850.000  3538.980  3546.870   7.890     1.000    461.768  3523.040    0.000  22.533    0.000
                                                          FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
 SECTION NO.      8.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.      8.000 TIME =      2.000 DAYS.
 TRIAL    TRIAL        COMPUTED     CRITICAL
  NO.       WS            WS           WS
   0.   3545.429      3544.520
   1.   3545.523      3544.534     3545.473
 **** 165850.000  3545.523  3553.437   7.915     1.000    461.569  3529.601    0.000  22.568    0.000
                                                          FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
 SECTION NO.      9.000
 ** SUPERCRITICAL **  Using Critical Water Surface +
 SECTION NO.      9.000 TIME =      2.000 DAYS.
 TRIAL    TRIAL        COMPUTED     CRITICAL
  NO.       WS            WS           WS
   0.   3551.742      3551.088
   1.   3551.836      3551.107     3551.786
 **** 165850.000  3551.836  3559.739   7.903     1.000    460.689  3535.872    0.000  22.550    0.000
                                                          FLOW DISTRIBUTION (%) =     0.000 100.000    0.000
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SECTION NO.     10.000
** SUPERCRITICAL **  Using Critical Water Surfæe +
SECTION NO.     10.000 TIME =     2.000 DAYS.
TRIAL    TRIAL        COMPUTED     CRITICAL
 NO.      WS            WS           WS
  0.   3555.120     3554.568
  1.   3555.214     3554.608     3555.164
**** 165850.000  3555.214  3563.135   7.922    1.000   460.907  3539.276   0.000  22.577   0.000
                                                FLOW DISTRIBUTION (%) =    0.000 100.000   0.000
SECTION NO.     11.000
** SUPERCRITICAL **  Using Critical Water Surface +
SECTION NO.     11.000 TIME =     2.000 DAYS.
TRIAL    TRIAL        COMPUTED     CRITICAL
 NO.      WS            WS           WS
  0.   3558.610     3557.999
  1.   3558.704     3558.062     3558.654
**** 165850.000  3558.704  3566.566   7.862    1.000   463.531  3542.7S   0.000  22.492   0.000
                                                FLOW DISTRIBUTION (%) =    0.000 100.000   0.000
SECTION NO.     12.000
** SUPERCRITICAL **  Using Critical Water Surface +
SECTION NO.     12.000 TIME =     2.000 DAYS.
TRIAL    TRIAL        COMPUTED     CRITICAL
 NO.      WS            WS           WS
  0.   3564.423     3564.209
  1.   3564.517     3564.223     3564.467
**** 165850.000  3564.517  3572.441   7.925    1.000   460.265  3548.559   0.000  22.582   0.000
                                                FLOW DISTRIBUTION (%) =    0.000 100.000   0.000
SECTION NO.     13.000
** SUPERCRITICAL **  Using Critical Water Surface +
SECTION NO.     13.000 TIME =     2.000 DAYS.
TRIAL    TRIAL        COMPUTED     CRITICAL
 NO.      WS            WS           WS
  0.   3571.483     3570.067
  1.   3571.577     3570.081     3571.527
**** 165850.000  3571.577  3579.521   7.944    1.000   458.807  3555.588   0.000  22.609   0.000
                                                FLOW DISTRIBUTION (%) =    0.000 100.000   0.000
SECTION NO.     14.000
**** 165850.000  3578.026  3584.358   6.332    1.000   470.409  3560.559   0.000  20.185   0.000
                                                FLOW DISTRIBUTION (%)=    0.000 100.000   0.000
SECTION NO.     15.000
**** 165850.000  3581.569  3588.408   6.839    1.000   471.174  3564.790   0.000  20.979   0.000
                                                FLOW DISTRIBUTION (%) =    0.000 100.000   0.000
SECTION NO.     16.000
**** 165850.000  3586.002  3593.038   7.036    1.000   465.485  3569.257   0.000  21.278   0.000
                                                FLOW DISTRIBUTION (%) =    0.000 100.000   0.000
SECTION NO.     17.000
** SUPERCRITICAL **  Using Critical Water Surface +
SECTION NO.     17.000 TIME =     2.000 DAYS.
TRIAL    TRIAL        COMPUTED     CRITICAL
 NO.      WS            WS           WS
  0.   3592.457     3590.444
  1.   3592.550     3590.464     3592.500
**** 165850.000  3592.550  3600.453   7.902    1.000   459.532  3576.545   0.000  22.550   0.000
                                                FLOW DISTRIBUTION (%) =    0.000 100.000   0.000
SECTION NO.     18.000
**** 165850.000  3598.640  3606.317   7.677    1.000   463.003  3582.523   0.000  22.225   0.000
                                                FLOW DISTRIBUTION (%) =    0.000 100.000   0.000
SECTION NO.     19.000
**** 165850.000  3604.129  3611.455   7.325    1.000   459.218  3587.495   0.000  21711   0.000
                                                FLOW DISTRIBUTION (%) =    0.000 100.000   0.000
SECTION NO.     20.000
**** 165850.000  3607.697  3613.650   5.953    1.000   461.090  3589.319   0.000  19.572   0.000
                                                FLOW DISTRIBUTION (%) =    0.000 100.000   0.000

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MOBILE BED APPLICATION IN RIVER WITH DIKES AND DIVERSION CHANNEL.

ACCUMULATED TIME (yrs).... 0.005

FLOW DURATION (days)...... 1.000

UPSTREAM BOUNDARY CONDITIONS

| Stream Segment # 1<br>Section No. 20.000 | DISCHARGE<br>(cfs) | SEDIMENT LOAD<br>(tons/day) | TEMPERATURE<br>(deg F) |
|---|---|---|---|
| INFLOW | 165850.00 | 331060.03 | 60.00 |

TABLE SA-1. TRAP EFFICIENCY ON STREAM SEGMENT # 1
MOBILE BED APPLICATION IN RIVER WITH DIKES AND DIVERSION CHANNEL.
ACCUMULATED AC-FT ENTERING AND LEAVING THIS STREAM SEGMENT

| TIME | ENTRY | CLAY | | | SILT | | | SAND | | |
|---|---|---|---|---|---|---|---|---|---|---|
| DAYS | POINT | INFLOW | OUTFLOW | TRAP EFF | INFLOW | OUTFLOW | TRAP EFF | INFLOW | OUTFLOW | TRAP EFF |
| 2.00 | 20.000 | 0.00 | | | 39.19 | | | 153.59 | | |
| TOTAL= | 1.000 | 0.00 | 4.88 | ********** | 39.19 | 39.80 | -0.02 | 153.59 | 228.69 | -0.49 |

TABLE SB-1: SEDIMENT LOAD PASSING THE BOUNDARIES OF STREAM SEGMENT # 1

SEDIMENT INFLOW at the Upstream Boundary:

| GRAIN SIZE | LOAD (tons/day) | GRAIN SIZE | LOAD (tons/day) |
|---|---|---|---|
| CLAY.............. | 0.00 | MEDIUM GRAVEL..... | 7626.37 |
| COARSE SILT....... | 51306.01 | COARSE GRAVEL..... | 0.00 |
| VERY FINE SAND.... | 35961.68 | VERY COARSE GRAVEL | 0.00 |
| FINE SAND......... | 45795.65 | SMALL COBBLES..... | 0.00 |
| MEDIUM SAND....... | 49360.64 | LARGE COBBLES..... | 0.00 |
| COARSE SAND....... | 55180.24 | SMALL BOULDERS.... | 0.00 |
| VERY COARSE SAND.. | 39072.37 | MEDIUM BOULDERS... | 51306.01 |
| VERY FINE GRAVEL.. | 28363.67 | LARGE BOULDERS.... | 279754.02 |
| FINE GRAVEL....... | 18393.41 | | |
| | | TOTAL = | 331060.03 |

SEDIMENT OUTFLOW from the Downstream Boundary

| GRAIN SIZE | LOAD (tons/day) | GRAIN SIZE | LOAD (tons/day) |
|---|---|---|---|
| CLAY.............. | 0.00 | MEDIUM GRAVEL..... | 7053.25 |
| COARSE SILT....... | 51306.01 | COARSE GRAVEL..... | 19217.23 |
| VERY FINE SAND.... | 35942.48 | VERY COARSE GRAVEL | 39719.60 |
| FINE SAND......... | 45706.70 | SMALL COBBLES..... | 40758.27 |
| MEDIUM SAND....... | 48101.89 | LARGE COBBLES..... | 20581.43 |
| COARSE SAND....... | 55270.92 | SMALL BOULDERS.... | 8135.55 |
| VERY COARSE SAND.. | 33101.02 | MEDIUM BOULDERS... | 0.00 |
| VERY FINE GRAVEL.. | 225.60 | LARGE BOULDERS.... | 0.00 |
| FINE GRAVEL....... | 1272.47 | | |
| | | TOTAL = | 406392.41 |

TABLE SB-2: STATUS OF THE BED PROFILE AT TIME = 2.000 DAYS

| SECTION NUMBER | BED CHANGE (ft) | WS ELEV (ft) | THALWEG (ft) | Q (cfs) | TRANSPORT RATE (tons/day) CLAY | SILT | SAND |
|---|---|---|---|---|---|---|---|
| 20.000 | 9.21 | 3607.70 | 3600.83 | 165850. | 0. | 51306. | 236606. |
| 19.000 | -2.33 | 3604.13 | 3585.85 | 165850. | 0. | 51306. | 240285. |
| 18.000 | -1.18 | 3598.64 | 3580.11 | 165850. | 0. | 51306. | 255221. |
| 17.000 | -2.31 | 3592.55 | 3573.99 | 165850. | 0. | 51306. | 273377. |
| 16.000 | -1.50 | 3586.00 | 3566.57 | 165850. | 0. | 51306. | 290629. |
| 15.000 | -2.02 | 3581.57 | 3560.07 | 165850. | 0. | 51306. | 332039. |
| 14.000 | -1.31 | 3578.03 | 3557.50 | 165850. | 0. | 51306. | 351286. |
| 13.000 | -0.97 | 3571.58 | 3554.56 | 165850. | 0. | 51306. | 348732. |
| 12.000 | -0.94 | 3564.52 | 3547.08 | 165850. | 0. | 51306. | 351884. |
| 11.000 | -1.30 | 3558.70 | 3539.84 | 165850. | 0. | 51306. | 368396. |
| 10.000 | 1.93 | 3555.21 | 3540.42 | 165850. | 0. | 51306. | 352[illegible]2 |
| 9.000 | -0.41 | 3551.84 | 3534.78 | 165850. | 0. | 51306. | 350793. |
| 8.000 | -0.60 | 3545.52 | 3527.98 | 165850. | 0. | 51306. | 355464. |
| 7.000 | -0.31 | 3538.98 | 3521.67 | 165850. | 0. | 51306. | 356854. |
| 6.000 | -0.28 | 3532.37 | 3515.09 | 165850. | 0. | 51306. | 357855. |
| 5.000 | -0.27 | 3525.78 | 3508.50 | 165850. | 0. | 51306. | 358979. |
| 4.000 | -0.24 | 3519.19 | 3501.92 | 165850. | 0. | 51306. | 359734. |
| 3.000 | -0.23 | 3512.55 | 3495.32 | 165850. | 0. | 51306. | 360268. |
| 2.000 | -0.24 | 3505.95 | 3488.71 | 165850. | 0. | 51306. | 360935. |
| 1.000 | 0.76 | 3499.37 | 3483.10 | 165850. | 0. | 51306. | 355086. |

$$END

0 DATA ERRORS DETECTED.

TOTAL NO. OF TIME STEPS READ = 2
TOTAL NO. OF WS PROFILES = 2
ITERATIONS IN EXNER EQ = 400

COMPUTATIONS COMPLETED
RUN TIME = 0 HOURS, 0 MINUTES & 0.00 SECONDS

## APPENDIX-12, SILT OBSERVATION RECORD OF BEAS RIVER AT BHUNTAR (IN HACTARE METER)

| Month | Year | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 |
| Jan | 0.249 | 0.200 | 0.210 | 0.123 | 0.503 | 0.173 | 0.237 | 0.241 | 0.335 | 0.180 | 0.178 |
| Feb | 0.186 | 0.213 | 0.298 | 0.219 | 0.439 | 1.318 | 1.877 | 0.417 | 0.250 | 4.000 | 0.185 |
| Mar | 0.430 | 0.943 | 0.777 | 2.764 | 6.417 | 6.621 | 3.286 | 3.065 | 1.145 | 0.403 | 0.549 |
| Apr | 0.631 | 2.214 | 1.760 | 2.939 | 2.811 | 2.934 | 5.128 | 4.635 | 2.381 | 3.790 | 1.510 |
| May | 3.992 | 6.597 | 4.000 | 7.058 | 12.903 | 4.021 | 8.097 | 5.397 | 5.010 | 3.758 | 6.802 |
| Jun | 18.112 | 16.472 | 12.727 | 40.247 | 22.360 | 46.321 | 12.942 | 14.569 | 25.392 | 25.436 | 33.592 |
| Jul | 56.121 | 59.608 | 40.409 | 293.270 | 27.013 | 48.301 | 65.702 | 55.761 | 226.530 | 149.411 | 172.970 |
| Aug | 62.260 | 38.265 | 30.406 | 97.054 | 39.347 | 45.220 | 26.640 | 50.761 | 15.330 | 135.250 | 43.766 |
| Sep | 11.387 | 11.446 | 10.745 | 198.170 | 10.064 | 17.902 | 12.245 | 74.677 | 3.120 | 21.607 | 125.840 |
| Oct | 1.203 | 0.610 | 0.916 | 1.885 | 0.571 | 0.620 | 0.875 | 1.040 | 0.780 | 0.480 | 0.628 |
| Nov | 0.295 | 0.361 | 0.220 | 0.509 | 0.259 | 0.309 | 0.173 | 0.320 | 0.278 | 0.173 | 0.273 |
| Dec | 0.310 | 0.312 | 0.184 | 0.434 | 0.214 | 0.240 | 0.204 | 0.181 | 0.197 | 1.166 | 0.195 |
| **Sum** | **155.176** | **137.241** | **102.652** | **644.672** | **122.901** | **173.980** | **137.406** | **211.064** | **280.748** | **345.654** | **386.488** |

*Source: Irrigation and Public Health Department, Kullu*