PEMBERTON VALLEY
DYKING DISTRICT

Ryan River Hydraulic Model and Dyking Assessment

Final Report
February 2009

STATEMENT OF LIMITATIONS

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KWL File No. 713.029 - 300

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CONTENTS

FIGURES

TABLES

Executive Summary

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EXECUTIVE SUMMARY

In November 2007, the Pemberton Valley Dyking District (PVDD) retained Kerr Wood Leidal Associates Ltd. (KWL) to conduct an assessment of the capacity of the existing channel and the adequacy of the existing dyking system to contain the design 200-year flood flows using a hydraulic model. The scope of work of this study includes the following:

- Information Collection: obtain background information and conduct site investigations.
- Hydrologic Investigation: update the design flood flows for the Ryan River and estimate flows for calibration event.
- Hydraulic Assessment: develop a base map of the river and infrastructure, develop a Mike 11 hydraulic model, calibrate the model, simulate the design flows, and assess the channel capacity and the adequacy of the existing dyking system.
- Reports and Meetings: project initiation and progress meetings and draft and final report preparation.

A hydrological assessment was completed to estimate the peak discharges for the Ryan River for both the October 2003 flood event, which was used as the calibration event for the model, and the 200-year design discharge. Discharge records from the Ryan River were available for the October 2003 event from a station operated by Regional Power upstream of the study area. However, it is believed that the rating curve used to estimate the discharges may be underestimating the larger discharge values. Using the Regional Power Record to calculate unit run off from the Upper Ryan River results in a value less than half of that recorded on Pemberton Creek and was lower than the unit runoff for the Lillooet River. Therefore, the Regional Power data was disregarded and a linear interpolation of the unit runoff versus drainage area using Pemberton Creek and Lillooet River was used to estimate peak 2003 discharge at the upstream end of the study area. Using this approach, the peak discharge for the 2003 event was estimated to be approximately 450 m^3/s.

A regional flood analysis was conducted to estimate the 200-year peak discharge (Q200) for the Ryan River. This analysis used historical Water Survey of Canada records from the Coquihalla at Needle, Lillooet River near Pemberton, Birkenhead River near the Mouth, and Cheakamus River above the Miller Creek plus Cheakamus near Mons combined gauges to develop regional Mean Annual Flood (MAF) versus drainage area estimates and regional normalized MAF versus Q200 Ratios. Based on this analysis, the peak Q200 was estimated to be 560 m^3/s. This is lower than the less detailed assessment estimate prepared by D. Reksten for the Lillooet River Corridor Study prepared by KWL in 2002. However, it is roughly equal to that used in the older 1992 floodplain mapping study.

The hydraulic assessment of the Ryan River was completed using an update to the model developed for the Lillooet River Corridor Study. These updates included extending the Ryan River model branch to the upstream end of the study areas and adding river cross-section data surveyed in 2006, bridge crossings at Pemberton Meadows Road and the PVDD Gravel Pit access, floodplain storage reaches, and a weir to represent the dyke breach that occurred during the October 2003 flood event. The model was calibrated using the peak flow estimates prepared during the hydrological assessment. The Manning's "n" roughness values used in the model were adjusted until good match was established between modelled water level profiles and surveyed high water marks from the October 2003 event.

Once calibrated, the model was used to develop Q200 flood profiles along the Ryan River. These profiles assumed that dykes would be upgraded such that no overtopping would occur into the floodplain between the Ryan River and Lillooet River dykes. This analysis indicates that a significant length (approximately 10.8 km or 70%) of the existing Ryan River dyke is below the modelled Q200 water level. A comparison was made between the modelled Q200 water surface profile and the MoE 1992 floodplain levels. This indicated that, in general, the design water profile in this study is higher than the original 1992 mapping, especially at the upstream end of the study area. This is likely the result of the high Manning's "n" values (0.055 to 0.065) that were needed in order to calibrate the model in this area. The higher roughness used in the upper reaches of the model may be the result of a possible debris flood or sustainable aggradation which occurred in this area in 2003 which would have increased water levels in this area above "clear water" conditions.

Based on the results of the Ryan River hydraulic modelling, this report includes the following recommendations:

1. Further research be conducted to assess the influence of debris flows and debris floods on the upper section of the dyked reach of the Ryan River in order to refine the freeboard allowance criteria in this section.

2. A conceptual plan be prepared to assess flood protection improvement options for the Ryan River. This plan should review environmental impacts, flooding impacts, and capital costs of raising existing dykes to meet the design profile compared with other options such as offset dykes or spillways to allow controlled overflow into the floodplain.

3. Continue on-going monitoring of dyke crest gauges during flood events to allow sufficient warning time for evacuation of local residences.

4. Install a hydrometric station near the upstream end of the study area to provide a system for flood forecasting and warning for the Ryan River.

Section 1

Introduction

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1. INTRODUCTION

1.1 BACKGROUND

The Ryan River has a drainage area of approximately 419 km^2 and is a tributary to the Lillooet River. The lower portion of the present day Ryan River was the main channel for the Lillooet River prior to the Mackenzie Cut (over 50 years ago). The Ryan River watershed is a steep catchment that experiences flooding under a variety of climatic conditions. The Ryan River and its tributary creeks are known to have debris flow and debris flood potential. The river does not have any long-term flow or water level gauges within the study area, and, as a result, previous flow estimations required regional hydrologic analyses.

In 2002, Kerr Wood Leidal Associates Ltd. (KWL) conducted an "Engineering Study for the Lillooet River Corridor" that included some assessment and recommendations related to the Ryan River. This study recommended that additional cross-sections be surveyed for the Ryan River, detailed river modelling be conducted, sediment process be evaluated, and an appropriate management plan be developed for the area (Areas 2 and 3).

During the 2003 Pemberton flood, a dyke breach and riprap failures occurred on the Ryan River. A substantial amount of material was deposited and transported within the channel. A high water mark survey of the flood was conducted which was used for flood documentation and could also be used for hydraulic model calibration.

In 2005, the PVDD submitted an application for funding under the Provincial Natural Hazard Mitigation Fund (NHMF) to conduct a survey of the Ryan River in order to enable the modelling and assessment of the need for sediment removal and dyke construction and/or upgrades. This funding application was not approved.

KWL conducted a high level review of the dyke levels relative to the 1990 floodplain mapping. By comparing the floodplain mapping, to a limited dyke crest survey (spot shots), KWL found that the existing dyke is below the design flood elevation over an appreciable length. In addition to this, the Q200 design flow used for the 1990 floodplain mapping is lower than the Q200 design flows estimated in 2002 by KWL. This did not take into account any channel aggradations since 1990, which would worsen the situation. Without a recent river survey and an updated hydraulic assessment (modelling), it was not possible to predict the degree to which the dykes are low.

The PVDD continued to seek provincial funding throughout 2005 and 2006, however, the Province indicated that funding was not available at those times.

In 2006, KWL conducted a survey of the Ryan River for the PVDD in order to provide the basis for an assessment of the existing channel capacity, the adequacy of the dyking system, and the need for sediment removal. The survey included 44 cross sections of the river channel and dykes over a 15 km distance starting at the downstream confluence with the Lillooet River. The cross-sections indicate that some areas have aggraded, however, an assessment of the net aggradations or degradation for each cross section was not conducted as a part of that project. Also, the survey confirmed that the dyke is low as compared to the 1990 design Q200 flood level.

1.2 SCOPE OF WORK

In November 2007, the PVDD retained KWL to conduct an assessment of the capacity of the existing channel and the adequacy of the existing dyking system to contain the design Q200 flood flows using a hydraulic model. The scope of work of this study includes the following:

- Information Collection: obtain collection and conduct site investigations.
- Hydrologic Investigation: update the design flood flows for the Ryan River and estimate flows for calibration event.
- Hydraulic Assessment: develop a baseplan of the river and infrastructure, develop a Mike 11 hydraulic model, calibrate the model, simulate the design flows, and assess the channel capacity and the adequacy of the existing dyking system.
- Reports and Meetings: project initiation and progress meetings and draft and final report preparation.

1.3 STUDY AREA

The study area included in this assessment extends from the upstream end of the PVDD Ryan River Dyke to the confluence of the Ryan River and Lillooet Rivers. A location plan showing the extent of the study area is shown in Figure 1.

The study area covers the lower reaches of the Ryan River. The most upstream reach of the Ryan River in the study area (approx 1 km long) consists of a braided channel within the Ryan River fan with an average gradient of 0.95%. Downstream of this section there is an abrupt change in the gradient of the channel at the edge of the fan with the average decreasing to 0.11%. Below this change in gradient is the middle section of the study area (approx. 7 km long) which consists of a non-braided slightly meandering channel with some gravel bars. In the lower 8 km of the study area, the gradient further reduces to an average of 0.08%, the size of the meanders increase, and the gradient reduces further. This lower portion of the Ryan River flows in the historic channel of the Lillooet River, which was diverted to its current location as part of the Mackenzie Cut.

The hydraulic model used in this study extends beyond the bounds of the lower reaches of the Ryan River. The model was initially developed for the "Engineering Study for the Lillooet River Corridor" produced by KWL in 2002 and includes the Lillooet River from the Upper Forestry Bridge to Lillooet Lake. It includes the lower reaches of the other major tributaries including Miller Creek, Pemberton Creek, Green River, and Lillooet River. Further details about the hydraulic model are discussed in Section 3 of this report.

1.4 PROJECT TEAM

KERR WOOD LEIDAL ASSOCIATES LTD.

- Mike Currie, Technical Reviewer
- Stefan Joyce, Project Manager
- Jack Lau, GIS and CADD Technologist
- Craig Sutherland, Project Engineer and Modeller
- Wendy Yao, Senior Modeller

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- Jeff Westlake, Operations and Maintenance Manager

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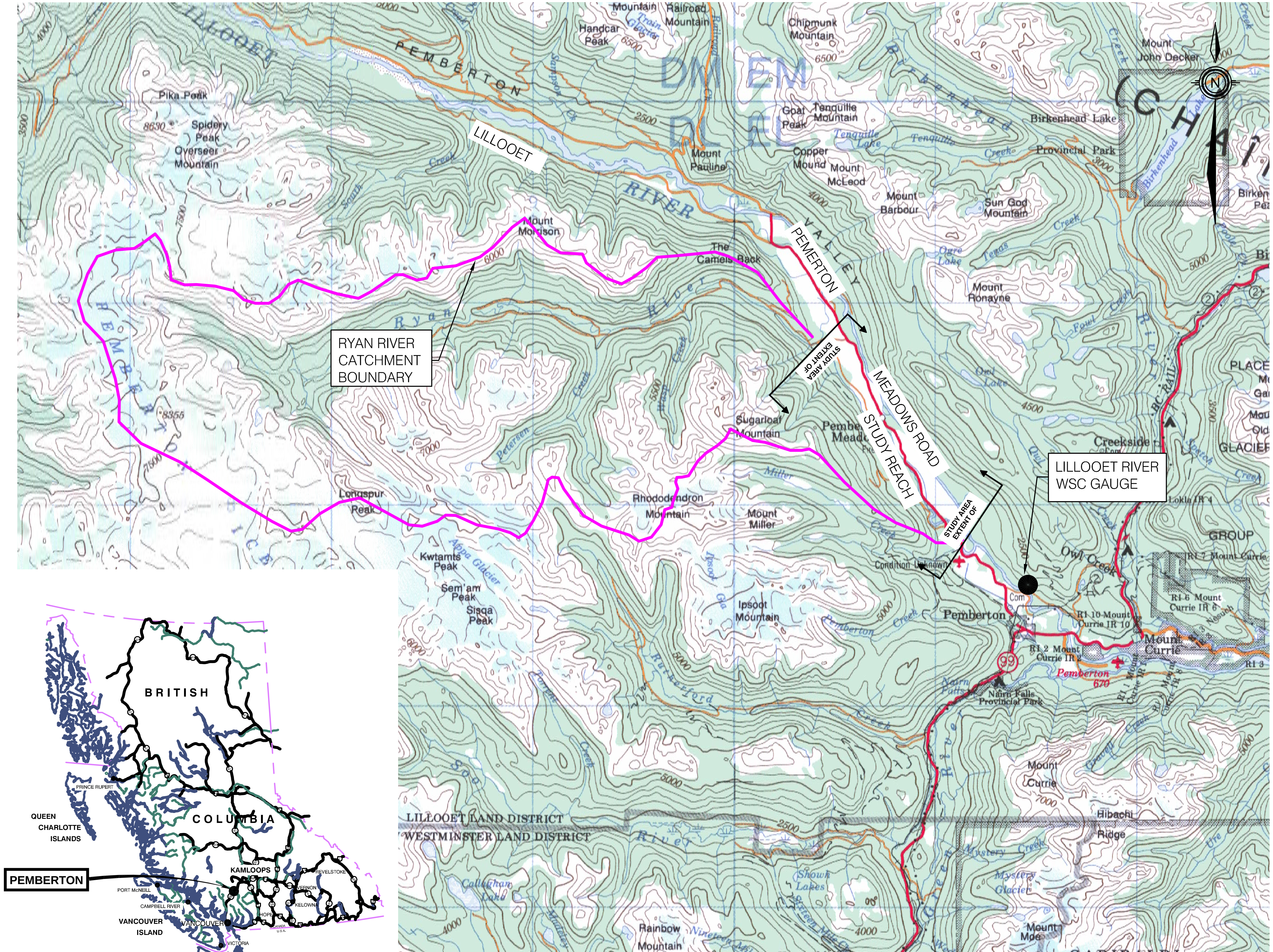
RYAN RIVER HYDRAULIC MODELLING



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Scale in Metres 1:200000

Project No.	Date
713.029	JUNE 2008

LOCATION PLAN

FIGURE 1

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Section 2

Hydrology

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2. HYDROLOGY

2.1 HISTORICAL FLOODING

There are two dominant climatic factors that result in peak flows in the Pemberton Valley. The first is summer flooding from snow and glacier melt flows (mainly in July when seasonal high temperatures occur) and/or large summer rainfall events. The second is intense fall and early winter rainstorms or rain on snow events. The latter event typically produces the highest flood flows.

The fall and early winter rainstorms can be exacerbated by rapid rises in temperature due to warm fronts originating from subtropical zones in the Central Pacific, sometimes referred to as a "Pineapple Express". The highest peak river flows typically result from warm rain falling on shallow autumn snow, contributing to rapid snowmelt. This type of flooding usually occurs in October or November before the snowpack is of sufficient thickness to absorb much rain before releasing it to the lower ground and when the temperature is typically warm enough to produce rain in the entire watershed (as opposed to later in the season when the higher elevations are more likely to experience snow).

Major flood events in the Pemberton Valley occurred in October 1940, July 1948, October 1984, August 1991, and October 2003. Localized flooding also occurred in several lesser events since the 1940s.

2.2 OCTOBER 2003 CALIBRATION EVENT

For a period of about 12 days in mid October 2003, the Pacific Northwest was assailed by flows of warm wet air originating from the subtropical regions of the central Pacific Ocean. These events were directed against the South Coast of B.C. commencing on October 16. Rainfall records were set in Squamish with 239 mm in two days, 318 mm in three days, and 369 mm in four days. The Elaho River watershed in the Upper Squamish Valley experienced what early reports said was the greatest four-day deluge in B.C.'s history – 600 mm (Times Colonist October 21, 2003).

The series of low pressure fronts resulted in the rapid rise of river levels starting on about October 17. Flooding was particularly damaging in the Squamish – Pemberton corridor.

Washouts on October 18 on the Cheakamus River and Rutherford Creek closed Highway 99 and the BC Railway. Peak discharges were reached on October 18 and 19, and lesser secondary peaks occurred on October 20 and 22. The flood isolated the Pemberton area due to closure of all road and rail access routes. The flood also necessitated the evacuation of hundreds of people and damaged about 140 homes. On October 18, four motorists were killed when the Rutherford Creek Bridge on Highway 99 between Whistler and Pemberton washed out.

During the October 2003 event, water levels along the lower reaches of the Ryan River reached flood stage. The Ryan River dyke was overtopped near its upstream end, causing a breach of the dyke and local flooding. The PVDD repaired the approximately 75 m long breach as an emergency response activity.

Other flood response activities included unblocking one of four flap-gate culverts at an un-named slough and the reinforcement of low areas on the Boneyard dyke. Boils were observed at the Boneyard dyke with minor transport of sand.

Discharge records from the Water Survey of Canada (WSC) gauge on the Lillooet River (08MG005) indicate that the October 2003 event resulted in a peak instantaneous discharge of 1,490 m^3/s, the highest recorded discharge on record and just slightly smaller than the estimated peak Q200 discharge of 1,520 m^3/s. Although the Lillooet mainstream discharges approached the peak Q200 level, the local tributary discharges did not reach the same extreme level. The recorded peak instantaneous discharge for Pemberton Creek was 37.4 m^3/s, which is estimated to only have a return period of approximately 50-years.

No discharge records are available for the October 2003 event on the Ryan River within the study area. Water levels were recorded on the Ryan River approximately 13 km upstream of the study area by Ryan River Hydro near the location of the proposed small hydro project. As their objective is to monitor low flows for hydro production purposes, the rating curve developed for the site is accurate for low to medium flows. However, the accuracy of high to extreme discharges is questionable because the rating curve used to estimate the flows has been extrapolated from discharges measured at significantly lower water levels. The Ryan River Hydro flow records also indicate that the unit peak runoff (discharge per unit watershed area) is smaller than the recorded values for both the Lillooet River and Pemberton Creek. Consequently, the Ryan River Hydro data was not used to estimate flood flows.

The peak discharge for the October 2003 event for the lower Ryan River was estimated using unit runoff values for the Lillooet River and for Pemberton Creek. The unit runoff value for Ryan River was interpolated using the catchment areas of the Lillooet River and Pemberton River (see Table 2-1).

Table 2-1: October 2003 Flood Event Peak Discharges

Gauge	Drainage Area (km^2)	Peak Discharge (m^3/s)	Peak Unit Runoff ($L/s/km^2$)	Comment
Recorded Values				
Lillooet River near Pemberton	2,160	1,490	690	Water Survey of Canada Gauge.
Pemberton Creek near Pemberton	32	37.4	1,172	Water Survey of Canada Gauge.
Upper Ryan River	222	119	536	Private gauge operated by Ryan River Power. Unit runoff appears to be too low. Records from this gauge have not been included in the analysis.
Estimated Values used for Hydraulic Model Boundary Conditions[1]				
Ryan River	419	454	1,085	Input hydrograph developed by scaling discharge records for the Upper Ryan River gauge.
Lillooet River at Upper Forestry Bridge	1,570	1293	824	Input hydrograph developed by scaling discharge records for the Lillooet River near Pemberton gauge.
Miller Creek	78	90.6	1,162	Input hydrograph developed by scaling discharge records for the Pemberton Creek gauge.
Pemberton Creek	51	59.6	1,168	Input hydrograph developed by scaling discharge records for the Pemberton Creek gauge.
Green River	868	853	983	Input hydrograph developed by scaling discharge records for the Lillooet River near Pemberton gauge.
Birkenhead River	638	660	1,034	Input hydrograph developed by scaling discharge records for the Lillooet River near Pemberton gauge.
Note: October 2003 boundary conditions estimated using relationship between unit runoff and drainage area established utilizing records from Lillooet River and Pemberton Creek.				

The input hydrographs used as boundary conditions in the October 2003 calibration have been developed by scaling the recorded hydrographs for the Lillooet River and Pemberton Creek (see comments in Table 2-1). The shape and timing of the hydrographs for the October 2003 calibration event are shown in Figure 2. The recorded water levels for Pemberton Lake were used as the downstream boundary condition for the hydraulic model.

2.3 PEAK DESIGN FLOW BOUNDARY CONDITIONS

Peak design discharge estimates have been developed for the Ryan River in the past for the Lillooet River Corridor Study in 2002 and the Provincial Floodplain Mapping project in 1992. In order to review and update the previous design event estimates, a regional flood frequency analysis was carried out. This procedure uses annual peak discharge records from several regional hydrometric stations to develop mean annual flood discharge (MAF) versus drainage area and design peak flow versus mean annual flood ratios (Cr) to estimate design peak flows at ungauged locations.

A preliminary screening of regional stations was conducted to select a group of local stations having similar physical characteristics as the Ryan River catchment using the following criteria:

- watershed at least partially within hydrologic region 25 or 26 (Obedkoff, 2003);
- watershed area between 0.1 and 10 times the Ryan River Watershed area;
- minimum 8 years of data with records within the last 20 years;
- must no have significant regulation; and
- have MAR between 1,000 and 2,500 mm.

This group of stations was then further statistically screened using an L-moment analysis. The statistical test that describes the scale and shape of distributions can be used to measure the statistical similarity of distributions. The results of the screening and the stations selected are shown in Table 2-2.

A regression of the mean annual flood discharge versus drainage area and mean basin elevation was established for the selected regional stations including Coquihalla River at Needle, Lillooet River, Birkenhead River, Pemberton Creek, and Cheakamus River above Millar Creek as shown below:

$MAF = 0.753A^{0.950} \times E^{-0.102}$ where A is watershed area in square kilometres and E is average watershed elevation in metres.

The results of this regression indicate that a strong correlation exists between drainage area and mean basin elevation and the MAF, the regression having an R2 value of 99%. This regression was used to estimate a MAF of 109 m^3/s at the mouth of the Ryan River. The average Cr Ratio (Ratio of the Daily Q200 to Daily Mean Annual Flow) and average I/D Ratio (Instantaneous Flow to Daily Flow) from selected regional stations was then used to scale the MAF to a Q200 instantaneous discharge of 560 m^3/s, as shown below:

Q200 = Cr x 1/0 x MAF
Q200 = 3.664 x 1.38 x MAF

A comparison of the Q200 discharge estimated using the regional analysis approach and previous Q200 estimates prepared by D. Reksten for KWL in 2002 indicate that the new estimate is approximately 90 m^3/s lower. The 2002 estimate used records from Soo River and Rutherford Creek to estimate flood flows on the Ryan River. However, the new regional analysis indicates that these records may not be representative of the conditions on the Ryan River. This is likely due to both of these rivers being in a wetter hydrological region than Ryan River and the fact that the records for both Soo River and Rutherford Creek only cover the period from 1924 to 1947 which may not be representative of existing climate and watershed conditions. The new estimate is also closer to the original 1992 Ministry of Environment's (MoE) estimate prepared for the floodplain mapping study.

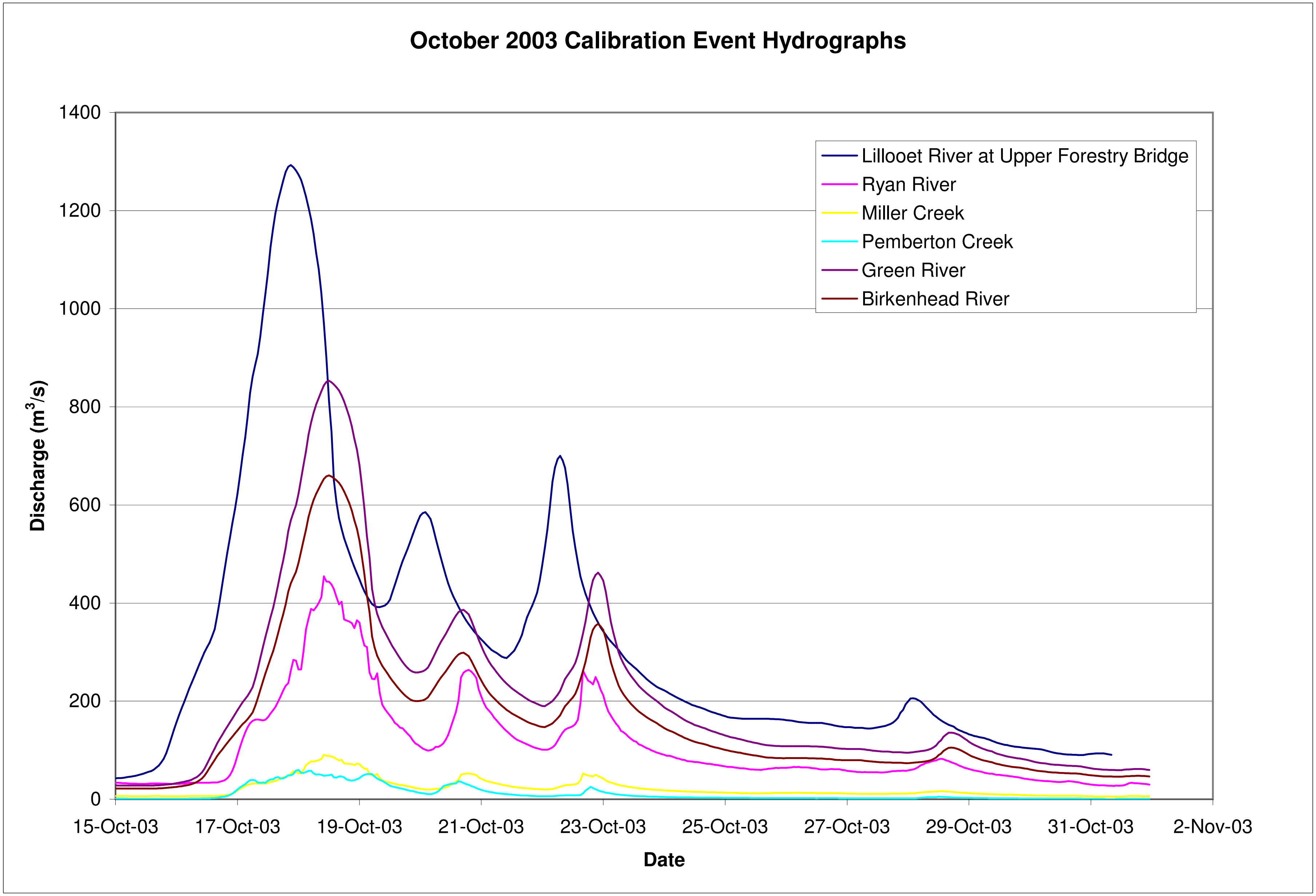
The shapes of the hydrographs used for the design Q200 model run are similar to those used in the calibration run. The same relative timing of peaks was used as in the calibration run. Input hydrographs is shown in Figure 3.

The peak water level in Lillooet Lake at the downstream end of the model is the same as that used in the original Lillooet River Study. No further analysis on Lillooet Lake levels was completed because there is no influence on water levels in Ryan River from Lillooet Lake levels.

Table 2-2: Regional Hydrometric Stations Selected for Regional Flood Frequency Analysis

Hydrometric Station Name	WSC Gauge #	Region[2]	Area[3] (km^2)	Mean Annual Runoff[4] (mm)	MAF (m^3/s)	Mean Basin Elevation (m)	I:D ratio	MaxQ (inst) (m^3/s)	MAF unit flow ($m^3/s/km^2$)	Max: MAF
Ryan River	-	26	419	-	-	1,730	-	-	-	-
Coquihalla - Needle	08MF062	26	79.9	1,330	23.2	1,380	1.26	65.3	0.290	2.8
Lillooet	08MG005	26	2,160	1,770	547	1,320	1.12	1,490	0.253	2.7
Nahatlatch[1]	08MF065	26	715	1,580	209	1,540	1.24	422	0.292	2.0
Birkenhead	08MG008	26	596	-	126.5	1,550	-	-	0.212	-
Pemberton	08MG025	26	31.9	1,520	11.8	1,410	1.55	32.1	0.370	2.7
Cheakamus R. above Millar Ck./Mons (combined)	08GA072/ 08GA024	25	285	2,150	98.6	1,740	1.11	331	0.346	3.4
Mamquam R. above Mashiter Ck.[1]	08GA054	25	334	2,409	153.7	1,187	1.62	369	0.460	2.4
Rutherford Creek near Pemberton[1]	08MG006	25	179	2,082	83.3	1,520	-	-	0.465	-
Soo River near Pemberton[1]	08MG007	25	283	2,117	103.2	1,420	-	-	0.365	-

Notes:
1. Excluded on the basis of L-moment analysis.
2. Watershed area must lie at least partly within Hydrologic Zone 25 or 26 (Obedkoff, 2003).
3. Watershed area must be between 0.1 and 10 times subject watershed.
4. Mean Annual Runoff between 1,000 mm to 2,500 mm.


October 2003 Calibration Event Hydrographs
1400
1200
1000
800
600
400
200
0
Discharge (m3/s)
Lillooet River at Upper Forestry Bridge
Ryan River
Miller Creek
Pemberton Creek
Green River
Birkenhead River
15-Oct-03
17-Oct-03
19-Oct-03
21-Oct-03
23-Oct-03
25-Oct-03
27-Oct-03
29-Oct-03
31-Oct-03
2-Nov-03
Date

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Ryan River Hydaulic Modelling

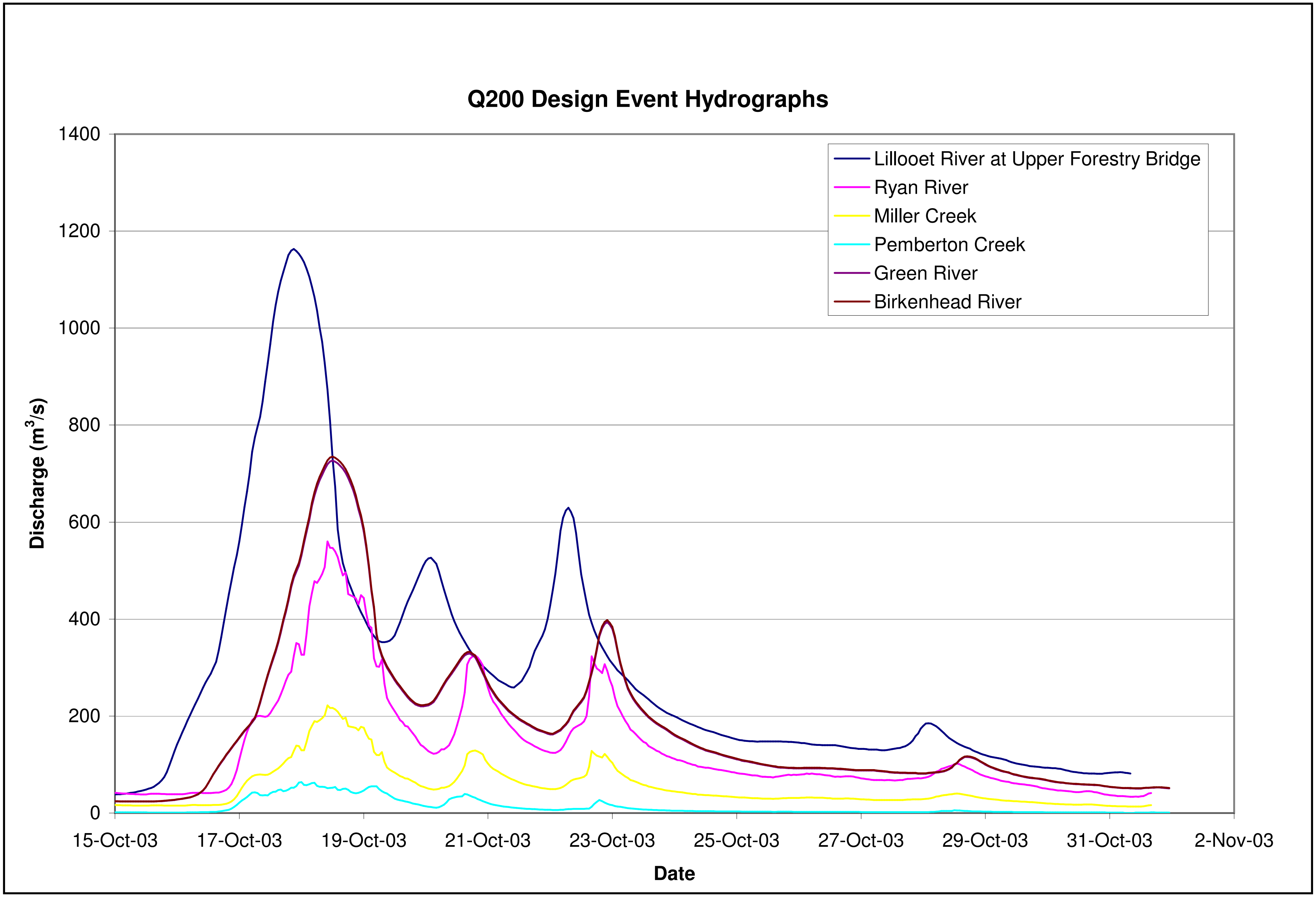

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Figure 3

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Section 3

Hydraulic Model

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3. HYDRAULIC MODEL

3.1 UPDATE TO DECEMBER 2002 LILLOOET RIVER CORRIDOR MODEL

Due to the backwater influence of the Lillooet River on the water levels in the lower reaches of the Ryan River, it was decided to update the December 2002 Lillooet River Corridor rather than developing a separate Ryan River model. This update included the following:

- extending the Ryan River model alignment from the Pemberton Meadows Road bridge to the upstream boundary of the study area (near the apex of the Alluvial Fan formed where the Ryan River enters the main Lillooet River Valley).
- adding the new cross-sections on the Ryan River surveyed in 2006 by KWL.
- adding a link channel to represent the dyke breach that occurred near Ryan River chainage 3+000 during the 2003 flood event.
- adding storage reaches to model the floodplain areas along the Ryan River as well as the floodplain area between the Ryan River and Lillooet River Dykes upstream of the Ryan River and Lillooet River confluence.

3.2 NOVEMBER 2003 EVENT MODEL CALIBRATION

In November 2003, a high water mark survey was conducted by KWL to establish a series of observed high water mark elevations along the lower reaches of the Ryan River (see Table 3-1). These elevations have been used to calibrate the hydraulic model.

Table 3-1: Ryan River Water Marks for November 2003 Flood Event

HWM #[1]	Dyke Chainage	River Chainage	Observed W/L Elevation	Existing Dyke Crest Elevation	Observed 2003 Freeboard
Ryan River Dyke					
Ry# 1	7+976	0+217	236.72	239.75	3.03
Ry# 2	8+493	0+832	229.99	231.11	1.12
Ry# 3	9+067	1+424	228.36	228.03	-0.33
Ry# 4	9+783	2+260	227.23	226.70	-0.53
Ry# 6	11+750	4+984	222.11	223.42	1.31
Ry# 7	12+331	5+758	221.38	222.37	0.99
Ry# 8	13+015	6+568	220.44	222.06	1.62
Ry# 9	13+812	6+972	220.25	221.25	1.00
Ry# 10	14+189	7+546	219.94	220.58	0.64
Ry# 11	14+733	7+997	219.54	220.24	0.70
Ry# 12	15+064	9+067	218.81	219.90	1.09
Ry# 13	16+110	9+417	218.17	218.85	0.68
Pemberton Meadows Road					
Ry# 14	16+829	9+855	217.91	218.35	0.44
Ry# 15	19+559	12+654	215.15	218.16	3.01
Ry# 16	19+795	13+519	214.88	215.48	0.60
Pemberton Meadows Road Bridge[2]					
Ry# 17	Upstream Side	13+869	216.12	217.57	1.45
Ry# 18	Downstream Side	14+084	214.51	217.57	3.06
Boneyard Dyke					
Ry# 19	20+000	14+121	214.36	216.07	1.71

Notes:
1. High Water mark Ry#5 was not recorded during original survey.
2. Freeboard to average bridge deck elevation.

The model was calibrated by adjusting the Manning's roughness values within an acceptable range for this type of channel until modelled water levels closely matched the observed values. A profile comparing the modelled water surface with the observed high water mark elevations is shown in Figure 4. The differences between the observed high water mark elevations and the modelled water surface are tabulated in Table 3-2.

Table 3-2: Ryan River Calibration

River Chainage	Observed Elevation	Modelled Elevation	Difference
0+217	236.72	236.00	0.72
0+832	229.99	230.36	-0.37
1+424	228.36	228.44	-0.08
2+260	227.23	227.49	-0.26
4+382	223.41	223.30	0.11
4+984	222.11	222.17	-0.06
5+758	221.38	221.29	0.09
6+568	220.44	220.39	0.05
6+972	220.25	220.19	0.06
7+546	219.94	219.92	0.02
7+997	219.54	219.74	-0.20
9+067	218.81	218.67	0.14
9+417	218.17	218.32	-0.15
9+855	217.91	217.78	0.13
12+654	215.15	215.24	-0.09
13+519	214.88	214.79	0.09
14+084	214.51	214.46	0.05
14+121	214.36	214.40	-0.04

The Manning's "n" values used to calibrate the model ranged from 0.065 to 0.02 for the upper reaches to the lower reaches, respectively. These values fall in the same range as those calibrated for the Lillooet River branch of the model developed in 2002. The Manning's "n" values in the upper reaches of the model are slightly higher than those typically used for cobble river bed conditions like the Ryan River. However, the higher Manning's "n" values required to match the observed 2003 conditions may indicate that debris flood, other "non-clear water" conditions with substantial deposition, and later degradation that occurred during the time of the peak water levels in the Ryan River in 2003.

3.3 DESIGN EVENT WATER PROFILE

The Q200 design event water level profile for the Ryan River was developed by routing the estimated Q200 design event hydrographs through the model. The modelled water level profile represents the estimated water surface along the thalweg of the Ryan River channel. In order to compare the design water level profile with the surveyed dyke crest profiles, the modelled water levels were projected from the Ryan River alignment to the Ryan River Dyke alignment. The projection used water level isolines (contours of equal water surface elevation) estimated from the original 1992 floodplain mapping (only the shape of the floodplain mapping isolines were used not the elevations).

The modelled Q200 water level profiles were compared with the original Q200 floodplain water levels developed by MoE in 1992 (see Figures 5a to 5c). It appears that the new water levels are generally higher than the original 1992 estimates. The most significant differences appear to occur near the upstream end of the study reach (from Dyke Chainage 8+400 to 11+800). There are two possible reasons why the new modelled water levels are higher than the original. They are as follows:

1. The survey completed in 2006 indicates that the average elevation of the bed of the channel has increased (i.e. the channel has aggraded) since the survey was completed for the 1992 Floodplain Mapping.

2. It is possible that the peak water levels from the 2003 flood event may have been influenced by debris flood (heavily sediment and debris laden water) conditions. Under these conditions, the observed peak water levels would have been higher than the “clear water” conditions assumed for the original Q200 floodplain mapping study. As the model has been calibrated to the observed 2003 peak water levels, the new Q200 water level profile may also be greater than clear water flow conditions in the upper reaches of the study area. This could be why the calibrated roughness (Manning’s “n”) values in this area are higher than those that would typically be used for gravel bed rivers.

It should be noted that the modeled Q200 water level profile is based on channel conditions at the time of the 2006 river survey and the flow conditions observed in the 2003 design event. The influence of potential future changes to channel geometry or other conditions that may reduce channel capacity (i.e., ice jams, debris jams, etc.) have not been included in the development of the Q200 design water level profile.

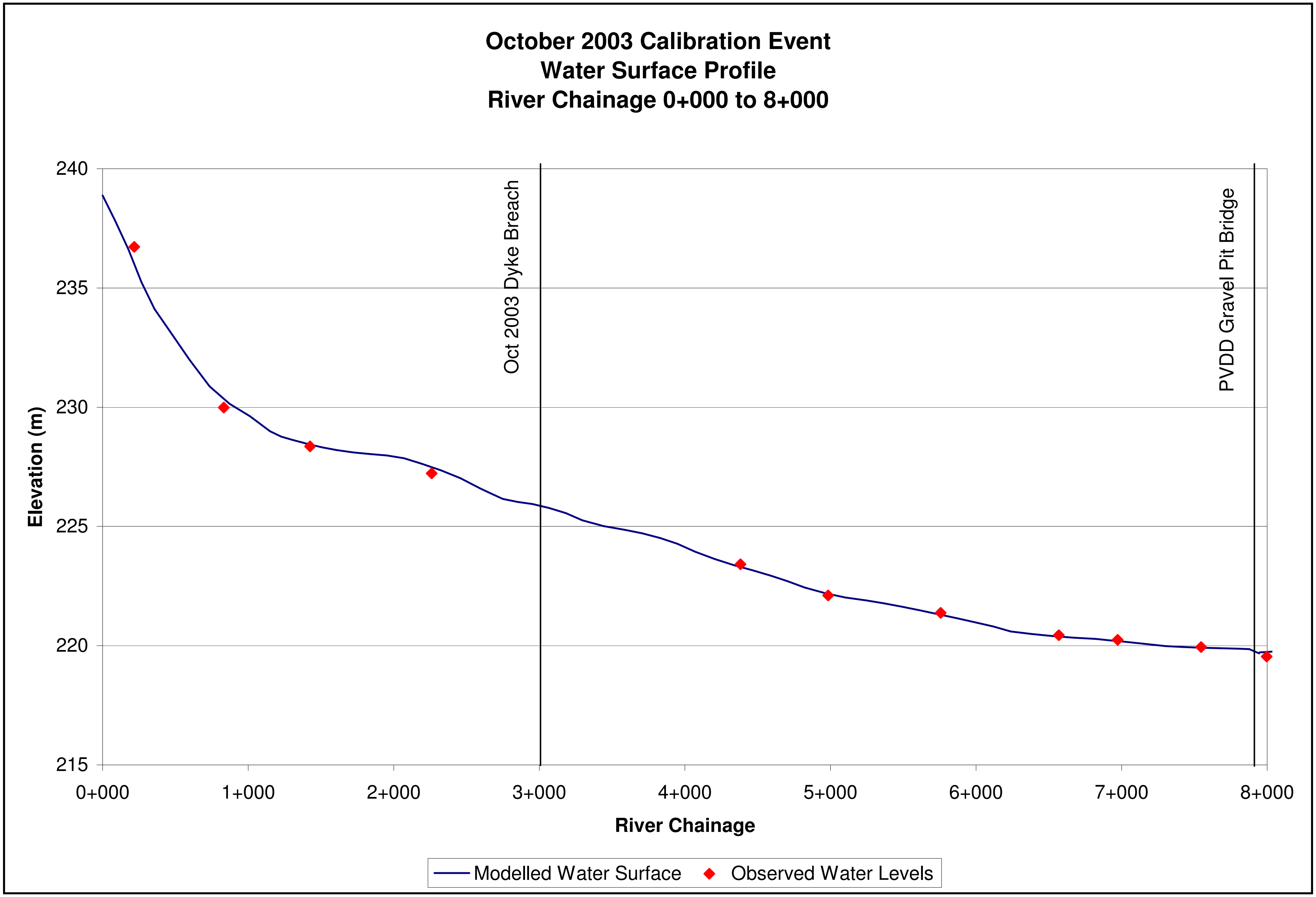
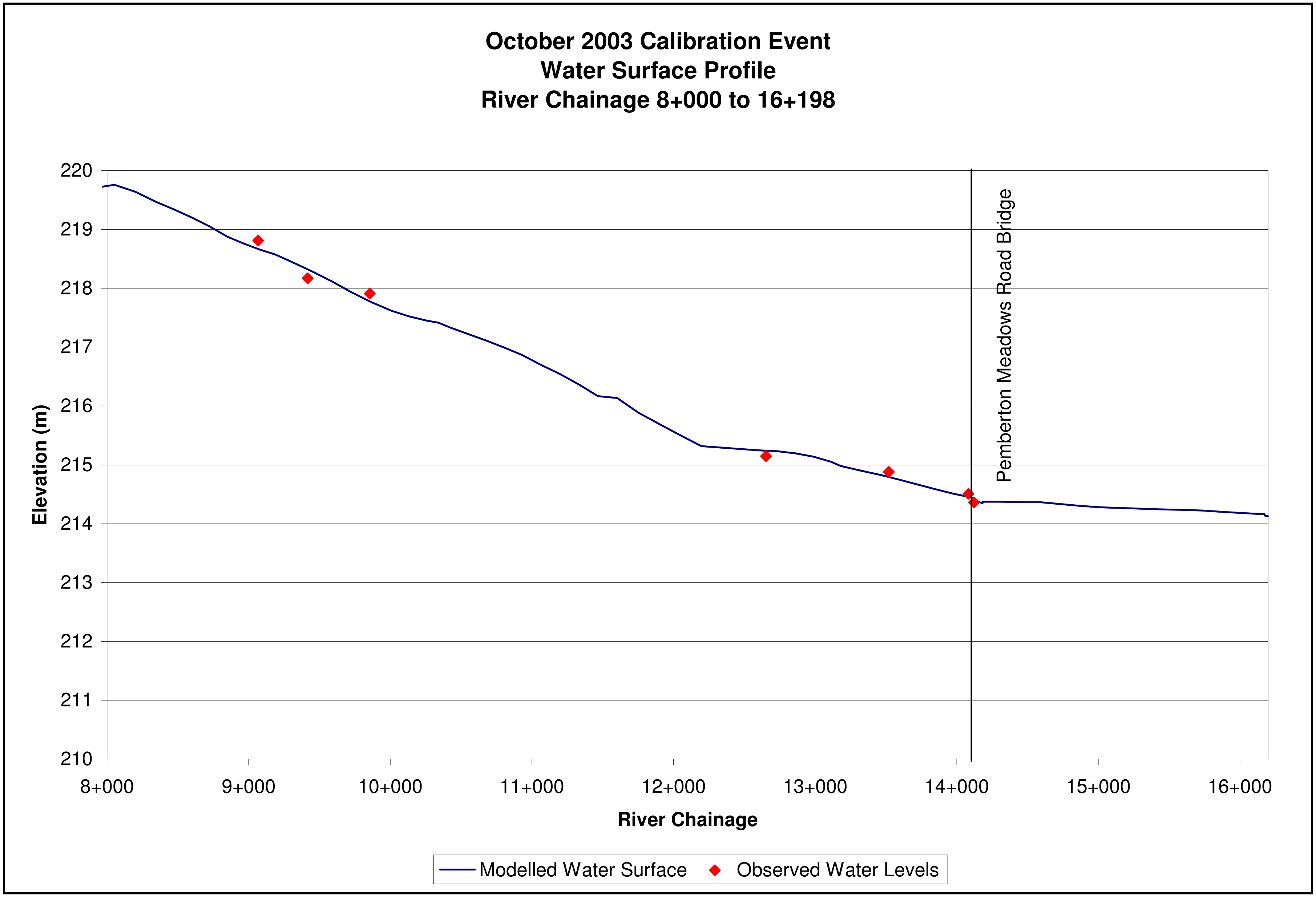

October 2003 Calibration Event
Water Surface Profile
River Chainage 0+000 to 8+000
240
235
230
225
220
215
Elevation (m)
0+000
1+000
2+000
3+000
4+000
5+000
6+000
7+000
8+000
River Chainage
Oct 2003 Dyke Breach
PVDD Gravel Pit Bridge
Modelled Water Surface
Observed Water Levels

Figure 4a


October 2003 Calibration Event
Water Surface Profile
River Chainage 8+000 to 16+198
220
219
218
217
216
215
214
213
212
211
210
Elevation (m)
8+000
9+000
10+000
11+000
12+000
13+000
14+000
15+000
16+000
River Chainage
Pemberton Meadows Road Bridge
Modelled Water Surface
Observed Water Levels

Section 4

Dyke Vulnerability

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4. DYKE VULNERABILITY

4.1 MINIMUM FREEBOARD ALLOWANCE

The provincial standard freeboard allowance for dykes and other flood protection measures is the more conservative of the following:

- the Q200 return period peak instantaneous flood level plus 0.3 m; or
- the Q200 return period peak daily flood level plus 0.6 m.

Typically for the Lillooet River and its tributaries, the former applies. However, as was discussed in the December 2002 "Engineering Study for the Lillooet River Corridor," additional freeboard allowance may be appropriate on rivers that are active in terms of bedload movement and sediment transport.

The upper reaches of the Ryan River could be considered to have significant bedload movement. Based on these observations, it is recommended that the freeboard allowance be increased to:

- 0.6 m above the Q200 return period peak instantaneous water level for the downstream section of the study area (from dyke chainage 10 + 700 m and downstream); and

- 0.9 m above the Q200 return period peak instantaneous water level for the upstream section of the study area (from dyke chainage 10 + 300 m and upstream).

Profiles of the dyke crest elevations with the modelled Q200 water surface profile and recommended freeboard allowances are shown in Figures 5a through 5c.

4.2 DYKE VULNERABILITY MAPPING

The vulnerability of the Ryan River dykes and Pemberton Meadows Road overtopping during the design Q200 event is shown in Figures 6a through Figure 6d. These figures also show the following three vulnerability classes:

- Dyke crest elevation is equal to or greater than the Q200 water level plus the freeboard allowance (shown in green).

- Dyke crest elevation is equal to or greater than the modelled Q200 water level but less than the Q200 water level plus freeboard allowance (shown in yellow).

- Dyke crest elevation is less than the modelled Q200 water level (shown in red).

Table 4-1 below shows the total lengths for each category for each dyke section along the Ryan River.

Table 4-1: Dyke Classification Lengths and Percentage of Total Length

Dyke Classification	Length of Dyke (m)	Percent of Total Ryan River Dyke Length
Dyke Crest higher than Q200 flood level plus freeboard (Green)[1]	3,200	21 %
Dyke crest between Q200 flood level and freeboard level (Yellow)[1]	1,300	9 %
Dyke crest lower than Q200 flood level (Red)[1]	10,750	70%
Note: Colours correspond with colour coding shown in Dyke Vulnerability Maps (Figures 6a through 6d).		

The dyke crest elevations are based on a differential GPS survey that was completed at the same time as the 2006 river survey. Where required, the elevations of the GPS survey were corrected to match the dyke crest elevations measured as part of the river channel cross sections. The crest elevations for a short section of the dyke near the point where the Ryan River dyke joins Pemberton Meadows Road (shown as a dashed line in Figure 5b) have been estimated due to limited GPS coverage in that area. The profile in this area was estimated by assuming the Pemberton Meadows Road crest is a constant elevation to the intersection with the Ryan River Dyke at station 16+480. The crest elevation was then assumed to have constant slope between the elevation at the intersection to the first recorded elevation on the dyke.

4.3 DYKE CREST GAUGE AND FLOOD WARNING

A dyke crest gauge was installed in 2006 adjacent the flood boxes passing under Pemberton Meadows Road (near dyke chainage 18+700). This gauge can be used to estimate remaining freeboard between the water level and the dyke crest near the gauge location.

The hydraulic model has also been used to allow estimation of remaining freeboard at other critical areas low area along the dyke crest based on readings at the Pemberton Meadows Road Gauge. Table 4-2 below shows the approximate remaining freeboard (elevation difference between modelled water level and the dyke crest) translated to key locations at various readings on the Pemberton Meadows Road dyke crest gauge.

Table 4-2: Freeboard Estimates Based on Dyke Crest Gauge Readings

Location	Dyke Chainage	Remaining Freeboard to Dyke/Road Crest (m)			
Pemberton Meadows Road Dyke Crest Gauge	18+700	1	0.5	0.3	0
Transition from Pemberton Meadows Road to Ryan River Dyke	16+500	0.83	0.27	-0.01	-0.37
PVDD Gravel Pit Bridge[1]		1.77	1.17	0.86	0.66
Upstream end of Ryan River Dyke	7+761	7.54	6.32	6.16	5.86
Note: Freeboard from soffit of bridge stringers.					

4.4 DYKE IMPROVEMENTS AND IMPACTS

The dyke vulnerability mapping discussed in Section 4.2 of this report shows that a majority of the existing dyke along the Ryan River is below standard. Raising the dykes is one option for improve the reliability of the flood control system. Raising the dykes would confine all the flow within the Ryan River channel which could lead to changes in river levels downstream.

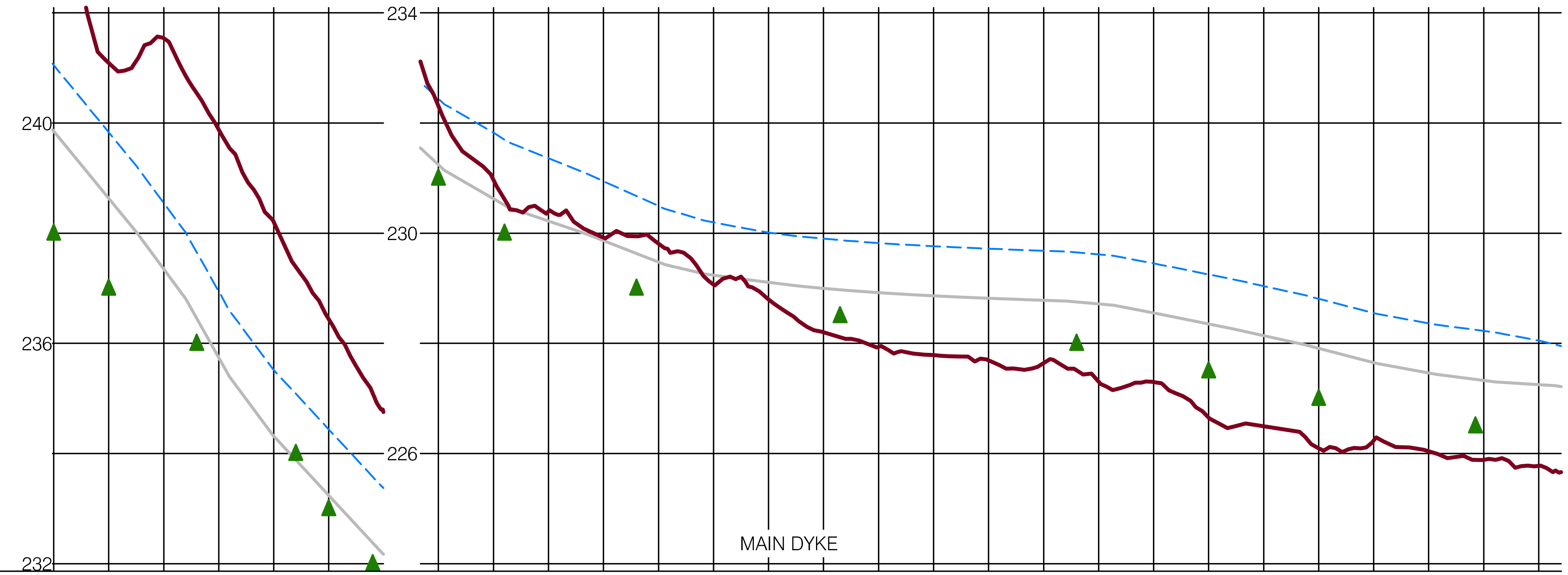
In order to assess any downstream impacts, a comparison was made between the results of the Q200 Design Event model with full dyke rising and the Q200 Design Event model with a breach occurring similar to the 2003 event. This modelling indicates that there would be an insignificant increase to water levels downstream (less than 2 cm at the confluence of Ryan River and Lillooet River). This is most likely due to the relatively small influence that the smaller discharges from the Ryan River would have on water levels on the Lillooet River. It may also be due to the timing of the peak flows that was used in the modelling. Since the larger Lillooet River peak was assumed to occur before the Ryan River peak, changes to the timing and magnitude of the peak of the smaller Ryan River flow are likely to have less impact than if they occurred at the same time. However, further assessment of the effect of event timing as well as the hydraulics of Ryan River dyke breaches would be needed to determine the magnitude of the downstream impacts

Other potential options for improving the flood control system include:

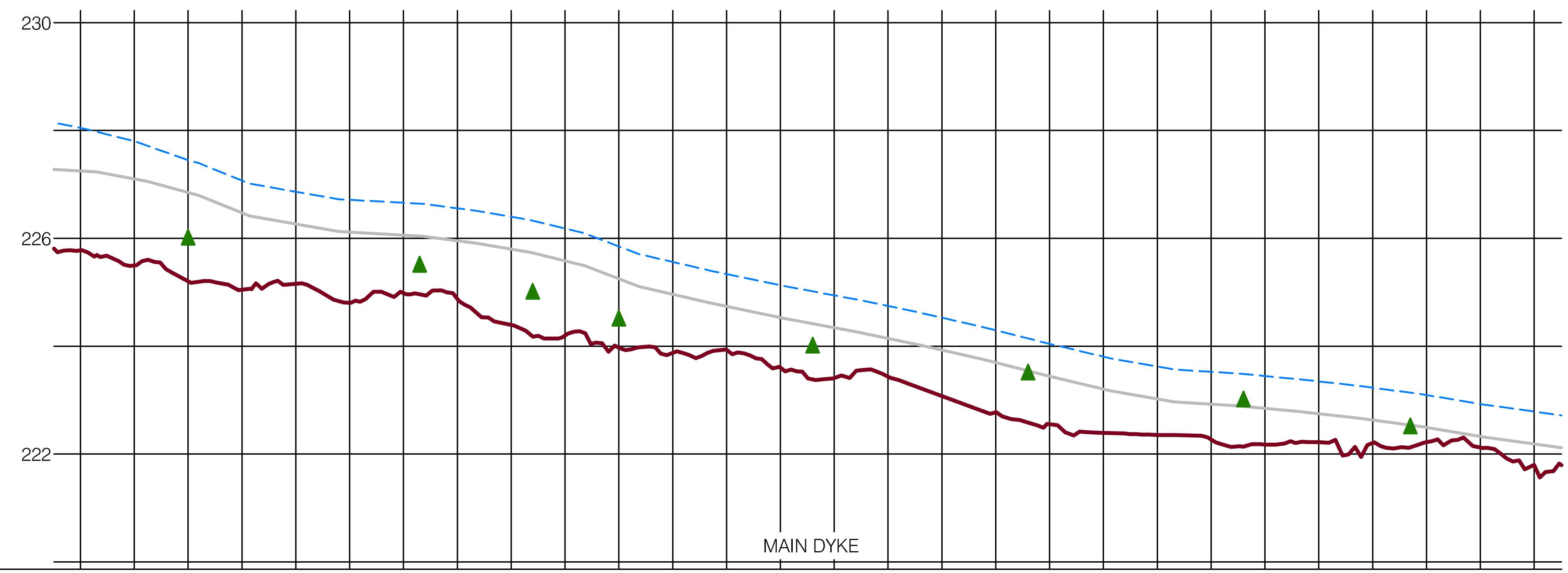
- removing the existing dykes and constructing set-back dykes which would allow some storage of water in the floodplain during flood events; and
- constructing a by-pass channel near the upstream end of the dyke system to carry a portion of the Ryan River flow directly to the Lillooet River.

No detailed assessment of these options has been completed. Further assessment would be required prior to selecting an appropriate measure.

PEMBERTON VALLEY
DYKING DISTRICT
RYAN RIVER HYDRAULIC MODELLING



DYKE CHAINAGE (m)	DIFFERENCE FROM Q200 DESIGN PROFILE TO DYKE CREST (m)
7+700	3.603
7+800	1.260
7+900	2.994
8+000	2.939
8+100	2.721
8+200	1.999
8+300	1.371
8+400	-0.136
8+500	-0.859
8+600	-0.963
8+700	-1.024
8+800	-0.684
8+900	-1.127
9+000	-1.213
9+100	-1.700
9+200	-1.886
9+300	-1.979
9+400	-2.028
9+500	-2.041
9+600	-2.308
9+700	-2.153
9+800	-2.603
9+900	-2.544
10+000	-2.716
10+100	-2.313
10+200	-2.322
10+300	-2.342
10+400	-2.275



DYKE CHAINAGE (m)	WATERLINE TO DYKE DIFFERENCE
10+400	-2.275
10+500	-2.307
10+600	-2.248
10+700	-2.024
10+800	-1.707
10+900	-1.909
11+000	-1.674
11+100	-1.680
11+200	-2.005
11+300	-1.985
11+400	-1.878
11+500	-1.688
11+600	-1.406
11+700	-1.524
11+800	-1.534
11+900	-1.308
12+000	-1.453
12+100	-1.521
12+200	-1.492
12+300	-1.416
12+400	-1.272
12+500	-1.256
12+600	-1.270
12+700	-1.127
12+800	-1.025
12+900	-0.873
13+000	-0.806
13+100	-0.989

LEGEND

- EXISTING DYKE/ROAD CENTERLINE
- 200 YEAR FLOOD LEVEL
- FREEBOARD ABOVE FLOOD LEVEL
- 1990 200 YEAR FLOOD LEVEL INCLUDING FREEBOARD

NOTE:

- DYKE / ROAD PROFILE FROM GPS SURVEY COMPLETE BY KWL IN JANUARY 2007
- FREEBOARD 0.9 m FROM CHAINAGE 7+700 TO 10+300
- FREEBOARD TAPPER FROM 0.9 TO 0.6 m FROM CHAINAGE 10+300 TO 10+700
- FREEBOARD 0.6 m FROM CHAINAGE 10+700 TO 21+880

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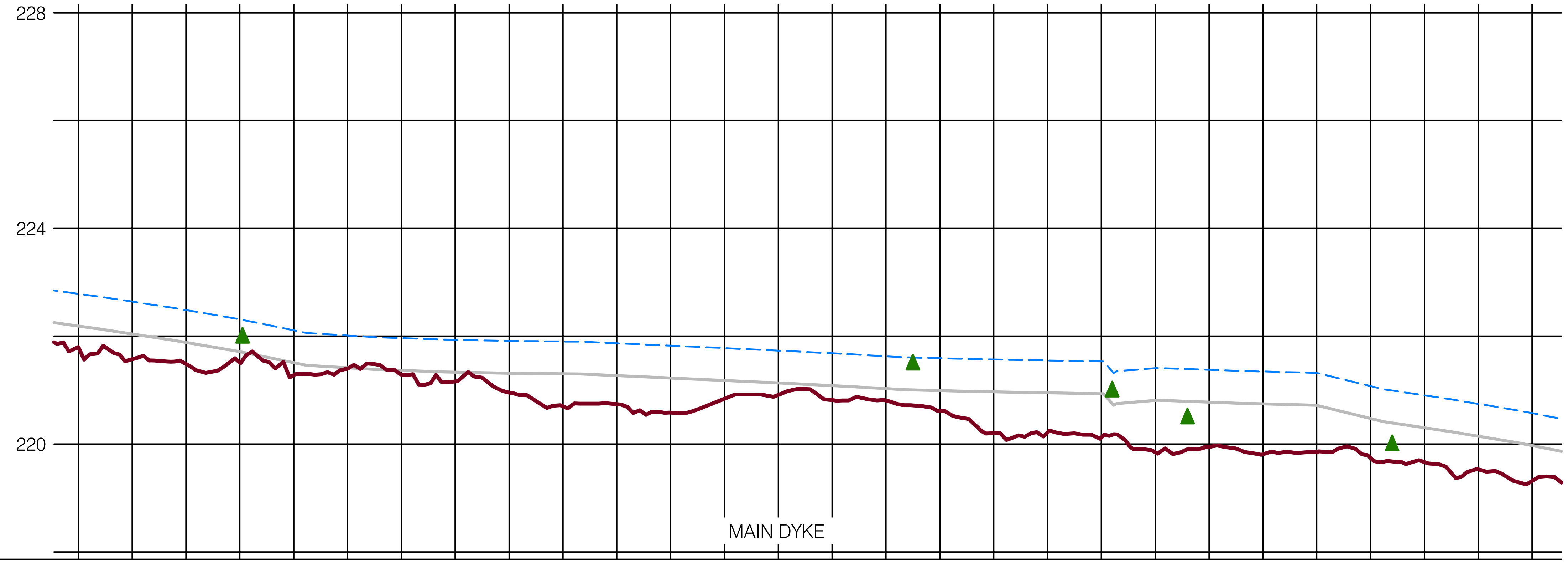
Scale in Metres H1:10000 V1:50

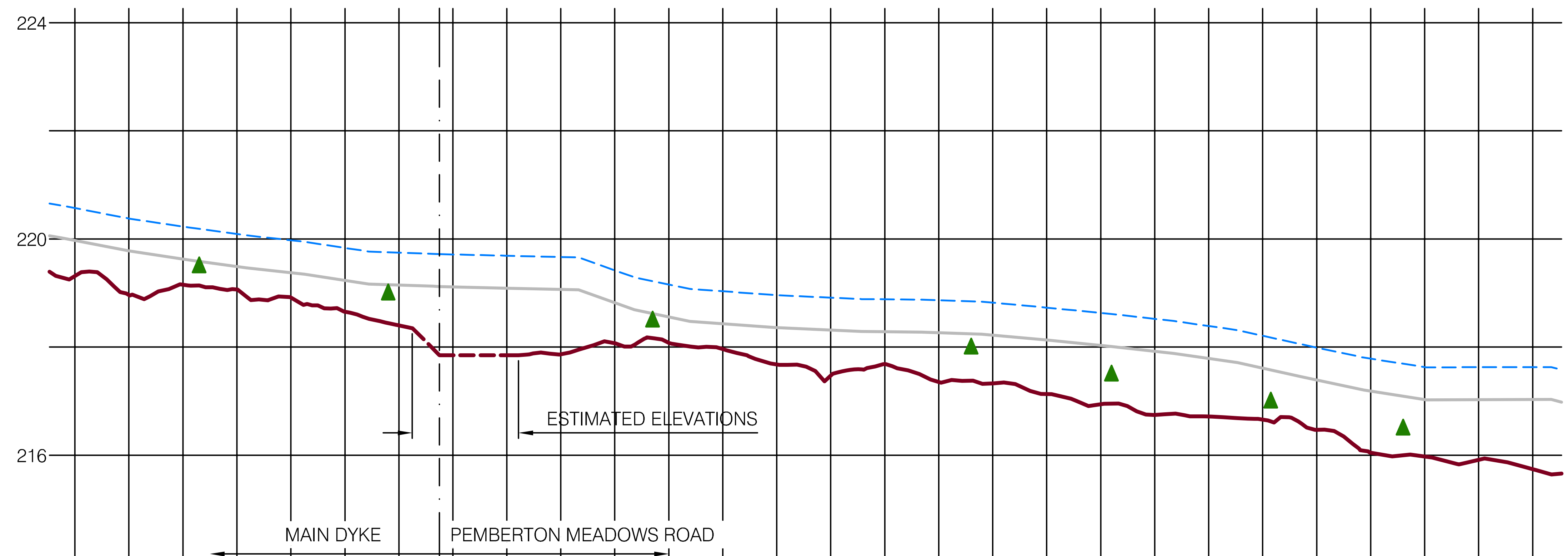
Project No.	Date
713.029	JUNE 2008

DYKE AND DESIGN WATER LEVEL PROFILES MAIN DYKE

FIGURE 5A



DYKE CHAINAGE (m)	DIFFERENCE FROM Q200 DESIGN PROFILE TO DYKE CREST (m)
13+100	-0.989
13+200	-1.067
13+300	-1.000
13+400	-0.805
13+500	-0.831
13+600	-0.615
13+700	-0.677
13+800	-0.773
13+900	-0.958
14+000	-1.203
14+100	-1.132
14+200	-1.242
14+300	-0.939
14+400	-0.820
14+500	-0.868
14+600	-0.822
14+700	-0.979
14+800	-1.365
14+900	-1.339
15+000	-1.409
15+100	-1.558
15+200	-1.426
15+300	-1.536
15+400	-1.467
15+500	-1.332
15+600	-1.238
15+700	-1.212
15+800	-1.257



DYKE CHAINAGE (m)	WATERLINE TO DYKE DIFFERENCE
15+800	-1.257
15+900	-1.415
16+000	-1.075
16+100	-1.025
16+200	-1.063
16+300	-1.182
16+400	-1.345
16+500	-1.870 / -1.864
16+600	-1.841
16+700	-1.800
16+800	-1.348
16+900	-1.080
17+000	-1.069
17+100	-1.283
17+200	-1.442
17+300	-1.199
17+400	-1.512
17+500	-1.494
17+600	-1.599
17+700	-1.689
17+800	-1.779
17+900	-1.670
18+000	-1.550
18+100	-1.519
18+200	-1.739
18+300	-1.655
18+400	-1.713
18+500	-1.887

PEMBERTON VALLEY DYKING DISTRICT
MAIN DYKE AND
RYAN RIVER HYDRAULIC MODELLING

LEGEND

- EXISTING DYKE/ROAD CENTERLINE
- 200 YEAR FLOOD LEVEL
- FREEBOARD ABOVE FLOOD LEVEL
- 1990 200 YEAR FLOOD LEVEL INCLUDING FREEBOARD

NOTES:

- DYKE / ROAD PROFILE FROM GPS SURVEY COMPLETE BY KWL IN JANUARY 2007
- ESTIMATED ELEVATIONS ASSUMED PEMBERTON ROAD IS LEVEL UP TO 16+475
- FREEBOARD 0.6 m FROM CHAINAGE 10+700 TO 21+880

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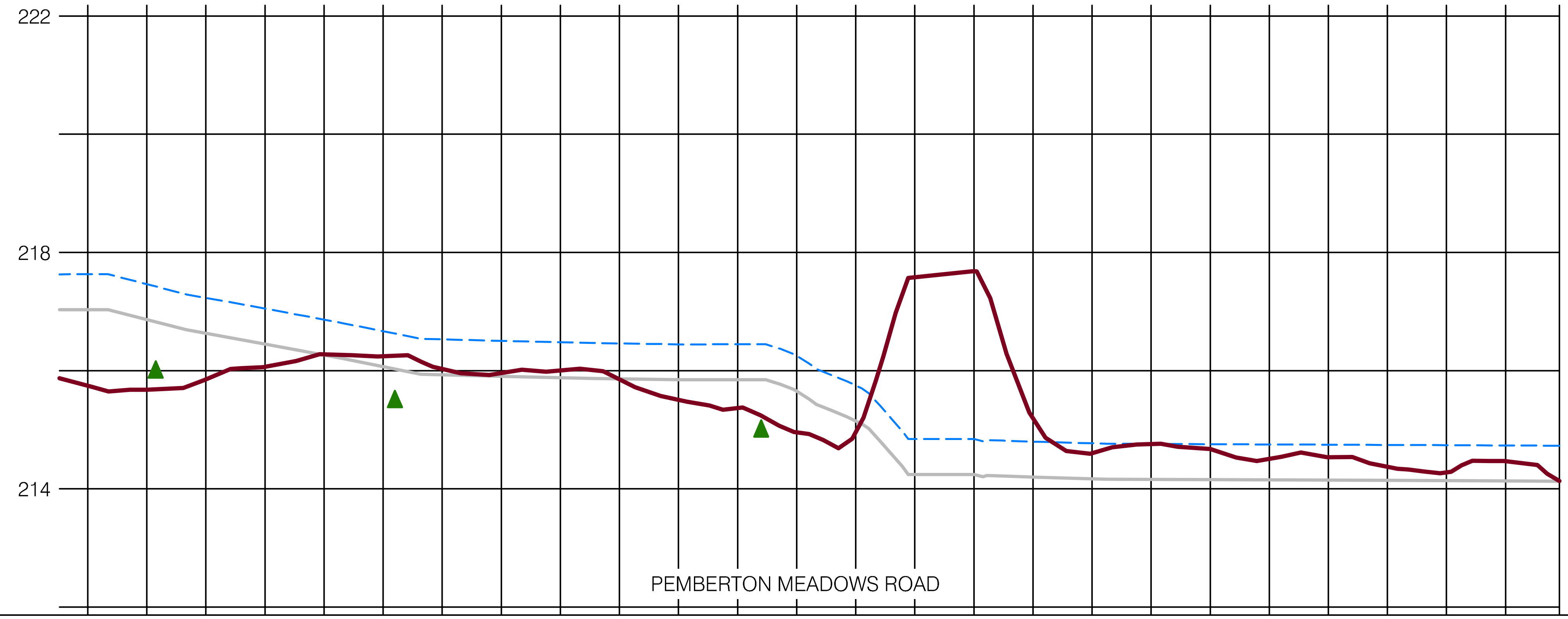
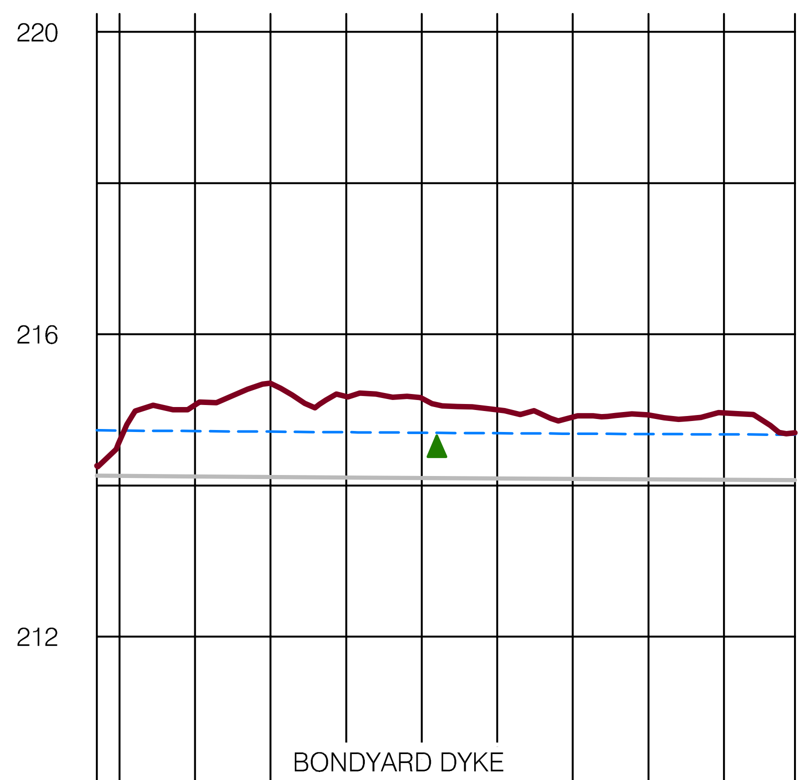
Project No.	Date
713.029	JUNE 2008

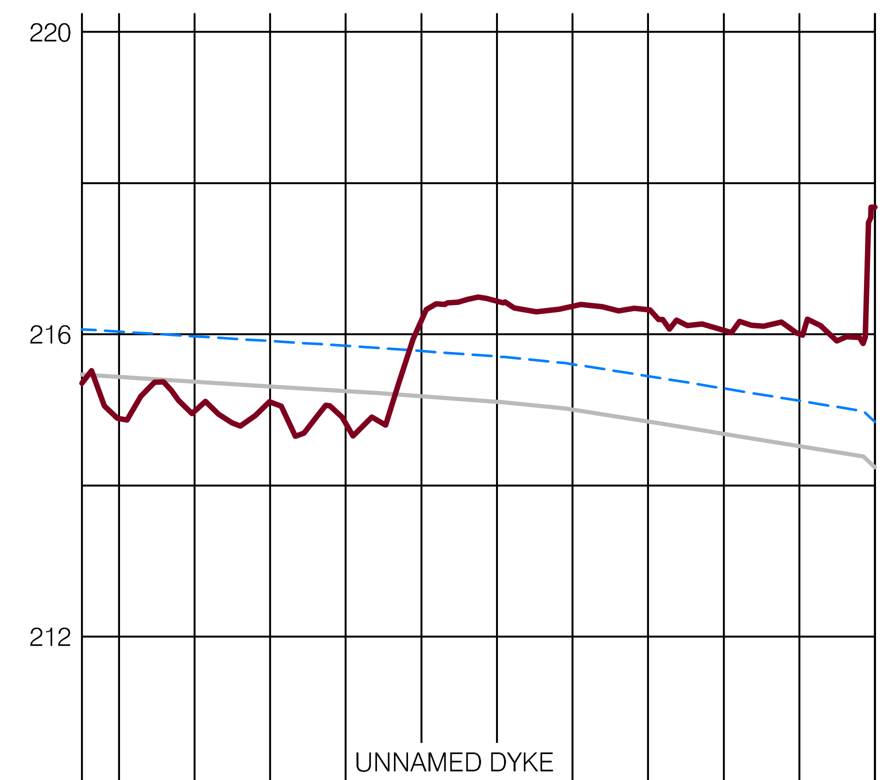
DYKE AND DESIGN WATER LEVEL PROFILES MAIN DYKE AND PEMBERTON MEADOWS

FIGURE 5B



DIFFERENCE FROM Q200 DESIGN PROFILE TO DYKE CREST (m)	DYKE CHAINAGE (m)
-1.887	18+500
-1.786	18+600
-1.379	18+700
-0.988	18+800
-0.589	18+900
-0.424	19+000
-0.501	19+100
-0.545	19+200
-0.479	19+300
-0.607	19+400
-0.939	19+500
-1.079	19+600
-1.296	19+700
-0.790	19+800
2.739	19+900
2.842	20+000
0.396	20+100
-0.170	20+200
-0.002	20+300
-0.083	20+400
-0.245	20+500
-0.213	20+600
-0.371	20+700
-0.461	20+800
-0.300	20+900
-0.596	20+980





Bondyard Dyke:

WATERLINE TO DYKE DIFFERENCE	DYKE CHAINAGE (m)
-0.138	20+980
0.346	21+100
0.638	21+200
0.474	21+300
0.456	21+400
0.309	21+500
0.219	21+600
0.252	21+700
0.283	21+800
0.026	21+880

Unnamed Dyke:

WATERLINE TO DYKE DIFFERENCE	DYKE CHAINAGE (m)
-1.151	1+000
-0.990	1+100
-0.809	1+200
-1.030	1+300
0.403	1+400
0.732	1+500
0.767	1+600
0.880	1+700
0.771	1+800
0.883	1+900
	2+000

PEMBERTON VALLEY
DYKING DISTRICT
RYAN RIVER HYDRAULIC MODELLING

LEGEND

- EXISTING DYKE/ROAD CENTERLINE
- 200 YEAR FLOOD LEVEL
- FREEBOARD ABOVE FLOOD LEVEL
- ▲ 1990 200 YEAR FLOOD LEVEL INCLUDING FREEBOARD

NOTE:

- DYKE / ROAD PROFILE FROM GPS SURVEY COMPLETE BY KWL IN JANUARY 2007
- FREEBOARD 0.6 m FROM CHAINAGE 10+700 TO 21+880
- FREEBOARD 0.6 m TOTAL CHAINAGE OF BONEYARD AND UNNAMED DYKE

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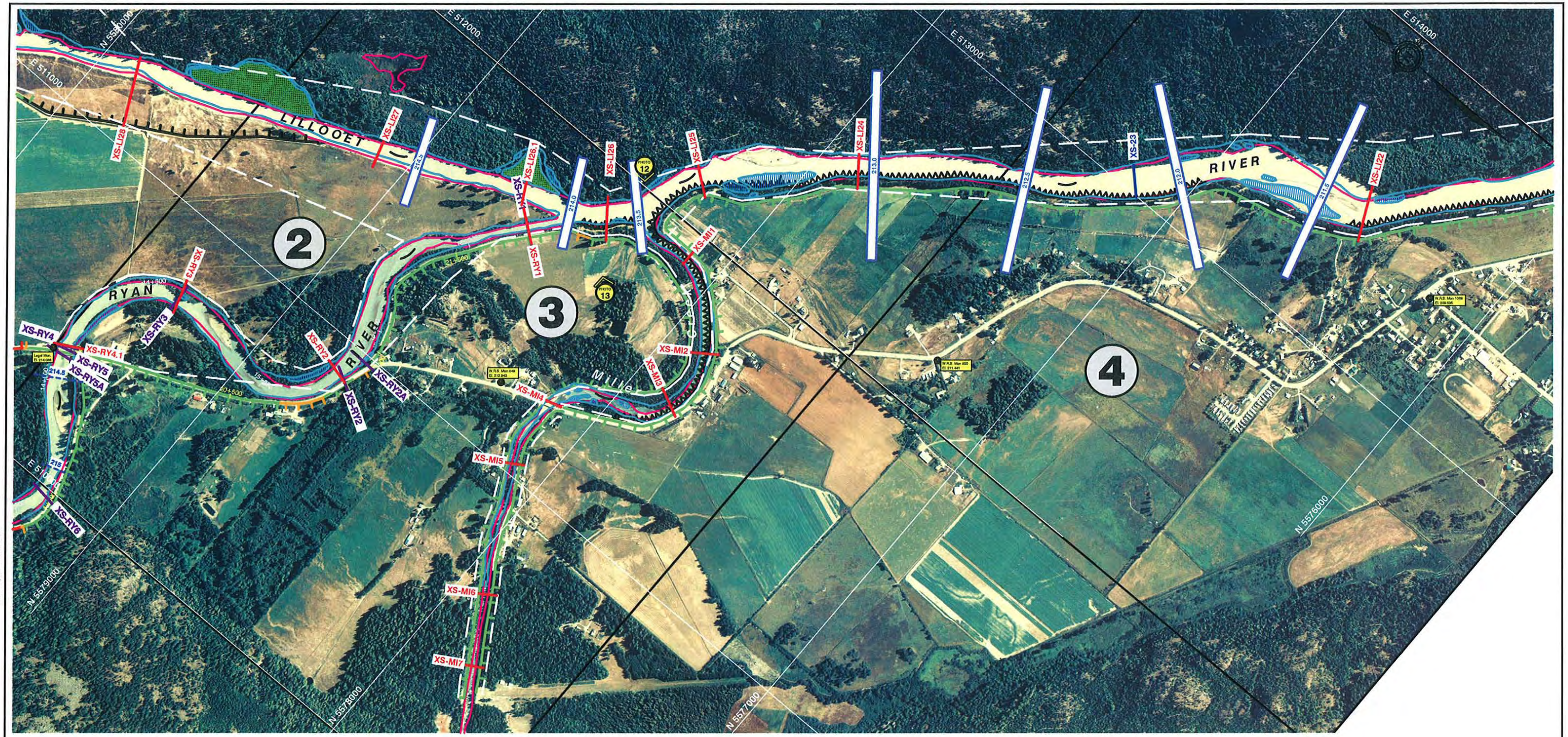
Scale in Metres H1:10000 V1:50

Project No.	Date
713.029	JUNE 2008

DYKE AND DESIGN WATER LEVEL PROFILES PEMBERTON MEADOWS, BONEYARD & UNNAMED
FIGURE 5C



Legend

Riprap
Constructed/Repaired Access Road
Constructed Ditch

Constructed Dyke:

Dyke Crest Higher than Freeboard Level
Dyke Crest between Q200 Water Level and Freeboard Level
Dyke Crest Lower than Q200 Water Level

Note: Freeboard along the Ryan River Dyke ranges from 0.6 m to 0.9 m from downstream to upstream end of study area.

203.0 * Design Flood Level
239.5 * Ryan River Design Flood Level
Photo Location
Survey Monument
Vegetated Gravel Bar
Gravel Bar/Island (Typical)
Reserve Boundary
† River Banks 1971
† River Banks 1987

2000 Modelled Area Boundary
Floodplain Area (BC Ministry of Environment Report, 1985)

Cross Section Surveys:

2001
Prior to 2001
2006 (KWL)

Pemberton Valley Dyking District
Ryan River Hydraulic Modelling
Dyke Vulnerability Maps

250 0 250
Scale in Metres

Figure 6A

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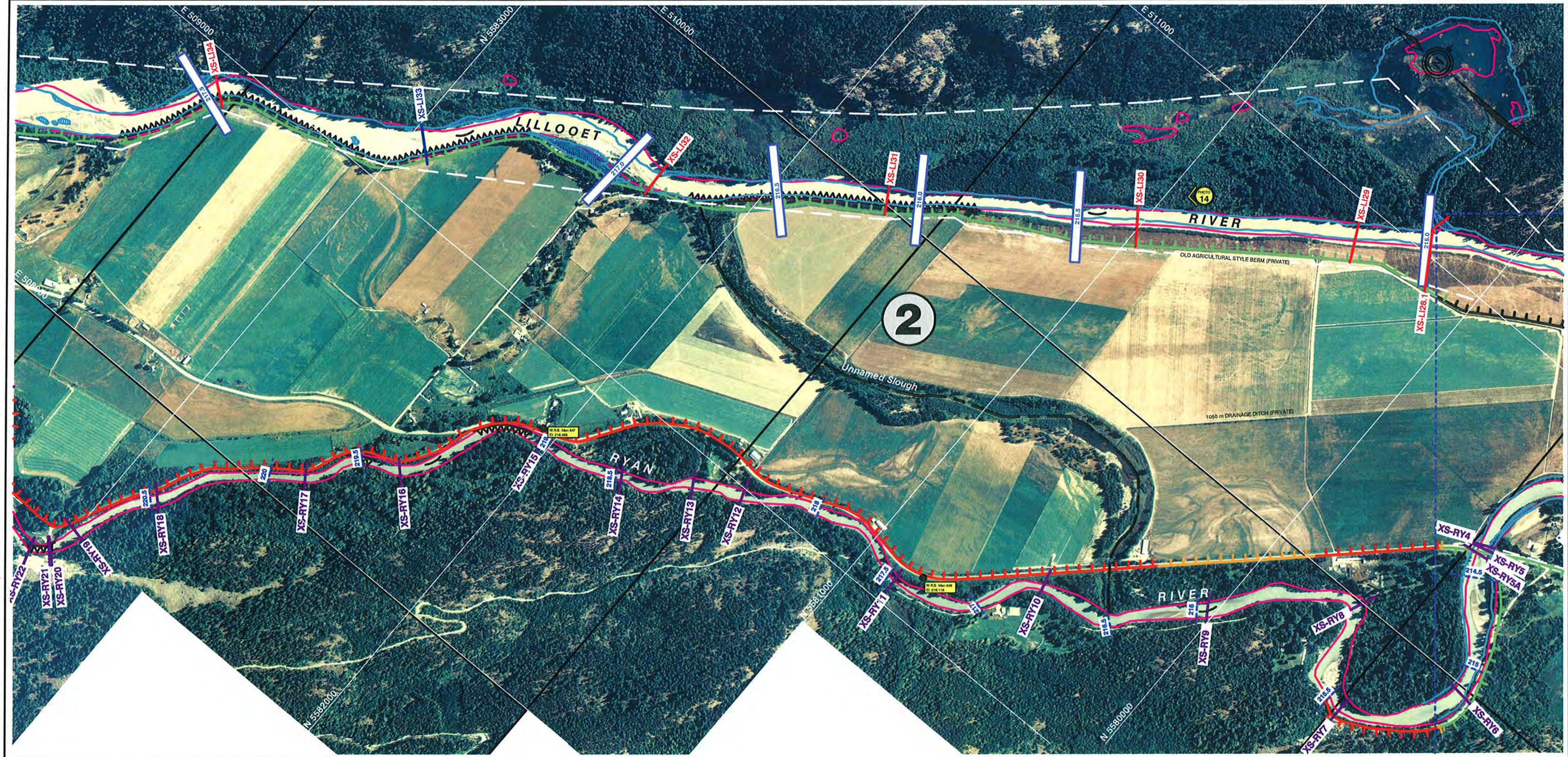

Legend

- Riprap
- Constructed/Repaired Access Road
- Constructed Ditch

Constructed Dyke:

- Dyke Crest Higher than Freeboard Level
- Dyke Crest between Q200 Water Level and Freeboard Level
- Dyke Crest Lower than Q200 Water Level

Note: Freeboard along the Ryan River Dyke ranges from 0.6 m to 0.9 m from downstream to upstream end of study area.

- 203.0 * Design Flood Level
- 239.5 * Ryan River Design Flood Level
- Photo Location
- Survey Monument
- Vegetated Gravel Bar
- Gravel Bar/Island (Typical)
- Reserve Boundary
- † River Banks 1971
- † River Banks 1987
- 2000 Modelled Area Boundary
- 8 Floodplain Area (BC Ministry of Environment Report, 1985)

Cross Section Surveys:

- 2001
- Prior to 2001
- 2006 (KWL)

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Pemberton Valley Dyking District
Ryan River Hydraulic Modelling
Dyke Vulnerability Maps

250 0 250
Scale in Metres

Figure 6B

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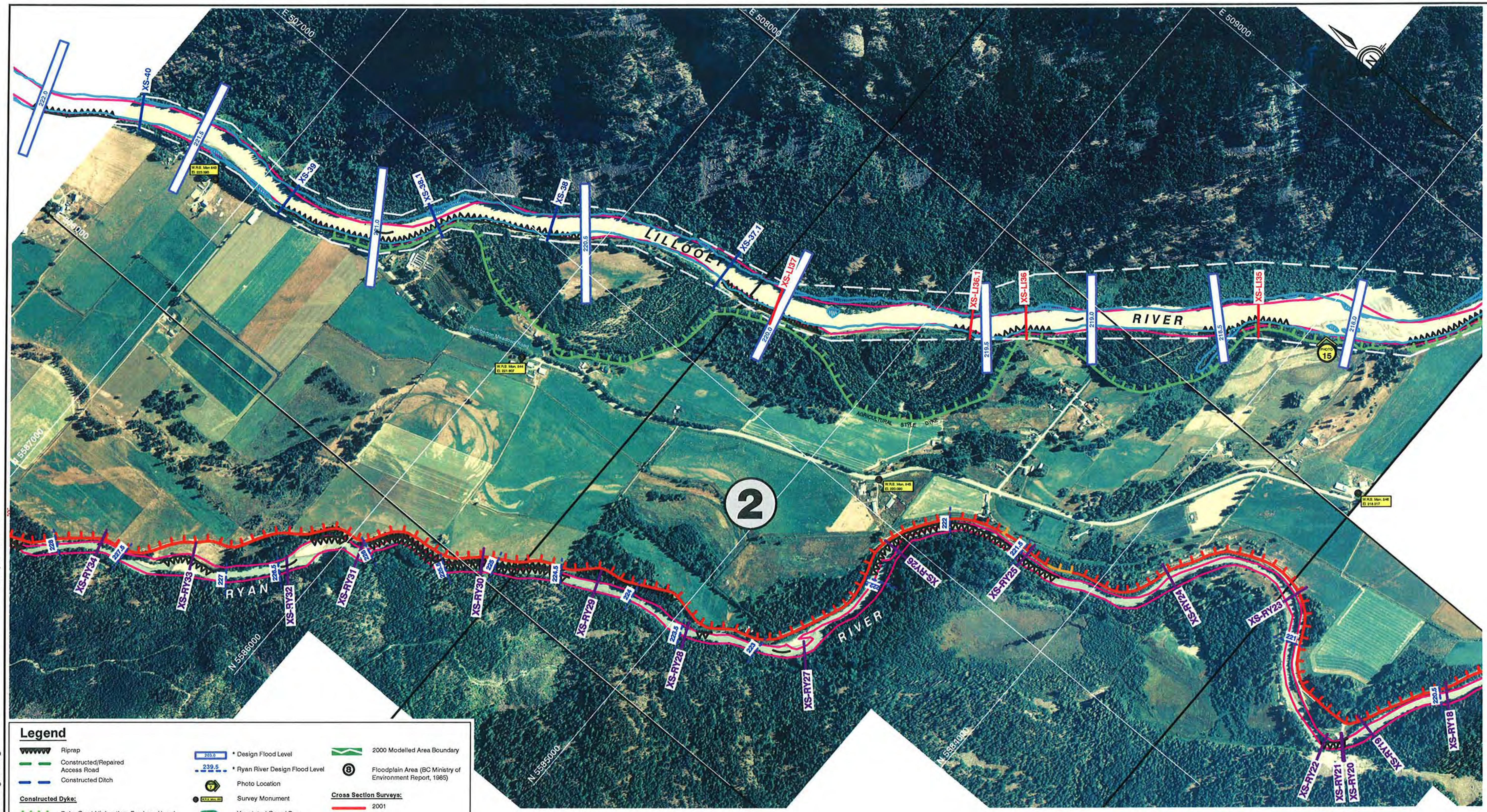

Legend

Riprap
Constructed/Repaired Access Road
Constructed Ditch

Constructed Dyke:

Dyke Crest Higher than Freeboard Level
Dyke Crest between Q200 Water Level and Freeboard Level
Dyke Crest Lower than Q200 Water Level

Note: Freeboard along the Ryan River Dyke ranges from 0.6 m to 0.9 m from downstream to upstream end of study area.

203.0 * Design Flood Level
239.5 * Ryan River Design Flood Level
Photo Location
Survey Monument
Vegetated Gravel Bar
Gravel Bar/Island (Typical)
Reserve Boundary
† River Banks 1971
† River Banks 1987

2000 Modelled Area Boundary
8 Floodplain Area (BC Ministry of Environment Report, 1985)

Cross Section Surveys:

2001
Prior to 2001
2006 (KWL)

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Pemberton Valley Dyking District
Ryan River Hydraulic Modelling
Dyke Vulnerability Maps

250 0 250
Scale in Metres

Figure 6C

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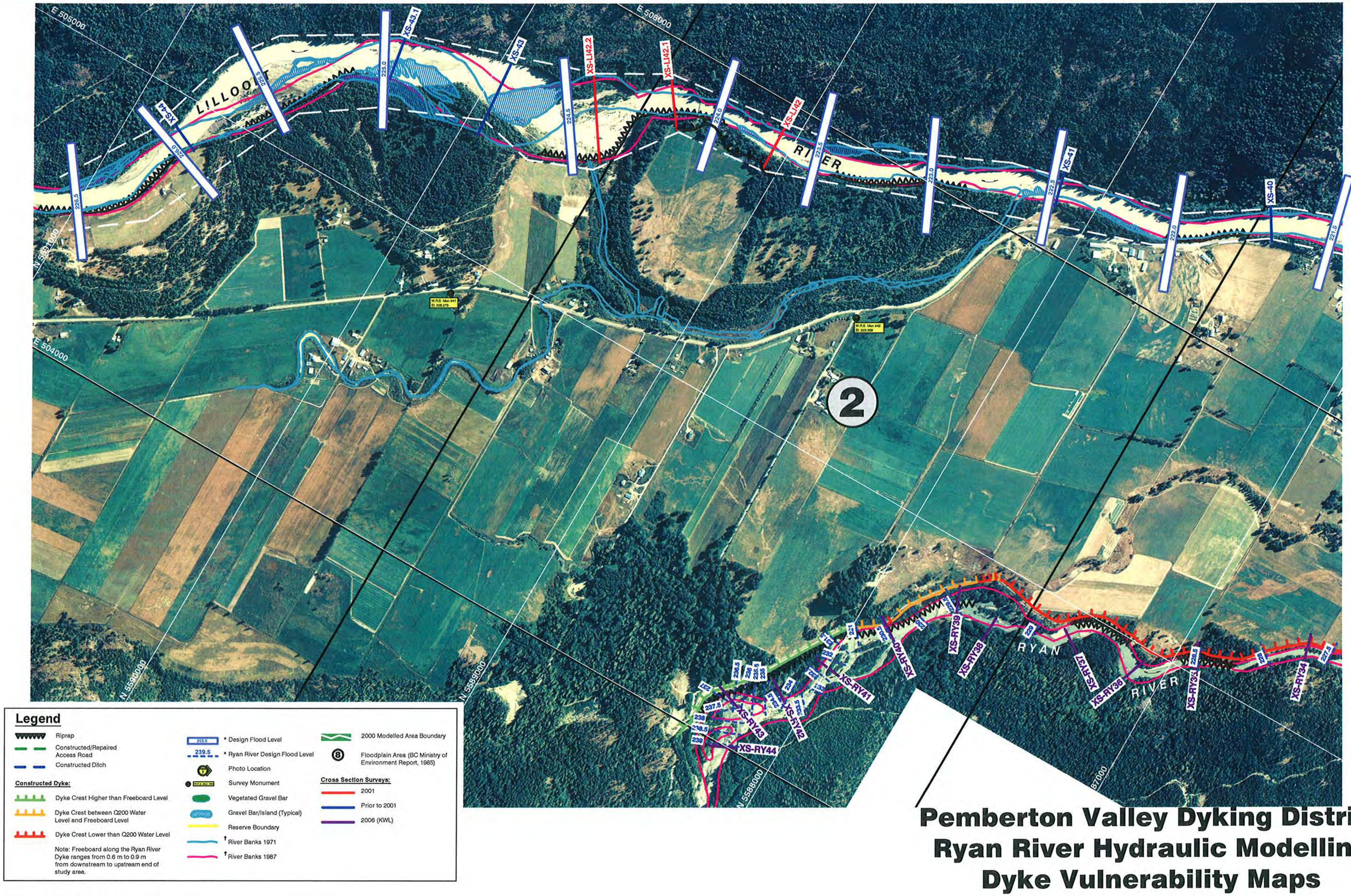

Pemberton Valley Dyking District
Ryan River Hydraulic Modelling
Dyke Vulnerability Maps

250 0 250
Scale in Metres

Figure 6D

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Section 5

Recommendations and Closure

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5. RECOMMENDATIONS AND CLOSURE

5.1 RECOMMENDATIONS

Based on the results of the Ryan River hydraulic modelling, it is recommended that:

1. Further research be conducted to assess the influence of debris flows and debris floods on the upper section of the dyked reach of the Ryan River in order to refine the freeboard allowance criteria or other measures in this section.

2. A conceptual plan be prepared to assess flood protection improvement options for the Ryan River. This plan should review environmental impacts, flooding impacts, and capital costs of raising existing dykes to meet the design profile compared with other options such as setback dykes or spillways to allow controlled overflow into the floodplain.

3. Continue on-going monitoring of dyke crest gauges during flood events to allow sufficient warning time for evacuation of local residences.

4. Install a hydrometric station near the upstream end of the study area to provide a system for flood forecasting and warning for the Ryan River.

5.2 CLOSURE

Prepared by:

KERR WOOD LEIDAL ASSOCIATES LTD.

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