Appendix 20 Flood Modelling

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1. INTRODUCTION

1.1 BACKGROUND

This appendix outlines the hydrologic and hydraulic modelling undertaken in relation to the Bickham Coal Mine project. In particular, this appendix examines the flood regime in the Pages River adjacent to the proposed mine, the safety of the mine pit from flooding and the impact on flood levels and flow velocities of the proposed overburden dump located on the edge of the floodplain immediately upstream of the Bickham Gorge. The results presented extend on the work presented in the following reports:

- **Murrurundi, Blandford and Willow Tree Flood Study** (1997)
  Prepared by Lyall Macoun Consulting Engineers Pty Ltd for Murrurundi Council.

- **Bickham Coal Mine Proposed Bulk Sample - Review of Environmental Factors. Flooding and Surface Water Assessment** (2003a).
  Prepared by Hughes Trueman for Bickham Coal Company.

- **Pages River Flood Study – Supplementary Report** (2003b).
  Prepared by Hughes Trueman for Bickham Coal Company.

- **Preliminary draft Surface Water Management and Flooding Report for Bickham Coal Mine** (2005).
  Prepared by Evans & Peck for Bickham Coal Company.

1.2 SCOPE

The hydrologic model used for this study was based on the RORB model developed and calibrated for the Murrurundi, Blandford and Willow Tree Flood Study undertaken by Lyall Macoun Consulting Engineers (LMCE, 1997). The hydrologic modelling is described in **Section 2**.

The hydraulic modelling was carried out using the HEC-RAS hydraulic model and is described in **Section 3**. The model extends from near the junction of Splitters Creek and Pages River for a distance of about 6 km downstream and includes the reaches of the river adjacent to the proposed mine pit and the proposed overburden dump near the northern boundary of "South Bickham" on the outer edge of the Pages River floodplain.

1.3 OBJECTIVES

The objective of the flooding assessment was to fulfil the requirements of the scope of studies specified by the Department of Planning for the Water Resource Assessment (WRA) and draft Water Management Plan (WMP), in particular:

4 b) **Site Information/Survey**
viii) Plan to identify 1: 100 year flood level

4 d) **Geomorphology/Watercourses**
i) Assessment of the impact of the proposal on the existing flow regime (ie flow quantity, velocity, frequency and duration) for all rainfall events up to a 100 year Average Recurrence Interval

The 100 year ARI flood extent, based on the results of the flood modelling, is shown on **Drawing 2.5** in **Appendix 27**.

The impacts of the proposed overburden dump, in terms of flood levels and velocities, are outlined in **Section 3.5** of this appendix. This appendix also provides an assessment of the flood risk to the mine pit itself.

The results of the modelling have been used for the assessment of geomorphological impacts of the proposal that are presented in **Appendix 21**.

2. HYDROLOGICAL MODELLING

2.1 SELECTION OF HYDROLOGIC MODEL

The hydrologic model used for this study was based on the RORB model developed and calibrated for the Murrurundi, Blandford and Willow Tree Flood Study undertaken by Lyall & Macoun Consulting Engineers (LMCE) in 1997. For this study the extent area covered by the RORB model was extended to include Splitters creek and a number of minor catchments that drain into the Pages River between the flow gauging station (Pages River @ Blandford - 210061) and the mine site.

2.2 DESCRIPTION OF THE RORB MODEL

The RORB hydrologic model envisages the catchment to be comprised of a series of concentrated storages which represent sub-catchments defined on watershed lines. All storage elements within the catchment are represented via the storage-discharge equation:

$$\mathbf{S = kQ^m} \qquad \textbf{Equation 2.1}$$

Where S = volume of storage,

Q = discharge,

k = a storage delay parameter,

m = a measure of the non-linearity of a catchment. When “m” is set equal to unity the routing response is linear for the catchment.

The storage parameter "k" within the general storage equation is modified to reflect the catchment storage and the reach storage as follows:

$$\mathbf{k = k_c . k_r} \qquad \textbf{Equation 2.2}$$

Where k_c = an empirical coefficient applicable to the entire catchment and stream network,

k_r = a dimensionless ratio called the relative delay time, applicable to an individual reach storage.

2.3 MODEL SETUP

Five sub-catchments, draining into the Pages River between the Blandford Gauging Station, and the mine site were added to the original RORB model prepared by LMCE. The layout of the RORB model catchments is shown in **Figure 2.1.**

The additional sub-catchment areas (denoted AB – AF) and sub-catchment areas used in the original RORB model (denoted A – Z) are listed in **Table 2.1**.

The storage delay and catchment non-linearity parameters from the original LMCE study which were adopted for this study are set out in **Table 2.2**.

Table 2.1: RORB Sub-Catchment Details

Sub-Catchment		Area (km^2)
Original Model Sub-Catchments *(Source: LMCE, 1997)*		
A-F	Pages River u/s Cohens Gully	64
G-H	Cohens Gully	2.3
J-K	Halls Creek	5.4
M	Campbells Creek	12
O	Murulla Creek	7.4
P-U	Warlands Creek	103
X-Z	Scotts Creek	55
A-Z	Pages River at gauging station	300
Additional RORB Sub-Catchments		
AB	Pages River	5.3
AC	Splitters Creek	34
AD	Pages River	1.2
AE	Tributary Creek	6.3
AF	Pages River	1.2

2.4 MODEL CALIBRATION

The procedure for the calibration and testing of the RORB model for the original study undertaken by LMCE involved the analysis of data from daily rain gauges and pluviometers in and adjacent to the Pages River catchment to ascertain the temporal and areal distribution of rainfall for rainfall events associated with significant floods for which there was a reliable flow record.

Isohyetal maps, prepared to cover the duration of each storm event, were used in conjunction with pluviographic data to estimate hyetographs of rainfall input for each sub-catchment of the RORB model.

Model calibration and testing was carried out using historic flood data from the Blandford gauging station (210061) for the following floods:

- January 1996
- February 1992
- January 1976
- October 1996.

The events used in the RORB model calibration process reported by LMCE were considered to be major floods in the 10 - 100 year ARI range. For those events a constant value for the storage parameter "k_c" of 9.5 gave the best fit to the observed flood hydrograph. The value of "m" adopted in the calibration process was 0.80, as recommended in the RORB manual. This value was retained for the estimation of design flows for both the LMCE model and the current model.

The calibration process showed that initial loss (IL) rates ranged between 12 and 80 mm and continuing loss (CL) rates ranged between 2.74 and 0.16 mm/h, but were generally less than the value of 2.5 mm/h commonly adopted for design flood estimation. Notwithstanding, there are insufficient data to warrant adoption of loss values other than those recommended by Walsh et al, 1991. The model parameters adopted by LMCE for generation of design flows are summarised in **Table 2.2**. These parameters were adopted for use in this current study.

Table 2.2
Adopted RORB Model Parameters

Parameters	Average Recurrence Interval (Years)				
	5	**10**	**20**	**50**	**100**
IL mm	55	55	55	50	40
CL mm/h	2.5	2.5	2.5	2.5	2.5
k_c	9.5	9.5	9.5	9.5	9.5
m	0.80	0.80	0.80	0.80	0.80

(Source: LMCE 1997)

The 1997 Flood Study undertaken by LMCE also involved calibration of the hydraulic model (MIKE-11) to observed flood levels for the 1996 flood in Murrurundi and Blandford. The hydraulic model calibration did not necessitate any modifications to the hydrologic model calibration.

2.5 DESIGN STORMS

2.5.1 Rainfall Intensity

In order to run the RORB model for the expanded catchment it was necessary to estimate the rainfall depths for the additional sub-catchments for a range of frequencies and durations. In LMCE's 1997 study rainfall depths for events up to the 100 year ARI were derived using principles outlined in Chapter 2 of *Australian Rainfall and Runoff* (AR&R) (Institution of Engineers Australia, 1998). Intensity-frequency-duration data over the entire catchment were generated. The steps involved in this process were:

- Five uniformly spaced points were used to define the areal distribution of rainfall over the study area. Thiessen weighting was used to determine the area of influence of each point.
- A computer program based on procedures outlined in AR&R was used to calculate the rainfall intensity at each grid point. The intensities derived were for frequencies of 5, 20, 50 and 100 year ARI and durations of 1 to 72 hours.
- For each design frequency and duration, a rainfall depth was calculated at each grid point.
- Finally, rainfall depths at the centroids of each RORB sub-area were estimated using the Thiessen areas. An areal reduction factor was applied to the depths prior to inclusion of the data in the RORB model.

For this study the rainfall depth calculated in the LMCE study for sub-catchment Z (the most downstream catchment on Scotts Creek) was applied to the additional sub-catchments which lie immediately adjacent to sub-catchment Z.

2.5.2 Areal Reduction Factors

The rainfalls derived using the processes outlined in ARR are applicable strictly at a point, however they can be used on areas up to 4 km^2. For larger areas it is not realistic to assume that the same intensity can be maintained over the entire area. A reduction in point values has to be made using an areal reduction factor (ARF). The LMCE study documented current research into appropriate ARF values which would be suitable for application to the rainfall depths entered into the RORB model. The results of this research are shown in **Table 2.3**. These ARFs were adopted for the LMCE study and also for this current study.

Table 2.3
Adopted Areal Reduction Factors

Storm Duration (Hours)	Areal Reduction Factor
1	0.78
3	0.89
6	0.92
9	0.93
12	0.94
24	0.95

(Source: LMCE 1997)

For durations greater than 24 hours an ARF value of 0.95 was adopted.

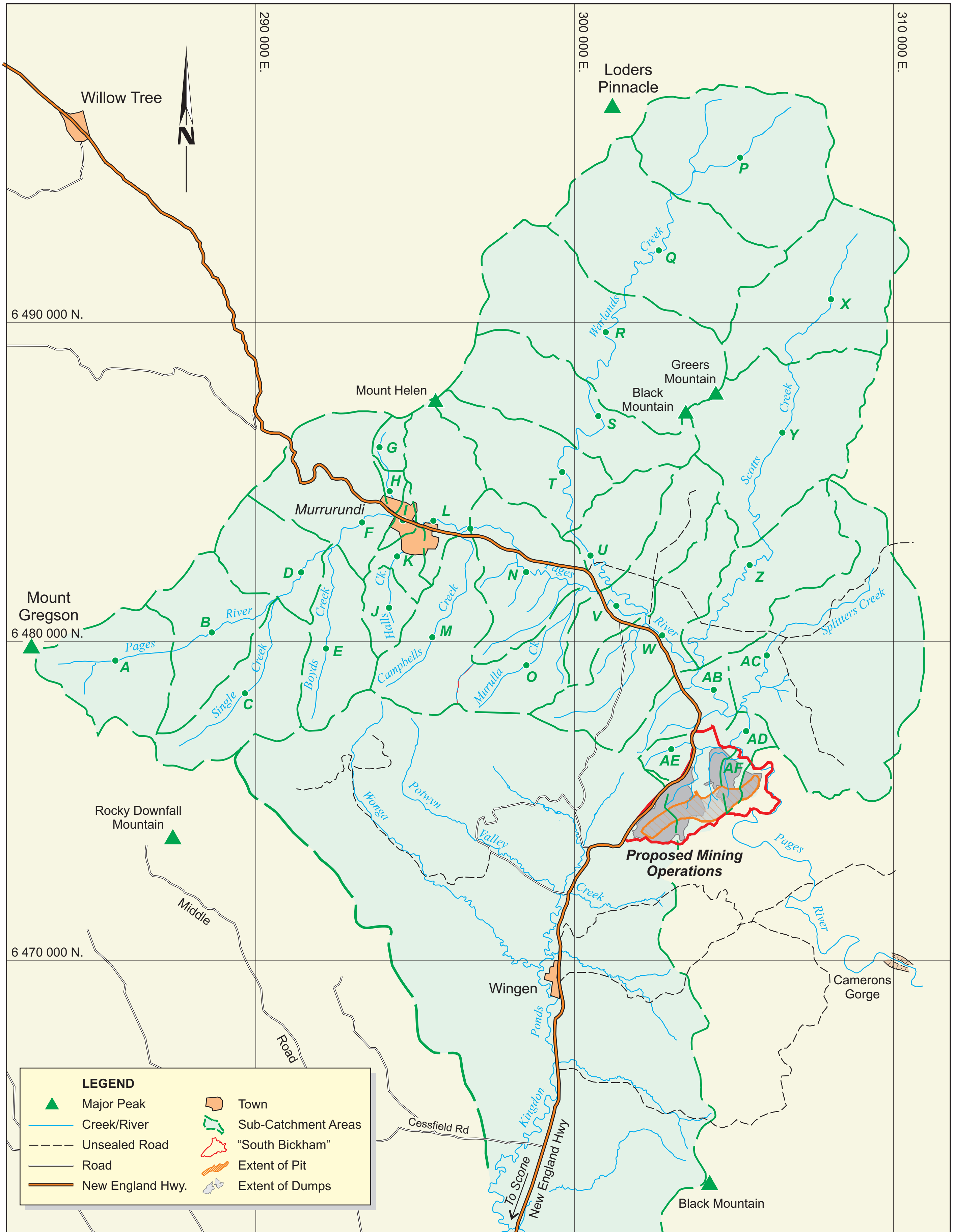
2.6 RESULTS

Table 2.4 lists the peak flows at the mine site for a range of storm durations and frequencies. The peak flood is shown in bold in the table. It can be seen that the critical duration for events on the catchment ranges between 30 and 36 hours. The peak flow corresponding to each ARI was used as the input to the hydraulic modelling to estimate flood levels at the project site.

Table 2.4
Design Discharges - Pages River at Bickham Coal Mine Site

Storm Duration (hours)	Peak Discharge (m^3/s)				
	5 y ARI	10 y ARI	20 y ARI	50 y ARI	100 y ARI
24	205	325	-	-	-
30	**524**	**722**	**956**	1,162	1,384
36	432	641	929	**1,232**	**1,496**
48	-	-	**-**	1,211	1,449

For purposes of assessing the effects of an extreme flood, a peak flow of three times the 100 year ARI flow (4,488 m^3/s) was adopted.



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Appendix 20 - Flood Modelling

RORB MODEL LAYOUT

Date: February 2009	Assignment: 21667	**Figure 2.1**

3. HYDRAULIC MODELLING

3.1 SELECTION OF HYDRAULIC MODEL

The HEC-RAS Version 3.1.3 (May 2005) hydraulic model is the current windows-based release from US Army Corps of Engineers, Hydrologic Engineering Centre. It has been used to carry out the detailed hydraulic assessment of flood levels adjoining the mine site. HEC-RAS is an integrated package of hydraulic analysis programs capable of performing both one-dimensional steady and unsteady flow water surface profile calculations. The model is appropriate for this study because the section of the Pages River running adjacent to the proposed mine site has a well defined channel and floodplain.

The steady flow component of the model, which was used for the hydraulic modelling of the Pages River adjacent to the proposed Bickham Coal Mine, can handle a full network of channels, a dendritic system or a single river reach and is capable of modelling subcritical, supercritical and mixed flow water surface profiles.

Given that the Bickham Gorge acts as a hydraulic control on flood conditions in the reach of the river adjacent to the location of the overburden dump, the loss of flood storage volume caused by the dump (<15%) will have minimal impact on the flood regime. Accordingly, a steady flow model was considered appropriate for assessing the extent of the 100 year ARI flood and the impact on flood levels and velocities for input to the geomorphologic assessment (see **Appendix 21**), in accordance with the requirements of the DoP scope, set out in **Section 1.3** above.

3.2 SITE INSPECTION

The river has been inspected on a number of occasions since 2003 along the reach of the river represented in the hydraulic model. Appropriate values of Manning's "n" for the hydraulic model were selected based on observations during the site inspections. It was also observed during an inspection in 2003 that flood debris was caught in branches of trees, presumably from the flood that occurred in November 2000 (230 m^3/s at the Blandford gauging station). The approximate level of these flood marks, together with the recorded flow at the Bickham gauge were used to check the flood levels given by the HEC-RAS model.

3.3 HEC-RAS MODEL SETUP

The hydraulic model extends for a distance of 6 km downstream from near the junction of Splitters Creek and the Pages River and encompasses the sections of river adjacent to the proposed overburden dump and the mine pit. For reference purposes the cross sections have been identified by the chainage upstream (-ve numbers) and downstream (+ve numbers) relative to a cross section that approximately corresponds to the northern boundary of "South Bickham". The cross sections used in the model were based on surveyed river cross-sections obtained specifically for the study.

The configuration of the "developed" scenario incorporated the northern overburden dump in which cross-sections XS 20 to XS 478 were modified to represent the encroachment of the overburden dump onto the edge of the floodplain based on information provided by the Bickham Coal Company. The location of the toe of the dump varies from 250 to 300 m from the bank of the Pages River with an average of 270 m. At the toe, the slope of the overburden dump averages 1:4.5 (V:H).

The layout of the HEC-RAS model and the numbering of the cross sections is shown on **Figure 3.1**.

Appropriate roughness values were allocated to each part of each cross section to represent the different surface roughness across the river and adjoining floodplain. The adopted roughness values are set out in **Table 3.1**.

Table 3.1
Adopted Manning's Roughness Values

Manning's n	River Bed	River Banks	Overbanks
0.030	straight, clear, flat		Short grass (overburden dump)
0.035	some rocks		long grass
0.040	large rocks		grass with some shrub/brush
0.050	large boulders		scattered brush
0.060		rock banks, some vegetation	rock cliffs with some vegetation
0.070			light-medium brush
0.075			medium sized brush on rock
0.080		medium to dense brush	medium to dense brush

In the absence of any observed flood levels for a significant flood (>10 year ARI) with which to calibrate the hydraulic model for this reach of the Pages River, a flood level accuracy of $\pm$ 0.1 m is as good as could be expected.

3.4 MODEL SCENARIOS

The Department of Planning's scope for the Water Resources Assessment requires the assessment of the impacts of the project on the existing flow regime for events up to 100 year ARI. In addition, the risk of flooding of the pit was a consideration in the design of the mine. Accordingly, the flood regime in the vicinity of the mine and the impact of the overburden dump on flood levels and velocities for the full range of floods were assessed including the 5 year ARI flood (approximately bank full), 20 year ARI, 100 year ARI floods and an extreme flood (3 x 100 year ARI)

The design flows obtained from the RORB modelling were entered at the upstream end of the modelled river length and peak flood levels were determined at each cross section for each design floods. This approach was considered acceptable because no major lateral inflows occur along the modelled reach.

In addition, a sensitivity analysis was carried out for the 100 year ARI flood event (developed conditions) on a number of parameters in the hydraulic model as follows:

- Manning's roughness values ($\pm$20%)
- 100 year ARI discharge ($\pm$20%)
- Downstream boundary condition.

3.5 Results and Discussion

3.5.1 Impact of the Overburden Dump

The modelled 100 year ARI flood levels at the cross sections adjacent to and upstream of the proposed mine overburden dump are summarised in **Table 3.2** for "existing" conditions and "post-mine" conditions with the overburden dump in place.

Table 3.3 contains velocities on the left and right floodplain and within the channel for the same scenarios. The sections immediately adjacent to the overburden dump (XS 20 to XS 478) are shown shaded in **Table 3.2** and **Table 3.3** below and the numbers in bold indicate the maximum increase in each instance .

Table 3.2
100 year ARI Flood Levels Adjacent to Mine Overburden Dump

Cross Section	Water Level		
	Existing (m AHD)	Post-Mine (m AHD)	Difference (m)
-1456	393.20	393.20	0.00
-1078	392.33	392.34	0.01
-608	391.77	391.79	0.02
-332	391.51	391.54	0.03
0	391.14	391.18	**0.04**
20	391.26	391.30	**0.04**
60	391.26	391.29	0.03
119	391.26	391.27	0.01
203	391.26	391.27	0.01
271	391.26	391.26	0.00
427	391.26	391.25	-0.01
478	391.24	391.23	-0.01
608	391.13	391.13	0.00

Table 3.3
100 year ARI Velocities Adjacent to Mine Overburden Dump

Cross Section	Velocity (m/s)								
	Existing			Post-Mine			Difference		
	Chnl	Left Bank	Right Bank	Chnl	Left Bank	Right Bank	Chnl	Left Bank	Right Bank
-1456	2.06	0.96	0.81	2.06	0.96	0.81	0.00	0.00	0.00
-1078	3.43	0.79	1.66	3.41	0.80	1.66	-0.02	0.01	0.00
-608	2.19	0.25	1.17	2.17	0.25	1.16	-0.02	0.00	-0.01
-332	2.09	1.51	1.28	2.07	1.50	1.27	-0.02	-0.01	-0.01
0	2.49	1.61	0.59	2.47	1.60	0.59	-0.02	-0.01	0.00
20	1.40	0.61	0.62	1.36	0.59	0.74	-0.04	-0.02	0.12
60	1.27	0.69	0.69	1.31	0.71	0.90	0.04	0.02	0.21
119	1.02	0.53	0.79	1.19	0.62	1.12	0.17	0.09	0.33
203	0.76	0.50	0.65	0.98	0.64	0.99	0.22	0.14	**0.34**
271	0.58	0.31	0.49	0.88	0.48	0.83	0.30	**0.17**	**0.34**
427	0.52	0.15	0.52	0.83	0.24	0.85	**0.31**	0.09	0.33
478	0.59	0.18	0.62	0.83	0.26	0.89	0.24	0.08	0.27
608	1.46	0.77	0.64	1.46	0.77	0.64	0.00	0.00	0.00

Annexure 20A contains plots of all of the model cross sections, tables of flood levels and velocities and longitudinal profiles along the river for both existing and post-mine conditions.

The longitudinal flood profiles in **Annexure 20A** show that the Bickham Gorge (XS 724 to XS 1088) has a significant influence on flood behaviour on the floodplain located a short distance upstream (XS 20 to XS 478). The profiles for both the "existing" and "developed" conditions show that for floods larger than the 5 year ARI flood, the gorge provides a significant constriction in the Pages River which causes a steep hydraulic gradient and high velocities through the gorge and a relatively flat gradient, and correspondingly low velocities, in the area adjacent to the floodplain upstream of the gorge.

Key results from the analysis are:

- The existing 100 year ARI floods level range from approximately 393.20 m AHD at the upstream end of the model (XS -1456) to 369.84 m AHD at the downstream end (XS 4566).
- Along the length of the river included in the HEC-RAS model, the average difference in flood level between the 5 year ARI flood and 100 year ARI flood is approximately 3.4 m.
- Because of the backwater effect from the Bickham Gorge, in a 100 year ARI flood a level pool is created that extends about 700 m upstream (see longitudinal profiles in **Annexures 20A-4** and **20A-5**). Within this reach the 100 year ARI flood levels range from 3.7 to 5.0 m above the 5 year ARI flood level with an average of 4.25 m.
- Under existing conditions, velocities in the river channel are the same or less for a 100 year ARI flood than for a 5 year ARI flood, reflecting the backwater effect of the Bickham Gorge. It follows that the greatest threat to river channel stability occurs for minor floods (<5 year ARI) that will not be affected by the overburden dump;
- With the introduction of the overburden dump on the edge of the floodplain, the 100 year ARI flood levels would increase by a maximum of 0.04 m (40 mm) at the northern boundary of "South Bickham". At the upstream boundary of the model there would be no change in flood level. The small increase in flood level attributable to the presence of the overburden dump will not have any practical effect on upstream landholders and the effects will be indistinguishable from the impacts of natural changes in floodplain or channel vegetation or a build up of debris in the channel as indicated in the sensitivity analysis in **Section 3.6** below;
- The overburden dump would lead to a small increase in the velocity in some sections of the channel in a 100 year ARI flood. However these velocities remain significantly lower than the velocities that would occur in a 5 year ARI flood;
- In a 100 year ARI flood, the overburden dump would lead to a small increase in the average velocity on the floodplain but the floodplain velocities would remain below 1.2 m/s which is less than the acceptable limit for perennial pastures on very high erodibility soils.

The detailed geomorphology study in **Appendix 21** indicates that there will be minimal risk of the overburden dump leading to flow conditions that would cause scouring of the existing floodplain or the toe of the overburden dump. In order to further reduce the risk of scouring of the toe of the overburden dump, rock armouring will be provided along the base of the overburden dump up to 500 mm above the 100 year ARI flood level.

3.5.2 Flood Levels Adjacent to the Mine Pit

The HEC-RAS model was also run for an extreme flood event (3 x 100 year ARI) to assess the impact of a rare flood on the mine pit. The results for the 100 year ARI and PMF events are contained in **Annexure 20A** and summarised in **Table 3.4**. The table shows that relative to the lowest point on the rim of the mine pit (406 m AHD), the relevant maximum flood levels (at XS 1338) are about 21 m lower in the 100 year ARI flood and 15 m lower in an extreme flood. These results indicate that there is no risk of floodwater from the Pages River entering the mine pit.

Table 3.4
Flood Levels Adjacent to the Mine Pit

Flood	Flood Level (m AHD)	Freeboard (m)
100 Year ARI	385.12	20.88
Extreme	391.28	14.72

3.6 Sensitivity Analysis

The impacts on 100 year ARI water levels and velocities as a result of varying Manning's roughness (n), the 100 year ARI discharge (Q) and the downstream starting water level are shown in **Table 3.5**. The results represent the average change for the overall model and for the length of the Pages River adjacent to the proposed overburden dump (XS 20 to XS 478).

Table 3.5: Sensitivity Analysis Results – 100 Year ARI Flood

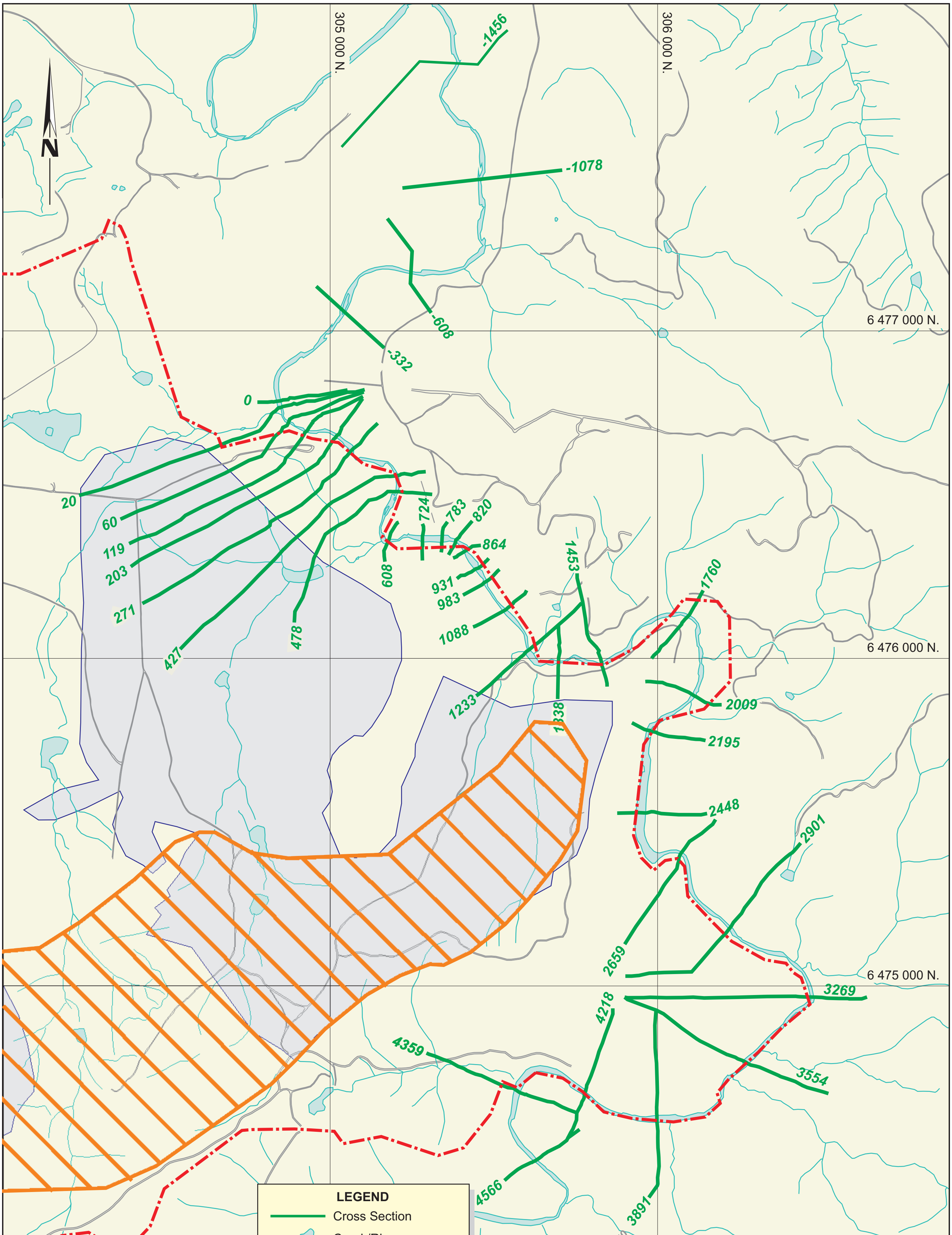
Parameter	Water level (m AHD)	Channel Velocity (m/s)	Left Overbank Velocity (m/s)	Right Overbank Velocity (m/s)
Over length of model				
n +20%	0.46	-0.32	0.04	0.02
n -20%	-0.47	0.45	-0.06	-0.05
Q +20%	0.77	0.14	0.12	0.15
Q -20%	-0.82	-0.17	-0.14	-0.19
Starting Depth	0.03	-0.03	0.00	0.00
Adjacent to overburden dump				
n +20%	0.37	-0.10	-0.03	-0.06
n -20%	-0.21	0.06	0.02	0.03
Q +20%	1.17	-0.08	-0.02	0.00
Q -20%	-1.25	0.14	0.00	-0.03
Starting Depth	0.00	0.00	0.00	0.00

It can be seen that, for the section of the Pages River adjacent to the proposed overburden dump, variation of the adopted Manning's "n" value by ±20% results in a change in flood levels of +0.37 m to -0.21 m. An increase in Manning's "n" of 20% is equivalent to a change on the floodplain from long grass to long grass with some brush (see **Table 3.1**) and indicates that a change in excess 40 mm (0.04 m) in the 100 year ARI flood level could occur as a result of minor changes in floodplain vegetation even if the overburden dump was not constructed on the edge of the floodplain.

The results in **Table 3.5** show that varying the 100 year ARI discharge by ±20% results in a change in the flood level of about ±1.2 m in the area of the model adjacent to the overburden dump. This significant variation in flood level is attributable to the constriction at the Bickham Gorge downstream of the floodplain where the overburden dump is proposed.

The velocities in the Pages River adjacent to the overburden vary by around ±0.1 m/s, when the flows and "n" values are varied by ±20%, which is not considered to be significant.

The downstream starting level has no influence on flood levels and velocities adjacent to the overburden dump as it is so far downstream.



0 500
Metres

LEGEND

- Cross Section
- Creek/River
- Road/Track
- "South Bickham"
- Extent of Pit
- Extent of Dumps

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	Appendix 20 - Flood Modelling	
HEC - RAS MODEL LAYOUT		
Date: February 2009	Assignment: 21667	**Figure 3.1**

4. SUMMARY AND CONCLUSIONS

This appendix presents the findings of the hydrologic and hydraulic modelling carried out to assess the impacts on flooding of the proposed Bickham Mine project.

The 100 year ARI flood extent, based on the results of the flood modelling, is shown on **Drawing 2.5** in **Appendix 27**.

The modelling shows that during a 100 year ARI flood, because of the constriction caused by the Bickham Gorge, flow velocities in the channel immediately upstream of the gorge are less than half of the velocities during a 5 year ARI flood which is confined within the river channel. Compared to existing flood levels, the presence of the proposed overburden dump on the edge of the floodplain upstream of the gorge would increase flood levels immediately upstream of the dump by a maximum of 40 mm in the 100 year ARI flood. The small increase in flood level attributable to the presence of the overburden dump would not have any practical effect on upstream landholders and the effect would be indistinguishable from the impacts of natural changes in floodplain or channel vegetation or a build up of debris in the channel.

The model analysis indicates that in a 100 year ARI flood the overburden dump would lead to a small increase in the velocity in some sections of the channel. However these velocities would remain significantly lower than the velocities that would occur in a 5 year ARI flood. In a 100 year ARI flood the overburden dump would also lead to a small increase in the average velocity on the floodplain but the floodplain velocities would remain below 1.2 m/s, which is less than the acceptable limit for perennial pastures on very high erodibility soils.

The impacts of the increases in velocity and flood level are considered and addressed in the detailed geomorphology study report (**Appendix 21**). The geomorphology study indicates that there will be minimal risk of the overburden dump leading to flow conditions that would cause scouring of the existing floodplain or the toe of the overburden dump. In order to further reduce the risk of scouring of the toe of the overburden dump, rock armouring will be provided along the base of the overburden dump up to 500 mm above the 100 year ARI flood level.

The flood modelling was also used to assess the risk of flooding of the mine pit. The analysis shows that the maximum flood level would be about 21 m below the lowest point on the rim of the pit during a 100 year ARI flood and about 15 m below the rim in an extreme flood.

In the absence of any observed flood levels for a significant flood (>10 year ARI) with which to calibrate the hydraulic model for this reach of the Pages River, a flood level accuracy of ± 0.1 m is as good as could be expected.

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ANNEXURE 20A

HYDRAULIC ANALYSIS RESULTS

20A-1 HEC-RAS Tabulated Results

20A-2 HEC-RAS Cross-Sections – Existing Conditions

20A-3 HEC-RAS Cross-Sections – Developed Conditions – XS 0 to XS 608

20A-4 HEC-RAS Longitudinal Profiles – Existing Conditions

20A-5 HEC-RAS Longitudinal Profiles – Developed Conditions

ANNEXURE 20A-1

HYDRAULIC ANALYSIS RESULTS

HEC-RAS Tabulated Results

5 year ARI HEC-RAS Results

Cross Section	Min Ch El	Existing				Developed				Difference			
		W.S. Elev	Vel Chnl	Vel Left	Vel Right	W.S. Elev	Vel Chnl	Vel Left	Vel Right	W.S. Elev	Vel Chnl	Vel Left	Vel Right
	(m)	(m)	(m/s)	(m/s)	(m/s)	(m)	(m/s)	(m/s)	(m/s)	(m)	(m/s)	(m/s)	(m/s)
-1456	384.00	390.93	2.02			390.93	2.02			0.00	0.00	0.00	0.00
-1078	383.86	389.83	3.15			389.83	3.15			0.00	0.00	0.00	0.00
-608	382.21	389.16	2.18			389.16	2.18			0.00	0.00	0.00	0.00
-332	381.95	388.14	3.22			388.14	3.22			0.00	0.00	0.00	0.00
0	381.24	387.48	2.37			387.48	2.37			0.00	0.00	0.00	0.00
20	381.14	387.60	1.39			387.60	1.39			0.00	0.00	0.00	0.00
60	380.94	387.51	1.73			387.51	1.73			0.00	0.00	0.00	0.00
119	380.87	387.34	2.03		0.32	387.34	2.03		0.32	0.00	0.00	0.00	0.00
203	380.32	387.12	1.85			387.12	1.85			0.00	0.00	0.00	0.00
271	380.00	386.96	1.76			386.96	1.76			0.00	0.00	0.00	0.00
427	379.29	386.39	2.29			386.39	2.29			0.00	0.00	0.00	0.00
478	379.05	386.21	2.32			386.21	2.32			0.00	0.00	0.00	0.00
608	378.43	386.23	1.15	0.14	0.11	386.23	1.15	0.14	0.11	0.00	0.00	0.00	0.00
724	378.27	385.70	2.98			385.70	2.98			0.00	0.00	0.00	0.00
783	378.52	384.78	4.38			384.78	4.38			0.00	0.00	0.00	0.00
820	378.47	384.53	3.58			384.53	3.58			0.00	0.00	0.00	0.00
864	378.43	384.48	2.63			384.48	2.63			0.00	0.00	0.00	0.00
931	378.34	384.27	2.27			384.27	2.27			0.00	0.00	0.00	0.00
983	377.62	384.15	2.05			384.15	2.05			0.00	0.00	0.00	0.00
1088	377.52	383.81	2.43	0.11	1.30	383.81	2.43	0.11	1.30	0.00	0.00	0.00	0.00
1233	376.76	383.41	2.32			383.41	2.32			0.00	0.00	0.00	0.00
1338	376.51	381.77	4.56			381.77	4.56			0.00	0.00	0.00	0.00
1453	375.70	380.62	3.78			380.62	3.78			0.00	0.00	0.00	0.00
1760	374.83	379.28	3.60			379.28	3.60			0.00	0.00	0.00	0.00
2009	373.33	378.28	3.62			378.28	3.62			0.00	0.00	0.00	0.00
2195	372.24	377.75	3.04			377.75	3.04			0.00	0.00	0.00	0.00
2448	372.17	377.11	3.05			377.11	3.05			0.00	0.00	0.00	0.00

5 year ARI HEC-RAS Results

Cross Section	Min Ch El	Existing				Developed				Difference			
		W.S. Elev	Vel Chnl	Vel Left	Vel Right	W.S. Elev	Vel Chnl	Vel Left	Vel Right	W.S. Elev	Vel Chnl	Vel Left	Vel Right
	(m)	(m)	(m/s)	(m/s)	(m/s)	(m)	(m/s)	(m/s)	(m/s)	(m)	(m/s)	(m/s)	(m/s)
2659	370.41	377.21	1.01			377.21	1.01			0.00	0.00	0.00	0.00
2901	369.82	376.51	2.79			376.51	2.79			0.00	0.00	0.00	0.00
3269	368.68	374.84	2.11			374.84	2.11			0.00	0.00	0.00	0.00
3554	368.34	374.50	2.20			374.50	2.20			0.00	0.00	0.00	0.00
3891	367.98	373.72	3.06			373.72	3.06			0.00	0.00	0.00	0.00
4128	366.38	372.11	2.53			372.11	2.53			0.00	0.00	0.00	0.00
4359	365.88	370.13	3.49			370.13	3.49			0.00	0.00	0.00	0.00
4566	364.48	367.74	4.51			367.74	4.51			0.00	0.00	0.00	0.00

Note: Location of overburden dump

20 year ARI HEC-RAS Results

Cross Section	Min Ch El	Existing				Developed				Difference			
		W.S. Elev	Vel Chnl	Vel Left	Vel Right	W.S. Elev	Vel Chnl	Vel Left	Vel Right	W.S. Elev	Vel Chnl	Vel Left	Vel Right
	(m)	(m)	(m/s)	(m/s)	(m/s)	(m)	(m/s)	(m/s)	(m/s)	(m)	(m/s)	(m/s)	(m/s)
-1456	384.00	392.73	1.76	0.66	0.48	392.73	1.76	0.66	0.48	0.00	0.00	0.00	0.00
-1078	383.86	391.51	3.75			391.51	3.75			0.00	0.00	0.00	0.00
-608	382.21	390.51	2.39		0.78	390.51	2.40		0.78	0.00	0.01	0.00	0.00
-332	381.95	389.62	3.06	1.42	0.99	389.64	3.03	1.42	1.00	0.02	-0.03	0.00	0.01
0	381.24	388.90	2.79	1.22	0.13	388.95	2.76	1.22	0.15	0.05	-0.03	0.00	0.02
20	381.14	389.04	1.71	0.40	0.41	389.08	1.69	0.41	0.41	0.04	-0.02	0.01	0.00
60	380.94	388.99	1.86	0.68	0.67	389.03	1.83	0.68	0.66	0.04	-0.03	0.00	-0.01
119	380.87	388.92	1.90	0.80	0.86	388.97	1.83	0.79	0.99	0.05	-0.07	-0.01	0.13
203	380.32	388.87	1.53	0.67	0.76	388.92	1.47	0.66	0.98	0.05	-0.06	-0.01	0.22
271	380.00	388.86	1.04	0.40	0.61	388.90	1.20	0.47	0.84	0.04	0.16	0.07	0.23
427	379.29	388.84	0.85	0.17	0.65	388.83	1.21	0.24	0.92	-0.01	0.36	0.07	0.27
478	379.05	388.81	0.84	0.19	0.71	388.80	1.14	0.25	0.94	-0.01	0.30	0.06	0.23
608	378.43	388.71	1.33	0.56	0.50	388.71	1.33	0.56	0.50	0.00	0.00	0.00	0.00
724	378.27	387.92	3.77			387.92	3.77			0.00	0.00	0.00	0.00
783	378.52	386.42	5.76			386.42	5.76			0.00	0.00	0.00	0.00
820	378.47	386.32	4.40			386.32	4.40			0.00	0.00	0.00	0.00
864	378.43	386.22	3.52			386.22	3.52			0.00	0.00	0.00	0.00
931	378.34	386.04	2.85			386.04	2.85			0.00	0.00	0.00	0.00
983	377.62	385.88	2.65			385.88	2.65			0.00	0.00	0.00	0.00
1088	377.52	385.59	2.85	0.57	1.94	385.59	2.85	0.57	1.94	0.00	0.00	0.00	0.00
1233	376.76	385.25	2.56	0.15	0.28	385.25	2.56	0.15	0.28	0.00	0.00	0.00	0.00
1338	376.51	383.62	4.76			383.62	4.76			0.00	0.00	0.00	0.00
1453	375.70	382.14	4.61			382.14	4.61			0.00	0.00	0.00	0.00
1760	374.83	380.67	4.35			380.67	4.35			0.00	0.00	0.00	0.00
2009	373.33	380.39	3.16	0.43	1.77	380.39	3.16	0.43	1.77	0.00	0.00	0.00	0.00
2195	372.24	379.83	3.40			379.83	3.40			0.00	0.00	0.00	0.00
2448	372.17	379.04	3.68			379.04	3.68			0.00	0.00	0.00	0.00

20 year ARI HEC-RAS Results

Cross Section	Min Ch El	Existing				Developed				Difference			
		W.S. Elev	Vel Chnl	Vel Left	Vel Right	W.S. Elev	Vel Chnl	Vel Left	Vel Right	W.S. Elev	Vel Chnl	Vel Left	Vel Right
	(m)	(m)	(m/s)	(m/s)	(m/s)	(m)	(m/s)	(m/s)	(m/s)	(m)	(m/s)	(m/s)	(m/s)
2659	370.41	379.27	1.21	0.11	0.07	379.27	1.21	0.11	0.07	0.00	0.00	0.00	0.00
2901	369.82	378.72	2.53	0.19	0.96	378.72	2.53	0.19	0.96	0.00	0.00	0.00	0.00
3269	368.68	376.79	2.60			376.79	2.60			0.00	0.00	0.00	0.00
3554	368.34	376.49	2.46			376.49	2.46			0.00	0.00	0.00	0.00
3891	367.98	375.62	3.57	0.73	0.71	375.62	3.57	0.73	0.71	0.00	0.00	0.00	0.00
4128	366.38	374.11	2.82	0.35	0.38	374.11	2.82	0.35	0.38	0.00	0.00	0.00	0.00
4359	365.88	371.45	4.52			371.45	4.52			0.00	0.00	0.00	0.00
4566	364.48	368.78	5.41			368.78	5.41			0.00	0.00	0.00	0.00

Note: [ ] Location of overburden dump

100 year ARI HEC-RAS Results

Cross Section	Min Ch El	Existing				Developed				Difference			
		W.S. Elev	Vel Chnl	Vel Left	Vel Right	W.S. Elev	Vel Chnl	Vel Left	Vel Right	W.S. Elev	Vel Chnl	Vel Left	Vel Right
	(m)	(m)	(m/s)	(m/s)	(m/s)	(m)	(m/s)	(m/s)	(m/s)	(m)	(m/s)	(m/s)	(m/s)
-1456	384.00	393.20	2.06	0.96	0.81	393.20	2.06	0.96	0.81	0.00	0.00	0.00	0.00
-1078	383.86	392.33	3.43	0.79	1.66	392.34	3.41	0.80	1.66	0.01	-0.02	0.01	0.00
-608	382.21	391.77	2.19	0.25	1.17	391.79	2.17	0.25	1.16	0.02	-0.02	0.00	-0.01
-332	381.95	391.51	2.09	1.51	1.28	391.54	2.07	1.50	1.27	0.03	-0.02	-0.01	-0.01
0	381.24	391.14	2.49	1.61	0.59	391.18	2.47	1.60	0.59	0.04	-0.02	-0.01	0.00
20	381.14	391.26	1.40	0.61	0.62	391.30	1.36	0.59	0.74	0.04	-0.04	-0.02	0.12
60	380.94	391.26	1.27	0.69	0.69	391.29	1.31	0.71	0.90	0.03	0.04	0.02	0.21
119	380.87	391.26	1.02	0.53	0.79	391.27	1.19	0.62	1.12	0.01	0.17	0.09	0.33
203	380.32	391.26	0.76	0.50	0.65	391.27	0.98	0.64	0.99	0.01	0.22	0.14	0.34
271	380.00	391.26	0.58	0.31	0.49	391.26	0.88	0.48	0.83	0.00	0.30	0.17	0.34
427	379.29	391.26	0.52	0.15	0.52	391.25	0.83	0.24	0.85	-0.01	0.31	0.09	0.33
478	379.05	391.24	0.59	0.18	0.62	391.23	0.83	0.26	0.89	-0.01	0.24	0.08	0.27
608	378.43	391.13	1.46	0.77	0.64	391.13	1.46	0.77	0.64	0.00	0.00	0.00	0.00
724	378.27	390.03	4.50			390.03	4.50			0.00	0.00	0.00	0.00
783	378.52	387.70	7.23			387.70	7.23			0.00	0.00	0.00	0.00
820	378.47	387.75	5.37			387.75	5.37			0.00	0.00	0.00	0.00
864	378.43	387.61	4.51	0.08	0.29	387.61	4.51	0.08	0.29	0.00	0.00	0.00	0.00
931	378.34	387.46	3.51	0.14	0.14	387.46	3.51	0.14	0.14	0.00	0.00	0.00	0.00
983	377.62	387.25	3.30	0.06	0.06	387.25	3.30	0.06	0.06	0.00	0.00	0.00	0.00
1088	377.52	387.00	3.21	0.81	2.69	387.00	3.21	0.81	2.69	0.00	0.00	0.00	0.00
1233	376.76	386.72	2.84	0.90	0.88	386.72	2.84	0.90	0.88	0.00	0.00	0.00	0.00
1338	376.51	385.12	5.10	0.80	0.56	385.12	5.10	0.80	0.56	0.00	0.00	0.00	0.00
1453	375.70	383.38	5.58	0.62	0.76	383.38	5.58	0.62	0.76	0.00	0.00	0.00	0.00
1760	374.83	381.88	5.09			381.88	5.09			0.00	0.00	0.00	0.00
2009	373.33	381.91	3.31	0.62	2.35	381.91	3.31	0.62	2.35	0.00	0.00	0.00	0.00
2195	372.24	381.20	3.98	0.55	0.34	381.20	3.98	0.55	0.34	0.00	0.00	0.00	0.00
2448	372.17	379.70	5.08			379.70	5.08			0.00	0.00	0.00	0.00

100 year ARI HEC-RAS Results

Cross Section	Min Ch El	Existing				Developed				Difference			
		W.S. Elev	Vel Chnl	Vel Left	Vel Right	W.S. Elev	Vel Chnl	Vel Left	Vel Right	W.S. Elev	Vel Chnl	Vel Left	Vel Right
	(m)	(m)	(m/s)	(m/s)	(m/s)	(m)	(m/s)	(m/s)	(m/s)	(m)	(m/s)	(m/s)	(m/s)
2659	370.41	380.22	1.62	0.27	0.30	380.22	1.62	0.27	0.30	0.00	0.00	0.00	0.00
2901	369.82	379.63	2.71	0.97	1.45	379.63	2.71	0.97	1.45	0.00	0.00	0.00	0.00
3269	368.68	378.46	2.27	0.55	1.43	378.46	2.27	0.55	1.43	0.00	0.00	0.00	0.00
3554	368.34	377.97	2.77	0.23	0.19	377.97	2.77	0.23	0.19	0.00	0.00	0.00	0.00
3891	367.98	376.95	4.16	1.24	1.55	376.95	4.16	1.24	1.55	0.00	0.00	0.00	0.00
4128	366.38	375.77	3.05	0.94	1.15	375.77	3.05	0.94	1.15	0.00	0.00	0.00	0.00
4359	365.88	372.69	5.46			372.69	5.46			0.00	0.00	0.00	0.00
4566	364.48	369.84	6.21			369.84	6.21			0.00	0.00	0.00	0.00

Note: [shaded box] Location of overburden dump

Extreme Event HEC-RAS Results

Cross Section	Min Ch El	Existing				Developed				Difference			
		W.S. Elev	Vel Chnl	Vel Left	Vel Right	W.S. Elev	Vel Chnl	Vel Left	Vel Right	W.S. Elev	Vel Chnl	Vel Left	Vel Right
	(m)	(m)	(m/s)	(m/s)	(m/s)	(m)	(m/s)	(m/s)	(m/s)	(m)	(m/s)	(m/s)	(m/s)
-1456	384.00	399.70	0.99	0.79	0.75	399.71	0.99	0.78	0.74	0.01	0.00	-0.01	-0.01
-1078	383.86	399.64	1.30	1.01	1.15	399.65	1.30	1.01	1.15	0.01	0.00	0.00	0.00
-608	382.21	399.57	1.34	0.34	1.27	399.59	1.34	0.34	1.26	0.02	0.00	0.00	-0.01
-332	381.95	399.53	1.57	1.33	1.15	399.54	1.57	1.33	1.14	0.01	0.00	0.00	-0.01
0	381.24	399.39	2.18	1.44	0.81	399.41	2.18	1.44	0.81	0.02	0.00	0.00	0.00
20	381.14	399.49	0.80	0.45	0.58	399.49	0.99	0.55	0.87	0.00	0.19	0.10	0.29
60	380.94	399.49	0.73	0.44	0.60	399.48	1.03	0.61	0.96	-0.01	0.30	0.17	0.36
119	380.87	399.49	0.55	0.38	0.61	399.47	0.92	0.63	1.13	-0.02	0.37	0.25	0.52
203	380.32	399.49	0.47	0.30	0.54	399.47	0.85	0.56	1.08	-0.02	0.38	0.26	0.54
271	380.00	399.50	0.44	0.25	0.46	399.47	0.86	0.48	0.97	-0.03	0.42	0.23	0.51
427	379.29	399.49	0.43	0.20	0.49	399.47	0.75	0.34	0.95	-0.02	0.32	0.14	0.46
478	379.05	399.48	0.53	0.17	0.67	399.46	0.77	0.25	1.01	-0.02	0.24	0.08	0.34
608	378.43	399.35	1.81	1.10	0.98	399.35	1.81	1.10	0.98	0.00	0.00	0.00	0.00
724	378.27	396.61	7.25	1.84	2.34	396.61	7.25	1.84	2.34	0.00	0.00	0.00	0.00
783	378.52	393.75	9.52	2.69	1.58	393.75	9.52	2.69	1.58	0.00	0.00	0.00	0.00
820	378.47	392.75	8.71	1.00	1.79	390.43	11.14	0.69	0.63	-2.32	2.43	-0.31	-1.16
864	378.43	392.34	8.24	0.71	2.23	392.34	8.24	0.71	2.23	0.00	0.00	0.00	0.00
931	378.34	393.12	5.48	1.67	1.78	393.12	5.48	1.67	1.78	0.00	0.00	0.00	0.00
983	377.62	393.03	5.05	1.64	1.72	393.03	5.05	1.64	1.72	0.00	0.00	0.00	0.00
1088	377.52	393.18	3.84	1.27	3.84	393.18	3.84	1.27	3.84	0.00	0.00	0.00	0.00
1233	376.76	393.36	2.50	1.72	1.48	393.36	2.50	1.72	1.48	0.00	0.00	0.00	0.00
1338	376.51	391.28	6.31	2.62	1.82	391.28	6.31	2.62	1.82	0.00	0.00	0.00	0.00
1453	375.70	387.50	9.35	2.23	2.70	387.50	9.35	2.23	2.70	0.00	0.00	0.00	0.00
1760	374.83	385.47	7.96	0.90	1.40	384.36	9.51	0.83	1.13	-1.11	1.55	-0.07	-0.27
2009	373.33	386.29	4.83	1.18	4.11	386.29	4.83	1.18	4.11	0.00	0.00	0.00	0.00
2195	372.24	384.78	6.60	2.09	1.13	384.78	6.60	2.09	1.13	0.00	0.00	0.00	0.00
2448	372.17	382.98	7.74	2.41	1.34	382.98	7.74	2.41	1.34	0.00	0.00	0.00	0.00

Extreme Event HEC-RAS Results

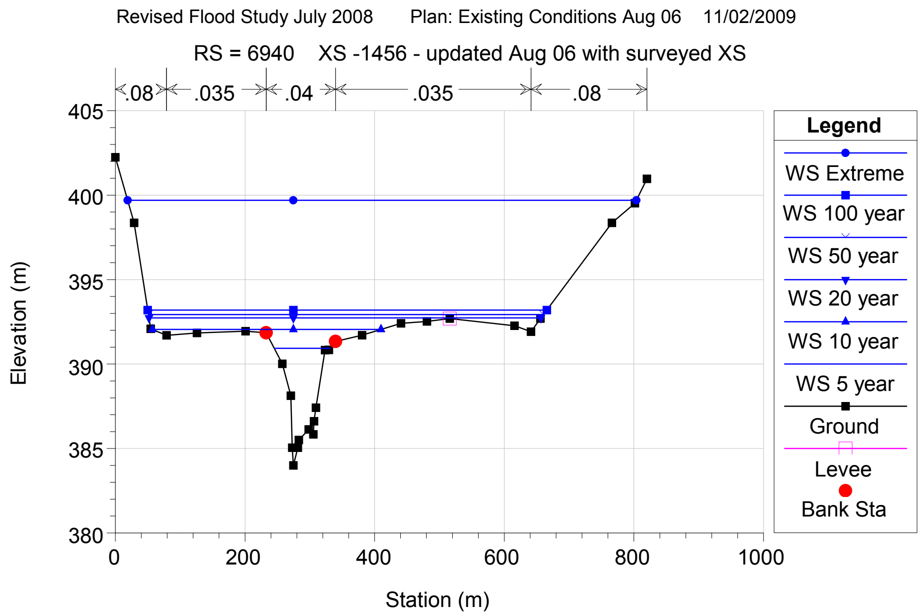
Cross Section	Min Ch El	Existing				Developed				Difference			
		W.S. Elev	Vel Chnl	Vel Left	Vel Right	W.S. Elev	Vel Chnl	Vel Left	Vel Right	W.S. Elev	Vel Chnl	Vel Left	Vel Right
	(m)	(m)	(m/s)	(m/s)	(m/s)	(m)	(m/s)	(m/s)	(m/s)	(m)	(m/s)	(m/s)	(m/s)
2659	370.41	383.96	2.91	0.92	1.06	383.96	2.91	0.92	1.06	0.00	0.00	0.00	0.00
2901	369.82	383.59	2.80	1.85	2.11	383.59	2.80	1.85	2.11	0.00	0.00	0.00	0.00
3269	368.68	383.50	1.37	0.59	1.92	383.50	1.37	0.59	1.92	0.00	0.00	0.00	0.00
3554	368.34	382.79	3.80	1.92	1.54	382.79	3.80	1.92	1.54	0.00	0.00	0.00	0.00
3891	367.98	382.15	4.90	2.51	2.58	382.15	4.90	2.51	2.58	0.00	0.00	0.00	0.00
4128	366.38	381.56	3.63	0.96	2.39	381.56	3.63	0.96	2.39	0.00	0.00	0.00	0.00
4359	365.88	377.52	7.57	1.95	0.25	377.52	7.57	1.95	0.25	0.00	0.00	0.00	0.00
4566	364.48	374.10	8.57	1.24	1.00	373.90	8.80	1.22	0.98	-0.20	0.23	-0.02	-0.02

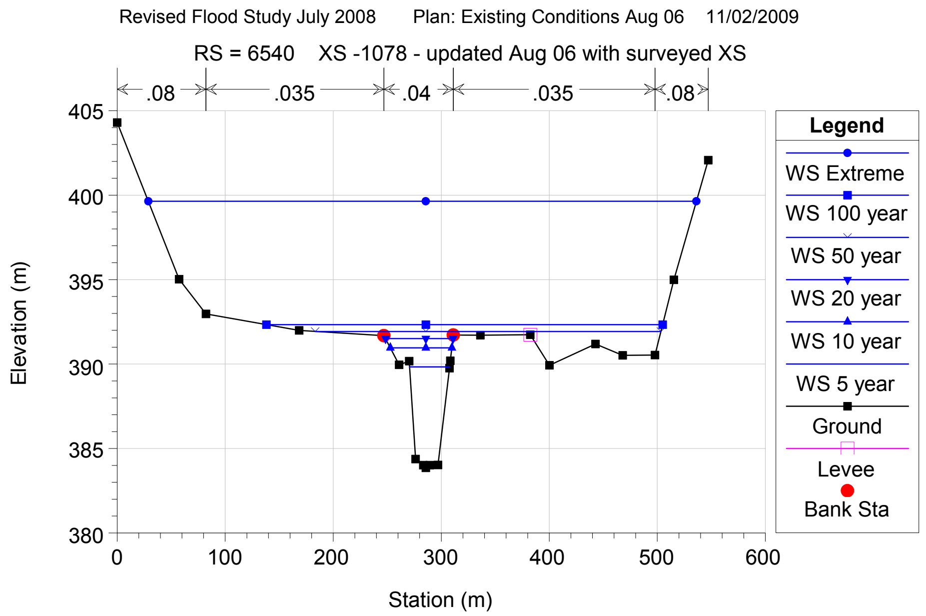
Note: Location of overburden dump

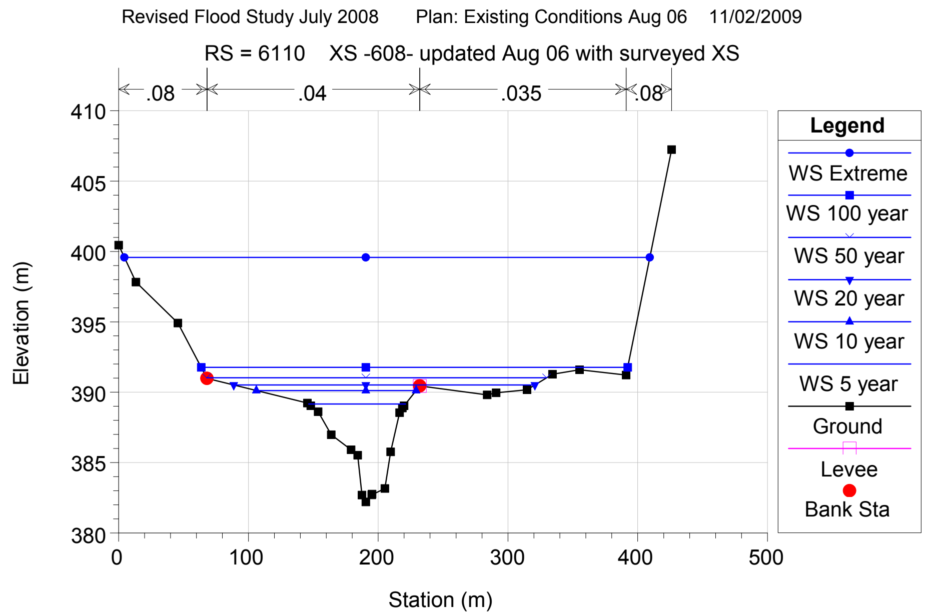
ANNEXURE 20A-2

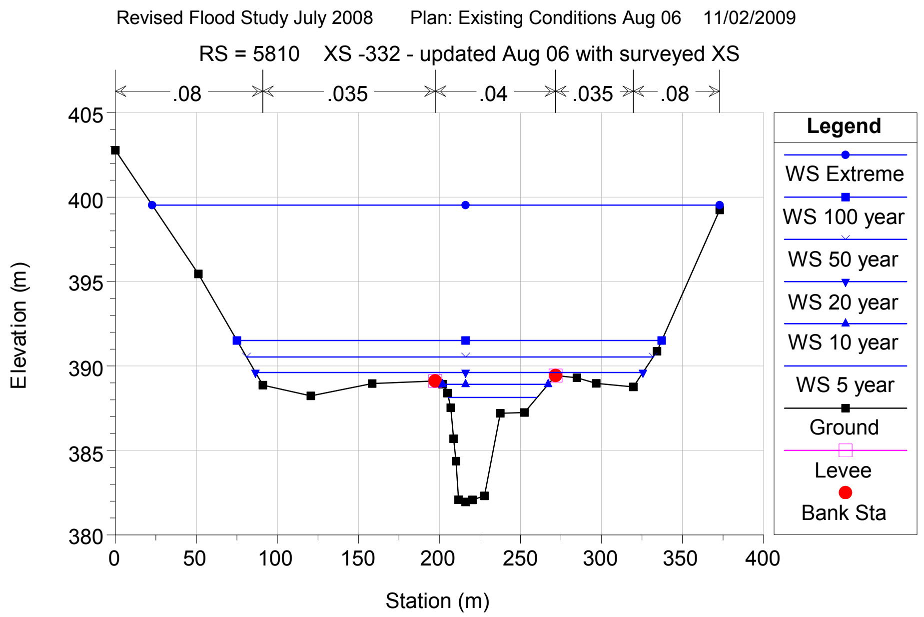
HYDRAULIC ANALYSIS RESULTS

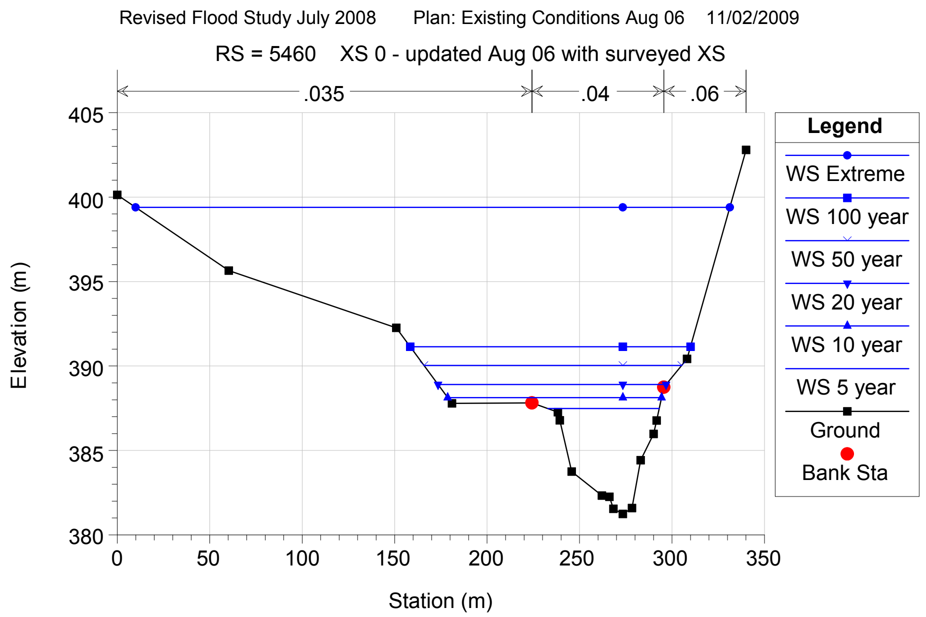
HEC-RAS Cross-Sections - Existing Conditions

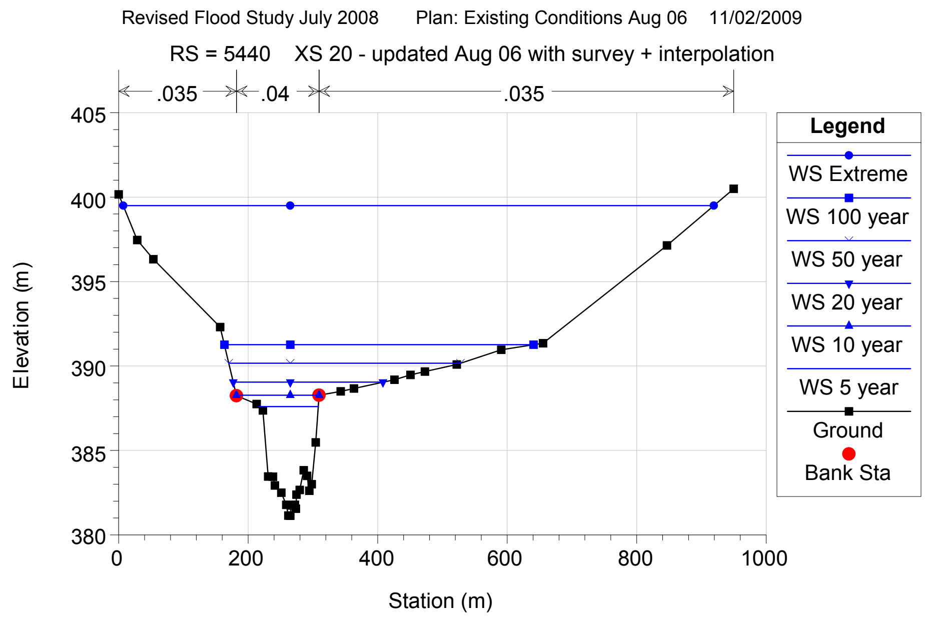

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 6940 XS -1456 - updated Aug 06 with surveyed XS
.08 .035 .04 .035 .08
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Levee
Bank Sta

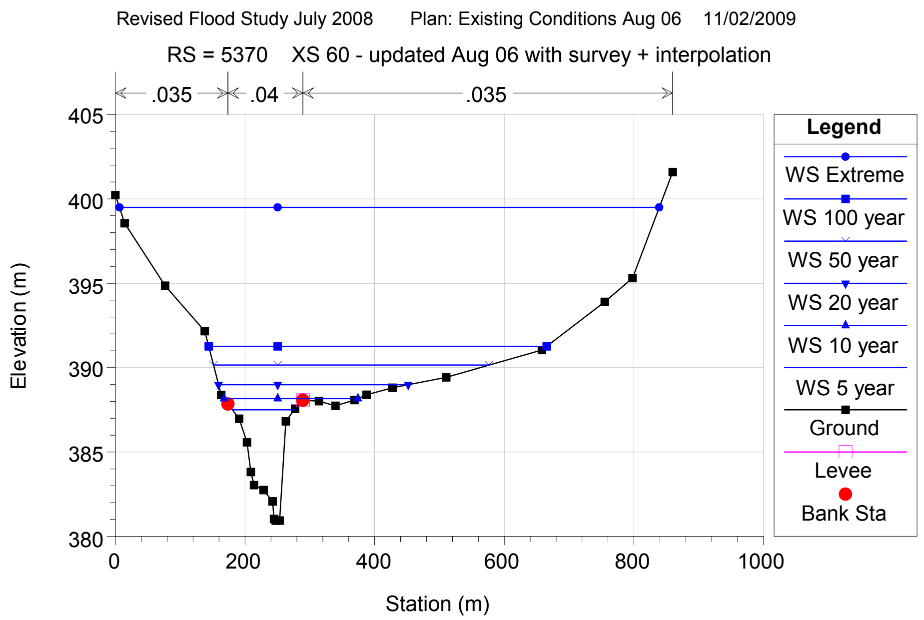

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 6540 XS -1078 - updated Aug 06 with surveyed XS
.08 .035 .04 .035 .08
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Levee
Bank Sta

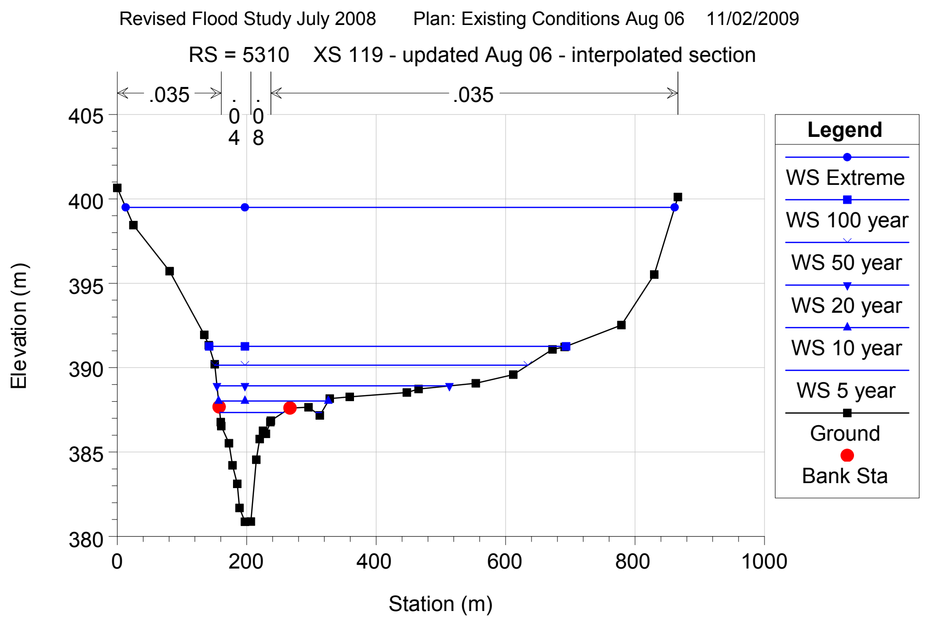

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 6110 XS -608- updated Aug 06 with surveyed XS
.08 .04 .035 .08
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Levee
Bank Sta

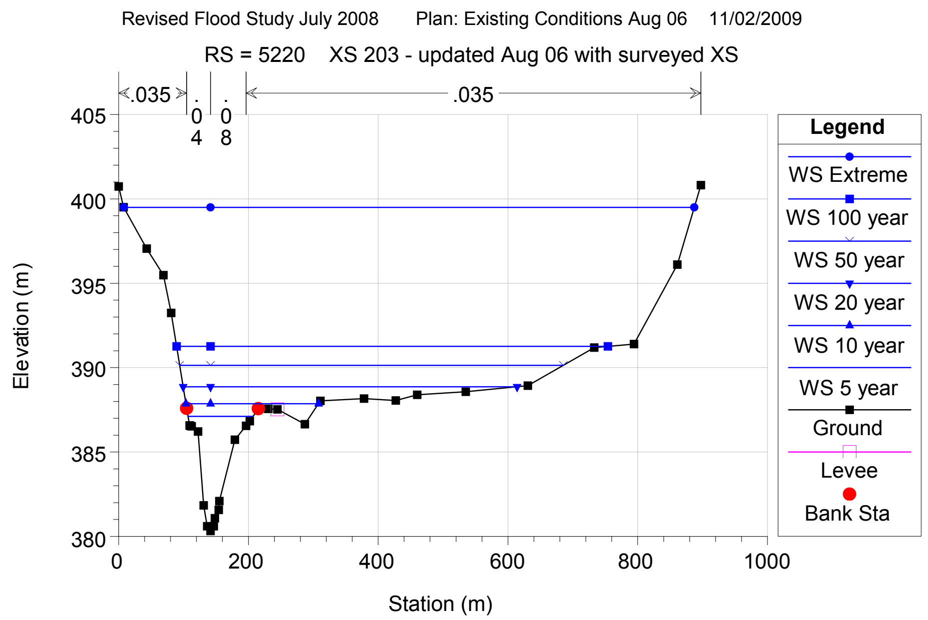

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 5810 XS -332 - updated Aug 06 with surveyed XS
.08 .035 .04 .035 .08
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Levee
Bank Sta

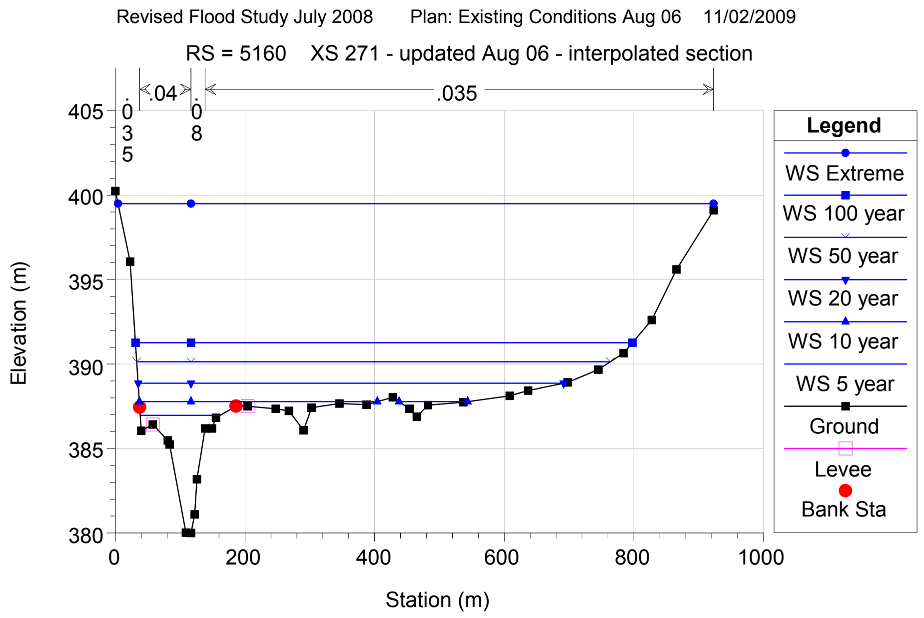

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 5460 XS 0 - updated Aug 06 with surveyed XS
.035 .04 .06
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Bank Sta

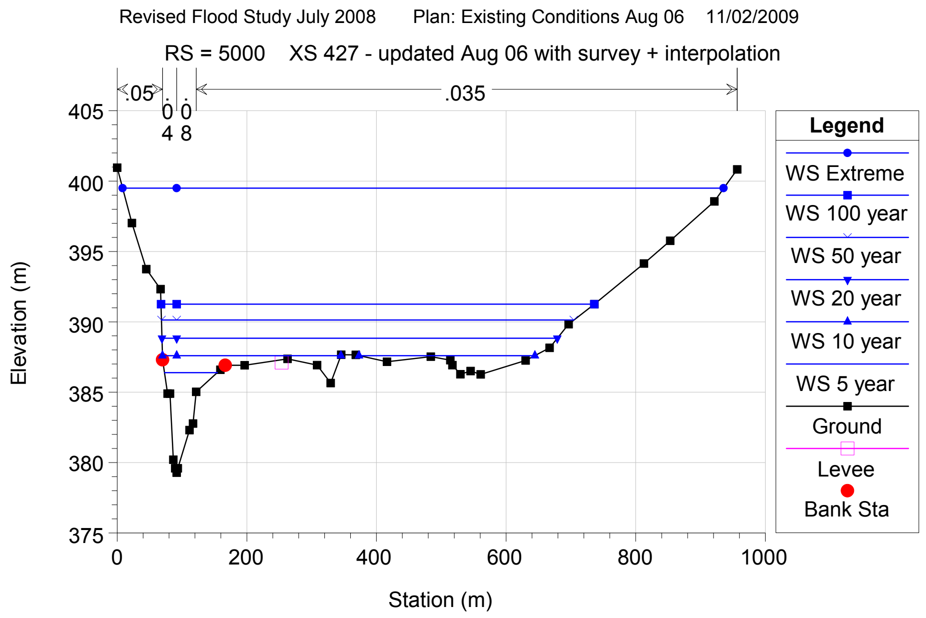

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 5440 XS 20 - updated Aug 06 with survey + interpolation
.035 .04 .035
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Bank Sta

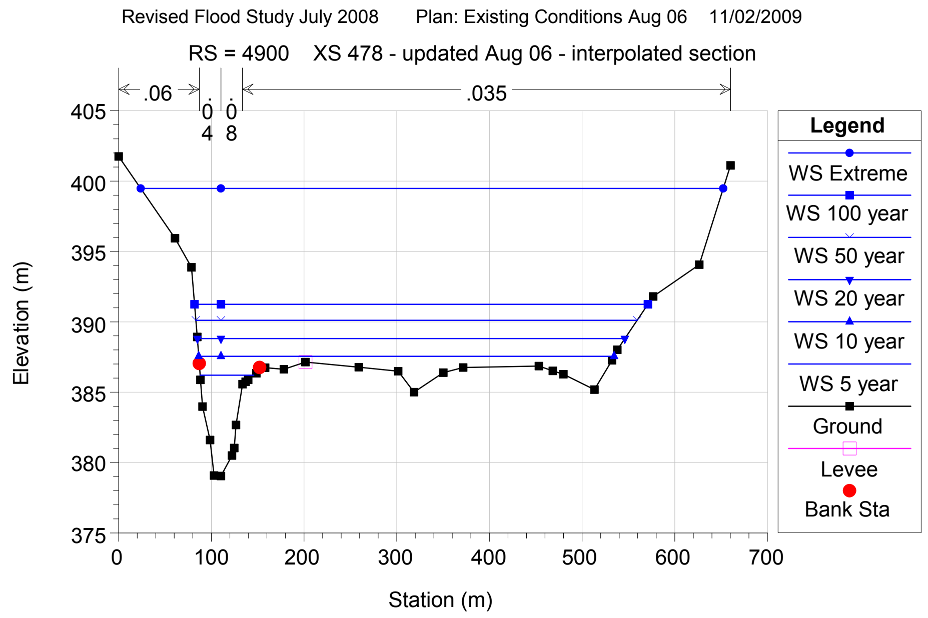

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 5370 XS 60 - updated Aug 06 with survey + interpolation
.035 .04 .035
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Levee
Bank Sta

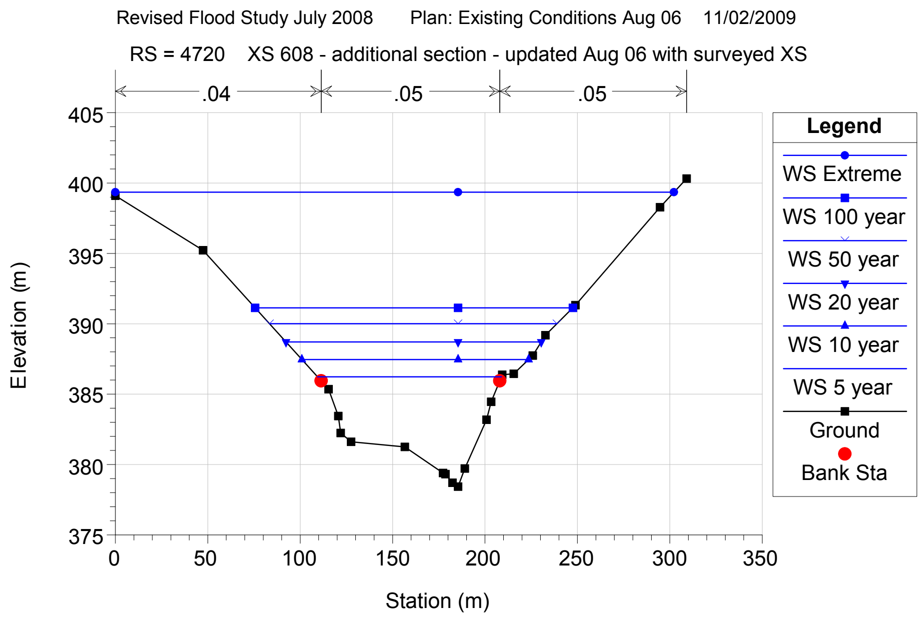

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 5310 XS 119 - updated Aug 06 - interpolated section
.035 .04 .08 .035
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Bank Sta

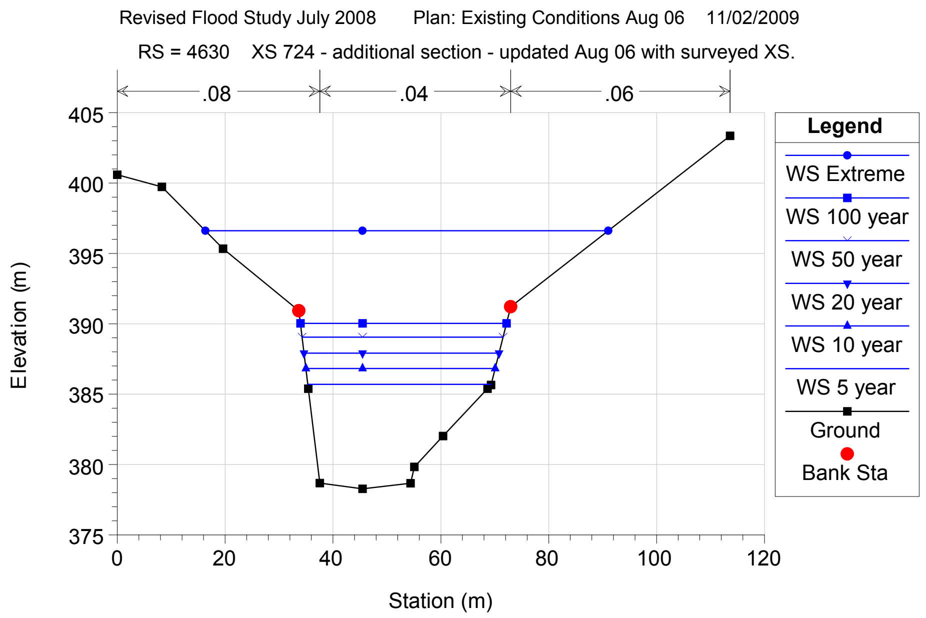

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 5220 XS 203 - updated Aug 06 with surveyed XS
.035 .04 .08 .035
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Levee
Bank Sta

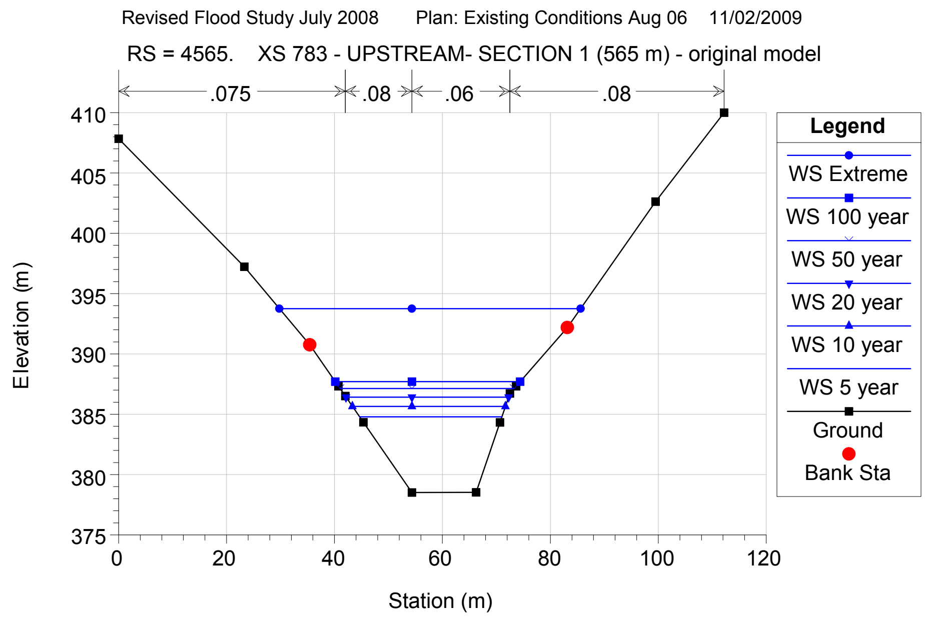

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 5160 XS 271 - updated Aug 06 - interpolated section
.04
.035
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Levee
Bank Sta

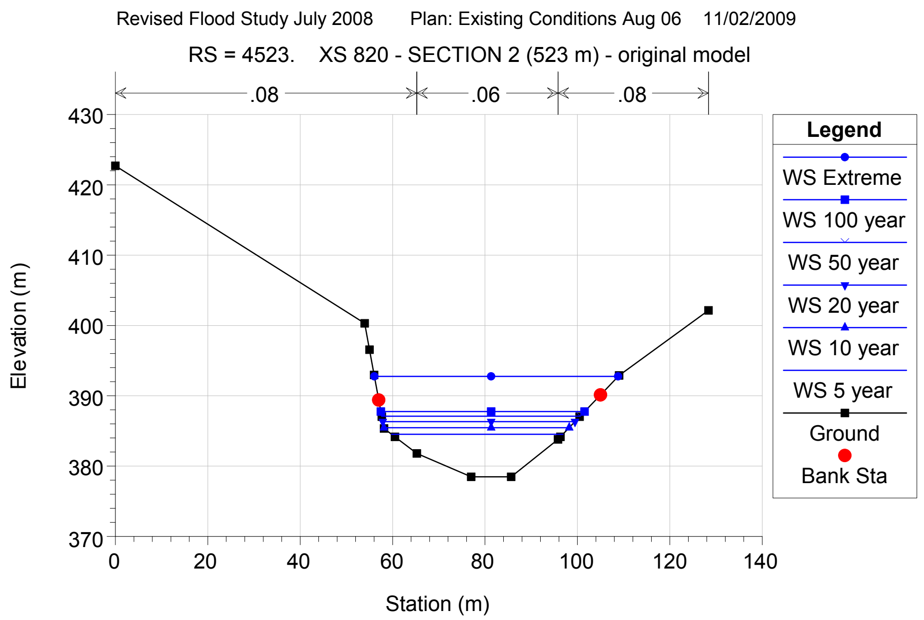

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 5000 XS 427 - updated Aug 06 with survey + interpolation
.05
.035
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Levee
Bank Sta

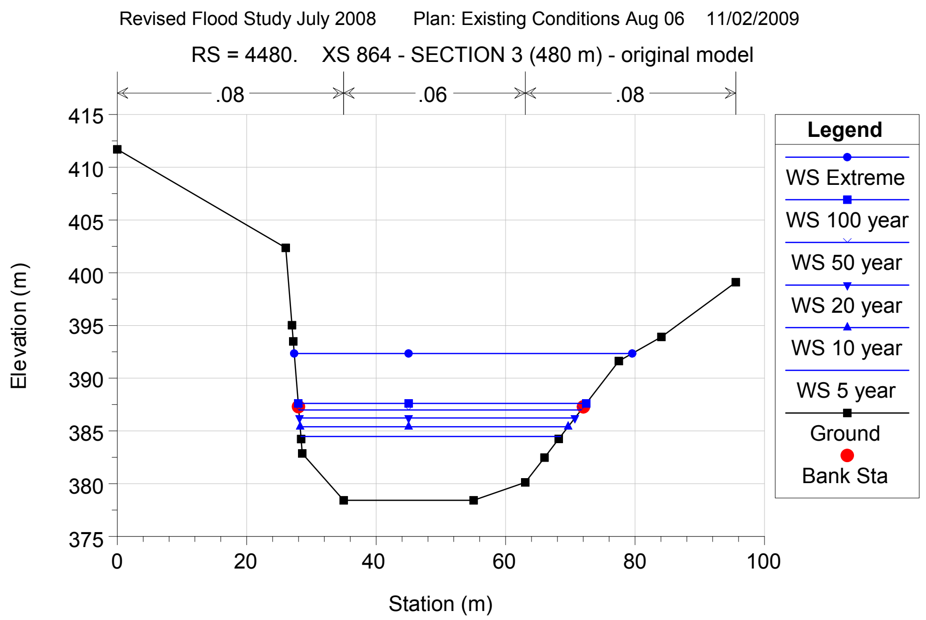

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 4900 XS 478 - updated Aug 06 - interpolated section
.06
.035
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Levee
Bank Sta

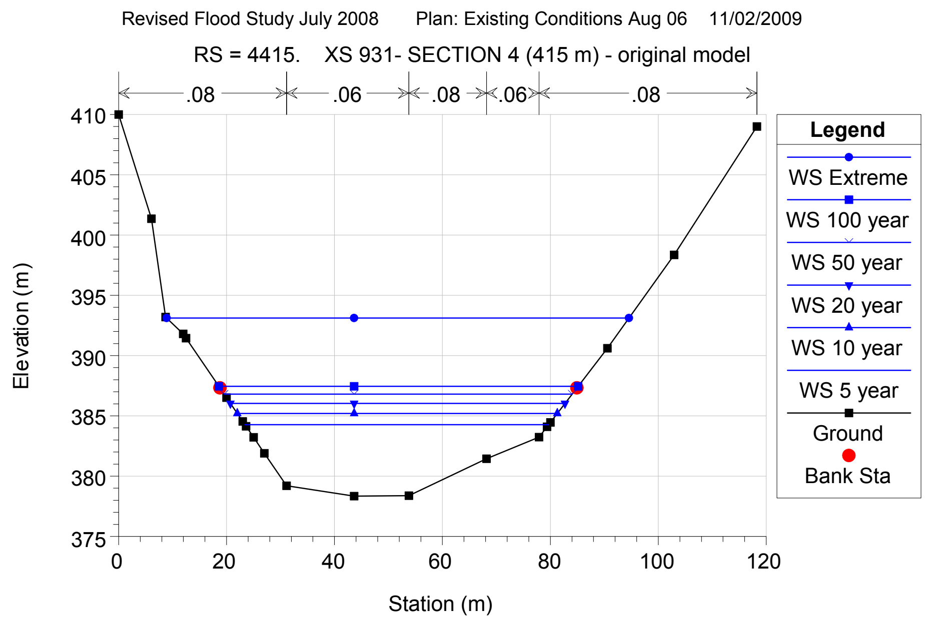

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 4720 XS 608 - additional section - updated Aug 06 with surveyed XS
.04
.05
.05
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Bank Sta

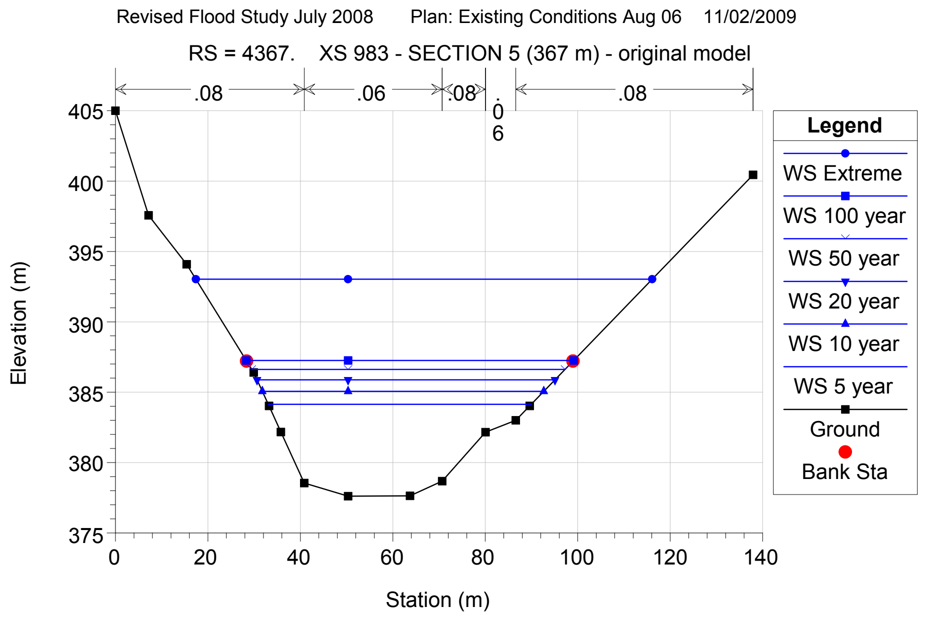
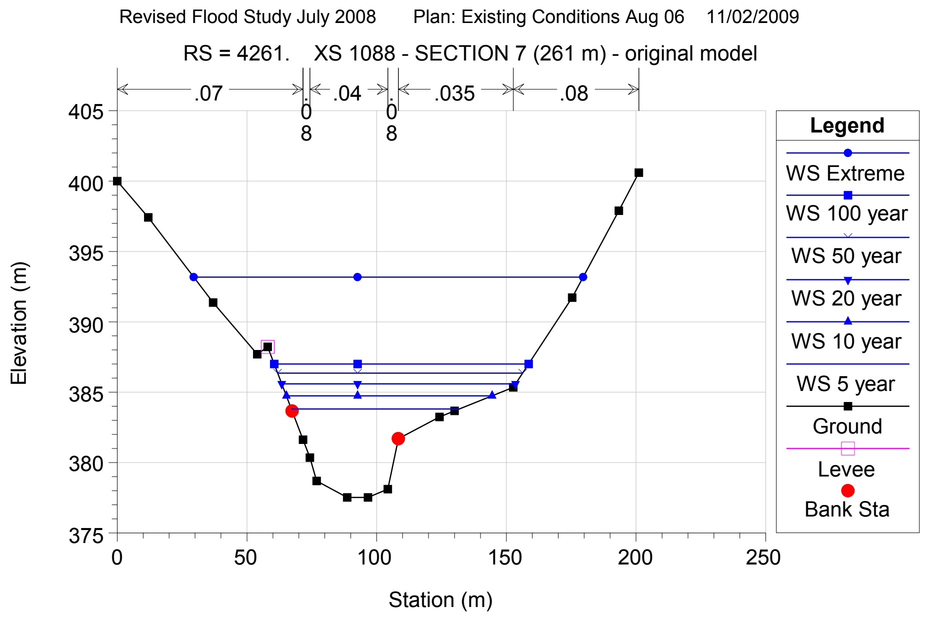
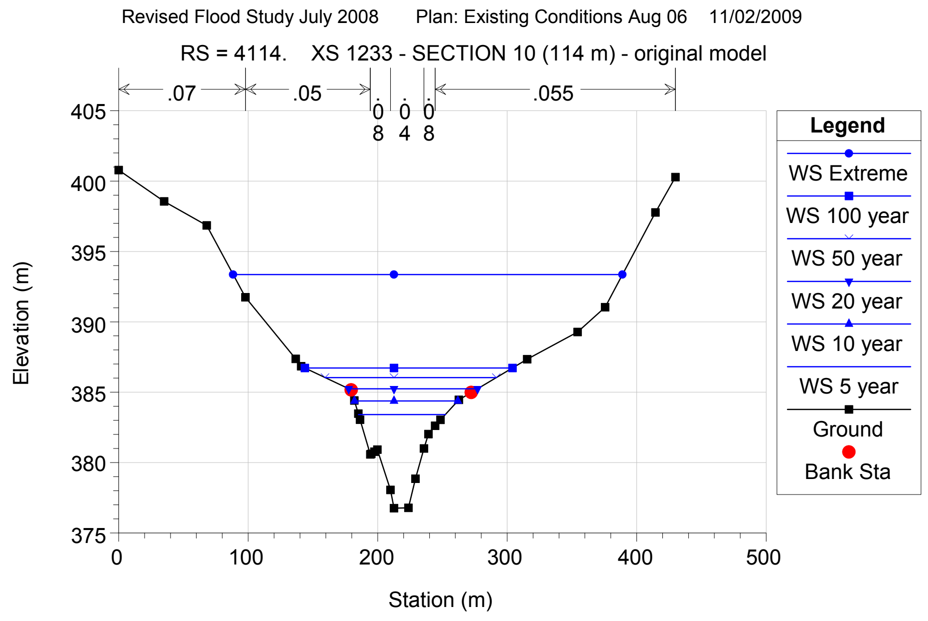
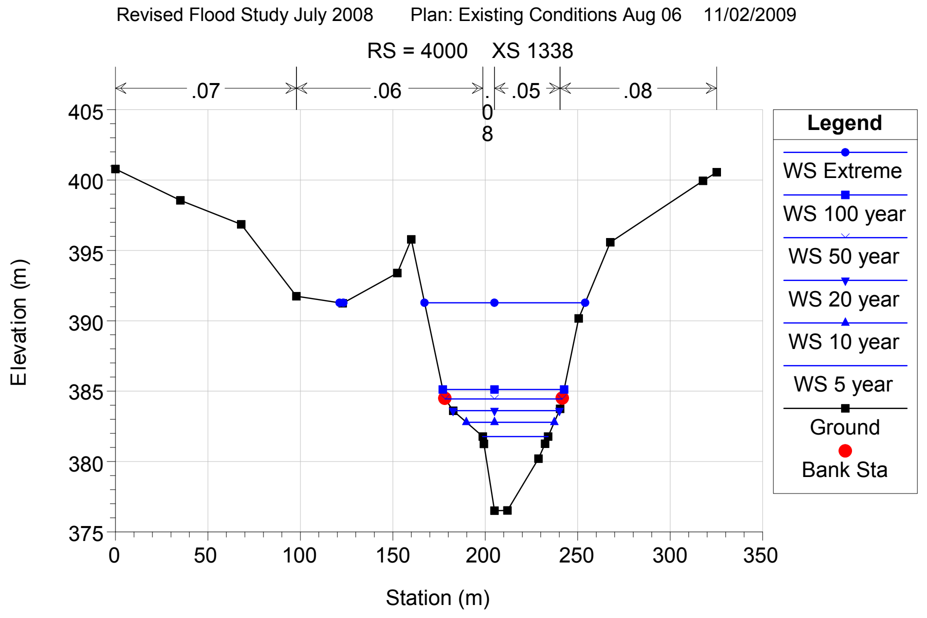
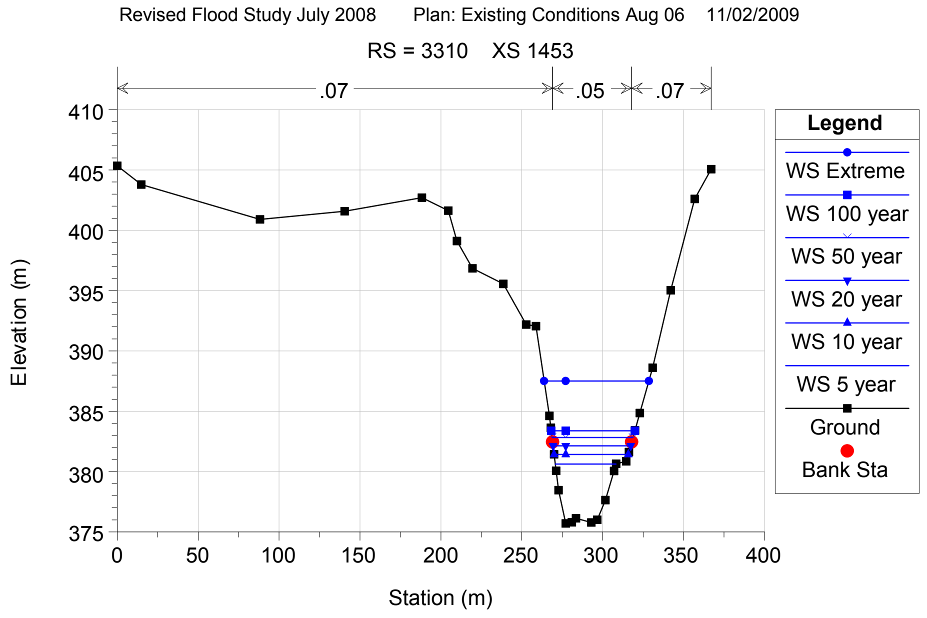
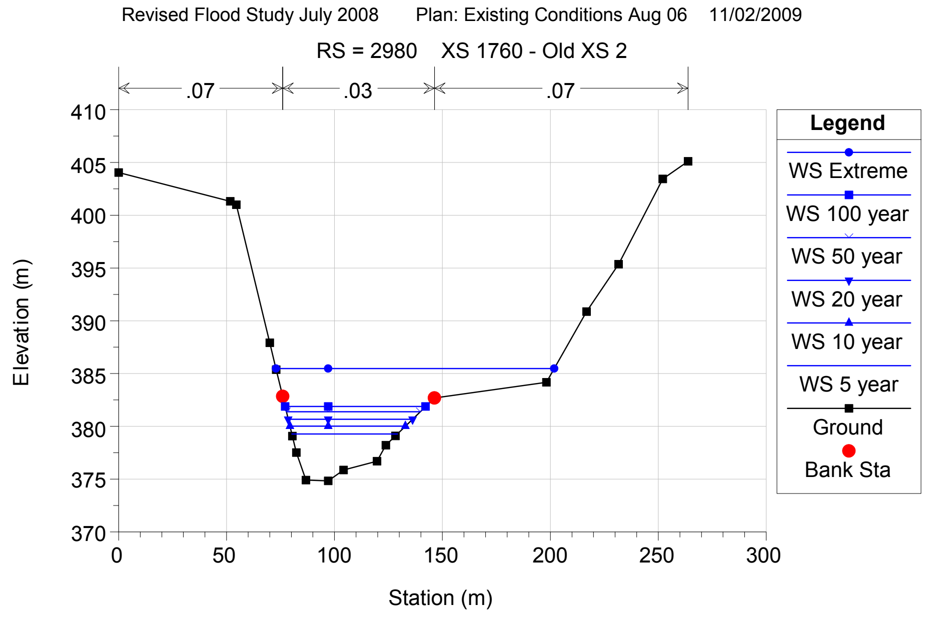
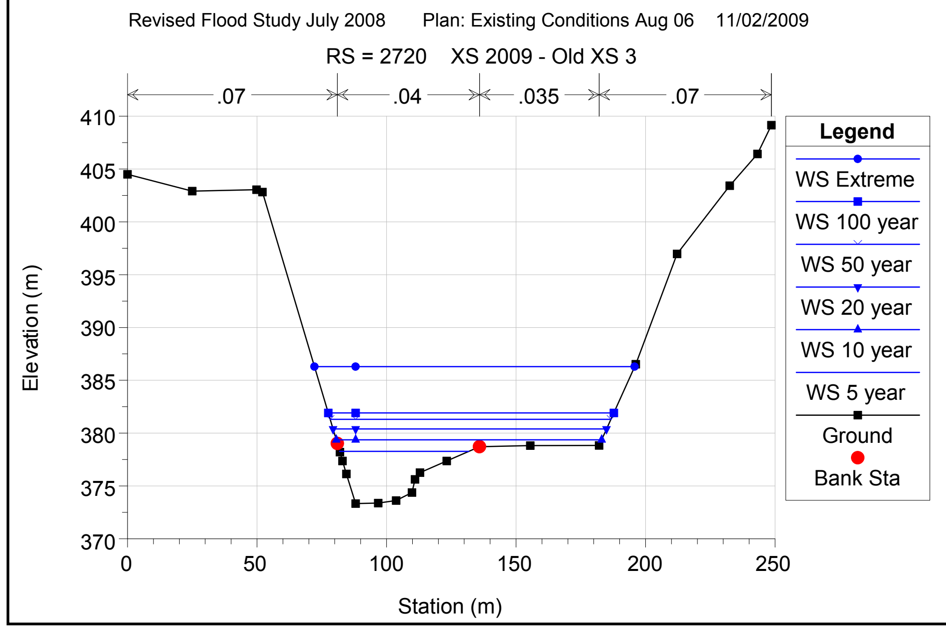
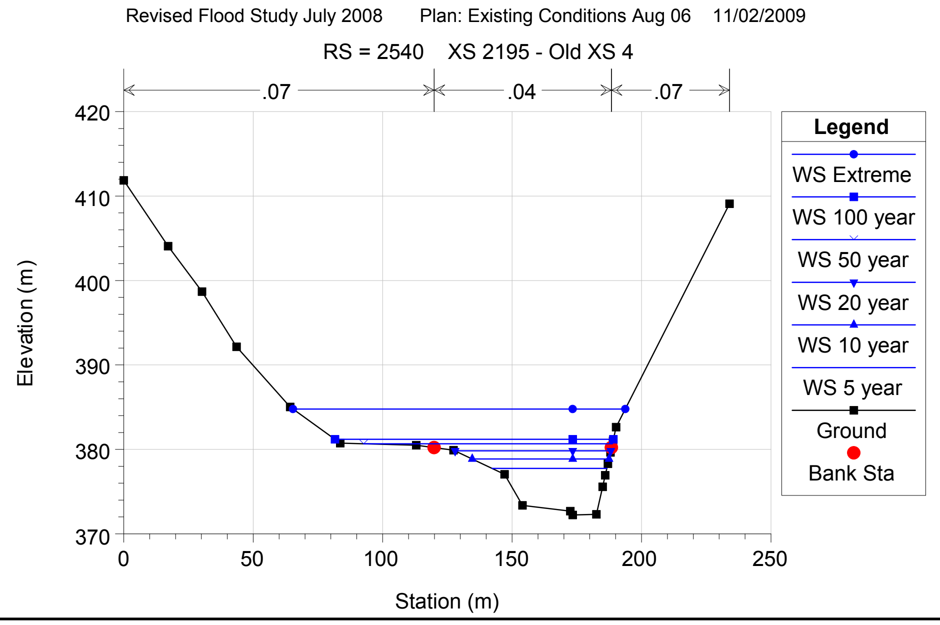
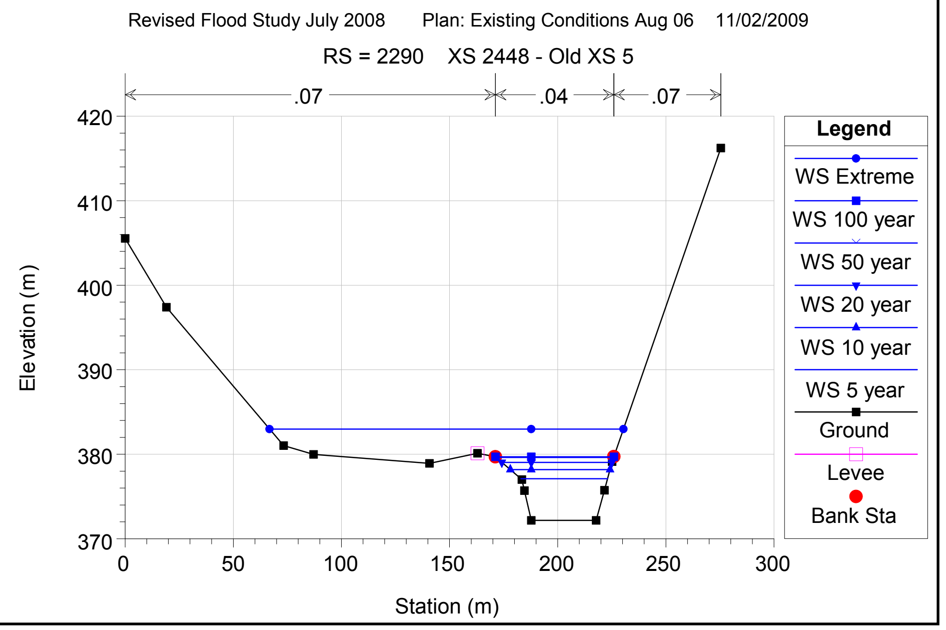

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 4630 XS 724 - additional section - updated Aug 06 with surveyed XS.
.08
.04
.06
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Bank Sta

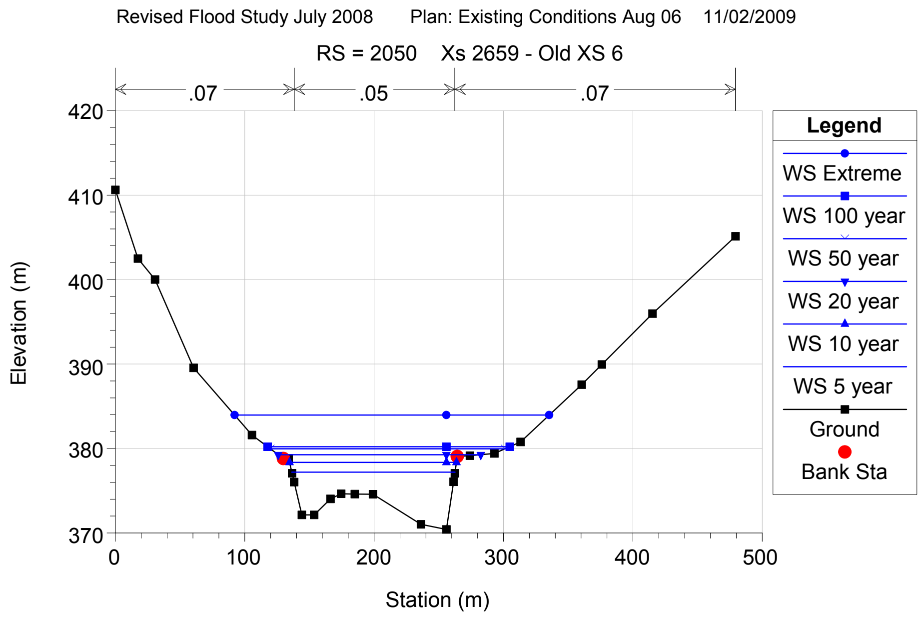

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 4565. XS 783 - UPSTREAM- SECTION 1 (565 m) - original model
.075
.08
.06
.08
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Bank Sta

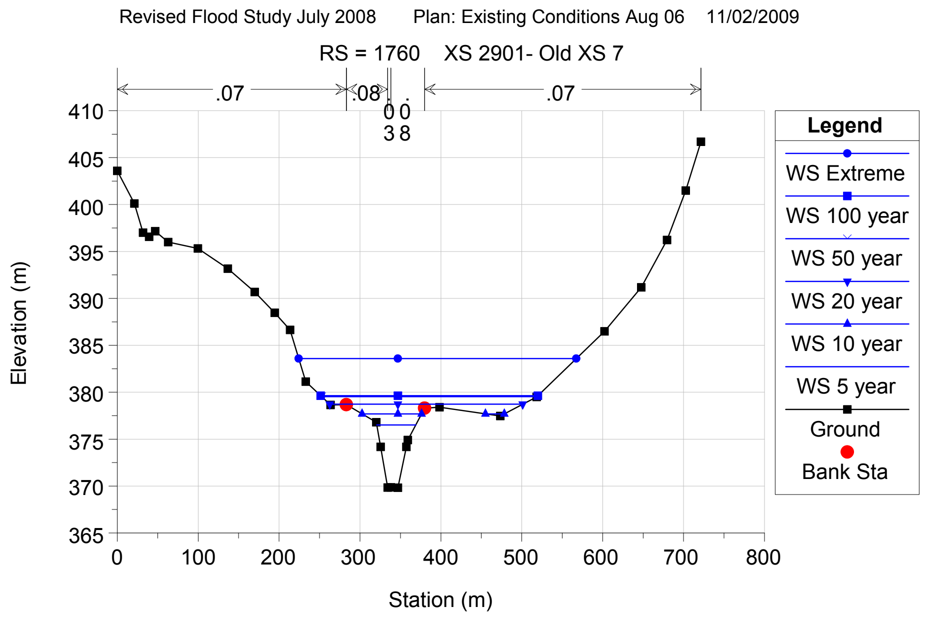

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 4523. XS 820 - SECTION 2 (523 m) - original model
.08
.06
.08
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Bank Sta

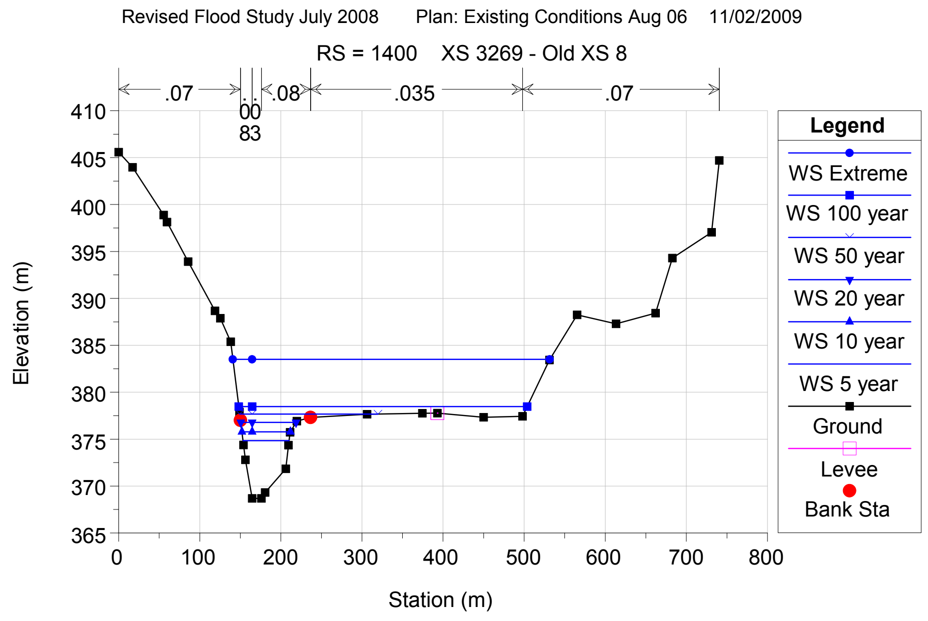

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 4480. XS 864 - SECTION 3 (480 m) - original model
.08
.06
.08
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Bank Sta

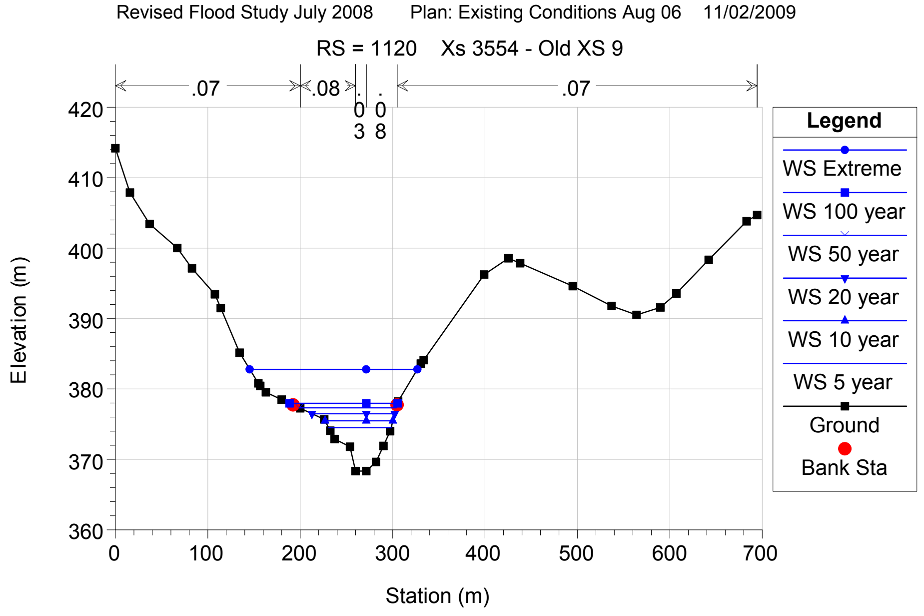

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 4415. XS 931- SECTION 4 (415 m) - original model
.08
.06
.08
.06
.08
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Bank Sta

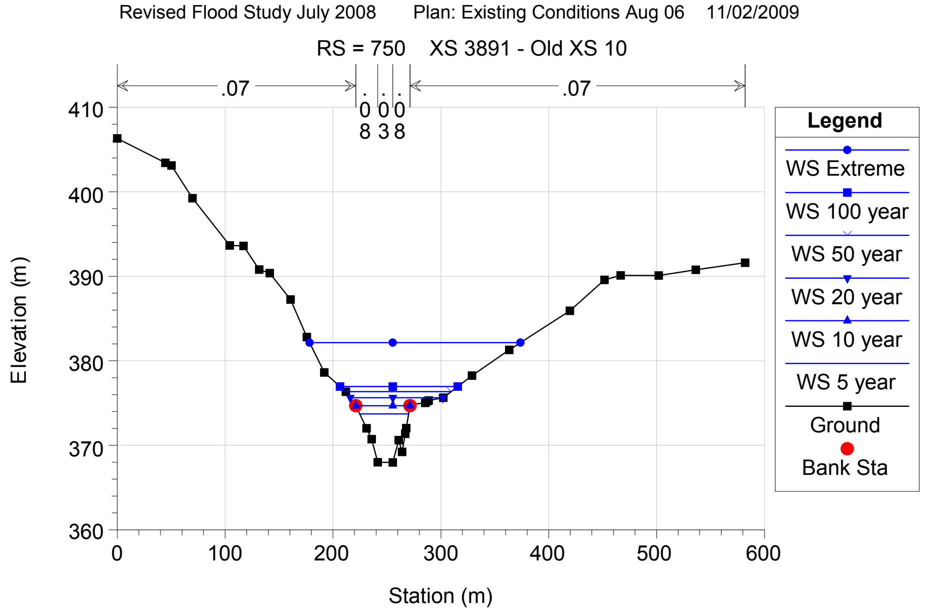

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 4367. XS 983 - SECTION 5 (367 m) - original model
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Bank Sta
Elevation (m)
Station (m)

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 4261. XS 1088 - SECTION 7 (261 m) - original model
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Levee
Bank Sta
Elevation (m)
Station (m)

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 4114. XS 1233 - SECTION 10 (114 m) - original model
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Bank Sta
Elevation (m)
Station (m)

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 4000 XS 1338
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Bank Sta
Elevation (m)
Station (m)

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 3310 XS 1453
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Bank Sta
Elevation (m)
Station (m)

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 2980 XS 1760 - Old XS 2
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Bank Sta
Elevation (m)
Station (m)

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 2720 XS 2009 - Old XS 3
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Bank Sta
Elevation (m)
Station (m)

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 2540 XS 2195 - Old XS 4
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Bank Sta
Elevation (m)
Station (m)

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 2290 XS 2448 - Old XS 5
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Levee
Bank Sta
Elevation (m)
Station (m)

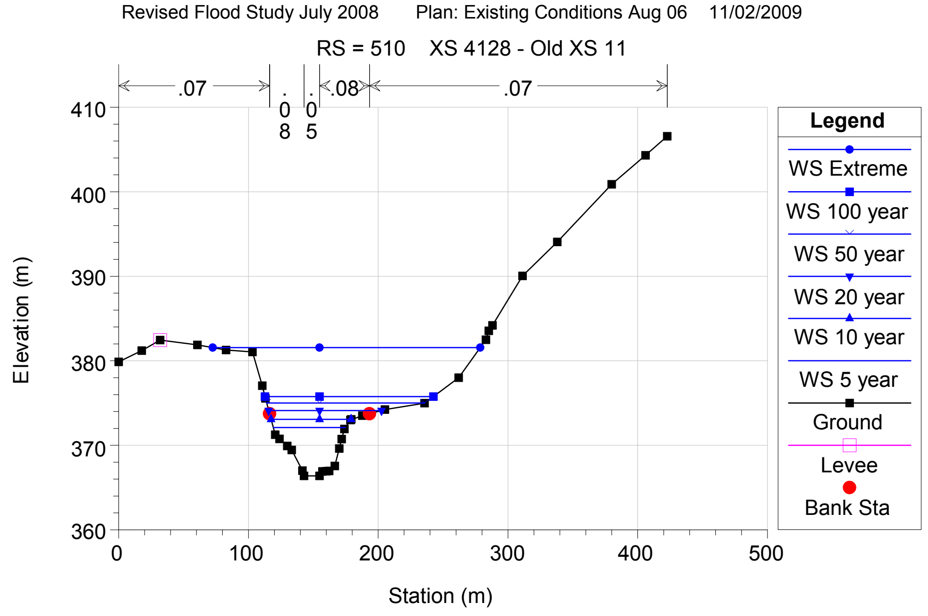

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 2050 Xs 2659 - Old XS 6
.07 .05 .07
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Bank Sta

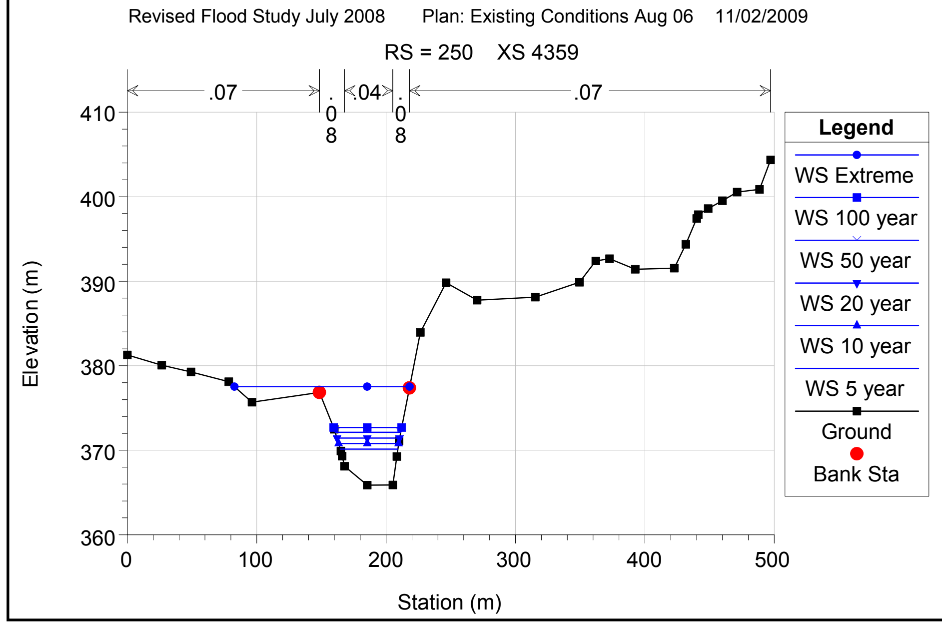

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 1760 XS 2901- Old XS 7
.07 .08 .07
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Bank Sta

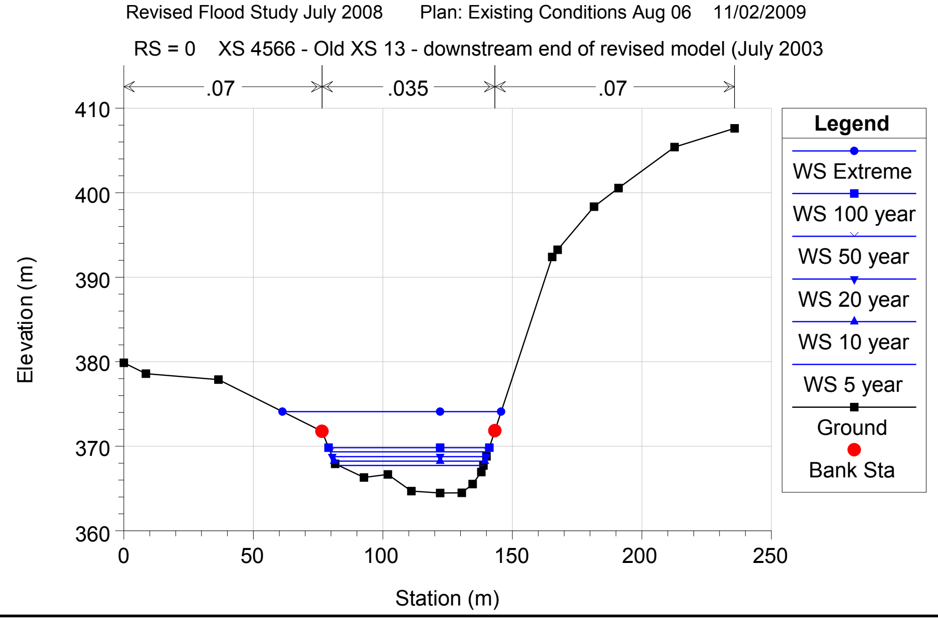

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 1400 XS 3269 - Old XS 8
.07 .08 .035 .07
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Levee
Bank Sta


Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 1120 Xs 3554 - Old XS 9
.07 .08 .07
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Bank Sta


Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 750 XS 3891 - Old XS 10
.07 .07
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Bank Sta


Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 510 XS 4128 - Old XS 11
.07 .08 .07
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Levee
Bank Sta


Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 250 XS 4359
.07 .04 .07
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Bank Sta

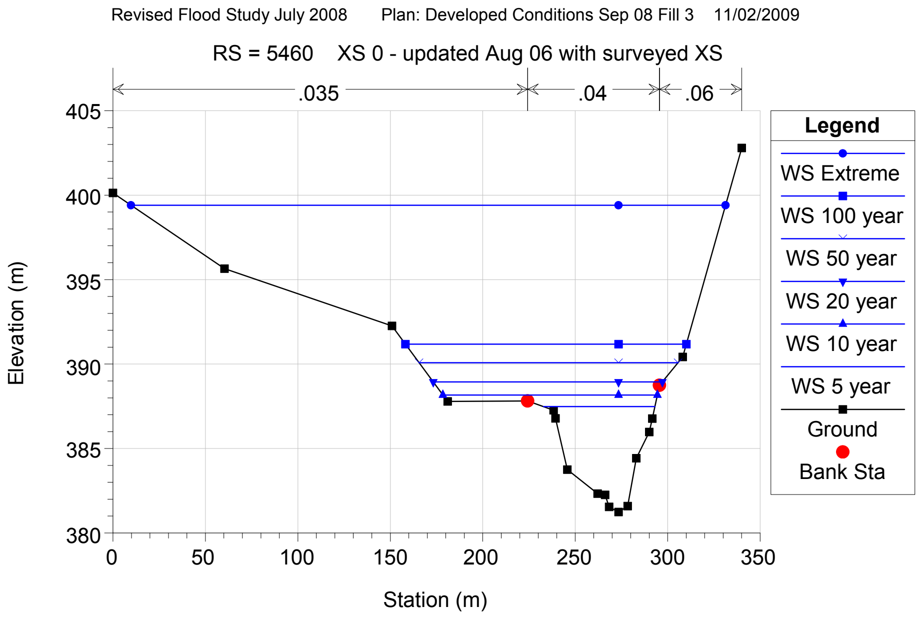

Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
RS = 0 XS 4566 - Old XS 13 - downstream end of revised model (July 2003
.07 .035 .07
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Bank Sta

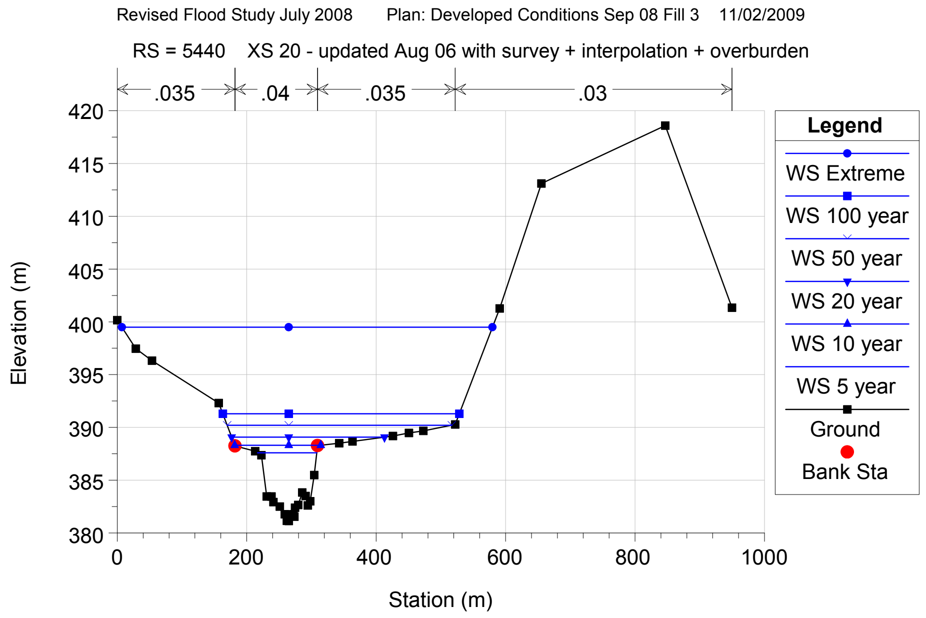
ANNEXURE 20A-3

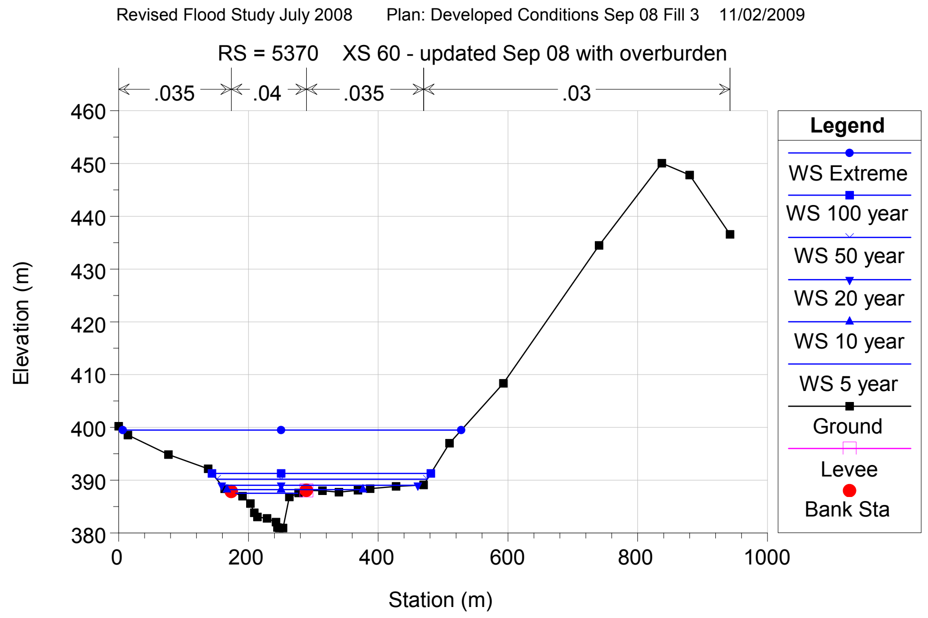
HYDRAULIC ANALYSIS RESULTS

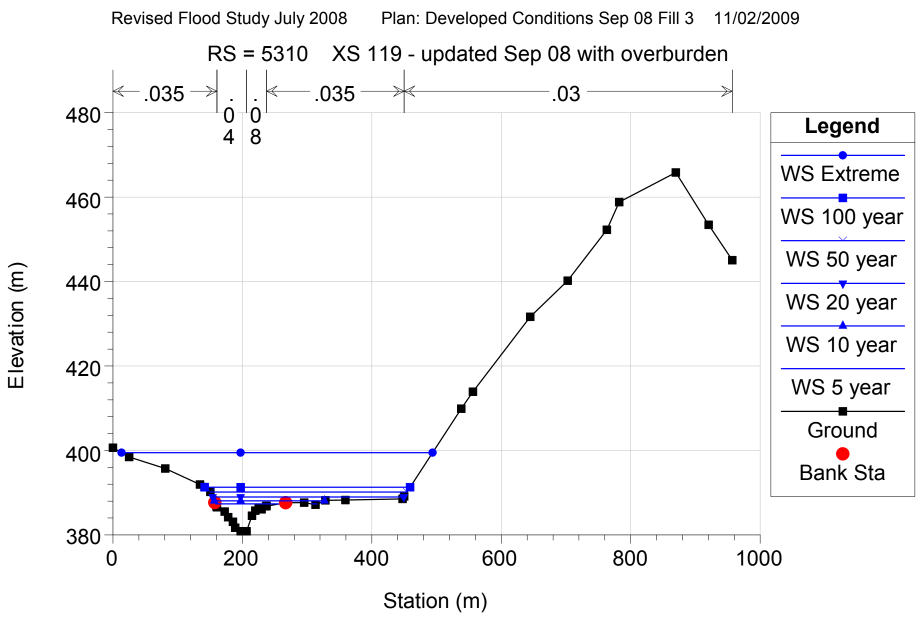
HEC-RAS Cross-Sections – Adjacent to Overburden Dump

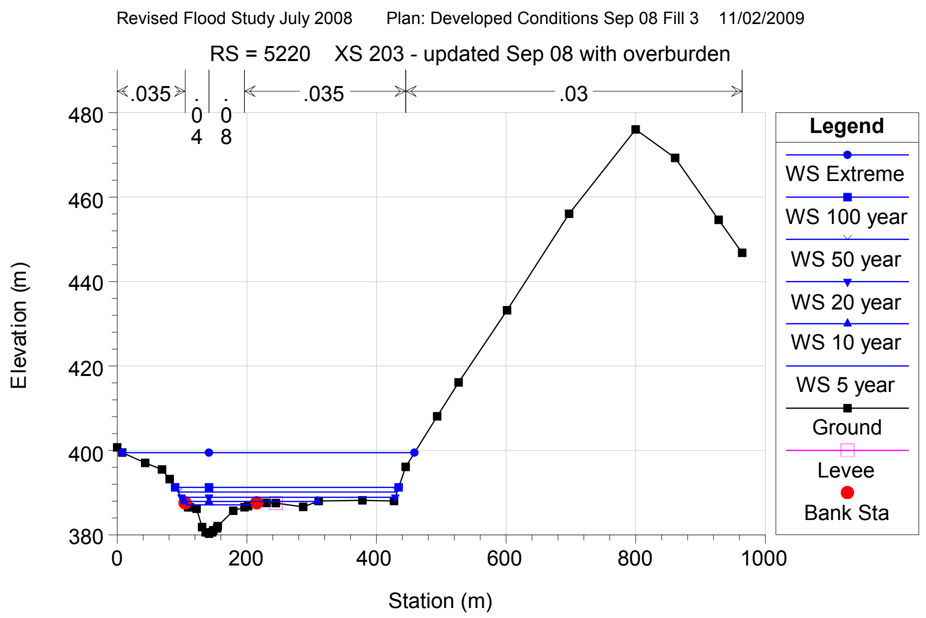
XS 0 to XS 608

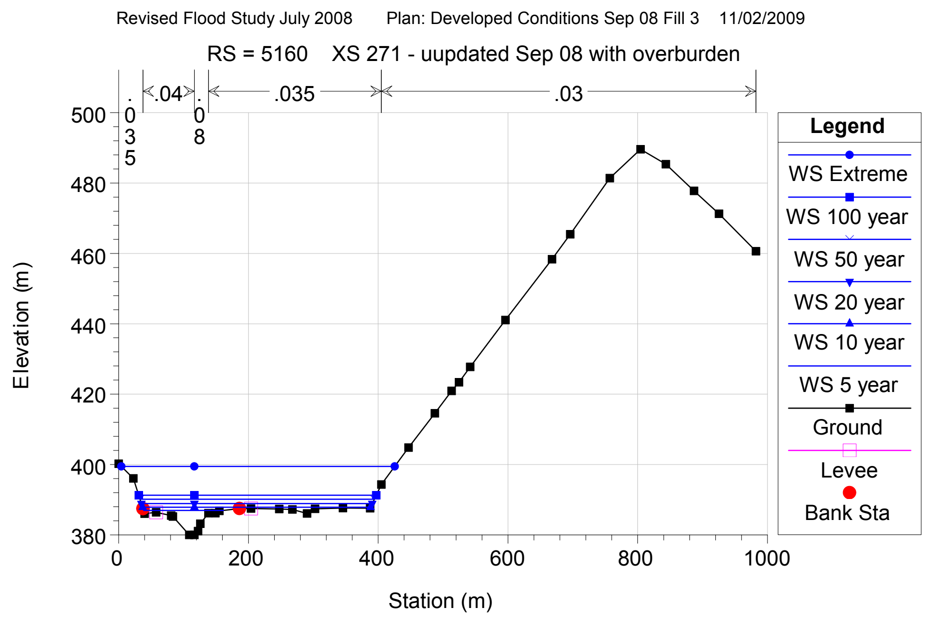

Revised Flood Study July 2008 Plan: Developed Conditions Sep 08 Fill 3 11/02/2009
RS = 5460 XS 0 - updated Aug 06 with surveyed XS
.035
.04
.06
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Bank Sta

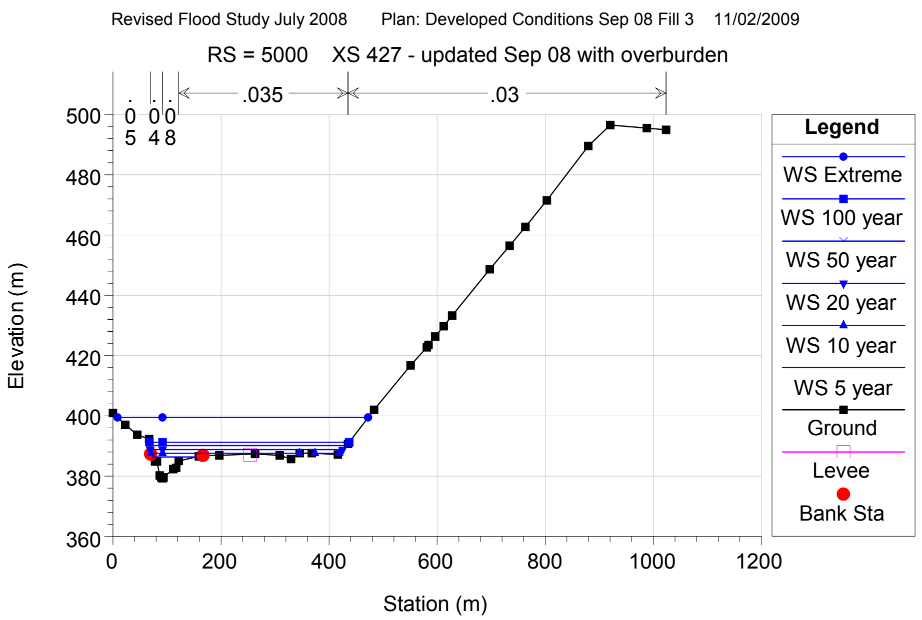

Revised Flood Study July 2008 Plan: Developed Conditions Sep 08 Fill 3 11/02/2009
RS = 5440 XS 20 - updated Aug 06 with survey + interpolation + overburden
.035
.04
.035
.03
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Bank Sta

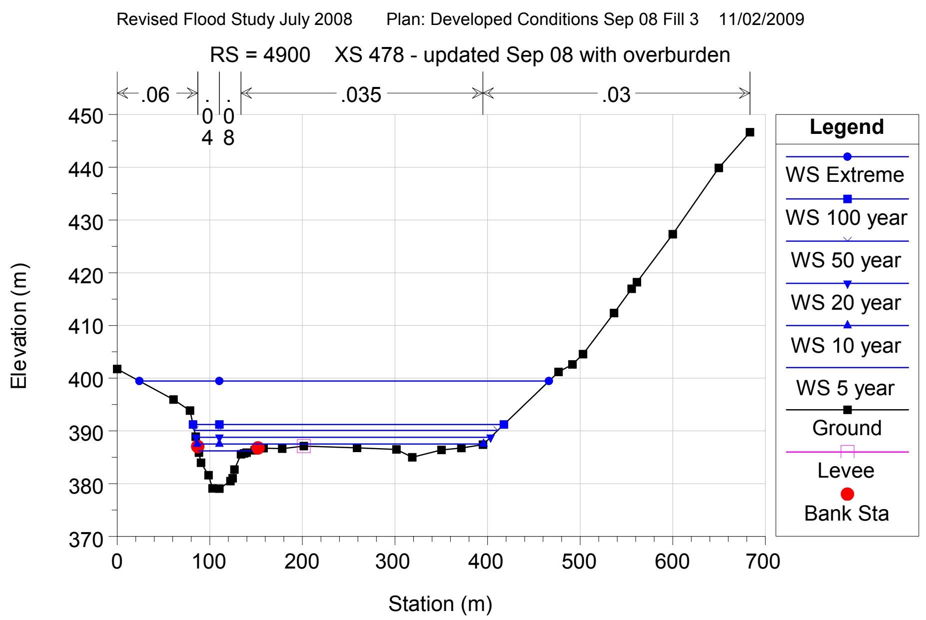

Revised Flood Study July 2008 Plan: Developed Conditions Sep 08 Fill 3 11/02/2009
RS = 5370 XS 60 - updated Sep 08 with overburden
.035
.04
.035
.03
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Levee
Bank Sta

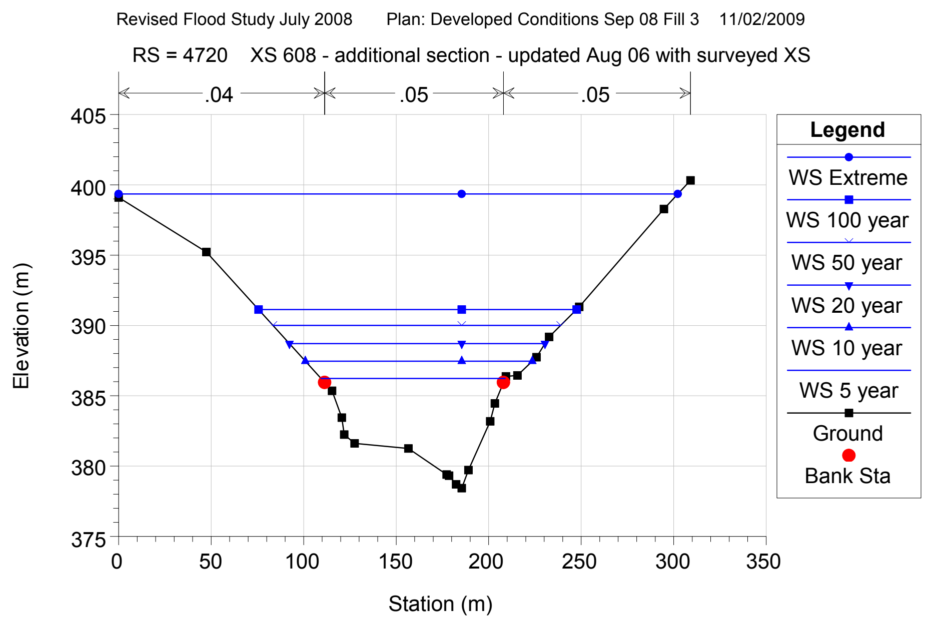

Revised Flood Study July 2008 Plan: Developed Conditions Sep 08 Fill 3 11/02/2009
RS = 5310 XS 119 - updated Sep 08 with overburden
.035
.035
.03
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Bank Sta


Revised Flood Study July 2008 Plan: Developed Conditions Sep 08 Fill 3 11/02/2009
RS = 5220 XS 203 - updated Sep 08 with overburden
.035
.035
.03
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Levee
Bank Sta


Revised Flood Study July 2008 Plan: Developed Conditions Sep 08 Fill 3 11/02/2009
RS = 5160 XS 271 - uupdated Sep 08 with overburden
.04
.035
.03
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Levee
Bank Sta


Revised Flood Study July 2008 Plan: Developed Conditions Sep 08 Fill 3 11/02/2009
RS = 5000 XS 427 - updated Sep 08 with overburden
.035
.03
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Levee
Bank Sta

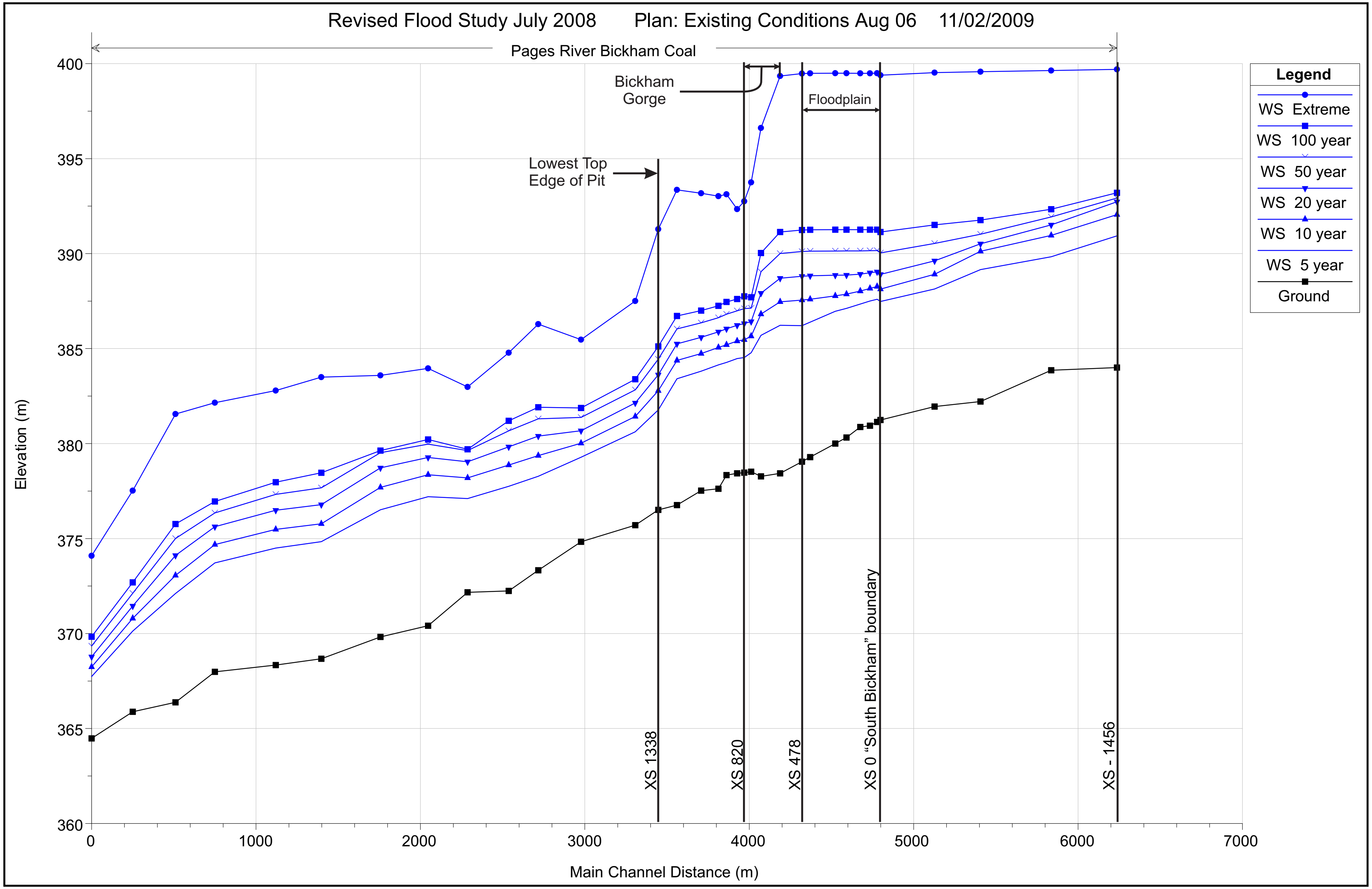

Revised Flood Study July 2008 Plan: Developed Conditions Sep 08 Fill 3 11/02/2009
RS = 4900 XS 478 - updated Sep 08 with overburden
.06
.035
.03
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Levee
Bank Sta


Revised Flood Study July 2008 Plan: Developed Conditions Sep 08 Fill 3 11/02/2009
RS = 4720 XS 608 - additional section - updated Aug 06 with surveyed XS
.04
.05
.05
Elevation (m)
Station (m)
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
Bank Sta

ANNEXURE 20A-4

HYDRAULIC ANALYSIS RESULTS

HEC-RAS Longitudinal Profiles – Existing Conditions

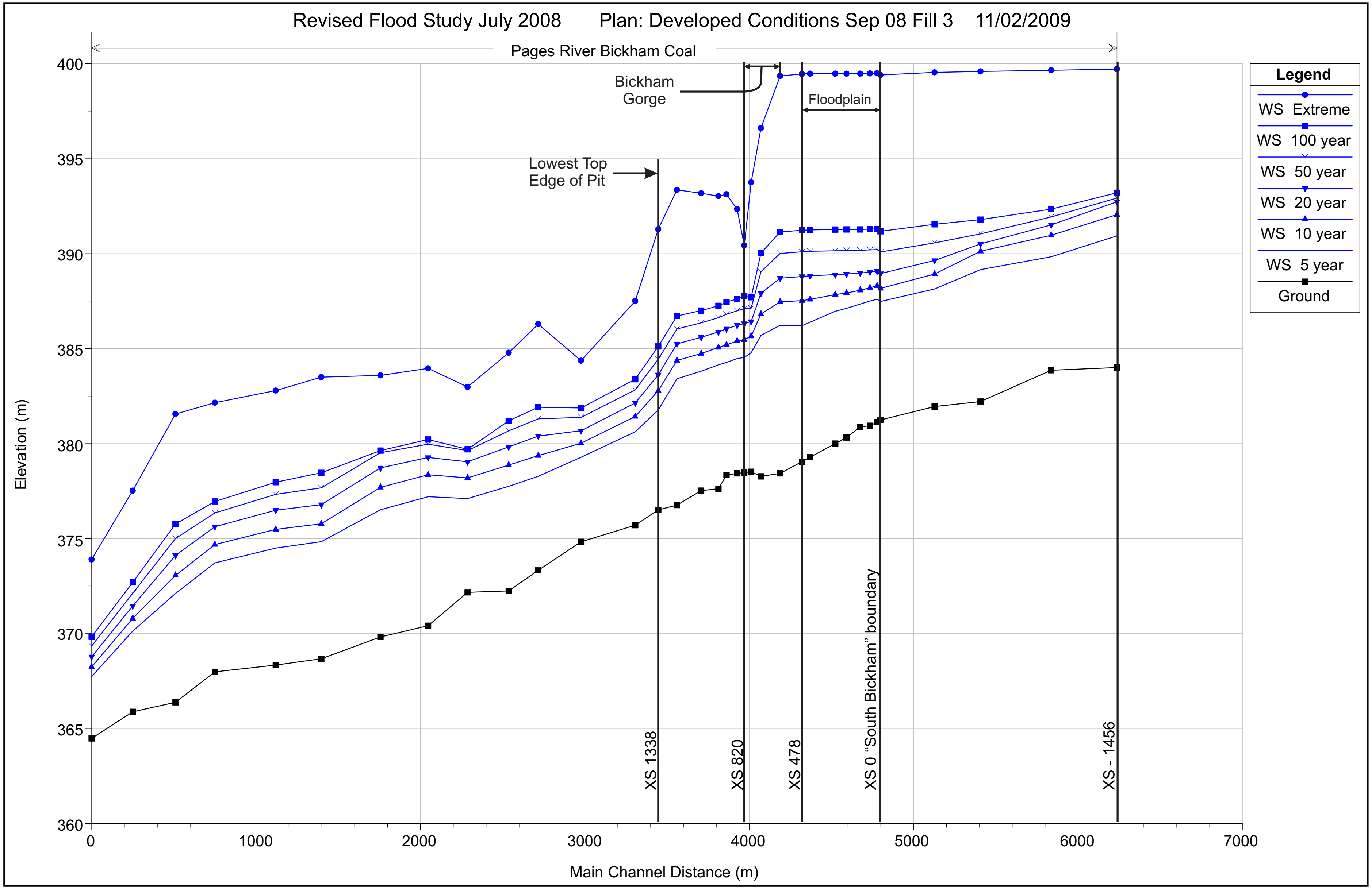


Revised Flood Study July 2008 Plan: Existing Conditions Aug 06 11/02/2009
Pages River Bickham Coal
Bickham Gorge
Floodplain
Lowest Top Edge of Pit
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
XS 1338
XS 820
XS 478
XS 0 "South Bickham" boundary
XS - 1456
Elevation (m)
Main Channel Distance (m)
400
395
390
385
380
375
370
365
360
0
1000
2000
3000
4000
5000
6000
7000

ANNEXURE 20A-5

HYDRAULIC ANALYSIS RESULTS

HEC-RAS Longitudinal Profiles – Developed Conditions



Revised Flood Study July 2008 Plan: Developed Conditions Sep 08 Fill 3 11/02/2009
Pages River Bickham Coal
Bickham Gorge
Floodplain
Lowest Top Edge of Pit
Legend
WS Extreme
WS 100 year
WS 50 year
WS 20 year
WS 10 year
WS 5 year
Ground
XS 1338
XS 820
XS 478
XS 0 "South Bickham" boundary
XS - 1456
Elevation (m)
Main Channel Distance (m)
360
365
370
375
380
385
390
395
400
0
1000
2000
3000
4000
5000
6000
7000

ANNEXURE 20B
PEER REVIEW OF FLOOD MODELLING

By Bewsher Consulting

Bewsher Consulting Pty Ltd

Bewsher Consulting has completed a peer review of this March 2009 Flood Modelling report prepared by Evans & Peck.

We consider the as-reported hydrological and hydraulic modelling is sound and furthermore the report's Summary and Conclusions chapter appropriately describes the overall findings.

Drew Bewsher
Director
27 March 2009

J1797L_1.doc

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