CITY OF GRANDE PRAIRIE FLOOD RISK MAPPING STUDY
ALBERTA FLOOD RISK MAPPING PROGRAM

FINAL REPORT

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EXECUTIVE SUMMARY

Northwest Hydraulic Consultants (**nhc**) were retained by Alberta Environment (AENV) in June 2006 to conduct a flood risk mapping study for the city of Grande Prairie. The study comes under the Alberta Flood Risk Mapping Program, whose primary objective is to identify, map and document flood risk areas in urban communities throughout Alberta. The study area (Figure 1-1) includes an approximate 21 km length of the Bear River (Figure 1-2).

A flood frequency analysis was conducted to estimate Bear River discharges at the study site for the 2-year to 1000-year return periods. A draft hydrology report was submitted to AENV in September 2006, accepted in October 2006, and a final report was prepared in November 2006 which incorporated minor revisions. The full hydrology report is presented as Appendix A and the flood estimates are listed in Table 3-1. The estimated 100-year design flood discharges at the upper and lower extents of the study reach are 104 m^3/s and 110 m^3/s respectively.

Orthophoto imagery and base mapping (including 0.5 m interval contour lines) originally developed by the City of Grande Prairie were provided by AENV. This information was supplemented by bridge and channel cross section surveys conducted by **nhc** in July and August 2006 and used to create a HEC-RAS model of the study reach. The model also incorporated available bridge design information obtained by **nhc** from Alberta Infrastructure & Transportation (AI&T) and from the City of Grande Prairie.

Calibration data were limited to highwater marks surveyed by AENV and AI&T following a major flood which occurred in 1990. An unconventional calibration approach, which incorporated a model sensitivity analysis, was performed due to the lack of discharge information to accompany the high water mark data. Satisfactory calibration results were obtained with a downstream starting slope of S = 0.0020 m/m in the upstream reach and a Manning roughness value for most channel areas of n = 0.045. Two different Manning roughness values were adopted for floodplain areas, corresponding to vegetative conditions. Floodplain areas with very dense riparian vegetation were modeled with n = 0.150; areas in the central portion of the study reach where this vegetation has been removed were modeled with n = 0.050.

Flood frequency maps showing the 10- and 100-year flood lines delineated through the study reach, as well as the location and designated number of all cross sections used in the HEC-RAS analysis, are

presented in Appendix B. The computed natural flood frequency water levels for each of the estimated discharges are summarized in Table 5-5 and on the flood frequency maps.

The encroachment analysis to establish the 100-year floodway and flood fringe areas determined that the 1 m depth criterion dominated in most cases. Flood risk maps showing the 100-year floodway and flood fringe areas, as well as the computed floodway water levels for the encroachment case at each cross section are presented in Appendix C. The computed 100-year natural and floodway water levels are presented in Table 6-1 and on the flood risk maps.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

DEFINITION OF TERMS

- All references to "left" and "right" bank assume that the observer is viewing the channel in a downstream direction.
- A "highwater mark" is a level noted during a flood, or evidence remaining after a flood event, which demarks the maximum water level rise. Strand lines formed by debris, silt lines left on trees and bridge piers, debris caught in tree limbs and ice scars on tree trunks are typical kinds of evidence looked for in the field following a flood event.
- The "study reach" is the total length of channel within the study area which is established as requiring a formal, detailed assessment of flood levels and flood risk boundaries.
- All "elevations" presented in this report have units of metres and are referenced to the Geodetic Survey of Canada datum.

ACKNOWLEDGMENTS

Thanks are expressed to Ms. Patricia Stevenson of River Engineering of Alberta Environment, for providing overall study management, cooperation and advice; Mr. Wilf Schneider of Alberta Infrastructure & Transportation, for providing information on road bridge structures; and Messrs. Frank Daskewech and Colin Ferinowski of the City of Grande Prairie, for providing information on bridge structures and on reservoir operating practices, as well as providing base mapping and DEM information.

The study was managed by Mr. Eugene Yaremko with technical support from Messrs. William Rozeboom, Peter Onyshko, Steffen Toxopeus, and Ms. Olena Czajkowski.

1.0 INTRODUCTION

1.1 THE STUDY

Northwest Hydraulic Consultants (**nhc**) were retained by Alberta Environment (AENV) in June 2006 to conduct a flood risk mapping study for the City of Grande Prairie. The study comes under the Alberta Flood Risk Mapping Program, whose primary objective is to identify, map and document flood risk areas in urban communities throughout Alberta. The purpose of the study is to estimate flood levels along the Bear River, which passes through the City of Grande Prairie. The study was performed in accordance with a memorandum of agreement between AENV and **nhc**, dated 09 June 2006 (AENV Agreement No. 07RSN012). The project managers for the study were Mr. Eugene Yaremko of **nhc** and Ms. Patricia Stevenson of AENV.

1.2 FLOOD RISK MAPPING PROGRAM

A document entitled “An Agreement Respecting Flood Damage Reduction and Flood Risk Mapping in Alberta” was signed in April 1989 by the Province of Alberta and the Government of Canada. The primary objectives of the Canada/Alberta Flood Damage Reduction Program were to:

- identify, map and designate flood risk areas in urban communities across Alberta;
- increase public awareness, through a public information program, of flood risk among the general public, industry and government; and
- encourage municipalities to develop zoning by-laws recognizing the designated flood risk maps.

Following the expiration of the Canada/Alberta Flood Damage Reduction Program, the Alberta Flood Risk Mapping Program was established by the Province of Alberta. Its primary objectives are to continue and complete the work of the original program.

Studies undertaken within the new program are guided by the document “General Terms of Reference for Hydraulic Studies, Alberta Flood Risk Mapping Program” and its antecedent “General Terms of Reference for Flood Risk Studies, Canada/Alberta Flood Risk Mapping Program”. A study undertaken for a particular community is further guided by the specific terms of reference for the study.

1.3 STUDY OBJECTIVES

Following the principles of the Alberta Flood Risk Mapping Program and satisfying the objectives outlined in the City of Grande Prairie Flood Risk Mapping Study terms of reference documents, the deliverables contained within this report are the following items:

- A hydrologic and flood frequency analysis of the Bear River at the City of Grande Prairie, and flood discharge estimates for the 2- to 1000-year return periods (Appendix A).
- Flood Frequency Maps showing the 10- and 100-year flood lines for the study reach, the location and designated number of all cross sections used in the hydraulic analysis, as well as the computed flood frequency water levels at each cross section (Appendix B). Note that at a checkpoint meeting it was decided that because there were only minor differences in inundation limits for the 50- and 100-year events, the final maps for the City of Grande Prairie would show only the 10- and 100-year flood lines.
- Flood Risk Maps showing the 100-year floodway and flood fringe areas for the study reach, as well as the computed floodway water levels at each cross section (Appendix C).

Presented separately in electronic format is a “Flood Information Map” – this map shows the 100-year flood risk area superimposed on cadastral base mapping, including the floodway and flood fringe zones.

Also presented separately is a comprehensive work file containing relevant technical material generated during the course of the study.

1.4 STUDY AREA & REACH

The City of Grande Prairie is located approximately 400 km northwest of Edmonton, Alberta. The study area (Figure 1-1) includes an approximate 20 km length of the Bear River including meanders. This reach begins upstream at 132nd Avenue (Township Road 720) at the north end of the city and continues to a location which corresponds approximately to the latitude of 48th Avenue at the south end of the city.

2.0 FLOODING HISTORY

2.1 GENERAL INFORMATION

The Bear River at Grande Prairie drains an area of approximately 1500 km^2 located to the north and west of the city. As discussed in the March 1984 Bear River[1] Watershed Study by Marshall Macklin Monaghan, the watershed consists of two distinct hydrologic systems: (i) the drainage area above Bear Lake and (ii) the Grande Prairie Creek Watershed. The large size of Bear Lake, combined with its limited outflow capacity, attenuates even the largest inflows to the point where lake outflows are not significant to flooding in the city. High water associated with peak flows in Grande Prairie Creek have been observed to cause flow reversals in Bear River below Bear Lake and a companion reduction in the Grande Prairie Creek peak flow downstream of the confluence.

A dam on the Bear River, within the city limits, was originally constructed around 1948 to create a water supply reservoir and was reconstructed in 1975-76 by AENV. A considerable amount of re-channelization (straightening) of the river downstream from the dam has occurred; major cutoff construction was undertaken during the years 1965, 1966 and 1967. It is possible that this channelization was in response to high water events which occurred in 1963 and 1965. The combination of the dam and channelization has resulted in significant bed degradation and bank erosion in the reach downstream from the dam. Channel surveys conducted between 1968 and 1974 documented bed degradation of up to 2 m but typically around 0.6 m over that period. Riprap or gabion blankets have been constructed on the river bed and banks at most major bridge crossings within the city, both upstream and downstream of the dam.

Re-channelization has also occurred in the vicinity of 132nd Avenue, west of 116th Street. Abandoned Bear River channels are present west of this street, with a straight constructed channel now conveying river flows along the east side of 116th Street, north of 132nd Avenue.

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[1] The watercourse is labeled on government topographic mapping as Bear River both above and below Bear Lake. Prior reports including the Marshall Macklin Monaghan study have referred to the watercourse as Bear Creek. The former has been adopted for this study.

2.2 HISTORIC FLOODS

Information on historical floods in the study reach can be gleaned from a combination of Water Survey of Canada (WSC) streamflow records, Alberta Transportation & Infrastructure (AI&T) bridge file records, and an AENV report on channel degradation.

A WSC record of flows within the study reach are available only for years 1983 through 1987 at Station 07GE005, "Bear River near Grande Prairie". A longer period of WSC streamflow record is available in the upper basin for years 1969 through 2005 at Station 07GE005, "Grande Prairie Creek near Sexsmith". The peak flow in the WSC Grande Prairie Creek record, 64 m^3/s, occurred on June 12, 1990. This flow was more than double the second highest peak 30.8 m^3/s, on April 25, 1974.

Based on our interpretation of bridge file records from AI&T, large floods are believed to have occurred in the study reach in 1935, 1963, 1965 and 1990. Of these, the highest water levels occurred in 1965. The magnitude of these floods is unknown. Also, past high water marks may not reflect the current flood risk because of changes to the channel hydraulic capacity. These changes include: (1) significant degradation which has occurred downstream from the dam; (2) the reconstruction of the dam spillway in 1975-76; and (3) possible changes over time to the reservoir gate operating procedures.

AI&T Bridge File 01481 provides a sporadic account of events since 1907 at the 100th Avenue bridge. In 1911, a cross section indicated a high water mark 2.1 m above streambed, with top of bank at 3.4 m above streambed. The bridge was reconstructed in each of years 1912, 1920 and 1931. Subsequent compiled records are sporadic but suggest that the largest flood in the post-1931 bridge history (and possibly the longer post-1907 history) occurred in 1965. High water conditions are noted as having occurred in 1935 (Photo 1) and 1963 (Photo 2) but are characterized as being less than the 1965 level. There is a reference to a flood report having been prepared in 1974. The AI&T records for this site do not include any information on conditions for the 1990 flood.

An AENV report, "Bed Degradation on Bear Creek," makes note of a crest stage gauge site on Grande Prairie Creek near Claremont, located upstream from the above-mentioned WSC stream gauge near Sexsmith. For year 1965, a peak instantaneous flow of 73.6 m^3/s was estimated at the crest stage gauge, while the downstream peak discharge at the Bear River Reservoir spillway was 39.7 m^3/s.

2.3 RECENT FLOODS

The flood of June 1990 is the largest and best-documented flood since 1965. At the upstream “Grande Prairie Creek near Sexsmith” WSC stream gauge (Station 07GE005) it had a return period of approximately 50 years. However, because this gauge site is located in the upper basin above the complex hydraulic interactions (flow reversals) with Bear Lake, it is unlikely that this same recurrence interval would apply to the downstream study reach through the City of Grande Prairie.

Unfortunately, no records were available from AENV or the City of Grande Prairie which documented the 1990 flood peak water level at the Bear River reservoir, which could have been used with the spillway rating curve to estimate the peak flow in the study reach. The nearest available high water mark, obtained from AENV, was for the Highway 2 bypass located upstream from the reservoir.

The 1990 flood was a significant event which provides a reasonable baseline for establishing flood risk profiles for the City of Grande Prairie. However, for the study reach, the event peak flow and recurrence interval are unknown.

2.4 ICE JAM FLOODS

Representatives of the City and County of Grande Prairie reported no knowledge of floods caused by ice jams within the study reach. Bear Lake upstream of the study was identified as an occasional past source of ice, but the outlet channel is now so shallow as to release very little ice to the downstream system.

3.0 AVAILABLE DATA

3.1 HYDROLOGY REPORT

A flood frequency analysis for the Bear River at the City of Grande Prairie was completed by **nhc**, accepted by AENV in October 2006, and a final report submitted in November 2006. The final hydrology report is presented in Appendix A, with flood frequencies provided in Table 3-1. The estimated 100-year design flood peaks at the upper and lower extents of the study reach are 104 m^3/s and 110 m^3/s respectively. These values have been adopted for the study.

3.2 CROSS SECTION SURVEYS

3.1.1 BASE MAPPING & IMAGERY

Digital base mapping for the study was provided to **nhc** by AENV. This base mapping was originally produced and compiled under the direction of the City of Grande Prairie in 2002 and 2006, based on airphotographs taken in those years. At the checkpoint meeting held in November 2006 to present calibration results and preliminary floodplain map results, AENV determined that the digital base mapping and associated contours required additional processing to improve the map accuracy. Updated base mapping was provided by the City of Grande Prairie and AENV in December 2006 in the form of a digital elevation model (DEM) and 0.5 m interval digital contour lines.

The base mapping presented in this report includes a DEM, contour lines, and an orthophoto image originally photographed on 15 May 2002. All base mapping elements were provided in the 10TM 115^o, NAD 83 projection.

3.2.2 GROUND SURVEY DATA

Channel section surveys were performed by **nhc** during the months of July and August, 2006. A total of 47 cross sections were surveyed along the Bear River: 36 downstream and 11 upstream of the city reservoir. See Figure 1-2 for the surveyed cross section locations. The data were collected using RTK GPS equipment in the 3TM 120^o, NAD 83 projection and were subsequently converted by **nhc** to the 10TM 115^o, NAD 83 projection in November 2006. The survey data were accompanied by photographs taken by the survey crew (Photos 3 to 10).

Also shown in Figure 1-2, cross sections have been separated between those upstream and downstream of the city dam. In order to prevent confusion in the text due to similarly numbered sectors, the upstream cross section numbers have been prefixed "**u/s**" and those downstream "**d/s**".

3.2.3 Roadway Crossings

nhc also collected survey data for and produced sketches of six bridges within the study reach: the crossings of the Highway 2 bypass, 84th Avenue and 68th Avenue each consist of two bridge structures. A survey was also made at the walkway above the Bear Reservoir spillway, and a tape measurement was made from the walkway to the weir crest. The data were collected in the same format as the section data, and were subsequently converted to the same 10TM projection detailed previously.

Supplementary data for the crossing structures were obtained by **nhc** from City of Grande Prairie and AI&T records.

The bridge at the upstream study limit, 132nd Avenue, was replaced in October 2006 after the completion of field surveys. The HEC-RAS model incorporates the current bridge based on construction drawings.

3.3 Highwater Marks

Information on historical flood water levels was sought from a variety of sources, including AENV, AI&T, and the City of Grande Prairie. Information obtained from AENV consisted of highwater marks at five bridges through the study reach, for the flood of June 1990. Information from AI&T included 1990 highwater mark data for the 132nd Avenue and 84th Avenue bridges, and 1963 highwater mark data for the Highway 2 bypass and the 100th Avenue bridges. The AI&T files note that the water levels in 1965 were higher than those in 1963, but the amount is not quantified.

The AI&T data showed that water levels in 1963 (and 1965) were significantly higher (by more than 2 m) than those which occurred in 1990. However, the hydraulic conditions through the study reach have changed significantly since that time, so those past highwater marks do not reflect the existing channel capacity. High water conditions at the Highway 2 bypass are determined largely by the capacity (and gate setting) of the spillway at the Bear River Reservoir downstream from the bypass; the spillway was reconstructed in 1975 or 1976. In the reach with the 100th Avenue bridge, downstream from the spillway, major channelization works were undertaken in years 1965, 1966 and 1967, and a cutoff at the 99th Avenue bridge was constructed in 1973 and 1974.

Table 3-2 presents the high water marks for the June 1990 flood.

3.4 RATING CURVES

A rating curve for the Bear River reservoir spillway was obtained from the AENV construction plans dated August 1975. This rating curve is for an open gate condition and covers the water level range from the weir crest at Elev. 650.44 m to a maximum stage of Elev. 654.9 m, which corresponds to a discharge of 154.9 m^3/s. It was extended to the higher estimated 500- and 1000-year peaks of 173 m^3/s and 206 m^3/s by extrapolation of a best fit polynomial curve. Table 3-3 presents the rating curve used.

During summer months, the gates are closed and the reservoir water level is normally maintained in the range 652.3 m and 652.6 m. This water level range is equivalent to about a 25- to 50-year flood if the gates were open.

From interviews with the City of Grande Prairie staff, the spillway gates are normally left in open position during the winter and spring runoff period, and then are fully closed after the spring freshet. Operating procedures which would occur during a summer flood event, such as in June 1990, are unclear. For this study it is assumed that the gates would be open for all flood events.

4.0 RIVER & VALLEY FEATURES

4.1 RIVER SETTING

The Bear River watershed is located within the Wapiti Plain physiographic region of Alberta. Surficially, the watershed is dominated by glacial lake deposits consisting of silts and clays. Discharge through the study reach is very much controlled by a large Bear Lake – flood hydrographs leaving the lake are substantially attenuated. Grande Prairie Creek, which joins the Bear River downstream of the lake outlet, provides the flow regime and bedload sediment that establishes the regime of the Bear River channel in the study reach.

The upstream end of the study reach is within a transition where the Bear River channel meanders within a broad plain to where it begins down-cutting into the surrounding plain to meet the confluence level at the Wapiti River. A moderately wide stream-cut valley has formed to about u/s Cross Section 7 (Figure 1-2, upstream of city reservoir), after which the valley width becomes narrow and valley depth progressively greater downstream through the remaining length of study reach.

4.2 CHANNEL CHARACTERISTICS

There is a variation of the longitudinal slope of the Bear River through the study reach. This is illustrated in Figure 4-1 where there appears to be three distinct slopes:

- Station 0 to 12+500 S = 0.0018 (study reach downstream of dam)
- Station 14+500 to 17+000 S = 0.0015 (end of reservoir to u/s Cross Section 7)
- Station 17+500 to 20+000 S = 0.0003 (u/s Cross Section 7 to 132nd Avenue)

The downstream channel sub-reach has a meander pattern that progresses from straight, to moderately sinusoidal to moderately convoluted. The meanders are frequently constrained by the valley walls. As well, the channel in the upper end of this sub-reach has undergone extensive straightening via man-made cut offs, and there is a likelihood that this channel length has degraded to a point where bedrock is present at, or near the surface.

The middle length of channel has a meander pattern that varies from straight, to sinusoidal to convoluted. The channel and floodplain have become entrenched within the surrounding plain in response to a degrading downstream channel. Erosion of banks is a slow process so channel cutoff development would likewise be a slow process.

The meander pattern within the upstream channel sub-reach is moderately sinusoidal within the downstream half and highly sinusoidal within the upstream half. It is likely that the channel has formed within its own sediments so channel slope, width and depth are commensurate with the discharge regime and bed material load.

4.3 FLOODPLAIN CHARACTERISTICS

Except for the river upstream of u/s Cross Section 7, floodplain areas are principally located within the meander band width. Banks and floodplains are covered by dense vegetation. In general, the meander band width is contiguous with the entrenchment width.

4.4 MAN-MADE FEATURES

The principal man-made feature is a dam and reservoir owned and operated by the City of Grande Prairie. The dam has a 6 m approximate height. Attenuation of flood peaks is likely minor given a combination of small storage and loss of storage to sedimentation.

The other man-made features are the five roadway and single rail crossings:

- 132nd Avenue bridge – single municipal road having a bridge crossing that is currently being replaced
- Highway 2 bypass – dual bridges
- 99/100 Avenue – dual bridges
- Rail trestle bridge
- 84th Avenue - dual bridges
- 584th Avenue – bridge

5.0 CALCULATION OF FLOOD LEVELS

5.1 HEC-RAS PROGRAM

The U.S. Army Corps of Engineers computer program "HEC-RAS River Analysis Program" (Version 3.1.3, May 2005) was used to model and compute water levels for the present study. Basic inputs required by HEC-RAS are a series of cross sections along known lengths of a channel, roughness coefficients for the main channel and overbanks at each cross section, a water level and/or a channel slope at the downstream cross section and a flow.

The program applies the Bernoulli theorem between consecutive cross sections and is designed to: determine subcritical and/or supercritical flow profiles; assess the hydraulic effects of channel and floodplain adjustments such as channel straightening, encroachment, enlargement and diking; and estimate energy losses due to in-channel structures such as culverts, bridges, weirs and other obstructions. The analytical approach employed by HEC-RAS has the following potential limitations:

- It is assumed that flow is gradually-varied, so that the energy losses between cross sections can be estimated by the Manning formula using average conditions.
- It is assumed that flow is one-dimensional, therefore only velocity components in the principal direction of flow are accounted for in the equations and calculations.
- Changes in channel and floodplain geometry resulting from erosional processes that might arise during a flood cannot be directly accounted for or modeled.

On the basis of the river and valley characteristics previously described, it was concluded that the reach of the Bear River within the study area does not significantly violate any of the above criteria. The model created for the present study was operated for subcritical flow conditions.

5.2 GEOMETRIC DATA BASE

5.2.1 CROSS SECTION DATA

The 47 channel cross sections surveyed by nhc were extended using the DEM-derived 0.5 m interval contours originally provided by the City of Grande Prairie and subsequently updated by AENV and the City of Grande Prairie. The amount of extension in each case was sufficient to involve any floodplain area – these cross sections were then included in the HEC-RAS model. Where the survey data and contours did not correspond, particularly within the main channel and at the channel banks, the surveyed ground was taken as the more accurate.

Two HEC-RAS models were developed: (1) downstream of the dam outlet and (2) upstream of the dam.

For the downstream model, two additional cross sections were extrapolated downstream of the last surveyed cross section in order to provide a sufficient run-up length in the HEC-RAS model. Additional interpolated cross sections were generated at other locations, primarily at bridge crossings. The locations of all the non-surveyed cross sections are shown in Figure 1-2.

Non-surveyed cross sections were also generated for the upstream model. Figure 1-2 shows the extrapolated cross sections to be located within the reservoir and the interpolated cross sections to be located at the Highway 2 bypass crossing and at upstream end of the study reach, at the 132nd Avenue crossing.

Refer to Figure 1-2 and the maps included in Appendices B and C for cross section types, numbers, locations and extents. Refer to Figure 4-1 for a plot of the surveyed Bear River profile where cross section locations have been identified and refer to Table 5-1 for a list of cross section numbers, thalweg elevations and cumulative channel distances.

5.2.2 BRIDGES

Table 5-2 identifies the six bridges and the source of bridge information for each bridge. As indicated in Section 3.2.2, the **nhc** surveys included gathering supplemental bridge information.

5.3 HYDRAULIC PARAMETERS

5.3.1 EXPANSION & CONTRACTION COEFFICIENTS

To account for the effect of flow contraction or expansion on the energy balance between two cross sections, HEC-RAS multiplies the absolute difference in velocity head by a coefficient. Typically recommended[2] values for the contraction and expansion coefficients, respectively, are: 0.1 and 0.3 for

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[2] Brunner, G.W. *HEC-RAS River Analysis System User's Manual*. Version 3.1. Davis, California. Hydrologic Engineering Center, U.S. Army Corps of Engineers. November 2002.

gradual transitions; 0.3 and 0.5 for typical bridge sections; and 0.6 and 0.8 for abrupt transitions. Table 5-3(a) lists the coefficient values used for each cross section included in the HEC-RAS model.

5.3.2 Manning Roughness Values

Measured discharge and corresponding water level data would normally enable the calculation of Manning roughness values for the HEC-RAS model. In their absence, values were estimated based on observations made during the **nhc** field surveys conducted in July and August 2006 and using procedures found in literature.[3, 4]

Table 5-3(b) presents a summary of the Manning roughness values adopted for each of the model cross sections. The roughness values for each cross section were selected on the basis of the channel and bank vegetation conditions, as follows:

Vegetation Condition	Channel	Overbank
Willow growth	0.045	0.180
Cleared banks	0.040	0.050
Gabion section	0.030	0.030
Reservoir	0.025	0.050

These values represent a mid-range estimate of the roughness characteristics for the channel conditions which exist through the study reach. High and low estimates of roughnesses are discussed under model sensitivity.

5.4 Model Calibration

5.4.1 Methodology

A conventional model calibration was not possible due to the lack of a discharge estimate for the June 1990 flood. Also, several of the bridges within the study reach have been added or modified since the event. An additional obstacle to a conventional calibration is that the documented process of bed degradation below the reservoir has likely continued to occur over the 16 years since the highwater marks were observed.

[3] Chow, V.T. *Open-Channel Hydraulics*. New York, New York. McGraw-Hill Book Company. 1959.

In light of these challenges, the approach to calibration was to select roughness coefficients based on best judgment and to subjectively assess the position of the high water marks within the range of simulated water levels. By this process, the calibration takes the form of a "reality check" on the reasonableness of the results. While the exact magnitude and recurrence interval of the 1990 flood in the study reach is unknown, it was significant and likely had a recurrence interval in the range of 25 to 100 years. To be conservative in the mapping of flood inundation limits, it was felt to be desirable for the simulation results to show the highwater marks as being in the lower end of this range, closer to a 25-year event than a 100-year event.

5.4.2 CALIBRATION RESULTS

Using the highwater mark data listed in Table 3-2 and the frequency estimates listed in Table 3-1, the preceding calibration method was used with the HEC-RAS model created for the present study. Figure 5-1 shows the highwater marks in relation to the computed 25-, 50- and 100-year flood profiles based on the mid-range estimate of channel roughness characteristics. Table 5-4 lists the departures between the highwater marks and the 25- and 50-year flood levels

The calibration results show that the 1990 highwater marks are slightly (up to 0.28 m) higher that a 25-year flood and lower than a 50-year flood at most locations. The main exception is at the 99th and 100th Avenue bridges, where the highwater marks are between 0.07 m and 0.48 m lower than a 25-year flood. A review of the channel profile (Figure 5-1) shows high points at these bridges, which reflect bed armor that was placed to protect the bridge foundations against the ongoing degradation in this reach. Because the bed condition at the time of the 1990 flood is unknown, there is no basis for adjusting the model to match these highwater marks. The profiles plotted may be conservatively high at this short reach between the 100th Avenue bridge and the Bear River Reservoir spillway.

At the Highway 2 bypass bridge (upstream side), the 1990 highwater mark is very slightly (0.02 m) higher than a 50-year flood. The bridge at this location was completely re-constructed in 1994, four years after the highwater marks were recorded. Because the bridge and bed conditions at the time of the 1990 flood are unknown, there is no basis for adjusting the model to match this highwater mark.

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[4] Barnes, H.H. *Roughness Characteristics of Natural Channels*. Washington: U.S. Geological Survey, U.S. Department of the Interior, United States Government Printing Office. 1987

Overall, the calibration results are reasonably consistent with the 1990 flood having a recurrence interval of between 25 and 50 years, and this confirms the reasonableness of the simulations.

5.5 Computed Natural Water Surface Profiles

Table 5-5 lists the computed water surface elevations at each cross section in the HEC-RAS model for the 10-, 50- and 100-year flood peak discharges. Figure 5-2 presents the corresponding water surface profiles.

5.6 Model Sensitivity

5.6.1 Downstream Boundary Condition

Because no rating curve exists for the cross section at the downstream end of the downstream model, HEC-RAS was operated using the "normal depth" downstream boundary condition. The adopted channel slope was S = 0.0018 m/m, based on the surveyed channel data. Because channel section data were not obtained downstream from the study reach, the most downstream surveyed cross section was replicated at the downstream boundary based on this slope. Figure 5-1 identifies the downstream extent of the model which was developed by extrapolation, and shows the assumed slope relative to the surveyed upstream reach. This slope is the best estimate of the actual slope and further sensitivity analyses were not performed.

5.6.2 Manning Roughness Values

The sensitivity of the model to different Manning roughness (n) values was explored using values which represented the lower and higher extents of what would be reasonable for the study reach. As discussed earlier, mid-range values were used for the model calibration.

The roughness values for each cross section were selected on the basis of the channel and bank vegetation conditions, as follows:

Low Roughness n Values

Vegetation Condition	**Channel**	**Overbank**
Willow growth	0.035	0.150
Cleared banks	0.035	0.050
Gabion section	0.025	0.025
Reservoir	0.025	0.050

<u>High Roughness n Values</u>

Vegetation Condition	Channel	Overbank
Willow growth	0.055	0.200
Cleared banks	0.050	0.080
Gabion section	0.035	0.035
Reservoir	0.025	0.080

The channel Manning roughness was varied by ±20 % about the adopted value of n = 0.045, from n = 0.035 to n = 0.055, to assess the sensitivity of the computed water levels for the 100-year flood to changes in roughness.

The 100-year water surface profile computed using the low roughness values results in a water surface which, on average, is 0.29 m lower than the mid-range values used in the calibrated model. The difference ranges from no change (at the weir-controlled reservoir) to a maximum reduction of 0.50 m.

The 100-year water surface profile computed using the high roughness values results in a water surface which, on average, is 0.26 m higher than the mid-range values used in the calibrated model. The difference ranges from no change (at the weir-controlled reservoir) to a maximum increase of 0.42 m.

Figure 5-3 provides a plot of the computed 100-year water surface profile for each of the three channel Manning roughness values.

5.7 FLOOD FREQUENCY MAPS

Flood frequency maps are presented in Appendix B (Drawing No. 6813-101-FFM, Sheets 1, 2 and 3). The natural floodplain boundaries of the 10- and 100-year floods were constructed by plotting the computed levels (Table 5-5) along each cross section used in the model and connecting the points within the study reach using the provided 0.5 m contours as guides. Where there was a conflict between the surveyed ground data and the 0.5 m contours, the survey data were taken as correct. Thus, the plotted flood lines may not always correspond to the contour mapping. To determine whether or not a particular site is subject to flooding, reference should be made to the computed flood levels listed in Table 5-5 and on the maps in conjunction with site specific surveys.

There is currently no residential, commercial or industrial developments within the City of Grande Prairie that is affected by Bear River 100-year flooding. None of the roadways within the study area would be overtopped or outflanked during a 100-year event.

The flood levels computed produce an interesting result at the upstream end of Sheet 1, where it appears that flood waters would overtop 116th Street for the 10- and 100-year flood peaks. The Bear River crosses this street north of 132nd Avenue, so depending on channel capacity west of 116th Street, there could be a situation where overbank flow follows the old channel route that can be seen in the northwest corner of Sheet 1.

6.0 FLOODWAY DETERMINATION

6.1 TERMINOLOGY

The definitions of a floodway and a flood fringe, as adopted from the Canada/Alberta Flood Damage Reduction Program and applied to the current study, are as follows:

- Floodway – the stream channel and portion of the floodplain required to convey the 100-year design flood. No development is generally allowed in the floodway.
- Flood Fringe – the remaining portion of the floodplain, between the floodway and the boundary line of the 100-year design flood (i.e. the 100-year flood risk limit). Development may be allowed within the designated flood fringe.

6.2 FLOODWAY CRITERIA

The boundary separating the floodway and the maximum allowable flood fringe is determined through a process of successively restricting the floodway (encroachment) and re-computing water levels. The following floodway criteria (Figure 6-1) must be adhered to in determining the floodway boundary:

- The restricted floodway water surface cannot be higher than 0.3 m above the unrestricted natural water surface profile for the design flood.
- All areas in which the depth of water under natural flood conditions exceeds 1 m, or the flow velocities are greater than 1 m/s, must be part of the floodway. Exceptions may be made for areas of backwater and ineffective flow areas.

- No constriction shall be attempted where flow is supercritical and in no case should an encroachment extend into the main channel.

6.3 METHODOLOGY

HEC-RAS provides five methods to determine floodplain encroachment. Encroachment Method 4 was initially used. This method allows HEC-RAS to automatically restrict the floodplain at each cross section until a maximum 0.3 m increase in water surface is achieved. However, it became quickly evident that the 1 m depth criterion dominated the determination of the floodway boundary at the majority of cross sections. The floodway boundary established on this basis did not result in a condition that violated any of the remaining floodway criteria.

6.4 FLOODWAY RESULTS

6.4.1 LIMITING CRITERIA

The floodway criteria outlined in Section 6.2 and illustrated in Figure 6-1 were adhered to in establishing the encroachment stations and determining the floodway and flood fringe boundaries for the present study. As indicated previously, the 1 m depth limit controlled the delineation in most cases, and thus the floodway boundary is located inside the 100-year flood risk limit throughout the study reach.

The two boundaries are frequently coincident. This occurs where encroachment is unfeasible or not allowed as per the floodway definition criteria. For example, the floodway boundary is the same as the 100-year flood risk boundary where a bank abuts the toe of a valley wall.

6.4.2 DESIGN FLOOD PROFILE

Table 6-1 lists the computed 100-year natural and floodway water surface elevations with the water surface profiles plotted in Figure 6-2.

7.0 FLOOD RISK MAPS

7.1 GENERAL COMMENTS

Flood risk maps are presented in Appendix C (Drawing No. 6813-101-FRM, Sheets 1, 2 and 3).
The boundary of the 100-year floodplain produced under restricted (encroachment) conditions is referred to as "Flood Risk Limit of the 100-year Design Flood" and the floodway boundary is referred to as "Floodway Limit of the 100-year Design Flood". The boundaries were constructed by plotting the computed floodway water levels and selected encroachment stations along each cross section and connecting the resulting points using the provided 0.5 m contours as guides. Where there was a conflict between the surveyed ground data and the 0.5 m contours, the survey data were taken as correct.

Where a floodway limit is not shown, it can be assumed to be coincident with the flood risk limit. There may be isolated areas of high ground within the flood risk limit delineated on the maps. To determine whether or not a particular site is subject to flooding, reference should be made to the computed natural and floodway elevations listed in Table 6-1 and the floodway elevations noted on the maps.

7.2 AREAS WITHIN THE FLOODWAY

There are currently no residential, commercial or industrial developments within the Bear River floodway.

7.3 AREAS WITHIN THE FLOOD FRINGE

The majority of flood fringe area is located upstream of u/s Cross Section 8.

8.0 CONCLUSIONS

The present study has been conducted by **nhc** using standard hydraulic methodology based on the HEC-RAS computer program, as specified by the document "General Terms of Reference for Hydraulic Studies, Alberta Flood Risk Mapping Program". To obtain reliable results, this methodology normally requires a reasonable amount of calibration data in the form of observed water levels during past floods of known magnitude or frequency.

In the present study, available calibration data were limited to six highwater marks obtained from AENV records and AI&T bridge files, each noted at a different roadway crossing within the Bear River study reach. These highwater marks were a result of a June 1990 flood event - the actual peak discharge is unknown.

It was reconciled from regional flood peak data for the June 1990 flood event that the 1990 flood peak on the Bear River had a return period in the range of 25 to 100 years. The uncalibrated upstream and downstream models were used to compute the 25-, 50- and 100-year flood profiles and a comparison with the highwater marks suggested that the 1990 Bear River flood had a return period between 25 and 50 years. On this basis it was concluded that models are reasonably calibrated, although it must also be concluded that this does not constitute a calibration as generally understood.

nhc has conducted the present study on the basis of the specified methodology, available data and previous experience of river hydraulic studies. The company is not liable for errors in the flood risk mapping that may result from lack of data for hydraulic model calibration or flood line delineation.

TABLES

TABLE 3-1

Bear River Flood Frequencies
City of Grande Prairie Floodplain Study

T (years)	Bear River Upstream of City Dam m^3/s	Bear River Downstream of City Dam m^3/s
2	12	13
5	26	28
10	41	43
25	61	64
50	81	85
100	104	110
500	173	184
1000	206	218

TABLE 3-2

Bear River at Grande Prairie Highwater Mark Information - 1990

Road/Highway Location	Construction History (when known)	1990 HWM (metres)	Orientation, observer
132 Ave / 116 St	Built 1965, rebuilt 2006	658.60	0.7 m below deck (AIT)
Hwy 2 Bypass / 116 Ave	Rebuilt 1994	652.79	upstream side (AENV)
100 Ave (Westbound)	Built 1959	645.90 645.71	upstream side (AENV) downstream side (AENV)
99 Ave (Eastbound)	Built 1973	645.66 645.51	upstream side (AENV) downstream side (AENV)
84 Ave (Westbound)	Built 1988	641.96 641.82 641.86	upstream side (AENV) downstream side (AENV) 6.8 m below deck (AIT)
84 Ave (Eastbound)	Built after 1990		
68 Ave	no data		
Pedestrian bridge d/s of 68 Ave	no data	634.18	downstream side (AENV)

Table 3-3

Spillway Rating Curve
Bear River at Grande Prairie Reservoir

Discharge Return Period (years)	**Discharge** (m^3/s)	**Head on Weir** (m)	**Reservoir WL above crest El. GSC**
2	12	0.56	651.00
5	26	1.04	651.48
10	41	1.44	651.89
25	61	1.90	652.35
50	81	2.30	652.75
100	104	2.71	653.15
500	173	3.72	654.17
1000	206	4.14	654.58

TABLE 5-1

Bear River Cross Sections and Thalweg Levels

Reach	Cross Section	Bridge	Bridge HMW (elev. m)	Station (elev. m)	Thalweg (elev. m)
d/s	0.1			0	620.268
d/s	0.2			530	621.063
d/s	1			1006	621.777
d/s	2			1697	622.630
d/s	3			2385	624.208
d/s	4			2648	624.977
d/s	5			3119	625.800
d/s	6			3432	626.116
d/s	7			4395	626.941
d/s	8			4599	626.969
d/s	9			5037	627.753
d/s	10			5246	628.087
d/s	11			5636	629.030
d/s	12			5986	629.569
d/s	13			6230	629.783
d/s	14			6472	630.679
d/s	15	Ped Bridge	634.180	6727	631.365
d/s	16			6980	631.336
		68 Ave d/s		6987	361.336
		68 Ave u/s		7001	631.288
d/s	17			7007	631.288
d/s	18			8447	634.971
d/s	19			8607	634.971
d/s	20			8881	635.674
d/s	21			9068	635.699
d/s	22			9383	636.475
d/s	23			9678	636.994
d/s	24			9845	637.911
d/s	25			10165	637.771
d/s	26			10269	637.911
d/s	27			10634	639.760
		84 Ave d/s	641.820	10671	639.760
		84 Ave u/s	641.960	10697	639.900
d/s	27.6			10698	639.900
d/s	28			10714	639.974
d/s	29			11347	640.362
d/s	30			11673	640.857
d/s	30.4			11896	641.267
		Sewer d/s		11899	641.267

TABLE 5-1 (cont'd)

Reach	Cross Section	Bridge	Bridge HMW (elev. m)	Station (elev. m)	Thalweg (elev. m)
		Sewer u/s		11899	641.267
d/s	30.6			11900	641.267
d/s	31			12131	641.658
d/s	32			12379	641.642
d/s	33			12459	641.695
d/s	33.4			12504	642.075
		Trestle d/s		12509	642.075
		Trestle u/s		12515	642.075
d/s	33.6			12519	642.075
d/s	34			12665	643.748
d/s	34.1			12675	643.748
		99 Ave d/s	645.510	12677	643.748
		99 Ave u/s	645.660	12687	644.029
d/s	34.9			12689	644.029
d/s	35			12709	644.150
		100 Ave d/s	645.710	12714	644.150
		100 Ave u/s	645.900	12730	644.488
d/s	36			12734	644.488
d/s	37			12939	643.682
d/s	38			13222	643.952
d/s	39			13395	645.085
		Spillway	654.329	13448	650.440
u/s	0.1			13500	649.604
u/s	0.2			14101	649.886
u/s	0.3			14212	649.961
u/s	1			14543	650.356
		HWY 2 BP d/s		14559	650.356
		HWY 2 BP u/s	652.790	14585	650.573
u/s	2			14606	650.573
u/s	3			14691	651.028
u/s	4			15192	651.777
u/s	5			15715	652.129
u/s	6			16198	652.932
u/s	7			16930	653.713
u/s	8			17704	653.910
u/s	9			18189	654.393
u/s	10			18952	654.393
u/s	11			20044	654.546
u/s	12			20109	654.326
		132 Ave d/s		20117	654.326
		132 Ave u/s	658.600	20123	654.350
u/s	13			20130	654.350

TABLE 5-2

**Bridges in Bear River
Study Reach**

Bridge	Source of Design Drawings
Pedestrian	City of Grande Prairie
68 Avenue	City of Grande Prairie
84 Avenue	City of Grande Prairie
Rail Trestle	nhc field surveys
99^{th} /100^{th} Avenue	Alberta Transportation
Highway 2 By-pass	Alberta Transportation
132^{nd} Avenue	City of Grande Prairie

nhc

TABLE 5-3(a)
Bear River HEC-RAS Expansion and Contraction Coefficients
Downstream Model

Cross Section	Contraction	Expansion
0.1	0.1	0.3
0.2	0.1	0.3
1	0.1	0.3
2	0.1	0.3
3	0.1	0.3
4	0.1	0.3
5	0.1	0.3
6	0.1	0.3
7	0.1	0.3
8	0.1	0.3
9	0.1	0.3
10	0.1	0.3
11	0.1	0.3
12	0.1	0.3
13	0.1	0.3
14	0.1	0.3
15	0.1	0.3
16	0.3	0.5
68 Avenue Bridge	Bridge	
17	0.3	0.5
18	0.1	0.3
19	0.1	0.3
20	0.1	0.3
21	0.1	0.3
22	0.1	0.3
23	0.1	0.3
24	0.1	0.3
25	0.1	0.3
26	0.1	0.3
27	0.3	0.5
27.4	0.3	0.5
84 Avenue Bridge	Bridge	
27.6	0.3	0.5
28	0.3	0.5
29	0.1	0.3
30	0.1	0.3
30.4	0.1	0.3
30.5	Bridge	
30.6	0.1	0.3
31	0.1	0.3
32	0.1	0.3
33	0.1	0.3
33.4	0.3	0.5
33.5	Bridge	
33.6	0.3	0.5
34	0.3	0.5
34.1	0.3	0.5
99 Avenue Bridge	Bridge	
34.9	0.3	0.5
35	0.3	0.5
100 Avenue Bridge	Bridge	
36	0.3	0.5
37	0.1	0.3
38	0.1	0.3
39	0.1	0.3

TABLE 5-3(b)
Bear River HEC-RAS Manning Roughness (n) Coefficients
Downstream Model

Cross Section	n #1	n #2	n #3
0.1	0.18	0.045	0.18
0.2	0.18	0.045	0.18
1	0.18	0.045	0.18
2	0.18	0.045	0.18
3	0.18	0.045	0.18
4	0.18	0.045	0.18
5	0.18	0.045	0.18
6	0.18	0.045	0.18
7	0.18	0.045	0.18
8	0.18	0.045	0.18
9	0.18	0.045	0.18
10	0.18	0.045	0.18
11	0.18	0.045	0.18
12	0.18	0.045	0.18
13	0.18	0.045	0.18
14	0.18	0.045	0.18
15	0.18	0.045	0.18
16	0.18	0.045	0.18
68 Avenue Bridge			
17	0.18	0.045	0.18
18	0.18	0.045	0.18
19	0.18	0.045	0.18
20	0.18	0.045	0.18
21	0.18	0.045	0.18
22	0.18	0.045	0.18
23	0.18	0.045	0.18
24	0.18	0.045	0.18
25	0.18	0.045	0.18
26	0.18	0.045	0.18
27	0.03	0.03	0.03
27.4	0.03	0.03	0.03
84 Avenue Bridge			
27.6	0.03	0.03	0.03
28	0.03	0.03	0.03
29	0.18	0.045	0.18
30	0.18	0.045	0.18
30.4	0.18	0.045	0.18
30.5			
30.6	0.18	0.045	0.18
31	0.18	0.045	0.18
32	0.18	0.045	0.18
33	0.18	0.045	0.18
33.4	0.18	0.045	0.18
33.5			
33.6	0.18	0.045	0.18
34	0.03	0.03	0.03
34.1	0.03	0.03	0.03
99 Avenue Bridge			
34.9	0.03	0.03	0.03
35	0.03	0.03	0.03
100 Avenue Bridge			
36	0.03	0.03	0.03
37	0.05	0.04	0.05
38	0.05	0.04	0.05
39	0.05	0.04	0.05

#1 left floodplain
#2 channel
#3 right floodplain

TABLE 5-3(c)
Bear River HEC-RAS Expansion and Contraction Coefficients
Upstream Model

Cross Section	Contraction	Expansion
0.1	0.1	0.3
0.2	0.1	0.3
0.3	0.1	0.3
1	0.3	0.5
Highway 2 Bypass Bridge		
2	0.3	0.5
3	0.1	0.3
4	0.1	0.3
5	0.1	0.3
6	0.1	0.3
7	0.1	0.3
8	0.1	0.3
9	0.1	0.3
10	0.1	0.3
11	0.1	0.3
12	0.3	0.5
132 Avenue Bridge		
13	0.3	0.5

TABLE 5-3(d)
Bear River HEC-RAS Manning Roughness (n) Coefficients
Upstream Model

Cross Section	n #1	n #2	n #3
0.1	0.05	0.025	0.05
0.2	0.05	0.025	0.05
0.3	0.05	0.04	0.05
1	0.03	0.03	0.03
Highway 2 Bypass Bridge			
2	0.03	0.03	0.03
3	0.18	0.045	0.18
4	0.18	0.045	0.18
5	0.18	0.045	0.18
6	0.18	0.045	0.18
7	0.18	0.045	0.18
8	0.18	0.045	0.18
9	0.18	0.045	0.18
10	0.18	0.045	0.18
11	0.18	0.045	0.18
12	0.18	0.045	0.18
132 Avenue Bridge			
13	0.18	0.045	0.18

#1 left floodplain
#2 channel
#3 right floodplain

TABLE 5-4

Model Calibration to Mid-Range Estimate Roughness Values

			Simulated Water Surface Elevations, m		High Water Mark minus Simulation	
Bridge Location	**HEC-RAS Station (m)**	**High Water Mark, 1990 Flood, m**	**25-yr**	**50-yr**	**25-yr**	**50-yr**
Pedestrian Bridge	6,727	634.18	634.089	634.493	0.09	-0.31
84 Ave d/s	10,671	641.82	641.664	642.012	0.16	-0.19
84 Ave u/s	10,697	641.96	641.749	642.087	0.21	-0.13
99 Ave d/s	12, 677	645.51	645.579	645.959	-0.07	-0.45
99 Ave u/s	12,687	645.66	645.872	646.235	-0.21	-0.57
100 Ave d/s	12,714	645.71	645.933	646.282	-0.22	-0.57
100 Ave u/s	12,730	645.90	646.381	646.717	-0.48	-0.82
HWY 2 BP u/s	14,559	652.79	652.505	652.774	0.28	0.02
132 Ave u/s	20,123	658.60	658.586	659.065	0.01	-0.47

Notes:

1. High Water Mark for 132 Ave is as reported by Alberta Infrastructure and Transportation. All others are as reported by AENV
2. All other high water marks are as reported by Alberta Environment
3. Bridge at 68th Ave, HEC-RAS model station 6,987 m, did not exist in 1990
4. Bridge at 84th Ave was twinned sometime after 1990 (Model reflects current conditions)

TABLE 5-5(a)

Bear River Computed Flood Frequency Water Levels - Downstream Model

CROSS SECTION	COMPUTED NATURAL FLOOD LEVEL, (m)							
	2-YEAR	5-YEAR	10-YEAR	25-YEAR	50-YEAR	100-YEAR	500-YEAR	1000-YEAR
0.1	622.32	622.73	623.05	623.42	623.73	624.06	624.88	625.19
0.2	623.12	623.53	623.84	624.21	624.52	624.85	625.67	625.98
1	623.91	624.38	624.70	625.07	625.39	625.71	626.51	626.82
2	624.82	625.49	625.94	626.40	626.77	627.14	628.01	628.35
3	625.63	626.19	626.61	627.08	627.46	627.86	628.80	629.16
4	626.16	626.53	626.86	627.27	627.63	628.01	628.92	629.27
5	627.33	627.93	628.35	628.74	629.03	629.33	630.08	630.38
6	627.83	628.40	628.84	629.30	629.66	630.03	630.92	631.26
7	628.80	629.34	629.76	630.24	630.63	631.03	631.97	632.33
8	628.93	629.51	629.95	630.45	630.86	631.27	632.24	632.60
9	629.31	629.95	630.42	630.94	631.37	631.81	632.86	633.25
10	629.79	630.38	630.86	631.41	631.85	632.29	633.34	633.73
11	630.56	630.99	631.35	631.80	632.19	632.60	633.58	633.95
12	631.18	631.75	632.18	632.68	633.09	633.53	634.59	635.00
13	631.52	632.07	632.50	632.98	633.38	633.81	634.82	635.21
14	632.06	632.63	633.05	633.53	633.93	634.35	635.38	635.78
15	632.64	633.20	633.62	634.09	634.49	634.90	635.91	636.31
16	633.13	633.73	634.18	634.68	635.10	635.53	636.30	636.67
68 Avenue Bridge								
17	633.19	633.85	634.34	634.93	635.41	635.91	636.94	637.37
18	636.17	636.72	637.14	637.58	637.96	638.35	639.40	639.80
19	636.53	637.13	637.57	638.03	638.44	638.87	639.98	640.41
20	637.11	637.74	638.21	638.74	639.06	639.46	640.48	640.89
21	637.52	638.11	638.55	639.02	639.35	639.72	640.70	641.10
22	638.15	638.57	638.94	639.35	639.67	640.02	640.93	641.30
23	638.76	639.23	639.58	639.98	640.32	640.68	641.42	641.73
24	638.96	639.47	639.83	640.23	640.56	640.92	641.61	641.89
25	639.32	639.86	640.25	640.67	641.02	641.38	642.12	642.42
26	639.48	640.03	640.42	640.85	641.20	641.56	642.21	642.48
27	640.43	640.87	641.10	641.41	641.68	641.98	642.67	643.01
27.4	640.82	640.98	641.04	641.34	641.63	641.95	642.72	643.03
84 Avenue Bridge								
27.6	640.87	641.10	641.37	641.76	642.10	642.45	643.31	643.36
28	640.87	641.12	641.43	641.79	642.08	642.42	643.29	643.56
29	642.07	642.74	643.20	643.71	644.13	644.53	645.38	645.71
30	642.30	642.97	643.45	643.99	644.44	644.87	645.70	646.01
30.4	642.49	643.12	643.59	644.13	644.58	645.01	645.86	646.18
30.5 - Bridge								
30.6	642.50	643.13	643.60	644.13	644.59	645.02	645.87	646.19
31	642.85	643.43	643.88	644.41	644.87	645.31	646.25	646.61
32	643.29	643.85	644.28	644.80	645.24	645.69	646.67	647.04
33	643.42	644.01	644.45	644.97	645.40	645.85	646.84	647.22
33.4	643.49	644.08	644.52	645.04	645.47	645.92	646.92	647.30
33.5 - Bridge								
33.6	643.55	644.16	644.61	645.14	645.59	646.05	647.09	647.50
34	644.39	644.70	645.01	645.48	645.90	646.35	647.48	647.96
34.1	644.61	644.99	645.26	645.60	645.97	646.40	647.51	647.98
99 Avenue Bridge								
34.9	644.89	645.28	645.56	645.91	646.26	646.67	647.67	648.20
35	644.94	645.32	645.60	645.94	646.28	646.67	647.62	648.15
100 Avenue Bridge								
36	645.39	645.80	646.09	646.42	646.76	647.11	648.03	648.55
37	645.61	646.11	646.46	646.86	647.20	647.55	648.48	648.94
38	645.71	646.27	646.67	647.12	647.47	647.81	648.62	649.05
39	645.74	646.35	646.77	647.24	647.61	647.97	648.73	649.02

TABLE 5-5(b)

Bear River Computed Flood Frequency Water Levels - Upstream Model

CROSS SECTION	COMPUTED NATURAL FLOOD LEVEL, (m)							
	2-YEAR	5-YEAR	10-YEAR	25-YEAR	50-YEAR	100-YEAR	500-YEAR	1000-YEAR
0.1	650.94	651.32	651.71	652.18	652.60	653.03	653.95	654.20
0.2	651.18	651.76	652.00	652.27	652.64	653.06	653.97	654.22
0.3	651.30	651.82	652.04	652.29	652.65	653.06	653.96	654.21
1	651.65	652.01	652.24	652.48	652.75	653.08	653.90	654.12
Highway 2 Bypass Bridge								
2	651.72	652.12	652.41	652.74	653.06	653.42	654.25	654.54
3	651.88	652.30	652.61	652.96	653.28	653.63	654.51	654.81
4	653.04	653.55	653.95	654.36	654.67	654.98	655.57	655.89
5	653.58	654.08	654.48	654.91	655.24	655.57	656.08	656.38
6	654.24	654.67	655.04	655.44	655.77	656.10	656.77	657.08
7	655.43	656.12	656.65	657.18	657.60	657.73	658.35	658.58
8	656.10	656.86	657.46	658.08	658.56	658.98	660.01	660.43
9	656.36	657.14	657.74	658.38	658.89	659.36	660.50	660.94
10	656.65	657.34	657.90	658.50	659.00	659.46	660.59	661.02
11	657.03	657.61	658.09	658.59	659.07	659.52	660.63	661.05
12	657.05	657.64	658.12	658.59	659.07	659.52	660.63	661.05
132 Avenue Bridge								
13	657.05	657.65	658.13	658.60	659.08	659.55	660.67	661.07

TABLE 6-1(a)
Computed Floodway Water Levels - Downstream of Reservoir[1]
100-year Flood Peak

Cross Section No.	Natural (elev. m)	Encroached (elev. m)
0.1	624.06	624.07
0.2	624.85	624.86
1	625.71	625.72
2	627.14	627.15
3	627.86	627.87
4	628.01	628.01
5	629.33	629.35
6	630.03	630.05
7	631.03	631.04
8	631.27	631.28
9	631.81	631.82
10	632.29	632.30
11	632.60	632.60
12	633.53	633.53
13	633.81	633.81
14	634.35	634.36
15	634.90	634.90
16	635.53	635.53
17	635.91	635.92
18	638.35	638.35
19	638.87	638.83
20	639.46	639.67
21	639.72	639.87
22	640.02	640.11
23	640.68	640.72
24	640.92	640.94
25	641.38	641.40
26	641.56	641.58
27	641.98	642.01
27.4	641.95	641.92
27.6	642.45	642.56
28	642.42	642.53
29	644.53	644.58
30	644.87	644.92
30.4	645.01	645.05
30.6	645.02	645.06
31	645.31	645.34
32	645.69	645.72
33	645.85	645.87
33.4	645.92	645.94
33.6	646.05	646.06
34	646.35	646.35
34.1	646.40	646.41
34.9	646.67	646.67
35	646.67	646.69
36	647.11	647.14
37	647.55	647.59
38	647.81	647.93
39	647.97	648.07

1 - see Figure 1-2 for cross section locations

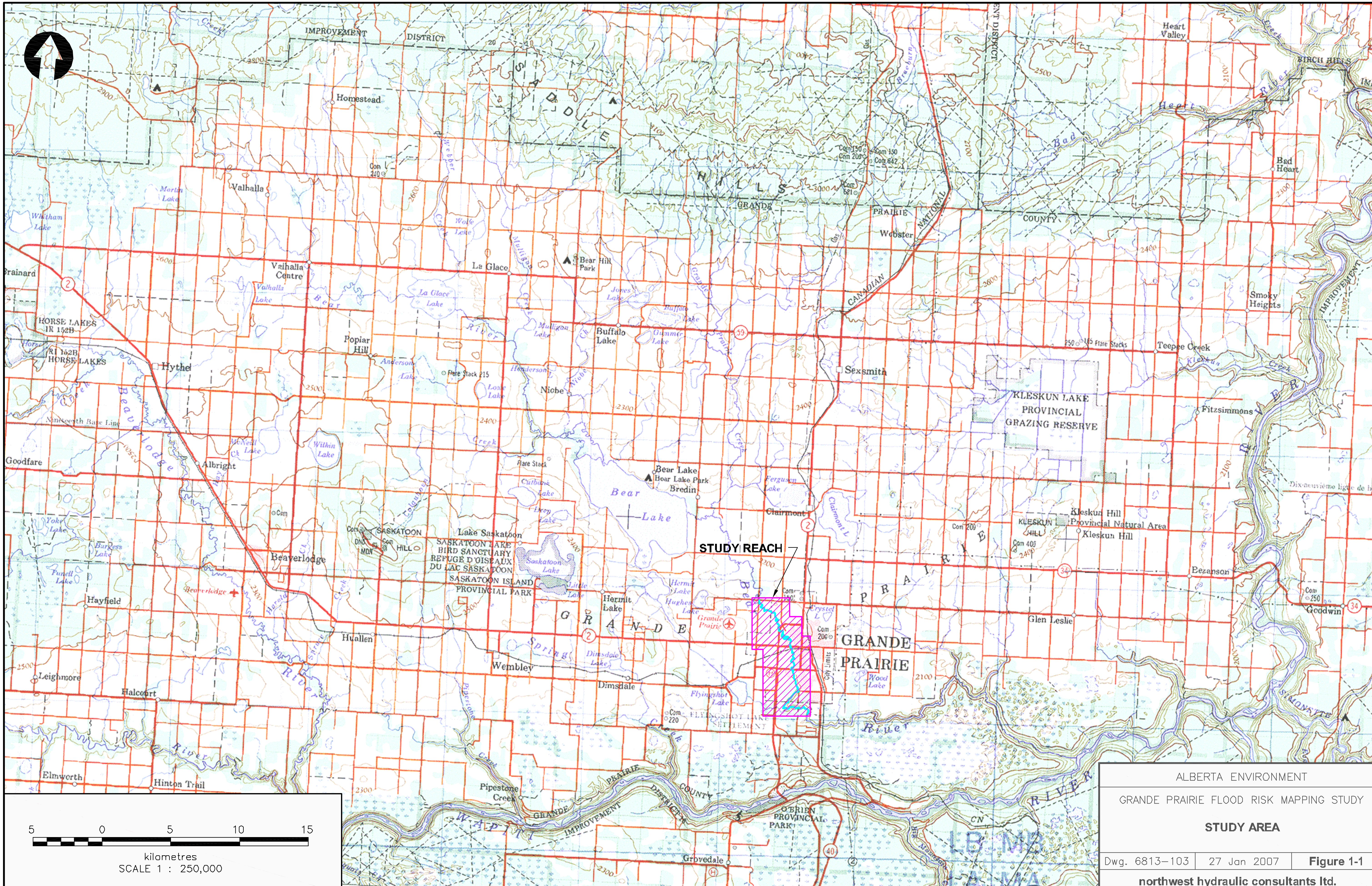
TABLE 6-1(b)

Computed Floodway Water Levels - Upstream of Reservoir[1]
100-year Flood Peak

Cross Section No.	Natural (elev. m)	Encroached (elev. m)
0.1	653.03	653.03
0.2	653.06	653.06
0.3	653.06	653.06
1	653.08	653.07
2	653.42	653.41
3	653.63	653.60
4	654.98	655.08
5	655.57	655.63
6	656.10	656.12
7	657.73	658.03
8	658.98	659.05
9	659.36	659.40
10	659.46	659.49
11	659.52	659.56
12	659.52	659.57
13	659.55	659.61

1 - see Figure 1-2 for cross section locations

FIGURES



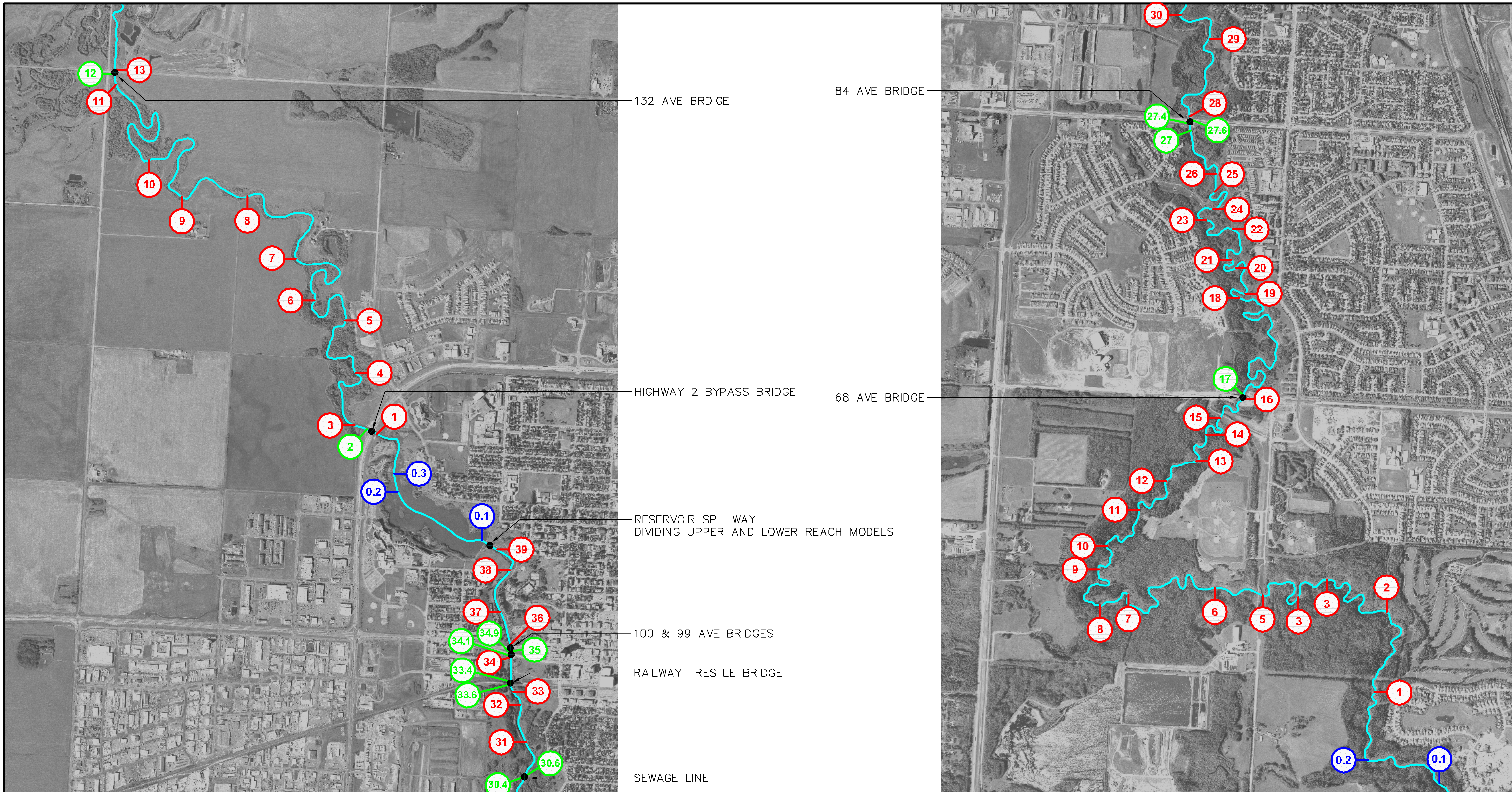
ALBERTA ENVIRONMENT

GRANDE PRAIRIE FLOOD RISK MAPPING STUDY

STUDY AREA

Dwg. 6813-103	27 Jan 2007	**Figure 1-1**

northwest hydraulic consultants ltd.



0 500 1000 1500 m

SCALE AS SHOWN

LEGEND:

24 SURVEYED CROSS SECTION

24.1 INTERPOLATED CROSS SECTION

CROSSING STRUCTURE

0.1 EXTRAPOLATED CROSS SECTION

IMAGE SOURCE:

PROVIDED BY: ALBERTA ENVIRONMENT AND CITY OF GRANDE PRAIRIE

RIVER CENTRELINE

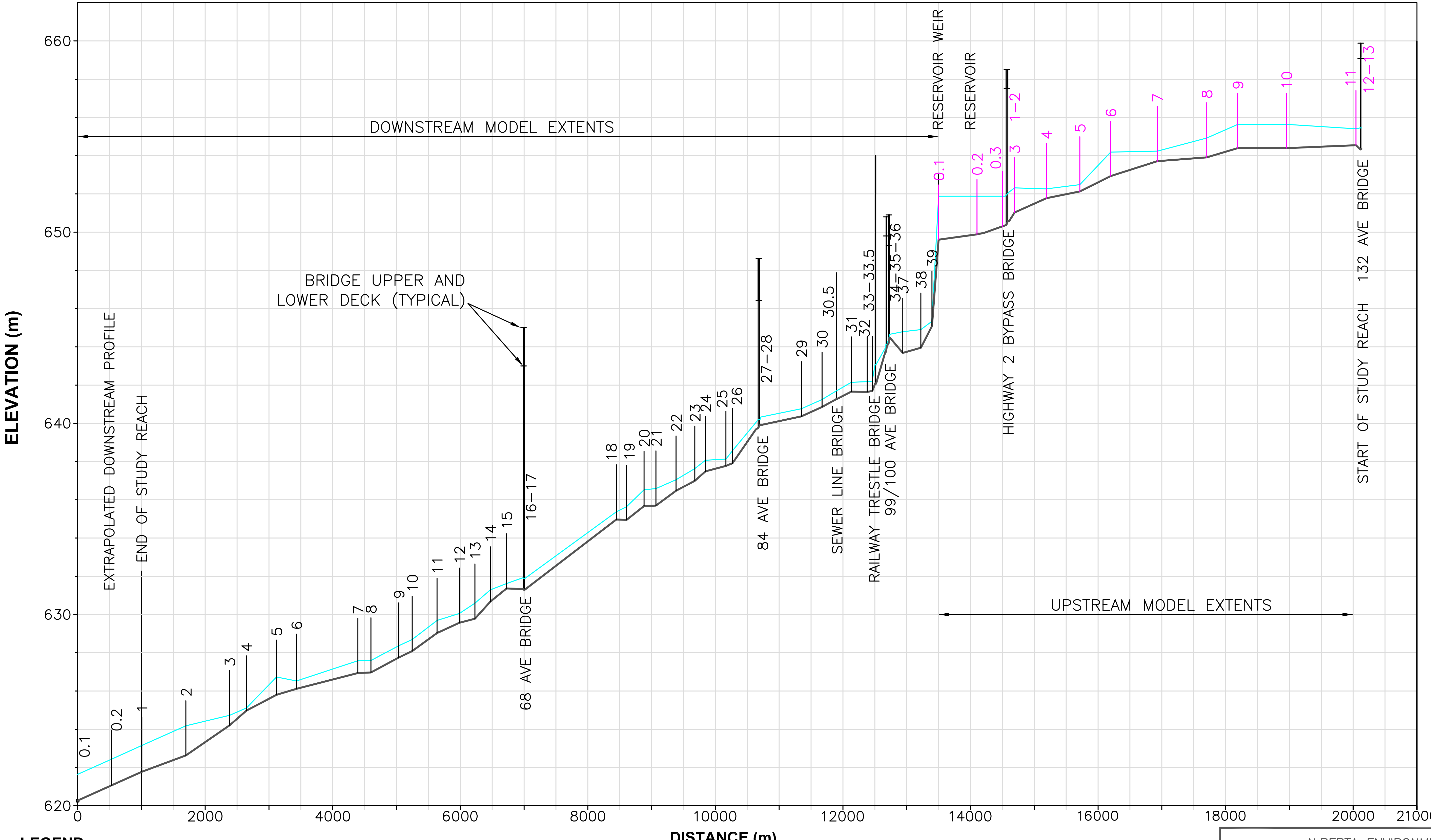
ALBERTA ENVIRONMENT

GRANDE PRAIRIE FLOOD RISK MAPPING STUDY
ALBERTA FLOOD RISK MAPPING PROGRAM

EXTENTS OF THE STUDY REACH

Dwg. 6813-101	25 Jan 2007	**Figure 1-2**

northwest hydraulic consultants



LEGEND:

- SURVEYED WATER ELEVATION
- GROUND
- 5 DOWNSTREAM MODEL CROSS SECTION
- 3 UPSTREAM MODEL CROSS SECTION

SURVEY DATA SOURCE:

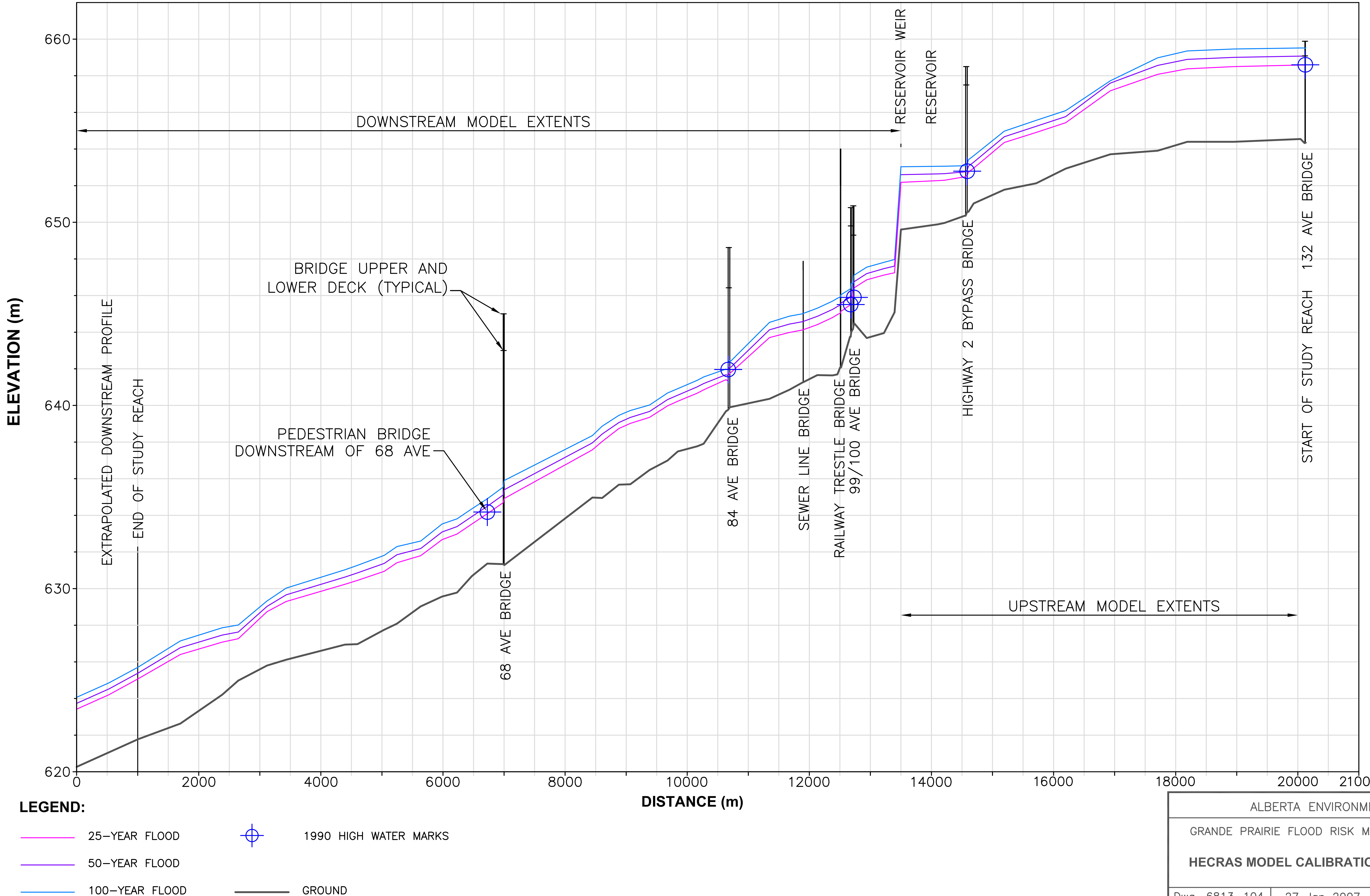
CROSS SECTIONS SURVEYED BY: NHC
DATE OF SURVEY: 19–22 JULY 2006, 9 AUGUST 2006
ORIGINAL PROJECTION: 3TM 120, NAD 83
PRESENTED PROJECTION: 10TM 115, NAD 83
FALSE NORTHING −5,000,000, FALSE EASTING +500,000
DATA CONVERTED BY: NHC IN AUGUST 2006

NOTE:

1. REFER TO FIGURE 1–2 FOR THE LOCATION OF CROSS SECTIONS

HORIZONTAL SCALE 1:60,000
VERTICAL SCALE 1:200

ALBERTA ENVIRONMENT		
GRANDE PRAIRIE FLOOD RISK MAPPING STUDY		
SURVEYED BEAR RIVER PROFILE		
Dwg. 6813–104	27 Jan 2007	**Figure 4-1**
northwest hydraulic consultants ltd.		



HORIZONTAL SCALE 1:60,000
VERTICAL SCALE 1:200

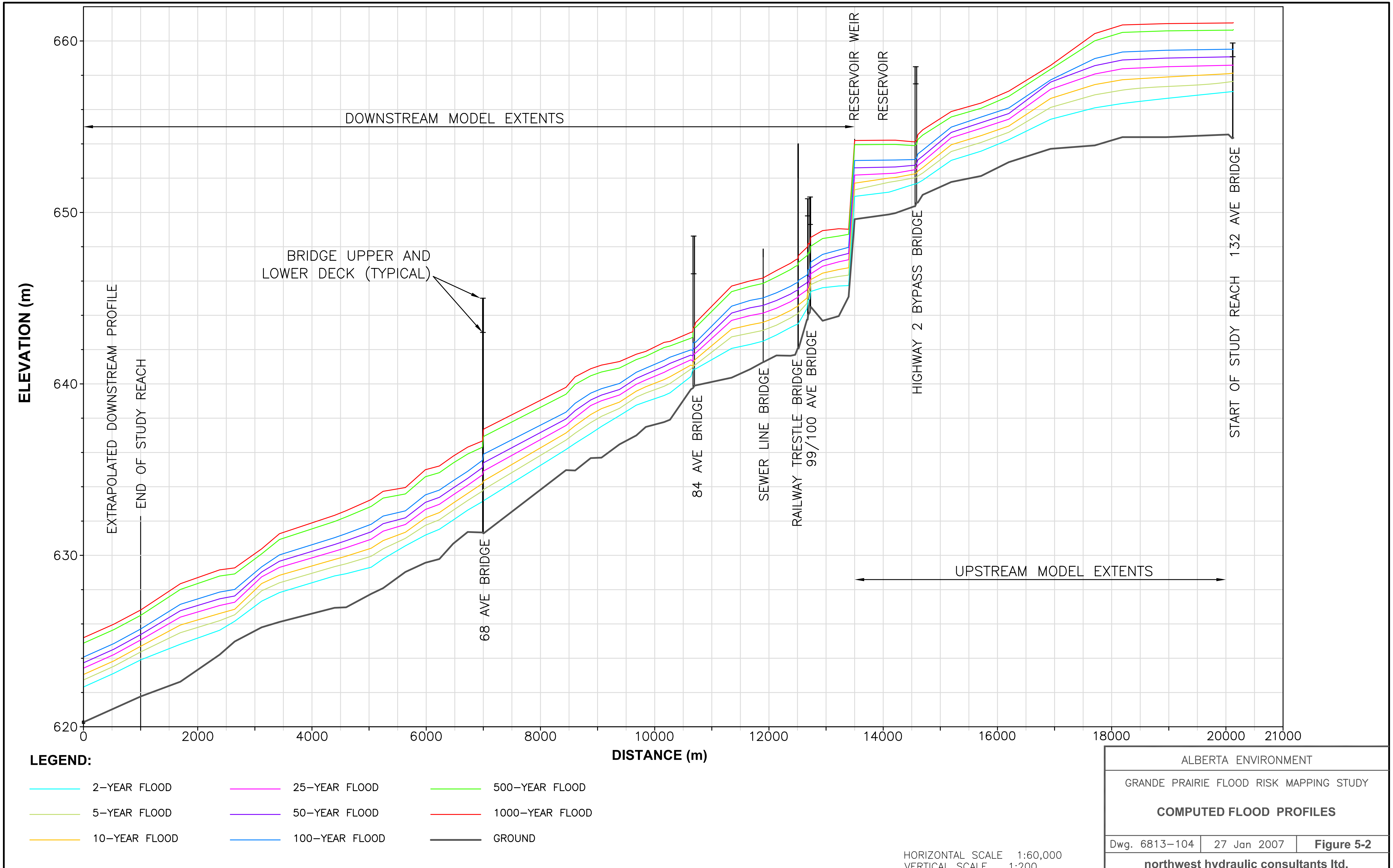
ALBERTA ENVIRONMENT

GRANDE PRAIRIE FLOOD RISK MAPPING STUDY

HECRAS MODEL CALIBRATION PROFILES

Dwg. 6813-104	27 Jan 2007	**Figure 5-1**

northwest hydraulic consultants ltd.



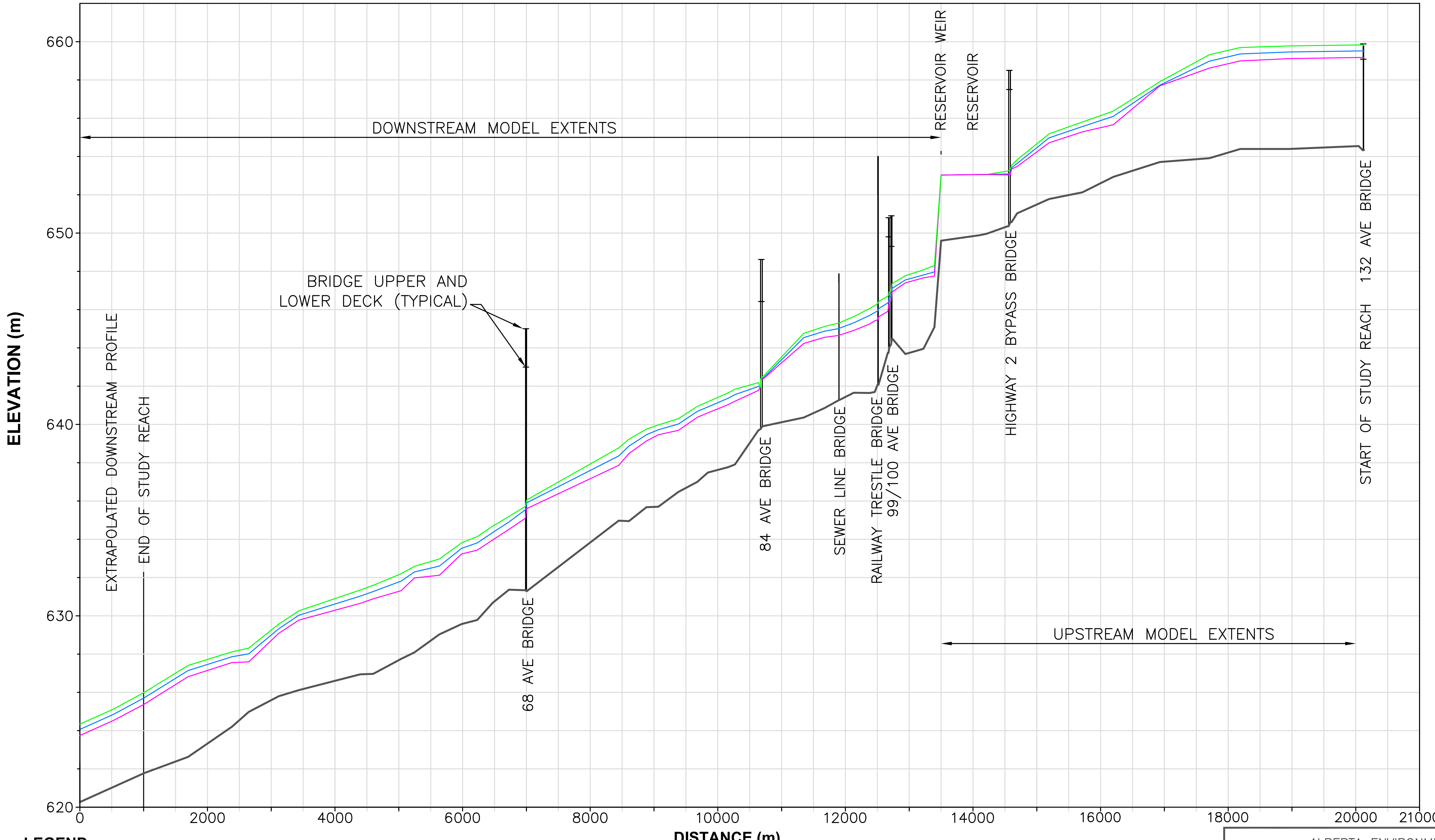
ALBERTA ENVIRONMENT

GRANDE PRAIRIE FLOOD RISK MAPPING STUDY

COMPUTED FLOOD PROFILES

Dwg. 6813–104	27 Jan 2007	**Figure 5-2**

northwest hydraulic consultants ltd.



LEGEND:

- n = 0.045 100 yr FLOOD BASE CASE
- n = 0.035 LESS ROUGH
- n = 0.055 MORE ROUGH
- GROUND

HORIZONTAL SCALE 1:60,000
VERTICAL SCALE 1:200

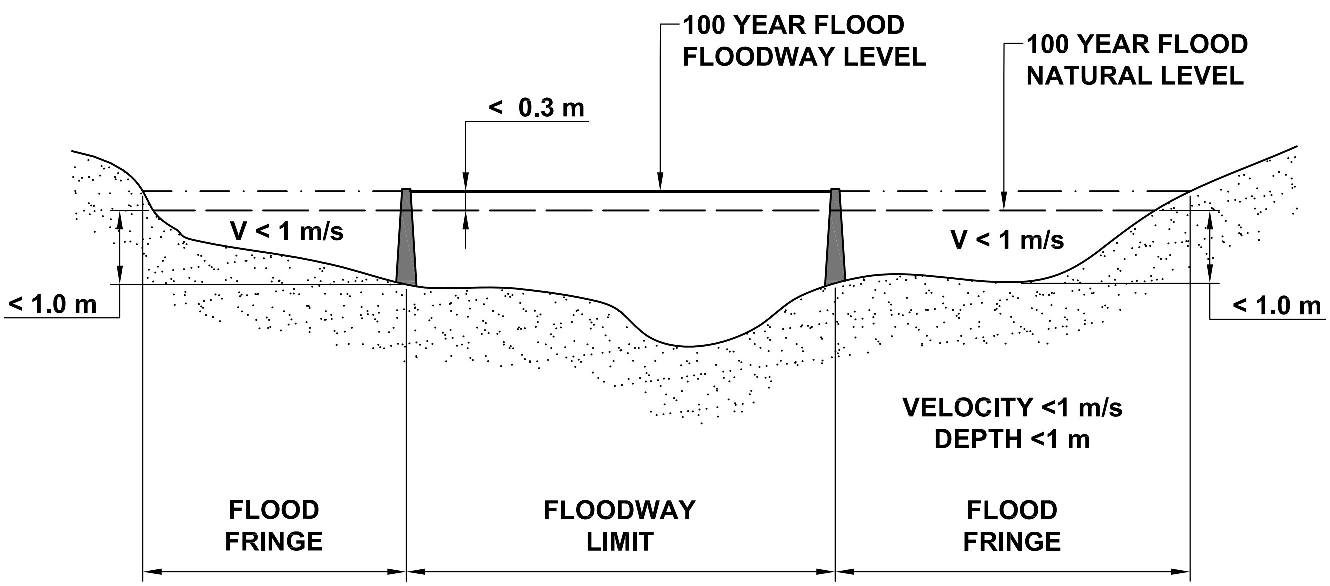
ALBERTA ENVIRONMENT

GRANDE PRAIRIE FLOOD RISK MAPPING STUDY

SENSITIVITY OF WATER LEVELS TO CHANNEL ROUGHNESS

Dwg. 6813–104	27 Jan 2007	**Figure 5-3**

northwest hydraulic consultants ltd.



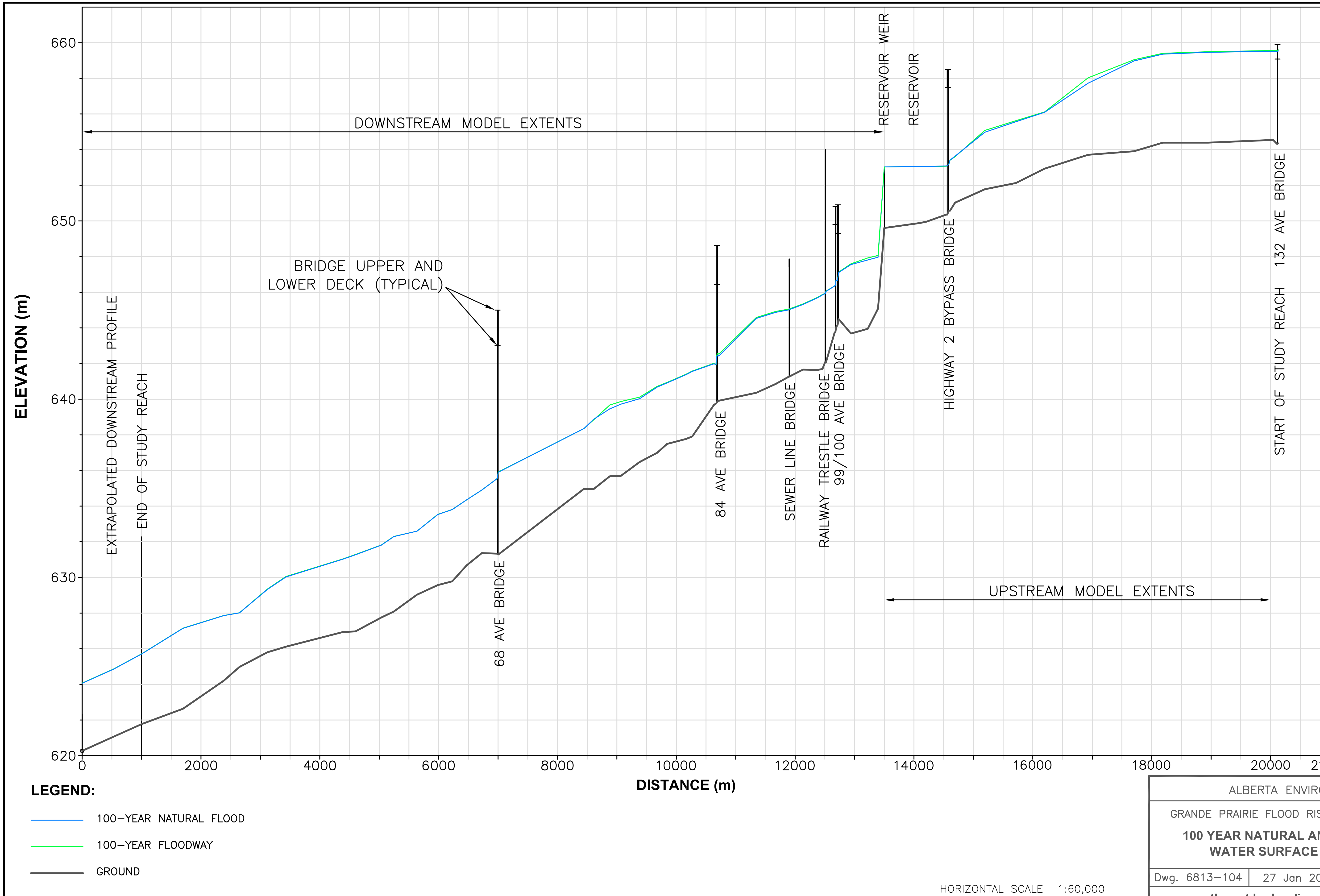
ALBERTA ENVIRONMENT

GRANDE PRAIRIE FLOOD RISK MAPPING STUDY

FLOODWAY CRITERIA SCHEMATIC

Dwg. 6813–108	27 Jan 2007	**Figure 6-1**

northwest hydraulic consultants ltd.



ALBERTA ENVIRONMENT
GRANDE PRAIRIE FLOOD RISK MAPPING STUDY
100 YEAR NATURAL AND FLOODWAY WATER SURFACE PROFILES
Dwg. 6813–104 | 27 Jan 2007 | **Figure 6-2**
northwest hydraulic consultants ltd.

PHOTOGRAPHS

Photo 1. Houses flooded during the 1935 flood. *(source: Alberta Infrastructure & Transportation)*

Photo 2. 100 Ave Bridge during the 1963 flood, viewing downstream. *(source: Alberta Infrastructure & Transportation)*

Photo 3. Looking downstream from XS 37. (100 Ave Bridge can be seen in the distance.)
(20 July 2006)

Photo 4. Railway Trestle Bridge downstream of 99 Avenue. *(20 July 2006)*

Photo 5. Looking upstream at XS 23.

Photo 6. Looking downstream from XS 10.

Photo 7. Viewing downstream at XS 32. *(21 July 2006)*

Photo 8. Beaver dam near XS 30. *(21 July 2006)*

Photo 9. Bridge at 132 Ave at the upstream study limit, looking downstream. *(19 July 2006)*

Photo 10. Looking downstream from XS 39. *(19 July 2006)*

APPENDIX A

City of Grande Prairie Flood Risk Mapping Study
Bear River Hydrology – Final Report

Prepared by:

northwest hydraulic consultants

November 2006

TECHNICAL NOTE

BEAR RIVER FLOOD HYDROLOGY
GRANDE PRAIRIE FLOOD RISK MAPPING STUDY

Submitted to:

Alberta Environment
Edmonton, Alberta

Submitted by:

Northwest Hydraulic Consultants Ltd.
Edmonton, Alberta

Prepared by:

Eugene K. Yaremko, P.Eng.

September 2006
revised November 2006

ref. 6813/5391

TABLE OF CONTENTS

1 INTRODUCTION

The Study requires delineation of the floodplain boundaries along Bear River through the city of Grande Prairie, Alberta. The Study reach as shown in Figure 1, begins at 132 Avenue at the north boundary of the city and extends approximately 10 km along the creek valley to the south end of Wedgewood golf course.

The purpose of this report is to provide a summary of our assessment of the annual flood peak risk for Bear River through the study reach. Discharges are greatly influenced by Bear Lake.

Various reports have been assembled that to some degree address Bear River flood hydrology - these reports, particularly Reference 2, have been substantially drawn upon as part of this study. These references are as follows:

- Reference 1 - "Bed Degradation on Bear Creek", Environmental Engineering Support Services, 1974.
- Reference 2 - "Bear Creek Watershed Study", Marshall Macklin Monaghan, for Alberta Environment Planning Division, March 1984.
- Reference 3 - "Bear Creek Flood Study", UMA Engineering Ltd. for Alberta Lands Inc., June 1998.
- Reference 4 - "Northwest Area Structure Plan", City of Grande Prairie, 2003.
- Reference 5 - "Bear River Reservoir, Radial gate Review", Associated Engineering for City of Grande Prairie, July 2003.

Our approach has been to draw upon considerably from findings in Reference 2 and to utilize additional Water Survey of Canada (WSC) hydrometric data that has been collected since 1983.

2 FLOOD FREQUENCIES

2.1 Background Findings

The basin and sub-basin boundaries are shown in Figure 1. Drainage areas of interest are as follows:

Bear River at confluence with Grande Prairie Creek:	1144 km^2
Grande Prairie Creek at Bear River confluence:	301 km^2
total	1444 km^2

Bear River at upstream end of study reach (132 Avenue):	1493 km^2
Sub-basin area: Grande Prairie Creek confluence to 132 Avenue:	49 km^2
Sub-basin area: 132 Avenue to downstream end of study area:	72 km^2
Bear River - downstream end of the study area:	1614 km^2

Grande Prairie Creek joins with Bear River about 1.5 km downstream of lake outlet. Clairmont Creek basin is assumed to be non-contributing.

Principal findings from Reference 2 are as follows:

- "…factors governing the magnitude of flood flows at Grande Prairie are the very large storage capacity of Bear Lake and the flat gradient of Bear River between the lake and the city of Grande Prairie."
- "The attenuation effect of Bear Lake on even the largest simulated inflows reduces outflow from the lake to negligible rates…".
- "…Fluctuations in (lake) level over the period for which lake level records are available (1960 to 2004) (ranged from Elev. 662.80 to 665.80 m); a 3 m difference…". (as a matter of interest, the recently surveyed streambed level at 132 Avenue is Elev. 664.30).
- "During most floods, flow will reverse in the section of Bear River between the lake and the confluence with Grande Prairie Creek. This flow reversal significantly reduces flood peaks in Grande Prairie."
- "The simulation of flood flows…indicates that the large size of Bear Lake, combined with its extremely limited outflow capacity, attenuates even the largest inflows to the lake to the point where outflows are not significant…".
- "With Bear Lake at an elevation of 665.0 m, about 7 to 15 percent of the total flow above the confluence of Grande Prairie Creek will enter Bear Lake for flood flows from a 10-year to 100-year event." (The corresponding percentage for a lake level of Elev. 663.5 m was computed to be about 20 to 25 percent of total flow.)
- "The flows (recommended flood peaks, with corresponding return periods) are:
    - 10-year 68 m^3/s
    - 50-year 95 m^3/s
    - 100-year 106 m^3/s

2.2 Grande Prairie Creek Flows Versus Peak Lake Levels

As shown by Table 1, the timing of Grande Prairie Creek annual flood peaks primarily occur during the spring runoff period and before Bear River reaches its annual maximum level. This was the case for 26 of the 33 years where the two dates can be compared in Table 1. Typically, the lake level during the winter and approaching spring runoff would be in the order of Elev. 663.1 m. As Grande Prairie Creek (GPC) discharge begins responding to snowmelt runoff, confluence water levels are higher than lake level, so a portion of GPC discharge begins flowing upstream along Bear River into Bear Lake. The combination of natural basin runoff into the lake, combined with GPC inflow, results in rising lake levels. The process is shown in Figure 2.

The record indicates that 1986 was a ‘wet’ year - GPC flows were relatively high. Rainfall likely worked to keep flows and thus lake levels high until the beginning of June. Note that maximum lake level occurs as GPC flow approaches zero.

The year 1992 represents a drier year than 1986, where the GPC peak was about one-third of the 1986 peak. It appears that rainfall was low during the snowmelt period. As for 1986, maximum lake level occurred as GPC flow approached zero.

It seems obvious that flows carried by GPC during the annual flood runoff period dominate Bear River flows downstream of its confluence with GPC. It has been estimated that as much as 80 percent of this flow is carried downstream to Grande Prairie, with the remaining flow travelling upstream to Bear Lake. Note that the Bear River drainage area at the confluence represents 97 percent of the drainage area at the upstream end of the study area and 93 percent at the downstream end.

2.3 Flood Frequencies (2006)

The analytical approach presented in Reference 2 is considered valid, reasonably robust, and with results applicable to the current floodplain study. Flood frequencies for Bear River have been estimated as follows:

- Flood frequency analysis of GPC annual flood peaks recorded by WSC gauge 07GE003 for period of record 1971-2003 (see Table 2).
- Adjust flood peaks to Bear River confluence - based on ratio of drainage areas raised to exponent of 0.8 $(301/157.5)^{0.8} = 1.67$.
- Adjust confluence peaks by 0.8, which represents Bear River flow downstream of confluence.

- Adjust peaks for added drainage area to upstream end of study area $(1493/1444)^{0.8} = 1.03$.
- Adjust peaks for added drainage area to downstream end of study area $(1614/1444)^{0.8} = 1.09$.

The flood peaks for the study reach downstream of the dam in Grande Prairie have not accounted for potential flood attenuation through the city reservoir. It is understood that protocol for reservoir operation requires that:

- Reservoir level during the winter months and approaching spring runoff will be at FSL of Elev. 650.4 m.
- For spring freshet period, the two radial gates at the spillway entrance are fully opened.
- At some point, primarily after freshet/rainfall runoff from GPC no longer has a significant influence on Bear Lake outflows - generally by mid-June, the gates are closed to allow the reservoir to fill. A drop of only 0.02 m of Bear Lake would be sufficient to raise the reservoir 2.5 m, so reservoir capacity is not significant. This, combined with the understanding that much of the reservoir volume has been infilled with sediment, indicates that attenuation of flood peaks would not be significant.
- During late summer/early fall, the reservoir would be drawn down to FSL.

Because no amount of reservoir attenuation has been accounted for, the flood frequencies provided in Table 2 can be considered conservative.

2.4 Regime Considerations

Based on surveyed cross sections, the channel width at what might be considered bankfull is about 11.0 m. The dominate discharge from the equation: $W = 1.8\ Q_D^{\ 1/2}$ (Imperial units) becomes 11.4 m^3/s. Typically, the dominant discharge is assumed to be representative of the 2-year flood peak. It should be noted that this discharge is reasonably close to the 2-year flood peak provided in Table 2 for the upstream end of the study area.

3 CONCLUSIONS AND RECOMMENDATIONS

Based on the approach and findings of the 1984 Marshall Macklin Monaghan study, combined with analysis of the current Grande Prairie Creek database, the recommended flood frequencies that would be applied to the floodplain study are provided in Table 3.

TABLES

TABLE 1

Timing of Annual Maximum Bear Lake Levels and Grande Prairie Creek Peaks (GPC)

Year	Maximum Lake Level *(elevation, m)*	Date	GPC Date
1970	n/a	n/a	May 2
1971	663.90	July 17	June 26
1972	665.25	May 7	April 27
1973	664.90	May 3	April 20
1974	665.80* (max)	May 3	April 25
1975	663.69	May 3	April 22
1976	664.13	April 28	April 12
1977	664.25	May 20	April 9
1978	663.50	May 1	April 29
1979	663.90	May 15	April 27
1980	663.14	May 1	April 15
1981	664.16	May 10	April 19
1982	663.80	May 13	April 29
1983	664.05	May 12	July 21
1984	663.33	July 2	June 8
1985	663.66	April 18	April 1
1986	664.12	May 20	May 6
1987	663.45	May 1	April 4
1988	663.10	May 20	July 3
1989	663.19	May 18	August 23
1990	664.50	June 15	June 12
1991	663.63	May 20	April 5
1992	663.71	April 30	April 1
1993	663.22	July 5	June 28
1994	664.60	May 1	April 22
1995	664.41	May 5	July 5
1996	665.00	May 2	April 16
1997	665.51	May 7	April 20
1998	663.60	May 1	April 7
1999	663.78	May 2	April 12
2000	663.98	May 5	September 3
2001	662.80* (min)	April 16	May 30
2002	664.34	June 1	May 14
2003	664.70	May 28	April 22
2004	n/a	n/a	July 4
2005	n/a	n/a	March 12

TABLE 2

Flood Frequencies[1]
Bear River

T (years)	GPC[2] (gauge) m^3/s	GPC/BR Confluence (x 1.67) m^3/s	BR[3] D/S of confluence (x 0.8) m^3/s	BR at U/S end of study area (x 1.03) m^3/s	BR at D/S end of study area (x 1.09) m^3/s
2	8.8	14.7	11.8	12.1	12.8
5	19.1	31.9	25.5	26.3	27.8
10	29.7	49.6	39.7	40.9	43.3
25	44.0	73.5	58.8	60.5	64.1
50	58.6	97.9	78.3	80.6	85.3
100	75.3	125.8	100.6	103.6	109.7
500	126.0	210.4	168.3	173.4	183.5
1000	150	250	200	206	218.4

[1] Based on log Normal frequency distribution (provided good fit to plotted points)

[2] GPC: Grande Prairie Creek

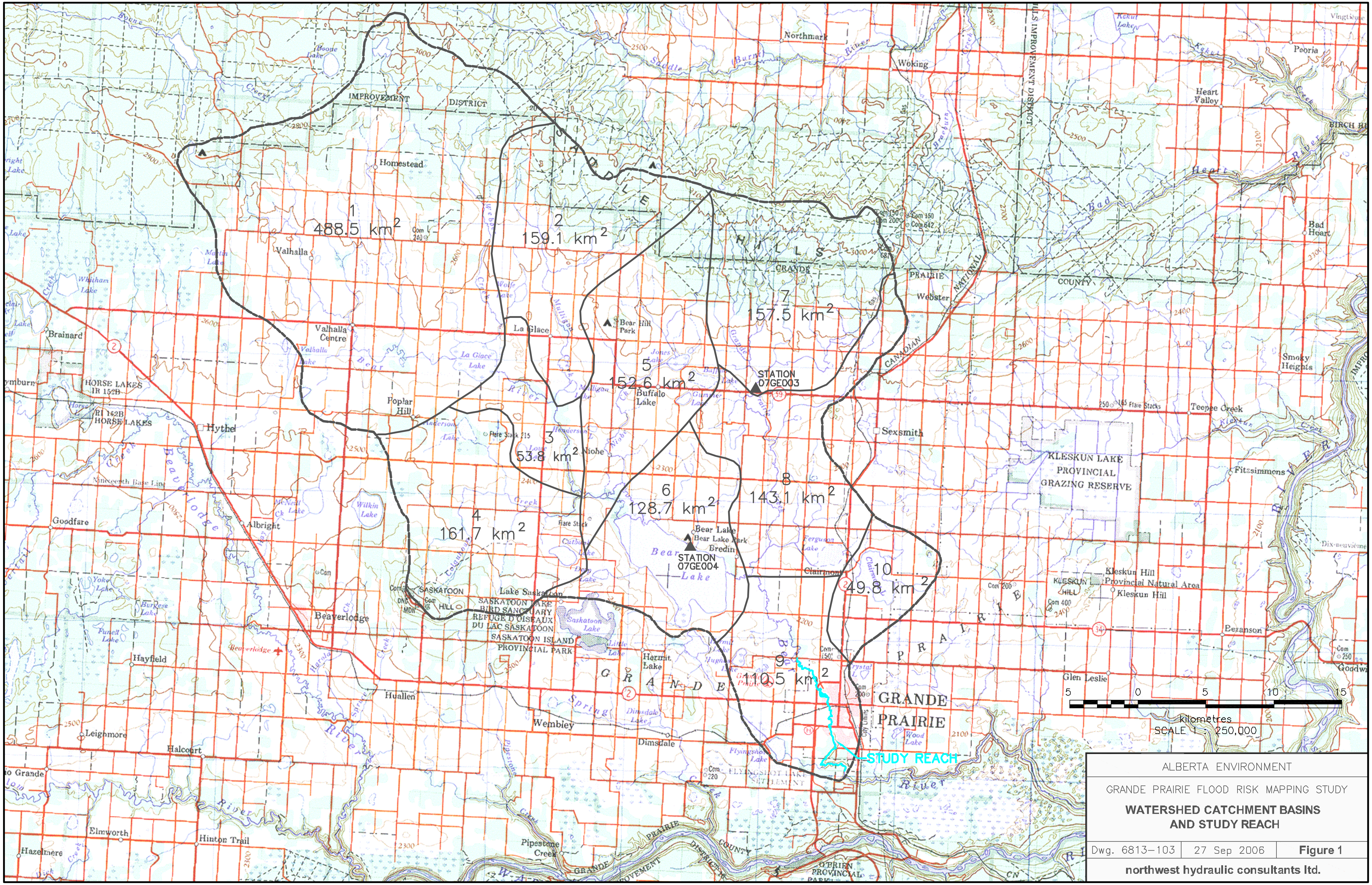
[3] BR: Bear River

TABLE 3

Recommended Flood Frequencies
City of Grande Prairie Floodplain Study

T (years)	Bear River Upstream of City Dam m^3/s	Bear River Downstream of City Dam m^3/s
2	12	13
5	26	28
10	41	43
25	61	64
50	81	85
100	104	110
500	173	184
1000	206	218

FIGURES



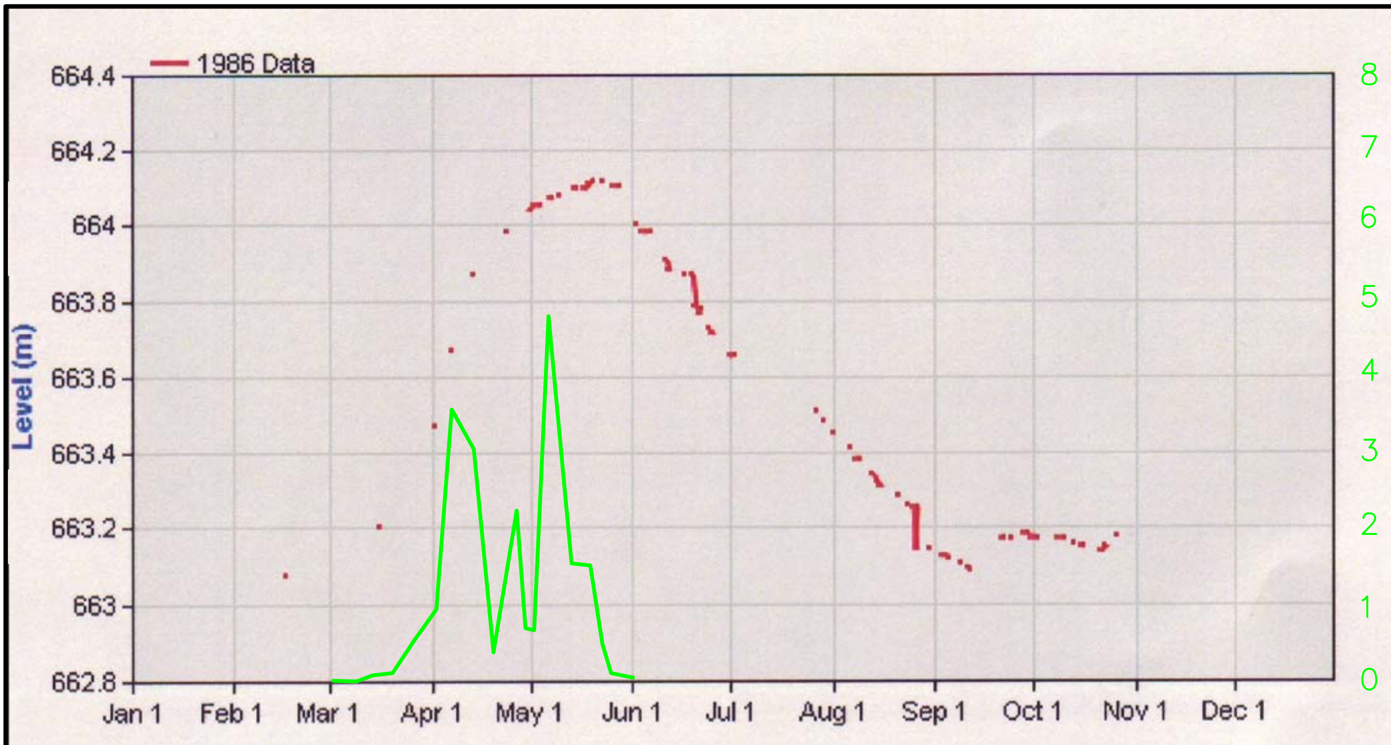
ALBERTA ENVIRONMENT

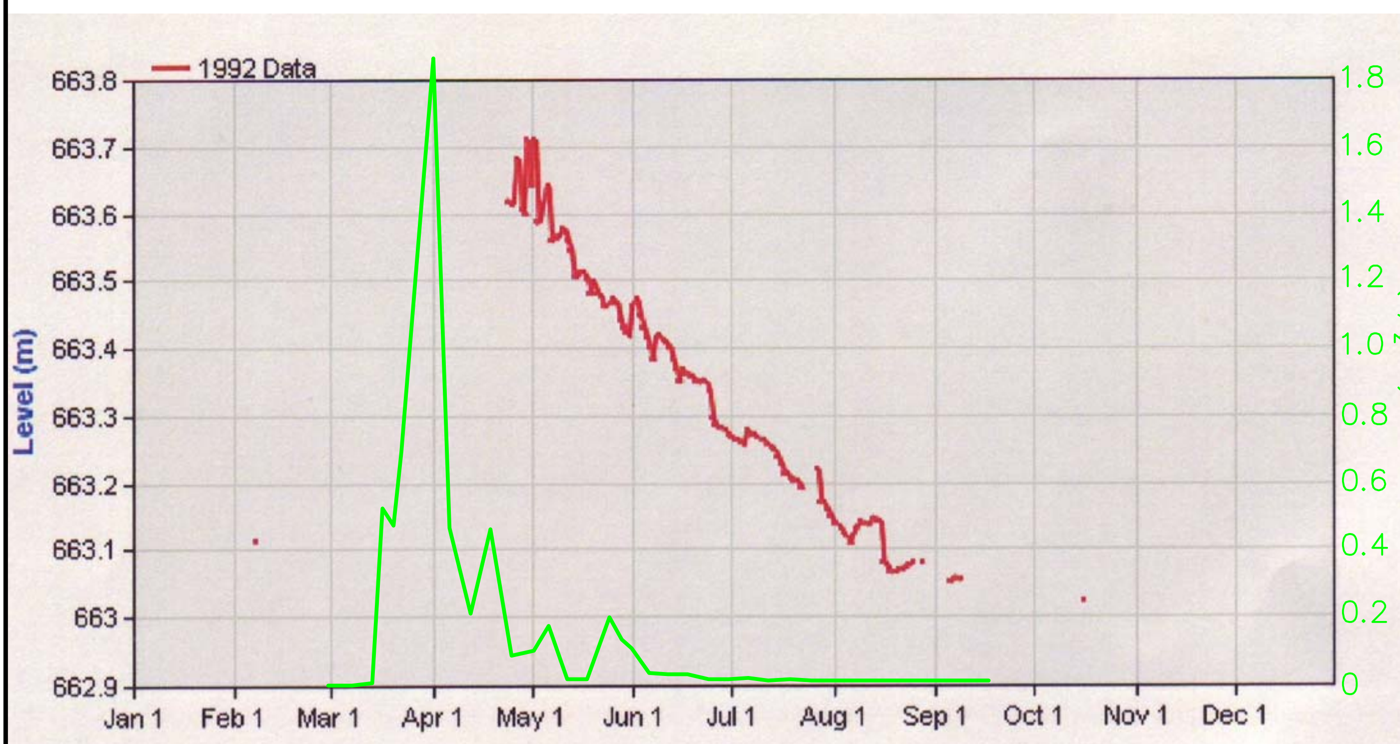
GRANDE PRAIRIE FLOOD RISK MAPPING STUDY

WATERSHED CATCHMENT BASINS AND STUDY REACH

Dwg. 6813–103	27 Sep 2006	**Figure 1**

northwest hydraulic consultants ltd.





BEAR LAKE LEVEL RECORDED AT STATION 07GE004

DAILY DISCHARGE RECORDED AT STATION 07GE003

ALBERTA ENVIRONMENT		
GRANDE PRAIRIE FLOOD RISK MAPPING STUDY		
BEAR LAKE LEVELS AND GRANDE PRAIRIE CREEK DAILY DISCHARGE		
Dwg. 6813–103	27 Sep 2006	**Figure 2**
northwest hydraulic consultants ltd.		

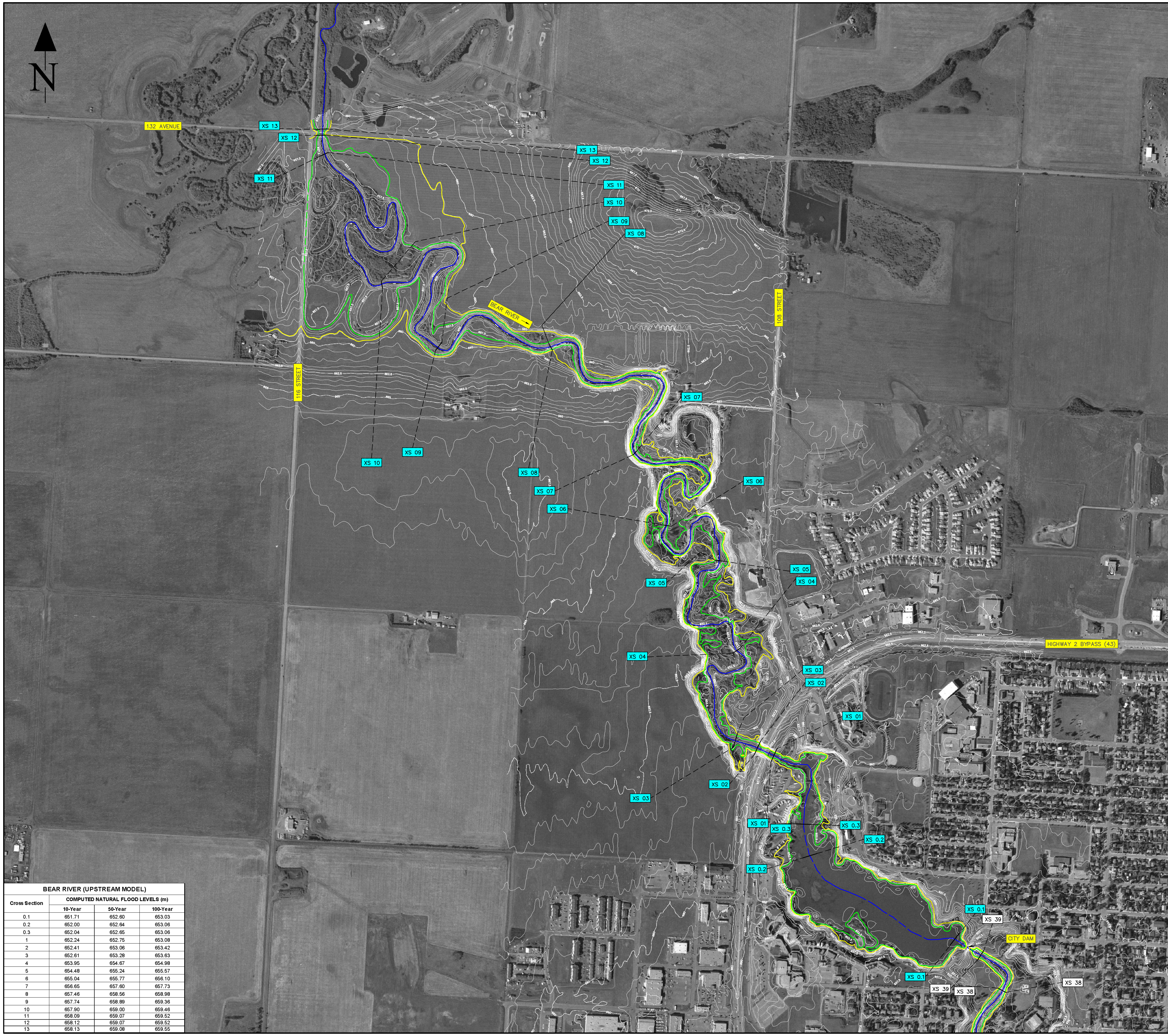
APPENDIX B

FLOOD FREQUENCY MAPS

Prepared by:

northwest hydraulic consultants

March 2007



BEAR RIVER (UPSTREAM MODEL)

Cross Section	COMPUTED NATURAL FLOOD LEVELS (m)		
	10-Year	50-Year	100-Year
0.1	651.71	652.60	653.03
0.2	652.00	652.64	653.06
0.3	652.04	652.65	653.06
1	652.24	652.75	653.08
2	652.41	653.06	653.42
3	652.61	653.28	653.63
4	653.95	654.67	654.98
5	654.48	655.24	655.57
6	655.04	655.77	656.10
7	656.65	657.60	657.73
8	657.46	658.56	658.98
9	657.74	658.89	659.36
10	657.90	659.00	659.46
11	658.09	659.07	659.52
12	658.12	659.07	659.52
13	658.13	659.08	659.55

Alberta ENVIRONMENT

LEGEND:

- FLOOD RISK LIMIT OF THE 100-YEAR FLOOD
- FLOOD RISK LIMIT OF THE 10-YEAR FLOOD
- RIVER CENTRELINE
- SURVEYED CROSS SECTION
- EXTENDED CROSS SECTION
- XS 07 CROSS SECTION NUMBER (UPSTREAM MODEL)
- XS 18 CROSS SECTION NUMBER (DOWNSTREAM MODEL)
- 2.5 METRE CONTOUR
- 0.5 METRE CONTOUR

NOTE:

WHERE ONE OF THE FLOOD RISK LIMITS IS NOT SHOWN, IT CAN BE ASSUMED TO BE COINCIDENT WITH THE NEXT HIGHER FLOOD RISK LIMIT.

WITHIN THE FLOOD LIMITS DELINEATED ON THIS MAP THERE MAY BE ISOLATED AREAS OF HIGH GROUND. TO DETERMINE WHETHER OR NOT A PARTICULAR SITE IS SUBJECT TO FLOODING, REFERENCE SHOULD BE MADE TO THE COMPUTED FLOOD LEVELS IN CONJUNCTION WITH SITE SPECIFIC SURVEYS WHERE DETAILED DEFINITION IS REQUIRED.

SCALE 1:5 000

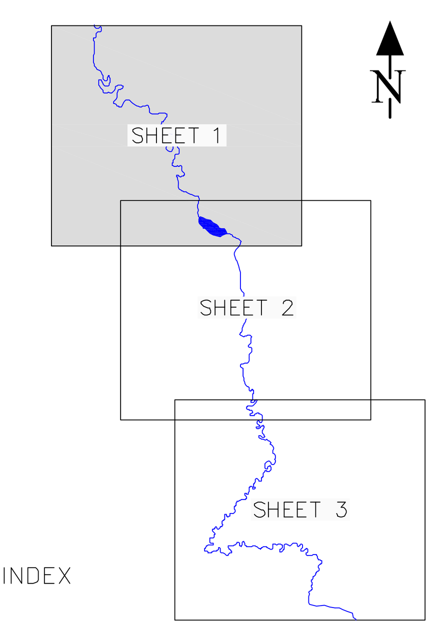
metres 0 100 200 300 400 500 600 metres
feet 0 500 1,000 1,500 2,000 feet

ORTHOPHOTO AND CONTOUR INFORMATION:

ORTHOPHOTO PROVIDED BY: CITY OF GRANDE PRAIRIE
ORTHOPHOTO DATE: 2002/2006
CONTOURS GENERATED BY: NORTHWEST HYDRAULIC CONSULTANTS LTD. BASED ON DEM INFORMATION PROVIDED BY THE CITY OF GRANDE PRAIRIE AND ALBERTA ENVIRONMENT
PROJECTION: 10TM 115°, NAD83
FALSE EASTING: +500,000 m
FALSE NORTHING: −5,000,000 m

CROSS SECTION INFORMATION:

CROSS SECTIONS SURVEYED BY: NORTHWEST HYDRAULIC CONSULTANTS LTD.
DATE OF SURVEY: JULY/AUGUST 2006



SHEET INDEX

PROJECT

GRANDE PRAIRIE FLOOD RISK MAPPING STUDY
ALBERTA FLOOD RISK MAPPING PROGRAM

FLOOD FREQUENCY MAP
SHEET 1

DESIGNED	CHECKED	DATE	JOB NO.	DRAWING NO.
E.K.Y, W.A.R.	E.K.Y.	2006 11 21	6813	6813−101
DRAFTED	APPROVED	SCALE	SHEET NO.	
S.W.T.	E.K.Y.	1: 5 000	FFM 1	

northwest hydraulic consultants ltd.

BEAR RIVER (DOWNSTREAM MODEL)			
Cross Section	COMPUTED NATURAL FLOOD LEVELS (m)		
	10-Year	50-Year	100-Year
0.1	623.05	623.73	624.06
0.2	623.84	624.52	624.85
1	624.70	625.39	625.71
2	625.94	626.77	627.14
3	626.61	627.46	627.86
4	626.86	627.63	628.01
5	628.35	629.03	629.33
6	628.84	629.66	630.03
7	629.76	630.63	631.03
8	629.95	630.86	631.27
9	630.42	631.37	631.81
10	630.86	631.85	632.29
11	631.35	632.19	632.60
12	632.18	633.09	633.53
13	632.50	633.38	633.81
14	633.05	633.93	634.35
15	633.62	634.49	634.90
16	634.18	635.10	635.53
17	634.34	635.41	635.91
18	637.14	637.96	638.35
19	637.57	638.44	638.87
20	638.21	639.06	639.46
21	638.55	639.35	639.72
22	638.94	639.67	640.02
23	639.58	640.32	640.68
24	639.83	640.56	640.92
25	640.25	641.02	641.38
26	640.42	641.20	641.56
27	641.10	641.68	641.98
27.4	641.04	641.63	641.95
27.6	641.37	642.10	642.45
28	641.43	642.08	642.42
29	643.20	644.13	644.53
30	643.45	644.44	644.87
30.4	643.59	644.58	645.01
30.6	643.60	644.59	645.02
31	643.88	644.87	645.31
32	644.28	645.24	645.69
33	644.45	645.40	645.85
33.4	644.52	645.47	645.92
33.6	644.61	645.59	646.05
34	645.01	645.90	646.35
34.1	645.26	645.97	646.40
34.9	645.56	646.26	646.67
35	645.60	646.28	646.67
36	646.09	646.76	647.11
37	646.46	647.20	647.55
38	646.67	647.47	647.81
39	646.77	647.61	647.97

Alberta
ENVIRONMENT

LEGEND:

- FLOOD RISK LIMIT OF THE 100-YEAR FLOOD
- FLOOD RISK LIMIT OF THE 10-YEAR FLOOD
- RIVER CENTRELINE
- SURVEYED CROSS SECTION
- EXTENDED CROSS SECTION
- XS 0.1 CROSS SECTION NUMBER (UPSTREAM MODEL)
- XS 18 CROSS SECTION NUMBER (DOWNSTREAM MODEL)
- 2.5 METRE CONTOUR
- 0.5 METRE CONTOUR

NOTE:

WHERE ONE OF THE FLOOD RISK LIMITS IS NOT SHOWN, IT CAN BE ASSUMED TO BE COINCIDENT WITH THE NEXT HIGHER FLOOD RISK LIMIT.

WITHIN THE FLOOD LIMITS DELINEATED ON THIS MAP THERE MAY BE ISOLATED AREAS OF HIGH GROUND. TO DETERMINE WHETHER OR NOT A PARTICULAR SITE IS SUBJECT TO FLOODING, REFERENCE SHOULD BE MADE TO THE COMPUTED FLOOD LEVELS IN CONJUNCTION WITH SITE SPECIFIC SURVEYS WHERE DETAILED DEFINITION IS REQUIRED.

SCALE 1:5 000

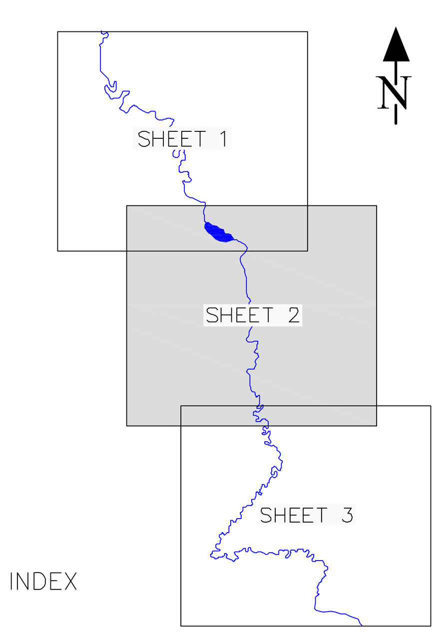
metres 0 100 200 300 400 500 600 metres
feet 0 500 1,000 1,500 2,000 feet

ORTHOPHOTO AND CONTOUR INFORMATION:

ORTHOPHOTO PROVIDED BY: CITY OF GRANDE PRAIRIE
ORTHOPHOTO DATE: 2002/2006
CONTOURS GENERATED BY: NORTHWEST HYDRAULIC CONSULTANTS LTD. BASED ON DEM INFORMATION PROVIDED BY THE CITY OF GRANDE PRAIRIE AND ALBERTA ENVIRONMENT
PROJECTION: 10TM 115°, NAD83
FALSE EASTING: +500,000 m
FALSE NORTHING: −5,000,000 m

CROSS SECTION INFORMATION:

CROSS SECTIONS SURVEYED BY: NORTHWEST HYDRAULIC CONSULTANTS LTD.
DATE OF SURVEY: JULY/AUGUST 2006



SHEET INDEX

PROJECT

GRANDE PRAIRIE FLOOD RISK MAPPING STUDY
ALBERTA FLOOD RISK MAPPING PROGRAM

FLOOD FREQUENCY MAP
SHEET 2

DESIGNED	CHECKED	DATE	JOB NO.	DRAWING NO.
E.K.Y. W.A.R.	E.K.Y.	2006 11 21	6813	6813–101
DRAFTED	APPROVED	SCALE	SHEET NO.	
S.W.T.	E.K.Y.	1: 5 000	FFM 2	

northwest hydraulic consultants ltd.

BEAR RIVER (DOWNSTREAM MODEL)			
Cross Section	COMPUTED NATURAL FLOOD LEVELS (m)		
	10-Year	50-Year	100-Year
0.1	623.05	623.73	624.06
0.2	623.84	624.52	624.85
1	624.70	625.39	625.71
2	625.94	626.77	627.14
3	626.61	627.46	627.86
4	626.86	627.63	628.01
5	628.35	629.03	629.33
6	628.84	629.66	630.03
7	629.76	630.63	631.03
8	629.95	630.86	631.27
9	630.42	631.37	631.81
10	630.86	631.85	632.29
11	631.35	632.19	632.60
12	632.18	633.09	633.53
13	632.50	633.38	633.81
14	633.05	633.93	634.35
15	633.62	634.49	634.90
16	634.18	635.10	635.53
17	634.34	635.41	635.91
18	637.14	637.96	638.35
19	637.57	638.44	638.87
20	638.21	639.06	639.46
21	638.55	639.35	639.72
22	638.94	639.67	640.02
23	639.58	640.32	640.68
24	639.83	640.56	640.92
25	640.25	641.02	641.38
26	640.42	641.20	641.56
27	641.10	641.68	641.98
27.4	641.04	641.63	641.95
27.6	641.37	642.10	642.45
28	641.43	642.08	642.42
29	643.20	644.13	644.53
30	643.45	644.44	644.87
30.4	643.59	644.58	645.01
30.6	643.60	644.59	645.02
31	643.88	644.87	645.31
32	644.28	645.24	645.69
33	644.45	645.40	645.85
33.4	644.52	645.47	645.92
33.6	644.61	645.59	646.05
34	645.01	645.90	646.35
34.1	645.26	645.97	646.40
34.9	645.56	646.26	646.67
35	645.60	646.28	646.67
36	646.09	646.76	647.11
37	646.46	647.20	647.55
38	646.67	647.47	647.81
39	646.77	647.61	647.97

Alberta ENVIRONMENT

LEGEND:

- FLOOD RISK LIMIT OF THE 100–YEAR FLOOD
- FLOOD RISK LIMIT OF THE 10–YEAR FLOOD
- RIVER CENTRELINE
- SURVEYED CROSS SECTION
- EXTENDED CROSS SECTION
- XS 07 CROSS SECTION NUMBER (UPSTREAM MODEL)
- XS 18 CROSS SECTION NUMBER (DOWNSTREAM MODEL)
- 2.5 METRE CONTOUR
- 0.5 METRE CONTOUR

NOTE:

WHERE ONE OF THE FLOOD RISK LIMITS IS NOT SHOWN, IT CAN BE ASSUMED TO BE COINCIDENT WITH THE NEXT HIGHER FLOOD RISK LIMIT.

WITHIN THE FLOOD LIMITS DELINEATED ON THIS MAP THERE MAY BE ISOLATED AREAS OF HIGH GROUND. TO DETERMINE WHETHER OR NOT A PARTICULAR SITE IS SUBJECT TO FLOODING, REFERENCE SHOULD BE MADE TO THE COMPUTED FLOOD LEVELS IN CONJUNCTION WITH SITE SPECIFIC SURVEYS WHERE DETAILED DEFINITION IS REQUIRED.

SCALE 1:5 000

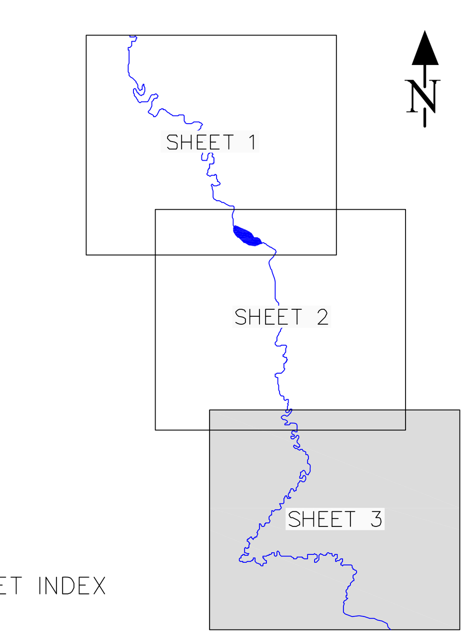
metres 0 100 200 300 400 500 600 metres
feet 0 500 1,000 1,500 2,000 feet

ORTHOPHOTO AND CONTOUR INFORMATION:

ORTHOPHOTO PROVIDED BY:	CITY OF GRANDE PRAIRIE
ORTHOPHOTO DATE:	2002/2006
CONTOURS GENERATED BY:	NORTHWEST HYDRAULIC CONSULTANTS LTD. BASED ON DEM INFORMATION PROVIDED BY THE CITY OF GRANDE PRAIRIE AND ALBERTA ENVIRONMENT
PROJECTION:	10TM 115°, NAD83 FALSE EASTING: +500,000 m FALSE NORTHING: −5,000,000 m

CROSS SECTION INFORMATION:

CROSS SECTIONS SURVEYED BY:	NORTHWEST HYDRAULIC CONSULTANTS LTD.
DATE OF SURVEY:	JULY/AUGUST 2006



SHEET INDEX

PROJECT

GRANDE PRAIRIE FLOOD RISK MAPPING STUDY
ALBERTA FLOOD RISK MAPPING PROGRAM

FLOOD FREQUENCY MAP
SHEET 3

DESIGNED	CHECKED	DATE	JOB NO.	DRAWING NO.
E.K.Y, W.A.R.	E.K.Y.	2007 02 28	6813	6813–101
DRAFTED	APPROVED	SCALE	SHEET NO.	
S.W.T.	E.K.Y.	1: 5 000	FFM 3	

northwest hydraulic consultants ltd.

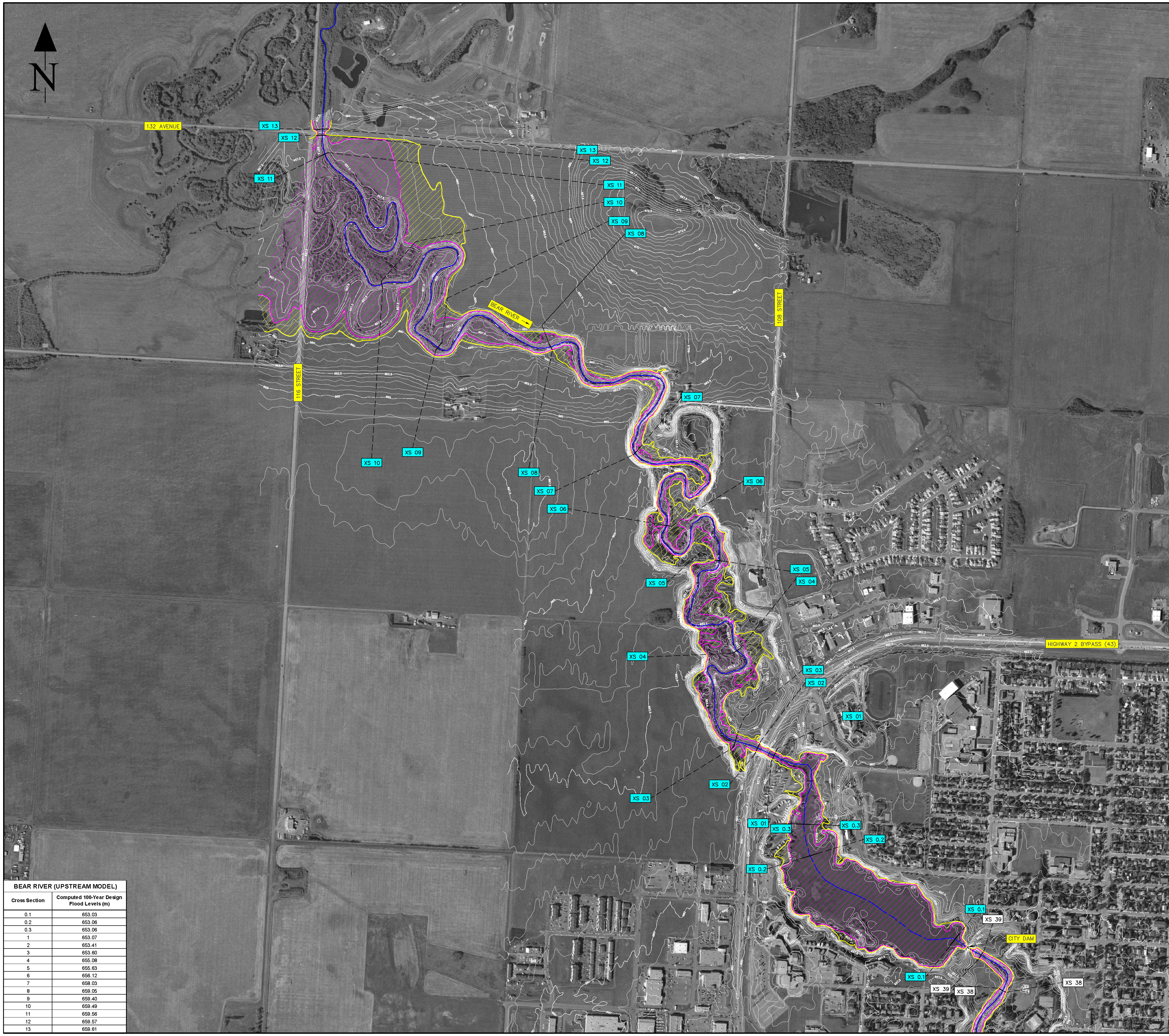
APPENDIX C

FLOOD RISK MAPS

Prepared by:

northwest hydraulic consultants

March 2007



BEAR RIVER (UPSTREAM MODEL)	
Cross Section	Computed 100-Year Design Flood Levels (m)
0.1	653.03
0.2	653.06
0.3	653.06
1	653.07
2	653.41
3	653.60
4	655.08
5	655.63
6	656.12
7	658.03
8	659.05
9	659.40
10	659.49
11	659.56
12	659.57
13	659.61

Alberta
ENVIRONMENT

LEGEND:

- FLOODWAY LIMIT OF THE 100-YEAR DESIGN FLOOD
- FLOODWAY LIMIT AREA OF THE 100-YEAR DESIGN FLOOD
- FLOOD RISK LIMIT OF THE 100-YEAR DESIGN FLOOD
- FLOOD FRINGE AREA OF THE 100-YEAR DESIGN FLOOD
- RIVER CENTRELINE
- SURVEYED CROSS SECTION
- EXTENDED CROSS SECTION
- XS 07 CROSS SECTION NUMBER (UPSTREAM MODEL)
- XS 18 CROSS SECTION NUMBER (DOWNSTREAM MODEL)
- 2.5 METRE CONTOUR
- 0.5 METRE CONTOUR

NOTE:

WHERE THE FLOOD RISK LIMIT OF THE 100-YEAR DESIGN FLOOD IS NOT SHOWN, IT CAN BE ASSUMED TO BE COINCIDENT WITH THE FLOODWAY LIMIT.

WITHIN THE FLOOD LIMITS DELINEATED ON THIS MAP THERE MAY BE ISOLATED AREAS OF HIGH GROUND. TO DETERMINE WHETHER OR NOT A PARTICULAR SITE IS SUBJECT TO FLOODING, REFERENCE SHOULD BE MADE TO THE COMPUTED FLOOD LEVELS IN CONJUNCTION WITH SITE SPECIFIC SURVEYS WHERE DETAILED DEFINITION IS REQUIRED.

SCALE 1:5 000

metres 0 100 200 300 400 500 600 metres
feet 0 500 1,000 1,500 2,000 feet

ORTHOPHOTO AND CONTOUR INFORMATION:

ORTHOPHOTO PROVIDED BY:	CITY OF GRANDE PRAIRIE
ORTHOPHOTO DATE:	2002/2006
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PROJECTION:	10TM 115°, NAD83 FALSE EASTING: +500,000 m FALSE NORTHING: −5,000,000 m

CROSS SECTION INFORMATION:

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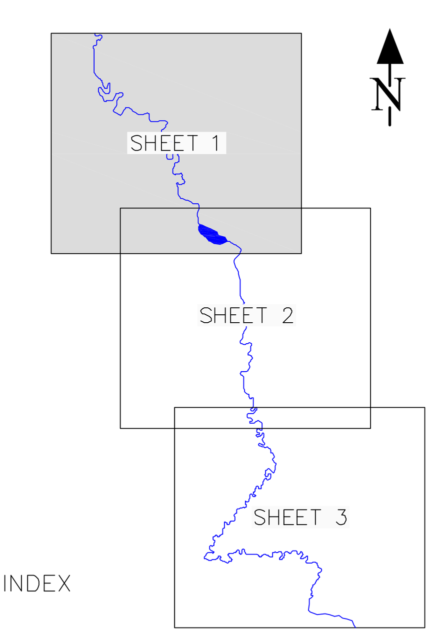
DATE OF SURVEY:	JULY/AUGUST 2006



SHEET INDEX

PROJECT

GRANDE PRAIRIE FLOOD RISK MAPPING STUDY
ALBERTA FLOOD RISK MAPPING PROGRAM

FLOOD RISK MAP
SHEET 1

DESIGNED	CHECKED	DATE	JOB NO.	DRAWING NO.
E.K.Y, W.A.R.	E.K.Y.	2006 11 21	6813	6813–101
DRAFTED: S.W.T.	APPROVED: E.K.Y.	SCALE: 1: 5 000	SHEET NO.: FRM 1	

northwest hydraulic consultants ltd.

BEAR RIVER (DOWNSTREAM MODEL)	
Cross Section	Computed 100-Year Design Flood Levels (m)
0.1	624.07
0.2	624.86
1	625.72
2	627.15
3	627.87
4	628.01
5	629.35
6	630.05
7	631.04
8	631.28
9	631.82
10	632.30
11	632.60
12	633.53
13	633.81
14	634.36
15	634.90
16	635.53
17	635.92
18	638.35
19	638.83
20	639.67
21	639.87
22	640.11
23	640.72
24	640.94
25	641.40
26	641.58
27	642.01
27.4	641.92
27.6	642.56
28	642.53
29	644.58
30	644.92
30.4	645.05
30.6	645.06
31	645.34
32	645.72
33	645.87
33.4	645.94
33.6	646.06
34	646.35
34.1	646.41
34.9	646.67
35	646.69
36	647.14
37	647.59
38	647.93
39	648.07

Alberta
ENVIRONMENT

LEGEND:

- FLOODWAY LIMIT OF THE 100-YEAR DESIGN FLOOD
- FLOODWAY LIMIT AREA OF THE 100-YEAR DESIGN FLOOD
- FLOOD RISK LIMIT OF THE 100-YEAR DESIGN FLOOD
- FLOOD FRINGE AREA OF THE 100-YEAR DESIGN FLOOD
- RIVER CENTRELINE
- SURVEYED CROSS SECTION
- EXTENDED CROSS SECTION
- XS 07 CROSS SECTION NUMBER (UPSTREAM MODEL)
- XS 18 CROSS SECTION NUMBER (DOWNSTREAM MODEL)
- 2.5 METRE CONTOUR
- 0.5 METRE CONTOUR

NOTE:

WHERE THE FLOOD RISK LIMIT OF THE 100-YEAR DESIGN FLOOD IS NOT SHOWN, IT CAN BE ASSUMED TO BE COINCIDENT WITH THE FLOODWAY LIMIT.

WITHIN THE FLOOD LIMITS DELINEATED ON THIS MAP THERE MAY BE ISOLATED AREAS OF HIGH GROUND. TO DETERMINE WHETHER OR NOT A PARTICULAR SITE IS SUBJECT TO FLOODING, REFERENCE SHOULD BE MADE TO THE COMPUTED FLOOD LEVELS IN CONJUNCTION WITH SITE SPECIFIC SURVEYS WHERE DETAILED DEFINITION IS REQUIRED.

SCALE 1:5 000

metres 0 100 200 300 400 500 600 metres
feet 0 500 1,000 1,500 2,000 feet

ORTHOPHOTO AND CONTOUR INFORMATION:

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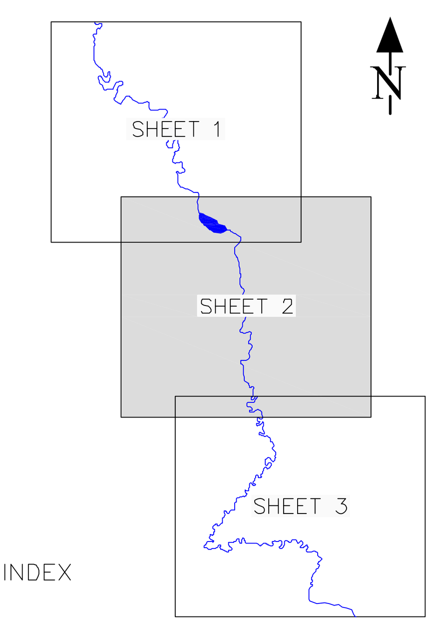

SHEET INDEX

PROJECT

GRANDE PRAIRIE FLOOD RISK MAPPING STUDY
ALBERTA FLOOD RISK MAPPING PROGRAM

FLOOD RISK MAP
SHEET 2

DESIGNED	CHECKED	DATE	JOB NO.	DRAWING NO.
E.K.Y, W.A.R.	E.K.Y.	2006 11 21	6813	6813–101
DRAFTED	APPROVED	SCALE	SHEET NO.	
S.W.T.	E.K.Y.	1: 5 000	FRM 2	

northwest hydraulic consultants ltd.

BEAR RIVER (DOWNSTREAM MODEL)	
Cross Section	Computed 100-Year Design Flood Levels (m)
0.1	624.07
0.2	624.86
1	625.72
2	627.15
3	627.87
4	628.01
5	629.35
6	630.05
7	631.04
8	631.28
9	631.82
10	632.30
11	632.60
12	633.53
13	633.81
14	634.36
15	634.90
16	635.53
17	635.92
18	638.35
19	638.83
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21	639.87
22	640.11
23	640.72
24	640.94
25	641.40
26	641.58
27	642.01
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27.6	642.56
28	642.53
29	644.58
30	644.92
30.4	645.05
30.6	645.06
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32	645.72
33	645.87
33.4	645.94
33.6	646.06
34	646.35
34.1	646.41
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35	646.69
36	647.14
37	647.59
38	647.93
39	648.07

Alberta
ENVIRONMENT

LEGEND:

- FLOODWAY LIMIT OF THE 100-YEAR DESIGN FLOOD
- FLOODWAY LIMIT AREA OF THE 100-YEAR DESIGN FLOOD
- FLOOD RISK LIMIT OF THE 100-YEAR DESIGN FLOOD
- FLOOD FRINGE AREA OF THE 100-YEAR DESIGN FLOOD
- RIVER CENTRELINE
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metres 0 100 200 300 400 500 600 metres
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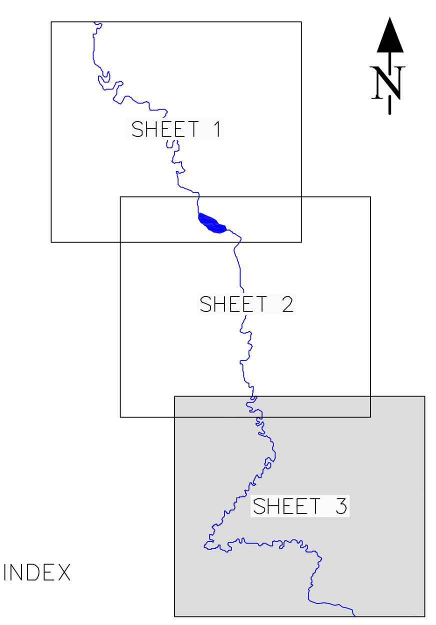

SHEET INDEX

PROJECT

GRANDE PRAIRIE FLOOD RISK MAPPING STUDY
ALBERTA FLOOD RISK MAPPING PROGRAM

FLOOD RISK MAP
SHEET 3

DESIGNED	CHECKED	DATE	JOB NO.	DRAWING NO.
E.K.Y, W.A.R.	E.K.Y.	2007 02 28	6813	
DRAFTED	APPROVED	SCALE	SHEET NO.	
S.W.T.	E.K.Y.	1: 5 000	FRM 3	6813−101

northwest hydraulic consultants ltd.