Mangaone Stream and Taonui Basin

Floodplain Hazard Assessment

Hydraulic Modelling and Mapping

Horizons Regional Council

Final Report
March 2007

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CONTENTS

1 INTRODUCTION 8

1.1 BACKGROUND 8
1.2 APPROACH 8
1.3 PROJECTIONS AND DATUM 9

2 PHYSICAL DESCRIPTION 10

2.1 SETTING 10
2.2 RAINFALL 10
2.3 FLOOD BEHAVIOUR 10

3 HYDROLOGICAL ASSESSMENT 12

3.1 METHODOLOGY 12
3.2 DATA AVAILABILITY 12
3.3 HYDROLOGICAL MODELLING – MANGAONE CATCHMENT 13
3.3.1 Model Build 13
3.3.2 Calibration 13
3.3.3 Design Events 14
3.3.4 Flood Frequency Analysis 15
3.4 MANGAONE – TAONUI MODEL CATCHMENTS 15
3.4.1 Catchment Delineation and Parameters 16
3.4.2 Catchment Rainfall and Runoff 16

4 HYDRODYNAMIC MODEL BUILD & CALIBRATION 17

4.1 MODEL DESCRIPTION 17
4.2 CHANNEL SELECTION – 1D OR 2D? 17
4.3 PHYSICAL DESCRIPTION 17
4.4 METHODOLOGY AND DATA AVAILABILITY 18
4.5 MIKE 11 MODEL BUILD 18
4.5.1 MIKE 11 Model Domain 18
4.5.2 Cross Sections 19
4.5.3 Structures 20
4.5.4 Boundaries and Catchment Connections 21
4.6 MIKE 21 MODEL BUILD 21
4.6.1 MIKE 21 Model Domain 21
4.6.2 Topography and Features 21
4.6.3 Source Inflows 22
4.6.4 Boundaries 23
4.6.5 Hydraulic Resistance 23
4.7 MIKE FLOOD MODEL BUILD 24
4.7.1 Linkages 24
4.7.2 Model Simulations 25
4.8 MODEL CALIBRATION 25
4.9 FINE GRID MODEL DEVELOPMENT 27
4.9.1 MIKE 21 Model Domain, Topography and Hydraulic Resistance 27
4.9.2 MIKE 11 Model Extent 27
4.9.3 MIKE 21 Source Inflows and Boundary Conditions 28
4.9.4 MIKE 11 Boundary Conditions and Catchment Connections 28
4.9.5 MIKE FLOOD Linkages 28
4.9.6 Model Simulations and Results 29

5 FLOOD RISK ASSESSMENTS 30
5.1 DESIGN EVENTS 30
5.2 SENSITIVITY ANALYSIS 32
5.2.1 Manning Number 32
5.2.2 Bridge and Culvert Blockages 32
5.2.3 Land Use Change 33
5.3 FLOOD EXTENT MARGINS 34
6 SUMMARY AND RECOMMENDATIONS 35
6.1 SUMMARY 35
6.2 RECOMMENDATIONS 36
6.2.1 Uncertainties and Freeboard 36
6.2.2 Model Improvement 36
7 REFERENCES 37

DRAWINGS *(Drawings 6 – 43 in separate volume)*

APPENDIX A – Hydrological Model Calibration Results
APPENDIX B – Field Cross Section and Structure Surveys
APPENDIX C – 2004 Water Level Calibration Comparison

DRAWINGS

No.	Description
1	*Study area*
2	*Rainfall and flow gauge locations*
3	*Catchment delineation and MIKE11 channels*
4	*Model Extents*
5	*Culvert and bridge structures included in the models*
6	*1976 flooding extent, 25m model*
7	*1988 flooding extent, 25m model*
8	*2004 flooding extent, 25m model*
9	*1976 flooding extent, 10m model*
10	*1988 flooding extent, 10m model*
11	*2004 flooding extent, 10m model*
12	*Maximum Flood Depth: 50-year ARI Flood - Existing*
13	*Maximum Flood Level: 50-year ARI Flood - Existing*
14	*Maximum Flood Speed: 50-year ARI Flood - Existing*
15	*Maximum Flood Hazard: 50-year ARI Flood - Existing*
16	*Maximum Flood Depth: 100-year ARI Flood - Existing*
17	*Maximum Flood Level: 100-year ARI Flood - Existing*
18	*Maximum Flood Speed: 100-year ARI Flood - Existing*
19	*Maximum Flood Hazard: 100-year ARI Flood - Existing*
20	*Maximum Flood Depth: 200-year ARI Flood - Existing*
21	*Maximum Flood Level: 200-year ARI Flood - Existing*
22	*Maximum Flood Speed: 200-year ARI Flood - Existing*
23	*Maximum Flood Hazard: 200-year ARI Flood - Existing*
24	*Maximum Flood Depth: 50-year ARI Flood - Existing (10m model)*
25	*Maximum Flood Level: 50-year ARI Flood - Existing (10m model)*
26	*Maximum Flood Speed: 50-year ARI Flood - Existing (10m model)*
27	*Maximum Flood Hazard: 50-year ARI Flood - Existing (10m model)*
28	*Maximum Flood Depth: 100-year ARI Flood - Existing (10m model)*
29	*Maximum Flood Level: 100-year ARI Flood - Existing (10m model)*
30	*Maximum Flood Speed: 100-year ARI Flood - Existing (10m model)*
31	*Maximum Flood Hazard: 100-year ARI Flood - Existing (10m model)*
32	*Maximum Flood Depth: 200-year ARI Flood - Existing (10m model)*
33	*Maximum Flood Level: 200-year ARI Flood - Existing (10m model)*
34	*Maximum Flood Speed: 200-year ARI Flood - Existing (10m model)*
35	*Maximum Flood Hazard: 200-year ARI Flood - Existing (10m model)*
36	*Change in flood extent due to +20% increase in Manning number - 50 year ARI*
37	*Change in flood extent due to -20% increase in Manning number - 50 year ARI*
38	*Change in flood extent due to 50% structure blockage - 50 year ARI*
39	*Change in flood extent due to 95% structure blockage - 50 year ARI*
40	*Increase in flood depth due to land use change - 50 year ARI*
41	*High and low margin flood extents - 50 year ARI*
42	*High and low margin flood extents - 100 year ARI*
43	*High and low margin flood extents - 200 year ARI*

1 INTRODUCTION

1.1 Background

The Manawatu region suffered severe flooding in February 2004, which resulted in large financial losses and social disruption. The area around Palmerston North was severely affected, with major rivers flowing near bank full capacity, and smaller rivers experiencing extreme flows which overtopped and broke through stopbank protection systems.

Figure 1-1 Flooding around Palmerston North in February 2004 (Source: Horizons Regional Council)

Horizons Regional Council contracted DHI Water & Environment to assess the risk of flooding in one of the affected areas, comprising the middle Mangaone Stream and Taonui Basin. The model study area lies to the immediate west of the city of Palmerston North, and extends from Fielding and Bunnythorpe in the north to Opiki in the south covering an area of approximately 220 square kilometres.

1.2 Approach

HRC have supplied DHI with a high accuracy land level data set acquired by an airborne laser survey (ALS, or LiDAR) of the entire study area. The availability of such data lends itself to a two-dimensional modelling approach, in which the land level data is used as the topographic input for modelling the overland and floodplain flows. As the study area also includes a number of large drains and small streams, a traditional one-dimension model has also been used in order to capture important flow characteristics of these channels. The two models – 2D floodplain model and 1D channel model, are dynamically linked to form a combined model describing in detail the complete physical flow characteristics in the study area.

1.3 Projections and Datum

All models have been built to NZMG map projection and levels refer to the Wellington datum. Where required conversions from Moturiki datum have been applied with a +76mm correction as advised by HRC.

2 PHYSICAL DESCRIPTION

2.1 Setting

The Mangaone – Taonui catchment is located to the north, west and south of Palmerston North and covers a combined area of 330 km^2. The upper catchments are located at higher elevations up to just over 300m, in contrast to the lower half of the catchment where the land levels range between 8-20m.

The Mangaone Stream is the largest watercourse, draining an area of approximately 157 km^2, eventually discharging to the Manawatu River just south of the city. The Mangaone is stopbanked from approximately 5km upstream of Palmerston North to the Manawatu confluence. High flows in the Mangaone are diverted away from the main population centre via a spillway located just upstream of the city at Flygers Line.

The Taonui stream is located to the west of the Mangaone and drains the remaining catchment to a low lying area known as the Taonui Basin. The basin is bordered by the Oroua stopbanks to the west and the Manawatu stopbanks to the south and east. The basin has been developed for agriculture through the construction of large drainage channels, of which Main Drain and Burkes Drain form the main backbone. These join and eventually discharge to the Manawatu River via a set of large floodgates near Rangiotu, see Figure 2-2.

The catchment is shown in Drawing 1 in the Drawings section at the end of this report.

2.2 Rainfall

Average annual rainfall at Palmerston North is 930mm, while the upper catchment averages 1200mm. Longs term rainfall is available from a number of gauges in Palmerston North, whereas a more recent gauge has been installed in the upper Mangaone catchment at Valley Road. These have highlighted the variability between rainfall in the upper and lower catchments, which in the 2004 floods indicated that twice as much rainfall fell in the upper catchment compared to Palmerston North.

2.3 Flood Behaviour

The Taonui Basin is used as a flood detention storage for excess floodwaters in the Mangaone, Oroua and Manawatu Rivers. Floodwaters enter the basin via a number of constructed spillways comprising the Flygers Line spillway on the Mangaone, Hamilton's Line on the Manawatu and Kopane and Rangiotu spillways, both on the Oroua, see Drawing 1. In past flood events the basin has also received floodwaters from overtopping and breaching of the Oroua and Mangaone stopbanks. Local runoff contributes to, but is not a major cause of, flooding in the study area.

Controlled spills from the Mangaone Stream occur when water levels in the river exceed a threshold large enough to activate a series of gates built into the Flygers Line spillway, see Figure 2-1. Floodwaters travel overland, joining with the local runoff in Whiskey Creek, and eventually entering the Taonui Basin. Similarly, spills from the Kopane spillway travel overland and through local drainage channels before reaching the basin. The Hamilton's Line and Rangiotu spillways discharge directly into the lower basin.

Figure 2-1 Mangaone Spillway, looking downstream

Drainage from the basin occurs via Burkes Drain through the Rangiotu floodgates – see Figure 2-2. The gates close when the water levels in the Manawatu rise higher than the levels in the drain. Burkes and Main Drain are extensively stopbanked to prevent backwater from the Manawatu, or accumulating drainage water, from prematurely inundating the surrounding land. Spillways have been constructed in the lower part of Burkes drain to allow excess water to spill into the basin. Floodwaters accumulating in the basin from these spills and upstream overland flows are ultimately drained via a series of smaller drainage channels which pass through the embankments. Backflows up these smaller drains are prevented by flapgates built into the structures–see Figure 2-2.

Figure 2-2 Rangiotu Gates (left) and Main Drain (right) – note flapgate entering on left bank

3 HYDROLOGICAL ASSESSMENT

3.1 Methodology

A hydrological assessment of the catchments is required in order to provide inflow hydrographs to the hydraulic model. The only available flow gauge within the catchment is on the Mangaone Stream near Milsons Line, just upstream of the Mangaone spillway. As the Mangaone is embanked through most of its length within the study area, and because the spillway diverts excess floodwaters away from the main channel, it was decided at the project conception stage not to include the Mangaone Stream itself in the modelling. Nevertheless, as the only flow gauge within the catchment, the Mangaone flow record provides a useful proxy from which calibration parameters for the remaining catchments can be based.

DHI's Urban Model B has been applied for this study. This incorporates a simple initial and continuing loss model together with a kinematic routing component. Input parameters comprise catchment slope and hydraulic length, as well as initial and continuing infiltration loss values for the various types of contributing catchments (pervious and impervious, of differing slopes). For more information refer to Ref./1/.

The Mangaone flow record has been used to derive initial and continuing loss parameters for historical design storms which have been applied to the remaining catchments for both historical and design event simulations. Major floods have occurred in June 1976, July 1988 and February 2004, and these have been used as the basis for calibration, together with smaller floods occurring after 2001 when additional rainfall data are available.

3.2 Data Availability

Rainfall records are available at two main gauges within the catchment – Mangaone at Milsons Line and Valley Road. Other gauges are located within the vicinity of Palmerston North; these are at the City Council building, the airport and the Agricultural Research Station. In order to fill gaps in the Milsons Line record during the 1988 event, and provide data for 1976, rainfall from the latter have been acquired by HRC and provided to DHI for the study.

Data	Availability	Comments
Rainfall		
Milsons Line	May 2001 -	6min interval
Valley Road	March 1987 -	6-15min interval, - daily in 1988 event
Agricultural Res. Stn	July 1998 & June 1976	6min interval
Discharge		
Mangaone @ Milsons Line	April 1978	15min intervals

Drawing 2 shows the raingauge and flow gauging stations available within the catchment.

3.3 Hydrological Modelling – Mangaone Catchment

3.3.1 Model Build

A hydrological model of the Mangaone catchment to the gauge at Milsons Line has been established using the Urban B model within the MIKE 11 Rainfall Runoff Module. The catchment area is 157.2 km^2. Catchment length and slope have been initially estimated as 10km and 20m/km respectively. Spatial weighting has been applied to the rainfall, with 90% weighting applied to Valley Road and 10% to Palmerston North.

3.3.2 Calibration

The model has been calibrated against a range of events. The main aim of the calibration is to determine initial and continuing losses for flood events, and therefore focus has been placed on reproducing the flood volumes for each event. A typical simulation is shown in Figure 3-1, for the 2004 event. The flood hydrograph is slightly advanced, but the peak discharge and volume are reproduced well. Attenuation of the flood peak could be achieved by including hydrodynamic routing of the flow which would better account for storage effects in the catchment.

Through trial and error, the best overall match for flood volume and peak flow was found for an initial loss of 20mm and continuing loss of 2mm/hr. These values have been adopted for the remaining catchments for design hydrograph generation.

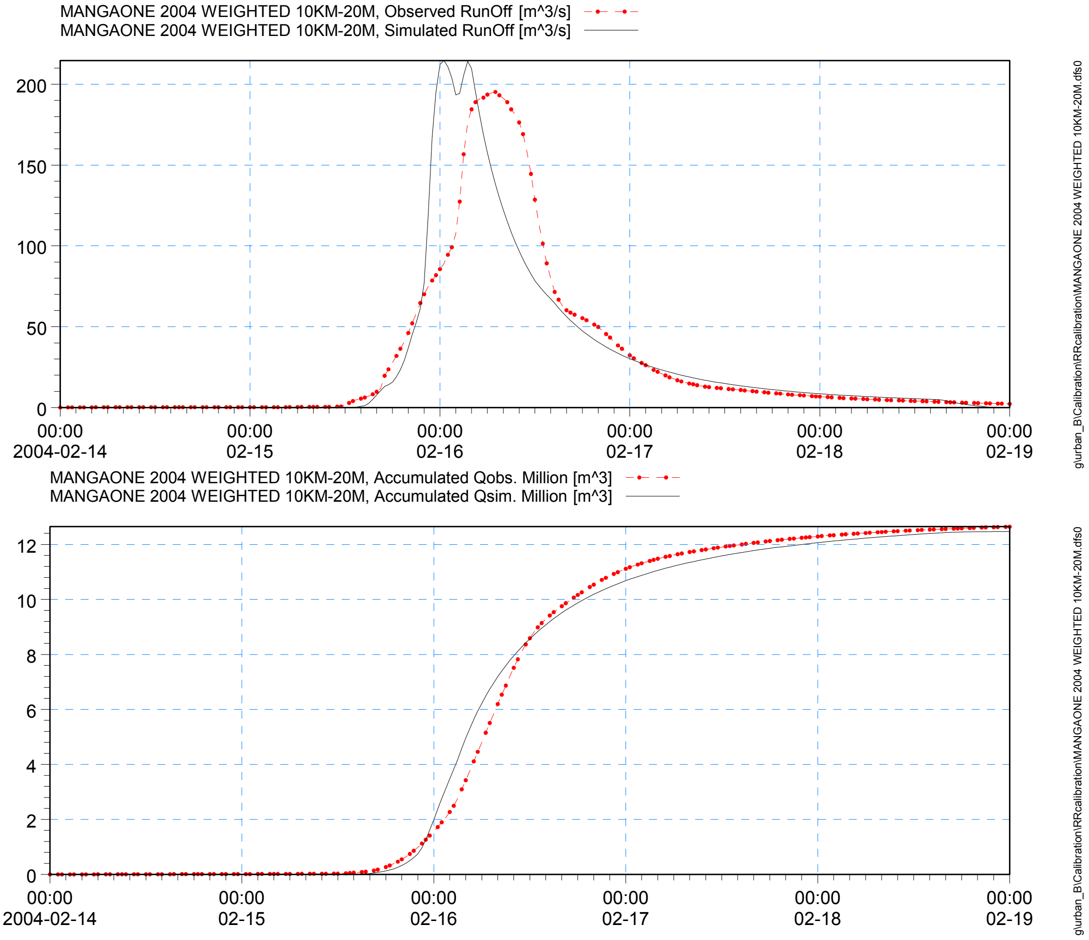

Figure 3-1 Hydrological Model calibration for the Mangaone catchment at Milsons Line – Feb 2004

Table 3-1 shows the results of the model calibration. Full results are shown in Appendix A.

Table 3-1 Hydrological Model calibration results

Event	R^2 error	Volume Error (%)
July 1988	0.81	-2.5
Oct 1998	0.73	-3.7
Aug 2001	0.67	3.0
July 2002	0.85	-1.7
Feb 2004	0.74	1.4

3.3.3 Design Events

In order to provide inflow hydrographs for the hydraulic model for the various annual recurrence intervals (ARIs) being considered, suitable rainfall inputs, in terms of both total depth and temporal distribution are required. The rainfall durations and distributions of historical flood producing storms were analysed and the 2004 event selected as the temporal basis for design event generation, using 24 hour rainfall depths, see Figure 3-2. Rainfall depths in the catchment area have been taken from HIRDS at both Valley Road and Palmerston North locations (Ref./2/). The HIRDS database extends to a maximum 150 year ARI. Rainfall depths for 200 year ARI storms were extrapolated from log-log plots of smaller events following advice from NIWA. Design rainfall depths are shown in Table 3-2.

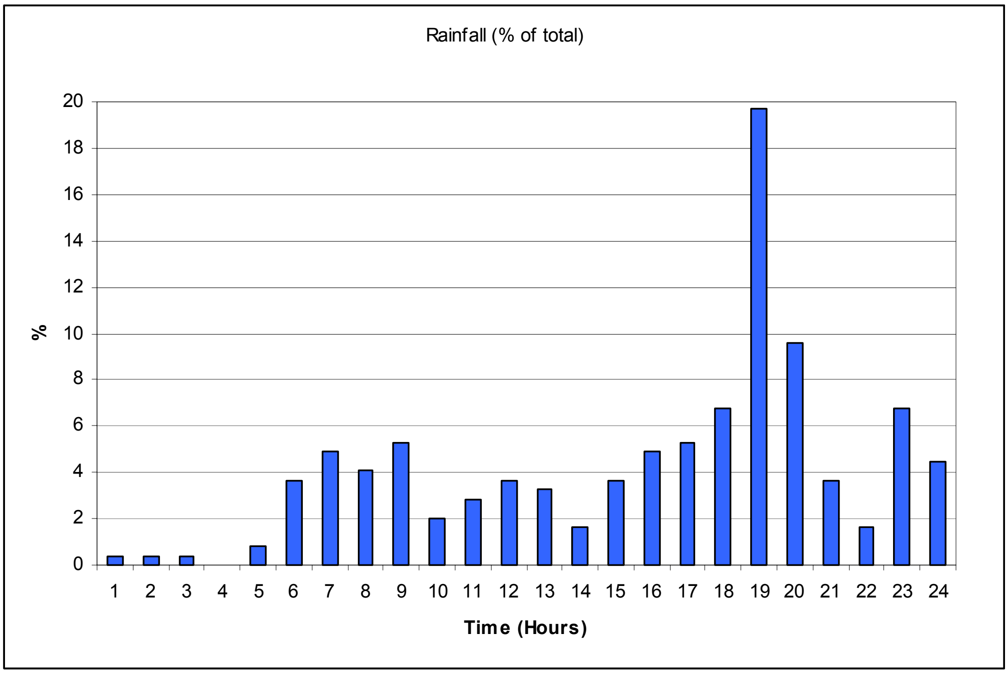

Figure 3-2 Distribution of rainfall events for design purposes (based on Valley Rd 2004)

Table 3-2 24 hour rainfall depths used for design hydrograph generation

ARI (years)	Palmerston North	Valley Road
50	95.8	111.6
100	112.4	131
200	126.5	147.5

By way of comparison, the 24 maximum hour rainfall depths at these locations is shown in Table 3-3.

Table 3-3 Observed maximum 24 hour rainfalls

Year	Palmerston North*	Valley Road
1976	97.6	-
1988	96.1	68.3
2004	55	109.6

**Milsons Line or Agricultural Research Station*

This indicates that the 1976 and 1988 events in Palmerston North corresponded approximately to a 50 year ARI, as did the 2004 event in Valley Road. The large spatial variation in rainfall in 2004 can be clearly seen, which resulted in large flood flows being generated in the upper Mangaone catchment.

3.3.4 Flood Frequency Analysis

In order to verify the derived design flood depths and rainfall distribution, the peak discharges simulated for each design rainfall event were compared to values obtained from a flood frequency analysis of the flow record at the Milsons Line gauge. NIWA and HRC have both carried out analyses of the gauge. As part of this study, DHI have also undertaken an analysis using the complete flow record to data, using DHI's EVA (Extreme Value Analysis) software (Ref/3/). The General Extreme Value (GEV) distribution has been used in all cases, but with slightly differing methods for obtaining the final extreme values.

Table 3-4 Comparison of Model predicted flows to Flood Frequency Analyses

Analysis Type	ARI (years)		
	50	***100***	***200***
NIWA (GEV)	221.7	273.3	333.6
HRC (GEV)	215.9	265.1	322.1
DHI (GEV)	220.6	273.4	335.6
Model	225.8	295.6	356.9

The results are shown in Table 3-4. These indicate the model simulations match well with the observed frequency distribution, with the model slightly over predicting the peak flows for higher return periods. This is to be expected as the larger events that have been observed are influenced by significant out of channel flow and storage. This would tend to skew the top of the distribution towards a smaller value compared to the situation if all water was retained in the channel. The error for the 200 year ARI is just over 6%, which is considered acceptable for this purpose.

3.4 Mangaone – Taonui Model Catchments

The model development described above relates to the Mangaone Stream catchment only. The hydraulic model covers a much larger area, on differing terrain, and runoff from these catchments is required for both the validation to observed events as well as the final flood risk mapping.

3.4.1 Catchment Delineation and Parameters

The study area has been delineated into 25 sub-catchments, with areas ranging from 2 to 22 km^2. The delineated catchments are shown in Drawing 3. The drainage path for each catchment was determined from a close analysis of the land level data, from which the hydraulic length and slope have been calculated. For all events initial and continuing losses of 20mm and 2mm/hr respectively have been assumed, as found from the Mangaone Stream calibration.

3.4.2 Catchment Rainfall and Runoff

Catchment rainfall is derived by weighting the two gauges at Valley Road and Palmerston North. Higher weighting to Valley Road is given to the upper catchments (north and east of the railway line), while catchments in and close to the Taonui Basin are weighted mainly toward the Palmerston North gauge.

In 2004 an additional gauge is available at Halcombe Road in Fielding (see Drawing 2). The maximum 24 hour rainfall at this gauge was 95mm on the 15th February, compared to 55mm in Palmerston North and 109.6mm at Valley Road. For the 2004 event only, a different weighting was therefore applied to the catchments in the north west of the study area utilizing this additional data.

Typical runoff hydrographs are shown in Figure 3-3 for Catchment 3 (steep upper catchment) and 14 (mid-catchment) for the February 2004 event.

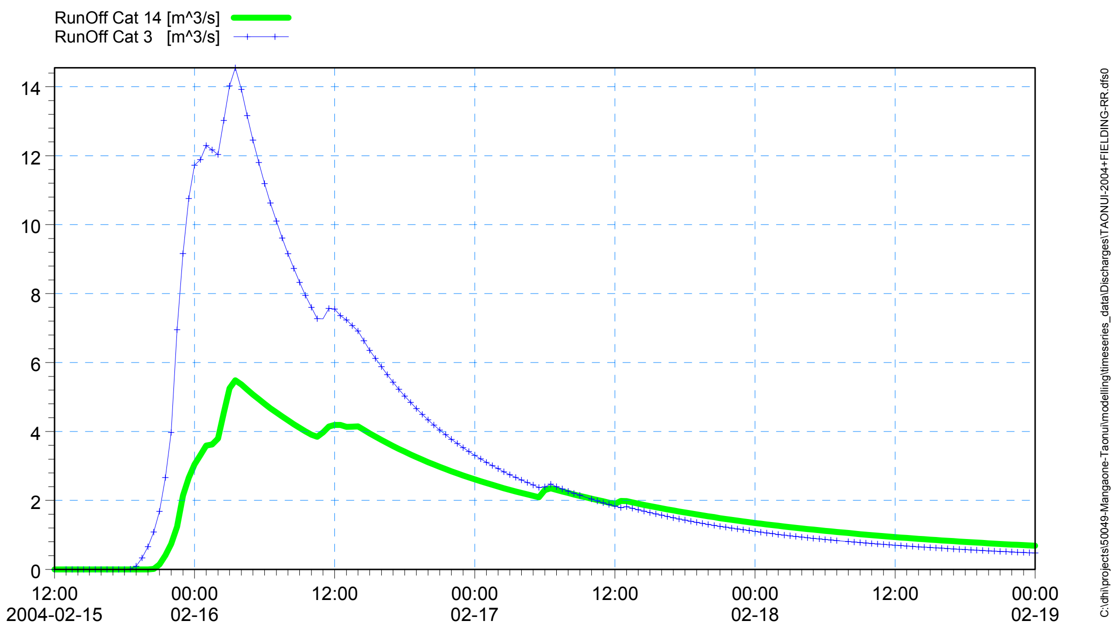

Figure 3-3 Runoff Hydrographs for Catchments 3 and 14, 2004.

4 HYDRODYNAMIC MODEL BUILD & CALIBRATION

4.1 Model Description

The hydrodynamic model comprises separate 1D and 2D models, dynamically linked to enable full exchange of flows between the two model domains. The modelling software used was MIKE 11 for the 1D component and MIKE 21 for the 2D component. The coupling between the two is provided via MIKE FLOOD (MF), see Ref./4/. Two separate MF models were developed, a coarse 25m grid model covering the entire study area, and a finer 10m grid model covering an area of interest around the Mangaone spillway. The model extents are shown in Drawing 4.

4.2 Channel Selection – 1D or 2D?

The 1D model component is necessary to enable important drainage and channel networks to be accurately represented in the combined model. As a general rule, channels less than 3-5 grid squares in width cannot be adequately resolved in a 2D grid. In addition, where channels are embanked, or include important hydraulic structures, these need to be represented in the 1D model.

The study area in the upper reaches includes many fine drainage channels which are observable from the LiDAR data. The decision to include these smaller channels in the 1D grid was made based on the importance to the overall drainage of the area. Channels were included in the 1D model where they were seen to play an important role in the overall conveyance capacity of the floodplain, but were too small to be resolved accurately in the 2D model grid.

The following descriptions relate to the development of the 25m model which was undertaken first. The fine grid 10m model incorporates all the features of the 25m model, with some additional refinements. These are described in section 4.9.

4.3 Physical Description

The model study area covers an area of approximately 220 km^2, making it one of the largest areas in which MIKE FLOOD modelling has been applied. The study area is bounded to the north and north east by the North Island Main Trunk Railway, to the east and south east by the Mangaone and Manawatu stopbanks and to the west by the Oroua stopbanks.

Topographic relief with the 2D model area varies from approximately 70m in the north west to less than 10m in the Taonui Basin. Drainage occurs mainly from the north east to the south west. Within the catchment area, the Mangaone Stream represents the largest river. It is stopbanked on the right bank from the Kairanga-Bunnythorpe Road and on the left bank from upstream of Setters Line. The stopbanks extend through Palmerston North and tie into the Manawatu stopbanks.

The Taonui Stream forms the other main drainage channel in the study area. It forms upstream of the railway line, and follows a south westerly course roughly parallel to the Oroua River. The river merges into Burkes Drain as it enters the Taonui Basin in the south western part of the model area. The basin has a highly developed hydraulic infrastructure comprising a large number of interconnected drains, of which Burkes Drain and Main Drain are the largest. The operation of this system has been described in Section 2.3.

In the middle catchment, a number of medium sized watercourses and drains exist, which convey local runoff down toward the Taonui Basin. Whiskey Creek is important in this respect, as it receives water released from the Mangaone Spillway at Flygers Line, although its capacity is not sufficient to take the entire flow. Whiskey Creek ultimately drains into Main Drain. Another significant watercourse follows the Kairanga-Bunnythorpe Road parallel to Whiskey Creek, and also joins Main Drain as it enters the Taonui basin. For the purposes of this study, this is referred to as Kairanga Drain.

4.4 Methodology and Data Availability

The LiDAR dataset provided by HRC formed the basis for the development of both the 1D and 2D models. HRC provided a series of 1km x 1km unthinned, flow enforced TINS for the project. For practical modelling purposes, a 1m grid was obtained from the LiDAR suppliers, and this has been used as the basis for the model build. Cross checks were made against the 1m grid and the original TINS to ensure the 1m grid captured the important elevation features of the floodplain. In addition to the land level data, HRC provided a wide range of GIS datasets including roads and railways, stopbanks, watercourses, soil types, land use as well as background topo maps and aerial photography. Also provided were relevant timeseries data, comprising spillways and breach flow and boundary water levels.

4.5 MIKE 11 Model Build

4.5.1 MIKE 11 Model Domain

The MIKE 11 model includes all of the important drainage channels within the study area as outlined in section 4.3, i.e. – Taonui Stream, Burkes Drain, Main Drain, Whiskey Creek and Kairanga Drain. Refer to Drawing 3. The Mangaone Stream itself is not included in the model, as this is embanked for most of its length within the model area, and therefore interacts to only a limited degree with other parts of the drainage network.

An exception to this is the stream which drains into the Mangaone at Richardsons Line, just north of the airport. This watercourse in stopbanked from the Mangaone upstream to where it crosses Richardsons Line. It is important as breaching or overtopping of this stopbank would result in floodwaters crossing the airport runway and inundating parts of Palmerston North City. To account for this interaction, a short reach of the stream (termed “Airport Stream” in this report) has been included in the MIKE 11 model, extending from the Milsons Line gauge recorder to the end of the stopbanks on Richardsons Line. Catchment inflows are directed to this branch, to allow drainage to the Mangaone, and also enable backwater effects from the Mangaone to be simulated. Spilling from this stream over the stopbanks is possible in reality, however this has been disabled in the model in order to ascertain the level of actual stopbanking necessary.

Special treatment has been applied to secondary drains in the Taonui Basin. These collect local runoff and drain through the Main Drain and Burkes Drain stopbanks via pipes or culverts fitted with non-return flapgates. During high water levels in the larger drains, the flapgates close preventing local runoff from draining, and causing local inundation to occur. A number of these structures have been included in the model in the Main Drain left bank to allow this effect to be simulated, as it was seen in the early stages of model development that these effects are important in terms of the total inundation occurring in the basin.

Figure 4-1 Detail of MIKE 11 channel description near Palmerston North Airport.

Burkes Drain also includes a number of spillways constructed in the embankments, to allow spilling from the channel into the basin when the Rangiotu flood gates close during high Manawatu river stages. These have been included in the MIKE 11 model as short branches incorporating a weir structure, and connecting to the 2D model of the floodplain.

4.5.2 Cross Sections

MIKE 11 model cross sections have been extracted from the LiDAR 1m grid at 100m intervals. A total of 560 cross sections have been extracted using the MIKE 11 GIS tool. A typical cross section is shown in Figure 4-2. The resolution of the LiDAR data is sufficient to describe the main properties of the cross section. An independent check of a number of cross sections has been carried out through field surveys, which is reported in Appendix B. The cross sections were processed to delineate the extent used in the MIKE 11 calculations and so to avoid duplication of conveyance and storage with the MIKE 21 extent. This is shown in the figure by the vertical red lines, which demarcate the extents of the MIKE 11 cross section used in the hydraulic calculations.

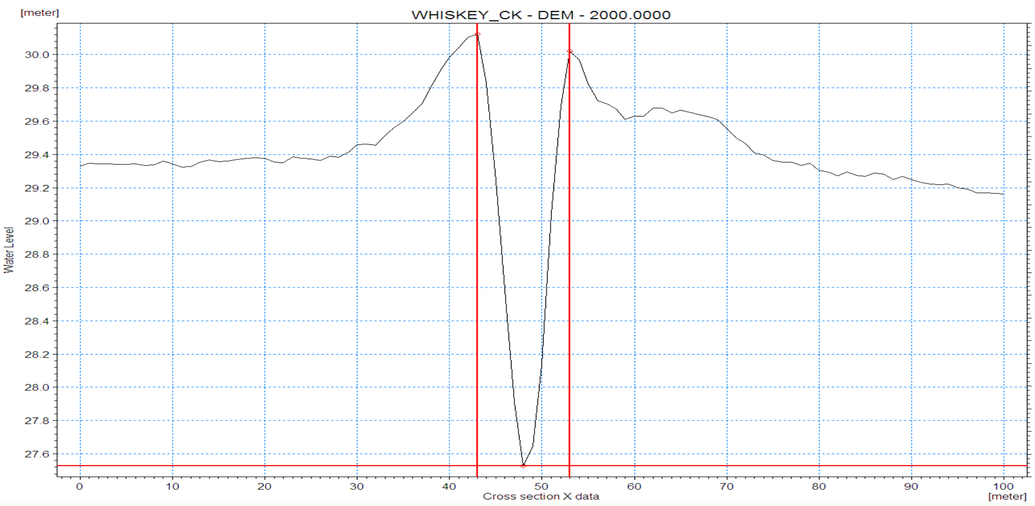

Figure 4-2 Cross section in Whiskey Creek extracted from LiDAR

4.5.3 Structures

A large number of bridges and culverts are present in the model area where roads cross the main drainage channels. Potentially important structures were initially identified from the LiDAR data and aerial photographs, see Drawing 5. A number of these were included in the cross section surveys to obtain geometries and levels for incorporation in the model. The balance were surveyed by DHI during a site visit on 6th July 2006. This proved to coincide with quite heavy rainfall in the catchment, and the importance of the identified structures for local drainage was confirmed during the field inspection. The DHI survey obtained the widths and depths/diameters for culverts and bridge openings and deck thicknesses. Using LiDAR data the soffit and invert levels of each structure has been estimated. Structure geometries used in the model are provided in Appendix B. A total of 16 culverts and 7 bridges have been included in the MIKE 11 model.

The Rangiotu floodgates at the downstream end of Burkes drain have been included as two sets of one-way culverts, each set representing the upper and lower gates respectively. The geometry of the structure was derived from drawings supplied by HRC.

A photographic record of each structure was also taken, and these have been archived for future use by HRC if required. Some examples are shown in Figure 4-3 below.

Figure 4-3 From Top Left clockwise: Nagaio Rd; Whiskey Creek at Rangitikei Line; Main Drain at Lockwood Road; Kairanga Drain at Longburn-Rongotea Road.

4.5.4 Boundaries and Catchment Connections

Inflows to the MIKE 11 model are all derived from the calibrated rainfall-runoff model. These are located from topographical considerations. Where the location of the catchment inflow is clearly defined (eg via a small stream or drain), these are applied at the identified point. Where the inflows are more diffuse, catchment inflows are linearly distributed along the appropriate MIKE 11 branch. A number of catchment inflows are defined outside the MIKE 11 model area and these are applied as source points in the MIKE 21 model. See Section 4.6.3 for further details.

The main downstream boundary of the MIKE 11 model is the Manawatu River water level downstream of the Rangiotu flood gates. This has been supplied for historical and design flood events by HRC.

The Airport Stream branch extends to the Milsons Line gauge in the Mangaone Stream so that this may be utilized as a boundary condition. Water levels are available here only from 1978, and therefore do not cover the 1976 flood event. However water levels at the gauge tend to reach a ceiling due to storage effects at this location, and to a lesser degree because of the effect of the Mangaone spillway just downstream of the gauge which spills excess flows out of the river. Therefore for the 1976 event the 2004 water levels were used, shifted in time so that the peak water level coincided with the peak spillway discharge provided by HRC.

For the design events, a single water level boundary was derived on the advice of HRC, by adding 200mm to the 2004 water level and again adjusting the timing so that the water level peak coincided with the peak of the spillway flows.

4.6 MIKE 21 Model Build

4.6.1 MIKE 21 Model Domain

The MIKE 21 model is bounded by the Oroua and Manawatu stopbanks to the south and west, the Mangaone stopbanks to the east and the railway line to the north. The coarse model grid size of 25m has been selected as a reasonable compromise between model resolution and practical model run times. The final model grid extends to 848 x 862 grid cells, just under 731,000 cells in total, of which 352,500 are non-land points.

4.6.2 Topography and Features

The 1 m grid supplied by AAM Hatch was used as the basis for model topography development. The 1m grid was interpolated to 25 metres in the first instance. In this process many fine grid features, such as embankments and roads are lost. Within the study area, particularly in the lower half, the presence of embankments and roads will have an important effect on the floodplain flows. It is therefore essential that these features are represented accurately in the model.

The process in which these features are introduced back into the model grid is known as "burning in" and briefly involves the following:

- Accurate digitization of embankment and road crest alignments
- Extraction of the underlying DEM values and conversion to 3D GIS layers
- Conversion of the 3D layers to raster coverages matching the model grid
- Replacing the interpolated model grid with the digitized grid
- Infilling of "holes" in the model grid, for example between river stopbanks

This is a time consuming process but the result is a 2D model grid that is hydraulically correct as it includes all of the land features that will affect the hydraulic behaviour of the overland flow.

Within the study area, all roads, and stopbanks on the Mangaone Stream, Main Drain and Burkes Drain have been burnt into the model grid. Guide banks downstream of the Mangaone and Kopane spillways have also been included. The final grid levels have been spot checked against the original 1m grid data to verify the burning in process has captured the important floodplain features.

4.6.3 Source Inflows

Source inflows to the MIKE 21 model domain take place at catchment outlets, where constructed spillways discharge onto the floodplain and where stopbank overtopping or breaching has taken place.

Constructed spillways are located at Kopane and Rangiotu on the Oroua River, Hamilton's Line on the Manawatu, and Flygers Line on Mangaone Stream. HRC have provided spillway hydrographs for historical and ARI events, where applicable. The peak discharges for each spill are indicated in Table 4-1.

Table 4-1 Maximum spill discharges (m^3/s) introduced to the MIKE 21 model

River	Location	Event Year			ARI (years)		
		1976	***1988***	***2004***	***50***	***100***	***200***
Mangaone	Spillway	30.0	22.0	70.2	114.0	114.0	114.0
	Derby Creek	55.0	-	50.0	55.0	65.0	80.0
	110m u/s Roberts Line	-	-	-	-	20.0	31.0
	180m d/s Roberts Line	-	-	-	-	20.0	20.0
	220m d/s Roberts Line	-	-	-	-	-	20.0
	500m d/s Setters Line	-	-	-	-	-	20.0
	600m d/s Flygers Line	23.0	-	-	-	-	-
Oroua	Kopane Spillway	-	-	88.0	31.0	68.0	110.0
	Rangiotu spillway	-	-	345.0	324.0	451.0	579.0
	Awahuri breach	-	-	93.0	-	-	-
	Camerons overtop	-	-	15.0	-	-	-
	Milsons overtop (2 locations)	-	-	59.0	-	-	-
	Golf course overtop	-	-	15.0	-	-	-
Manawatu	Hamilton's Line Spillway	-	-	-	-	-	76.0

To ensure model stability, the spill hydrographs are distributed across a number of grid cells. In some cases these are determined by physical constraints. For example the Mangaone spill guidebanks are approximately 100m apart, and consequently the spill flows are introduced to 4 x 25m cells.

Additional source inflows are introduced for catchment inflows. The catchments are nos. 1 to 7 inclusive; 17,19,21,23,24 and 25.

4.6.4 Boundaries

The 25m MIKE 21 model does not contain any open boundaries. Inflows to the model take place either through direct sources as described above, or from the MIKE 11 model via the MIKE FLOOD link. Outflows take place only through the MIKE 11 model linkages.

4.6.5 Hydraulic Resistance

A 2D hydraulic resistance map has been derived from the land use GIS layer supplied by HRC. Land uses types were mapped to various hydraulic resistances (Manning numbers) based on experience and accepted use in the industry. The adopted mapping is shown in Table 4-2. The vast majority of the floodplain in the study area is grassland and therefore is assigned a Manning n of 0.05. Pockets of urban development, forest or shelterbelts are assigned a value of 0.125. The final resistance map is shown in Figure 4-4.

Table 4-2 Adopted hydraulic resistance based on land use types

Description (LCDB2)	Code	n	M
High Producing Exotic Grassland	40	0.050	20
Pine Forest - Closed Canopy	66	0.125	8
Manuka and or Kanuka	52	0.125	8
Pine Forest - Open Canopy	65	0.125	8
Indigenous Forest	69	0.125	8
Orchard and Other Perennial Crops	32	0.125	8
Built-up Area	1	0.010	10
Short-rotation Cropland	30	0.050	20
Vineyard	31	0.125	8
Broadleaved Indigenous Hardwoods	54	0.125	8
Other Exotic Forest	67	0.125	8
Urban Parkland / Open Space	2	0.033	30
River	21	0.020	50
River and Lakeshore Gravel and Rock	11	0.020	50
Gorse and or Broom	51	0.125	8
Afforestation (imaged, post LCDB 1)	63	0.125	8
Deciduous Hardwoods	68	0.125	8
Lake and Pond	20	0.020	50
Major Shelterbelts	61	0.125	8
Surface Mine	3	0.050	20
Transport Infrastructure	5	0.100	10
Afforestation (not imaged)	62	0.125	8
Low Producing Grassland	41	0.050	20
Mixed Exotic Shrubland	56	0.050	20
Forest Harvested	64	0.125	8

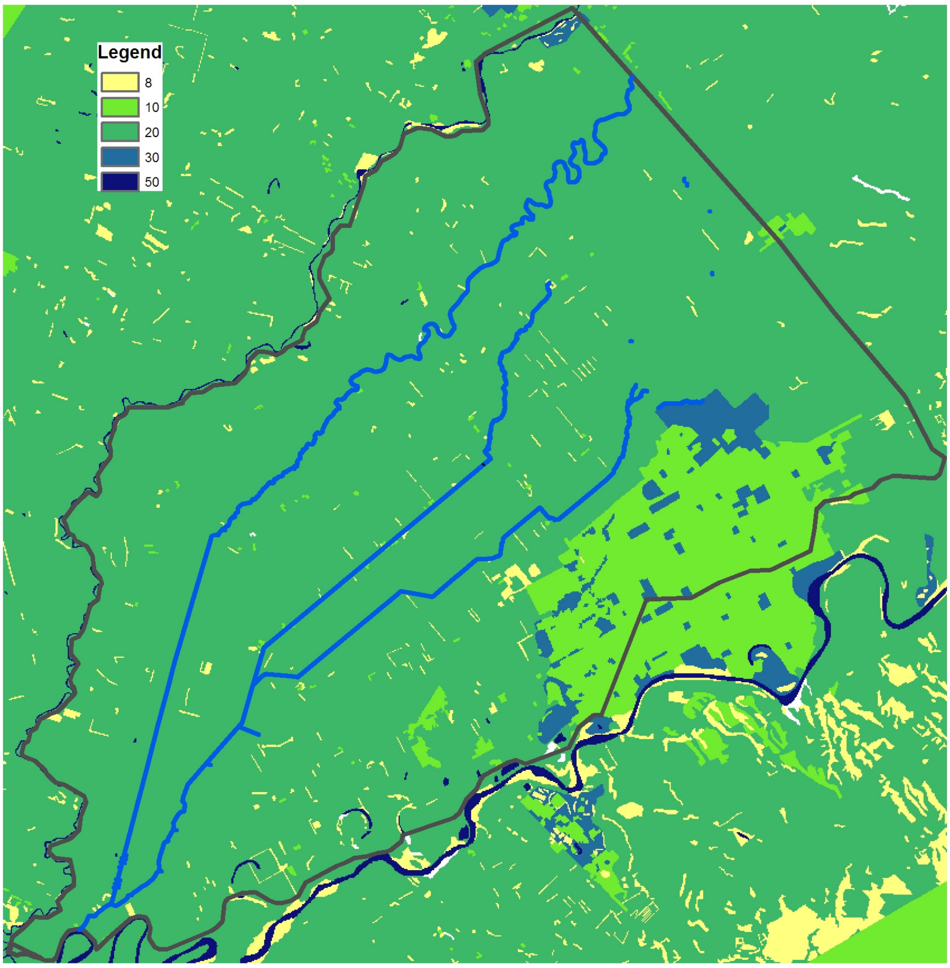

Figure 4-4 Generated hydraulic roughness map (M = 1/n)

4.7 MIKE FLOOD Model Build

4.7.1 Linkages

Dynamic linkages between the MIKE 11 and MIKE 21 models are achieved through the specification of each link in the MIKE FLOOD interface. MIKE FLOOD allows three types of linkages:

Standard – a MIKE 11 branch end is linked to one or more MIKE 21 cells
Lateral – a range of MIKE 11 chainages is linked to a range of MIKE 21 cells
Structure – a MIKE 11 structure is specified to add to or replace the flows across two adjacent MIKE 21 cells.

All three types have been implemented in the final model in a total of 57 separate linkages. These are briefly described in the following:

Burkes Drain Spillways. A total of 12 standard links (6 on each left and right bank) have been implemented to represent the spillways located at the downstream end of Burkes Drain.

Whiskey Creek and Triburary Upstream end. Standard links have been defined at the upstream ends of these branches to allow floodplain flows to enter the MIKE 11 system.

Taonui Stream, Whiskey Creek, Main Drain and Burkes Drain. Continuous lateral links have been defined along these channels to allow free exchanges of flood water between the floodplain and these large drainage channels. This ensures that the contribution to total floodplain conveyance of these channels is represented in the model.

Main Drain Flapgates. Three short MIKE 11 branches fitted with flapped culverts convey water from the floodplain on the left bank of Main Drain into the drain. The upstream ends of these branches are connected to the MIKE 21 grid via standard links. The flapgates will prevent drainage of this area during high water levels in Main Drain.

Airport Stream. This is an important branch that merits special treatment as overflows from this tributary can threaten Palmerston North. The downstream end of the branch uses a water level boundary at the Milsons Line gauge. The upstream end of the branch collects runoff from catchments 6 and 21 and is connected to the MIKE 21 grid via a standard link. The channel is stopbanked downstream of Richardsons Line. Overtopping of this bank is possible but has been disabled in order to determine the stopbank levels needed to prevent overtopping.

Structure Links. MIKE 21 uses the structure solutions available within the MIKE 11 model in cases where these may affect flows in the model grid. Within the model, a number of culverts which lie outside the MIKE 11 model extent have been incorporated via the MIKE FLOOD link.

4.7.2 Model Simulations

The coupled models are run with a 2 second timestep and results are saved every 30 mins. The model simulations take approximately 24 hours on a HPxw4300 3.8GHz computer. Model runs times are affected by the number of flooded cells and the number and density of MIKE FLOOD links. Lateral links in particular have a significant affect on model run times. MIKE 21 result files are approximately 1GB in size.

4.8 Model Calibration

HRC have provided observed flood extents as GIS layers for the 2004, 1988 and 1976 flood events. These have been digitized from aerial photographs taken during the events. In addition a number of spot levels have been obtained by HRC for the 2004 flood, from observations of the aerial photos and interviews with local residents. There are no other water level or flow gauges in the catchment. The data has been used to validate the model performance rather than as a framework for detailed calibration, which cannot be supported by the available data set. Initial model runs were undertaken and the results discussed at a workshop meeting with HRC in Palmerston North. As a result of the meeting a number of minor changes were made to the model, and for the 2004 event additional spills were introduced from the Oroua to account for observed inundation extents in this area.

A check against the 2004 spot levels shows a good match in many areas, particularly along the Mangaone spill path. The match achieved in the Taonui basin confirms the volume of water entering the basin is of the correct magnitude. There are a number of inconsistencies in the observed spot levels which have been checked by HRC, but remain unexplained.

The flood extent validations for 1976, 1988 and 2004 simulations are shown on Drawings 6, 7 and 8 respectively. The 2004 map also shows the location of observed levels. The differences between the simulated and observed peak levels at each of these locations is shown in Appendix C.

1976*:* The 1976 simulated extent matches the observed extent closely throughout most of the model area. The original simulation showed a much larger extent of flooding and therefore it was decided to reduce the rainfall inputs by 20% for the final simulation. This is justified by the spatial variability of the rainfall observed in later events and the fact that only one gauge recording is available (in Palmerston North) for 1976.

Notable differences can be observed at Milsons Line, just south west of the township of Kairanga and the upper catchment near Bunnythorpe. The additional overland spill path across Milsons Line is simulated in all three verification events. In 2004 an observed water level is also available upstream of Milsons Line which would confirm that this additional flowpath exists. The inundation near Kairanga is clearly observed in 1988 and 2004, and therefore was likely to have also occurred in 1976. The simulated inundation in the upper catchment is due to the fact that the smaller sub-grid sized channels in this area have not been included in the 1D model. Refinement of this part of the model is possibly required, including a refinement of the model grid size, and the inclusion of the Mangaone Stream in full, in order to provide suitable boundary conditions for the smaller streams which cross into the study area from north of the railway line.

1988: The observed extent for 1988 is quite patchy, especially upstream of Gillespies Line, and misses for example the certain inundation that would have occurred downstream of the Flygers Line spillway on the Mangaone. The flooding near Kairanga is however clearly shown, and as the 1988 event was similar in comparison to 1976 this would indicate that this flooding would also have occurred in the earlier event. The simulated flood extent on the Mangaone spillway flowpath upstream of the Longburn-Rongetea Road matches almost perfectly with the observations, indicating the spill flows and rainfall-runoff inputs are correct in this area. The model simulations indicate significant flooding further along this road between Kairanga and Kopane. Some flooding was observed in this area, including some passing over Aranui Road which has been partly simulated by the model. It is likely the observed flood extent in this area is incomplete. Flooding occurs in this area due to a reduction in channel conveyance combined with low bank levels on the Taonui Stream.

2004: This was the largest event simulated in terms of inundation extent. The February 2004 flood witnessed numerous stopbank failures and overtopping, as well as extensive flows occurring over the constructed spillways on the Mangaone Stream at Flygers Line and the Oroua spillways at Kopane and Rangiotu (refer to Table 4-1). The flooded extent has been reproduced well along the two main overland flood areas alongside the Mangaone and Oroua stopbanks. Spill flows, particularly those resulting from bank overtopping and breaching, are uncertain and have been modified where appropriate to match observed flood extents. For example the initially estimated Oroua spills at Camerons Line were doubled, and new spills were added close to the Fielding golf course where flooding had been observed. Unfortunately the flood extents in this area are incomplete but the simulated flood extent further south matches well with the observation confirming that some additional spills may have taken place near the golf course.

The patchy flooding which appears to occur along the Taonui Stream between Roberts Line and Milsons Line has not been reproduced. The channel conveyance capacity in this reach is relatively large due to the natural stream terraces which exist in the area. It seems unlikely therefore that overtopping of the natural river banks would have occurred unless low level overflow paths exist in the river bank. This would need to be confirmed by a more detailed field survey. Because of the nature of the dynamic coupling the model is not able to display the flooding which would have occurred within the 1D MIKE 11 model extents (which include the river terraces), which may explain some, but not all of the discrepancies in this area. It is possible that the observed flood extents are due to local drainage congestion but this would need to be confirmed via a closer examination of the drainage channels and overland flow paths in this area.

The secondary spill path across Milsons Line is again simulated in 2004. The observed flood level just upstream of the road is 34.99, compared to the simulated level of 34.83. The road level (from the LiDAR data) is approximately 34.6, which indicates that the road must have been overtopped in this area as predicted by the model. (Note the field cross section surveys at this location give road centreline levels of 34.86 and 34.88, see Appendix B, which would still indicate flooding had occurred). The familiar pattern of flooding south west of Kairanga is again simulated, but is not seen in the observed extent, although flooding in this area is almost certain to have occurred as it did in 1988.

Simulated inundation in the upper Mangaone tributary reaches matches reasonably well with the observation, but the results could be improved through model refinements as described previously.

The observed spot levels are shown on Drawing 8. Some anomalies can be seen in the observed data, for example a number of observed flood levels are shown outside of the observed flood extent. In addition some observed water levels in the lower Taonui basin, which would be expected to be to be fairly uniform, show large variations in level. The overall match in observed and simulated peak water levels is satisfactory. The simulated maximum water level in the Taonui basin is 9.61m, which is close to the observed range of 9.4-9.8m.In general the simulated water levels along the Oroua spill flowpaths are lower than those observed. This reflects the uncertainty in the Oroua spillway and breach flows. Water levels along the Mangaone spill flowpaths match closely with the observed levels.

4.9 Fine Grid Model Development

The development of the fine grid model of the area around the Mangaone Spillway followed closely the development of the larger 25m grid model. The model extent is shown on Drawing 4, and has been determined based on the required coverage of the fine grid model and the ability to define suitable boundary conditions.

4.9.1 MIKE 21 Model Domain, Topography and Hydraulic Resistance

A 10m grid has been defined for this model. The topography has been based on a corrected 1m grid covering the model area. The original 1m grid supplied by AAM Hatch was found to be in error with a horizontal north and east shift of 1 and 2 metres respectively. This was considered important for the 10m model and therefore a revised model grid was generated based on the new 1m LiDAR information.

As with the 25m model, important land level features were burnt into the model grid after identifying these from the LiDAR data. All of the features included in the 25m model have been incorporated, as well as a number of lesser features such as driveways and small drainage embankments. A roughness map based on a 10m grid has been generated in the same way as for the 25m model as described in Section 4.6.5.

4.9.2 MIKE 11 Model Extent

The MIKE 11 model used in the 25m grid model has been used as a basis for the fine grid model. Additional branches added comprise an extension of Whiskey Creek to upstream of the Kairanga-Bunnythorpe Road, and a cross branch connecting Whiskey Creek to Kairanga Drain. The relevant culverts and bridges have been retained in the MIKE 11 model. Taonui Stream and Burkes Drain have been removed and the MIKE 11 model terminates 200m downstream of the start of Main Drain, see Figure 4-5.

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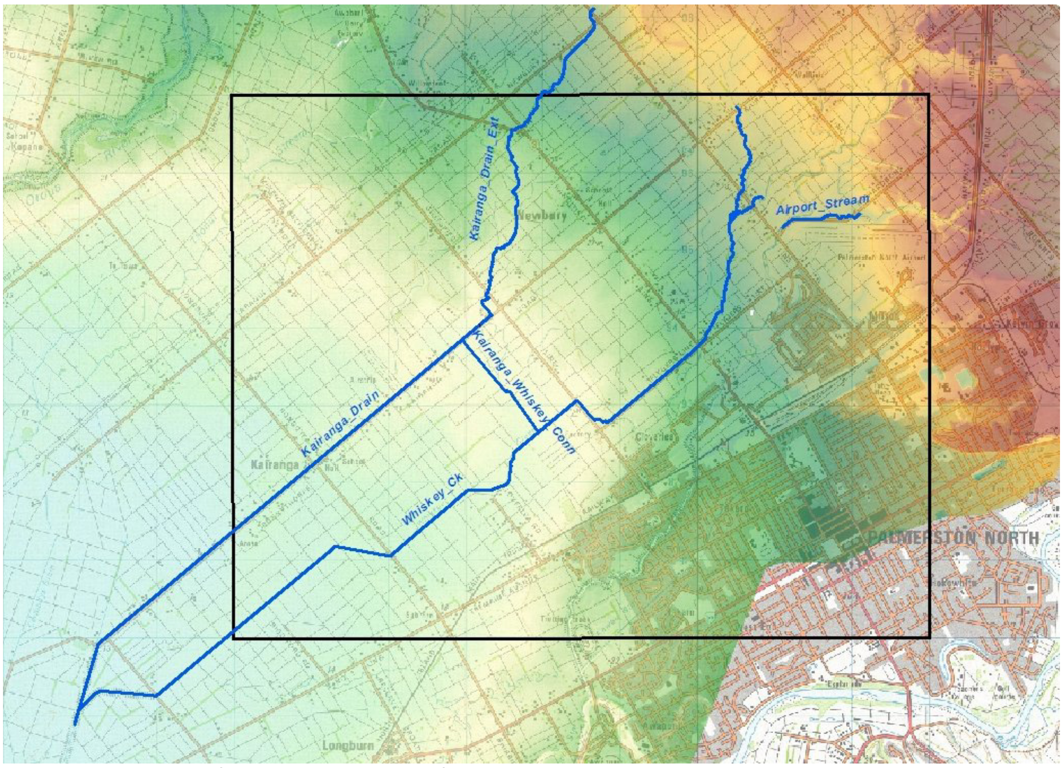


Figure 4-5 Extent of MIKE 11 domain in fine grid model.

4.9.3 MIKE 21 Source Inflows and Boundary Conditions

In the MIKE 21 domain source inflows are defined for runoff from catchments 6 and 21, plus spills from the Mangaone spillway, 600m downstream of Flygers Line (1976 only) and for the 200 year ARI only at Setters Line.

Other spills enter the model through the northern boundary, which is defined as an open flux boundary. Discharges across this line are extracted from the appropriate 25m model simulations and specified as boundary inputs for the fine grid model. Flows exit the MIKE 21 model through an open downstream boundary which has been defined with a fixed water level of 10m. Flows can also exit the MIKE 11 model via the MIKE FLOOD linkages.

4.9.4 MIKE 11 Boundary Conditions and Catchment Connections

The MIKE 11 model receives inflows from catchments 13 – 18 inclusive. Flows from catchments 4, 5, 7, 24 and 25 are represented in the northern inflow boundary extracted from the 25m model. The downstream water level boundary at Main Drain chainage 200 has been extracted for each simulation from the 25m grid model runs. The Airport Stream setup is identical to that used in the 25m grid model as described in Section 4.5.4.

4.9.5 MIKE FLOOD Linkages

The MIKE FLOOD linkages have been setup in a similar way to the 25m model. Continuous lateral links have been specified along the main drainage channels included in the model to permit free exchange between the 1D and 2D model domains. Standard links have been defined at the upstream ends of Airport and Wellsfield Streams, to allow overland flows to enter the MIKE 11 channels at these points. A total of 19 links have been specified in the model.

4.9.6 Model Simulations and Results

The fine grid model extends to 900 x 700 gridpoints, of which 420,000 are non-land points. The models run at a 2 second timestep and take approximately 27 hours to run.

Model simulations have been carried out for the 1976, 1988 and 2004 flood events, as well as 50, 100 and 200 year ARI events. The verification results are shown in Drawings 9-11.

As expected the 10m grid model simulations match closely with the 25m model extents. Some finer detail can be observed, for example water in the roadside drain on the upstream side of Milsons Line, but otherwise the flood extents are similar.

5 FLOOD RISK ASSESSMENTS

The validated MIKE FLOOD models have been used to generate flood depths and extents for the three ARI flood events selected. The results have been post processed to produce current speed and flood hazard (depth * velocity product).

5.1 Design Events

The MIKE FLOOD models have been used to simulate the 50, 100 and 200 year ARI events. Both the coarse 25m grid and fine 10m grid models have been used to generate the flood inundation extents. Catchment inflows have been generated from the calibrated hydrological model as described in Section 3, and additional spill flows supplied by HRC have been included as outlined in Table 4-1.

For the design events the timing of the Mangaone spills supplied by HRC and the natural catchment runoff is an important consideration. An analysis of the historical flood data available for 1976, 1988 and 2004 was made to determine the pattern of spillway runoff and catchment peak flows for each event. Catchment 17 was used as the basis for analysis, as this discharges close to the spillway and the relative timing of this runoff and the spillway flow is therefore an important indicator in terms of the overall impact.

The analysis shows that the catchment runoff peaks after the spillway peak as follows:

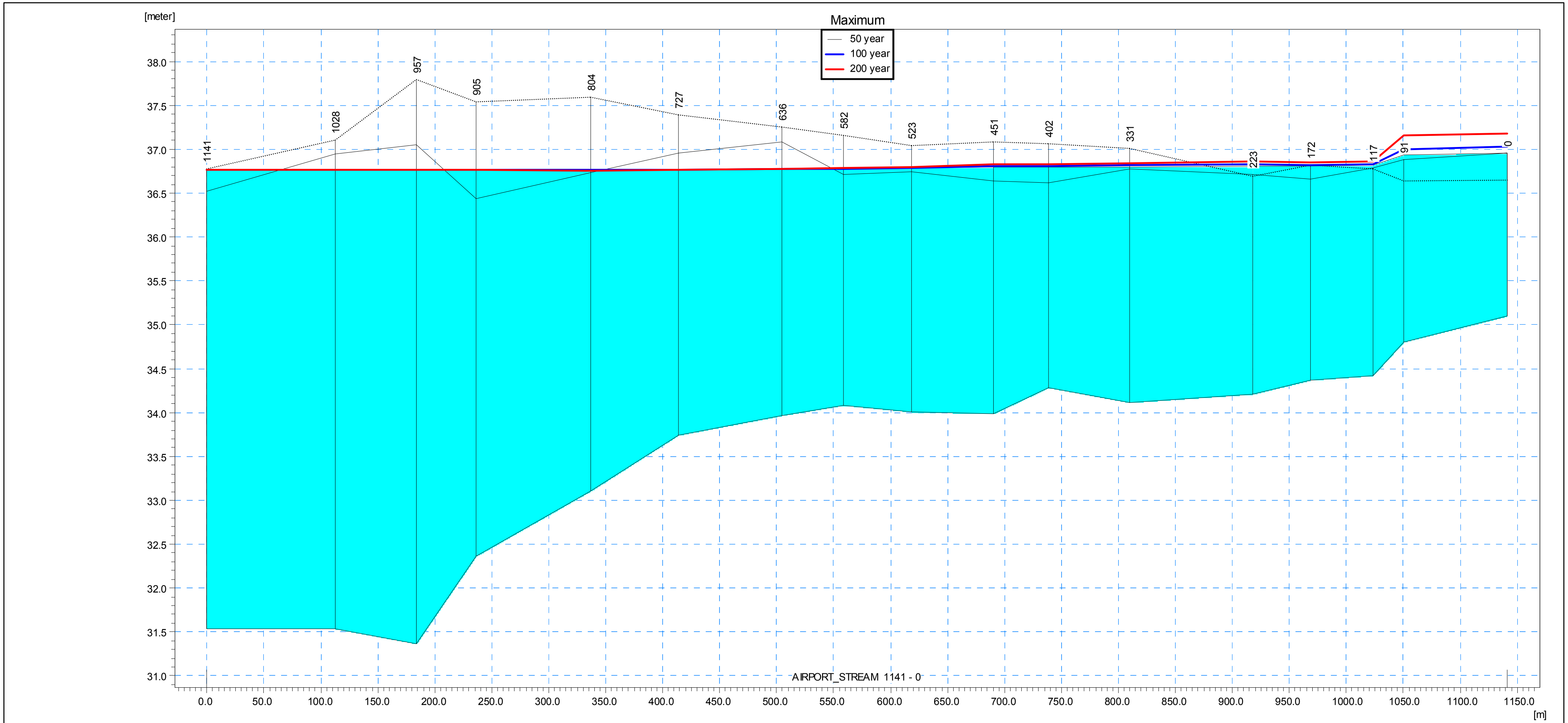
1976: 4-8 hours (two peaks)
1988: 1 -2 hours
2004: 3 hours

For the purposes of the design simulations, a lag time of 3 hours was selected, with the spillway flows adjusted accordingly.

The 25m grid model simulations are presented in Drawings 12 to 23 while the 10m grid model simulations are presented in Drawings 24 to 35.

Predicted inundation is similar to the extents observed in previous flood events. The effect of road crossings can be clearly seen, both in terms of increased ponding depths upstream, and higher flow speeds over the roads themselves. High flow speeds are also seen to occur downstream of the Mangaone and Kopane spillways, and between Setters and Milsons Line, where a natural constriction to the overland flow exists.

Flood levels in the Airport Stream have been determined assuming no spills take place; the model therefore provides the water levels assuming stopbanks are in place. The water level profile is shown in Figure 5-1. This indicates that the stopbank needs to be raised to a minimum of approximately 36.9 m, plus freeboard, to prevent overtopping in the 200 year ARI event. Additional and more detailed work is required to confirm these findings.



50 year	36.76	36.76	36.76	36.76	36.76	36.76	36.77	36.78	36.78	36.79	36.80	36.80	36.81	36.81	36.81	36.93	36.96
100 year	36.76	36.76	36.76	36.76	36.76	36.77	36.77	36.78	36.79	36.80	36.81	36.82	36.83	36.82	36.83	37.00	37.03
200 year	36.76	36.76	36.76	36.76	36.76	36.77	36.78	36.79	36.80	36.82	36.83	36.84	36.86	36.85	36.86	37.15	37.17

Figure 5-1 Longitudinal Water Level Profiles, Airport Stream, 50, 100 and 200 year ARI

Flood hazard has been classified according to the NSW Floodplain Development Manual (Ref. /5/) as shown in Figure 5-2. The MIKE 21 model results have been post-processed to compute the velocity-depth product at each grid cell and each timestep, and a maximum taken of the final result. High hazard areas are evident in the areas of high depth and velocity described above, most commonly at road crossings. The upper Mangaone tributary areas are also defined as high hazard as a result of high speeds in this area. The Taonui basin is determined as an area of high hazard due to depths over 1.0 metre. The majority of the hazard areas are classified as either "low" or "high" with little in between, which results from the narrow definition of this category according to Figure 5-2.

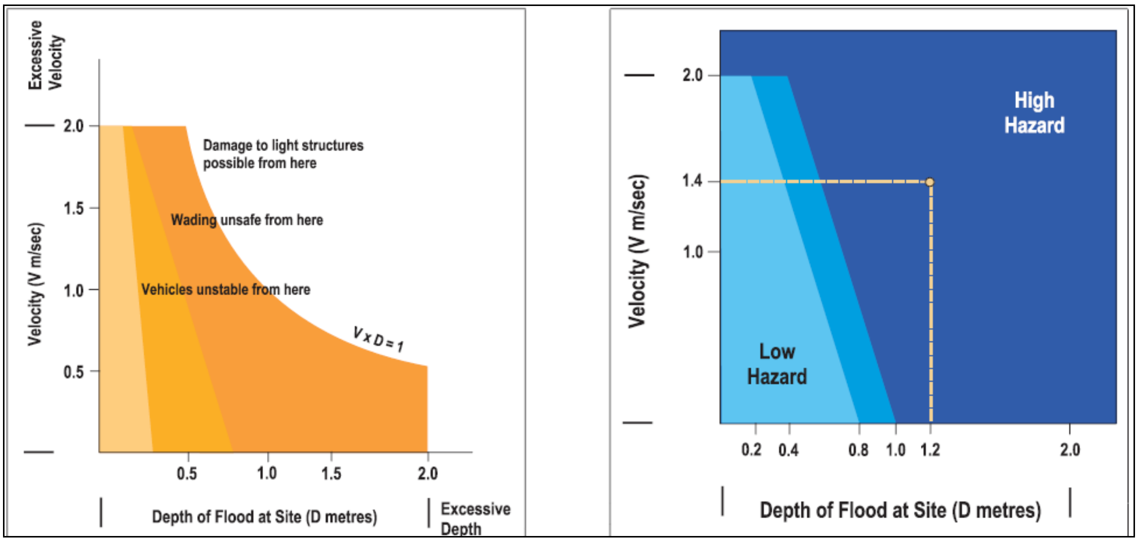


Figure 5-2 Floodplain Hazard Categories (Source: NSW Floodplain Development Manual, App. L)

5.2 Sensitivity Analysis

The sensitivity of the models to the input parameters has been tested through a series of additional simulations. Manning number changes, structure blockages and land use changes have been implemented in the model and the results analysed. The 25m model and 50 year ARI flood event have been selected as a basis for the sensitivity tests.

5.2.1 Manning Number

Two additional simulations have been undertaken to test the model sensitivity to the assumed flow resistance. The Manning number in both the MIKE 11 and MIKE 21 models has been modified by 20% above and below the assumed values. The results of the simulations are shown as difference maps (compared to the base case 50 year ARI) in Drawings 36 and 37.

The plots indicate that Manning number has only a limited affect on the extent of flooding and that the model is not overly sensitive to this parameter. A reduction of the Manning number along the Taonui Stream modifies the timing of the arrival of this peak in the Taonui Basin, leading to a small increase in flooding at the head of the basin.

5.2.2 Bridge and Culvert Blockages

Bridges and culverts have been included in both the MIKE 11 and MIKE 21 domains. Additional simulations were carried out assuming blockages of the structures. The amount of blockage to be allowed is not standardised and the best approach to dealing with this issue is still an area of on-going research. The Australian city of Wollongong suffered severe floods in 1998 caused in part by structure blockages which led to unforeseen cross catchment flooding occuring. The Wollongong City Council have since instigated a structure blockage policy to be adopted for all flood studies as follows: (Ref./6/)

i. 100% blockage for structures with a major diagonal opening width of less than 6m

ii. 25% bottom up blockage for structures with a major diagonal opening width of greater than 6m. For bridge structures involving piers or bracing, the major diagonal length is defined as the clear diagonal opening between piers/bracing, not the width of the channel at the cross-section.

iii. 100% blockage for handrails over structures covered in (i) and for structures covered in (ii) when overtopping occurs.

Most of the structures in the upper study area fall into category (i), but road bridges over the Taonui Stream, Main Drain and Burkes Drain are generally 8-10m wide.

Blockages of 50% and 95% have been investigated in the present study for sensitivity purposes. Circular culvert diameters were reduced accordingly, whilst for rectangular culverts the obvert level was reduced. The soffit levels were unchanged in both cases. Bridge blockages were simulated by introducing piers into the structure and specifying the appropriate blockage ratio. The results are shown in Drawings 38 and 39.

50% bridge blockages do not result in significant additional areas becoming flooded, however the 95% blockage case results in a new overland flow path resulting from the blockages of the structures on Milsons Line, in particular the bridge over the Taonui Stream (see structure no. 40 in Appendix B) and the culvert in the Karaingi Drain (structure no. 37). These flows eventually join the main overland flow path from the Flygers Line spillway. A blockage occurring at these structures is important as the secondary flow path is different to the primary channel drainage direction.

5.2.3 Land Use Change

HRC have provided a test case for assessing the affects of land use changes. These incorporate changes to both surface roughness and land levels. See Figure 5-3.

The land use changes have been incorporated in the model as follows:

Maize crops: Manning n set to 0.07 in model roughness map
Shelter belts: Manning n set to 0.125
New driveways: Land levels modified in model topography.

The effects of these changes in land use can be seen in Drawing 40. These are presented as changes in flood depth, which be seen to vary approximately in the range of +/- 20cm. As expected driveway raising results in increased flood depths upstream, with a reduction occurring downstream. Lowering driveways has a reverse effect. The effects of Manning number change in this simulation are not discernable as the effects of road level changes predominate.

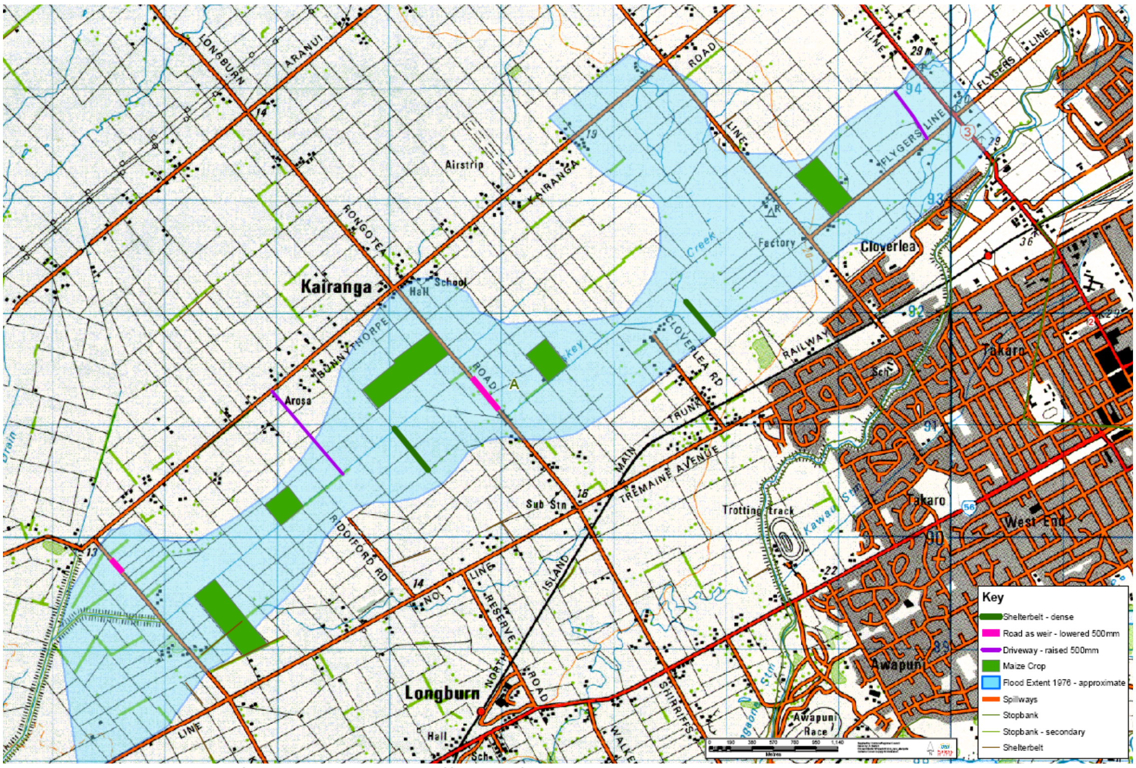


Figure 5-3 Test case for assessing the effects of land use changes

5.3 Flood Extent Margins

The aim of this exercise was to delineate the probable maximum and minimum flood extents taking into account "best case" and "worst case" assumptions of catchment runoff and inflows, flow resistance and bridge blockages. The two cases simulated were:

Low margin:	Manning number reduced by 20% Inflows reduced by 20% No bridge blockages
High Margin:	Manning number increased by 20% Inflows increased by 20% 95% bridge blockages

The most noticeable effect of the high margin simulations in terms of additional areas being flooded is the overland flow path resulting from the blockage of the bridge over the Taonui Stream on Milsons Line, as noticed in the bridge blockage simulations. In the 200 year event, some of this flow breaks away to the west and crosses Rangitikei Line very close to Kauwhata.

The high margin extents indicate a very worst case scenario. The main cause of the increased flood extent in the upper reaches is due to bridge blockages, although increased channel and surface roughness will also play a role. Increased flood extent in the lower Taonui basin will be primarily due to additional runoff volumes resulting from the higher rainfall.

6 SUMMARY AND RECOMMENDATIONS

6.1 Summary

A comprehensive flood model of the Mangaone Stream – Taonui Basin has been developed. The model comprises a dynamically coupled 1D channel model and a 2D overland flow model. Two versions of the model have been developed: a 25m grid model covering the entire basin, and a 10m grid model covering an area of interest around the Mangaone Spillway on Flygers Line.

A rainfall-runoff model of the catchment has been developed based on flow gauging information available for the Mangaone Stream at Flygers Line. This model has been calibrated against a number of events, including the February 2004 event. Based on the findings from this calibration, catchment runoff for sub-catchments in the study area has been computed based on HIRDS rainfall depths for 50, 100 and 200 year ARI (the 200 year ARI was extrapolated as HIRDS extends to only 150 year ARI) . The 2004 rainfall event temporal distribution was used as a basis for the design rainfall generation.

The 1D channel model includes the main drainage channels in the study area, including the Taonui Stream, Main Drain, Burkes Drain and Whiskey Creek. Notably the model does not include the Mangaone Stream itself or its tributaries. The decision to exclude this stream was decided at project inception stage. The assumption therefore is that the Mangaone Stream operates at bank full capacity and that tributary inflows do not enter the stream during flood events. The exception to this is the tributary entering just north of the airport, which is modelled with appropriate downstream boundary conditions taking into account flood levels in the Mangaone.

Channel cross sections have been extracted from the LiDAR air survey data. Hydraulic structures comprising culverts, bridges and flood gates have been included in the model utilizing a range of source data, including detailed field surveys.

The 2D model has been built directly from the LiDAR data. The data has been interpolated to 25m and 10m grids for each of the models. Important flow thresholds, mainly stopbanks and roads, have been retained in the interpolated grids through a manual manipulation process.

The two models have been dynamically linked to ensure free flow exchange can take place between the river channels and overland areas once water levels rise above bank levels.

The model has been verified against observed flood extents for three events: 1976, 1988 and 2004. In addition modelled maximum flood levels in 2004 have been compared with observed levels. The model has satisfactorily reproduced both the main patterns of observed flooding as well as the observed flood levels in most of the model area in 2004.

The verified model has been used to develop flood extent maps indicating flood depth, level, speed and hazard for each of the three ARI flood events considered. The sensitivity of the model to changes in channel and overland roughness, structure blockages and land use change have also been investigated. It has been found that flood extents are susceptible to large changes from structure blockages, mainly along the Taonui Stream. This is because, unlike the streams which receive spill flows from other rivers, the Taonui Stream in its mid and upper reaches only conveys flows from its own catchment. When this is no longer possible, flows break out of the stream and enter otherwise flood free land.

A significant flood threat is posed to the City of Palmerston North from flows breaking out of the small tributary that feeds into the Mangaone Stream just north of the airport. The simulations indicate that the embankment needs to be raised even for a 50 year ARI to prevent overtopping which would otherwise cause serious flooding in the city.

6.2 Recommendations

6.2.1 Uncertainties and Freeboard

The model has been developed to provide the basis for flood risk assessments in the Mangaone – Taonui Basin catchment. Based on the model verification results against observed flood extents and levels, it is reasonable to assume that confidence that can be placed in the model predictions. The main uncertainties in the model are as follows:

i. Inflows from spillways on the Oroua and Manawatu Rivers and Mangaone Stream

ii. Spatial distribution and depth of flood producing rainfall, affecting local catchment runoff

iii. Effect of the Mangaone Stream levels in the upper non-stopbanked reaches on tributary flooding

iv. Potential blockages at key bridge and culvert locations

v. Channel and overland flow hydraulic roughness

The high and low margin simulations illustrate the impacts of uncertainties in the rainfall, hydraulic roughness and structure blockages. Significant changes in flood extent and depth can occur due to these affects. Flood levels in the margins simulations vary by +/- 35cm between low and high margins. This would indicate that a freeboard requirement of at least 50cm would be required. Potential inundation caused by structure blockages should also be taken into account in any flood hazard planning for development or emergency management.

6.2.2 Model Improvement

The models developed as part of this study have been developed to a high level of accuracy using all available data, and can therefore be reliably used for flood hazard assessment purposes. An area of the model that requires improvement is the Mangaone stream and its tributaries upstream of the Flygers Line spillway. A fine grid model of this area has been proposed, which will include the Mangaone Stream itself as well as significant tributary channels in a detailed 1D channel description, so that flow capacities and the effects of undersized channels on flood behaviour can be accurately assessed. The development of this model will also provide a detailed description of the flood hazard around Bunnythorpe, which is understood to be a priority area.

The developed 10m and 25m models can be used for the purposes of flood hazard assessment within the catchment. Where fine scale detailed assessments are required, which may not be supported by the model grid, the usual practice would be to provide additional detail in the form of a 1D channel description, coupled with a refinement of the model grid in the area of interest. The models developed as part of this study can be used to provide boundary conditions to fine grid sub-models as required.

7 REFERENCES

/1/. DHI Water & Environment: *MIKE 11 Rainfall-Runoff Module Reference Manual*

/2/. NIWA: *High Intensity Rainfall Design System (HIRDS) Reference Manual,* June 2002

/3/. DHI Water & Environment: *EVA Reference Manual*

/4/. DHI Water & Environment: *MIKE FLOOD Reference Manual*

/5/. NSW Department of Infrastructure, Planning and Natural Resources, *Floodplain Development Manual*, April 2005.

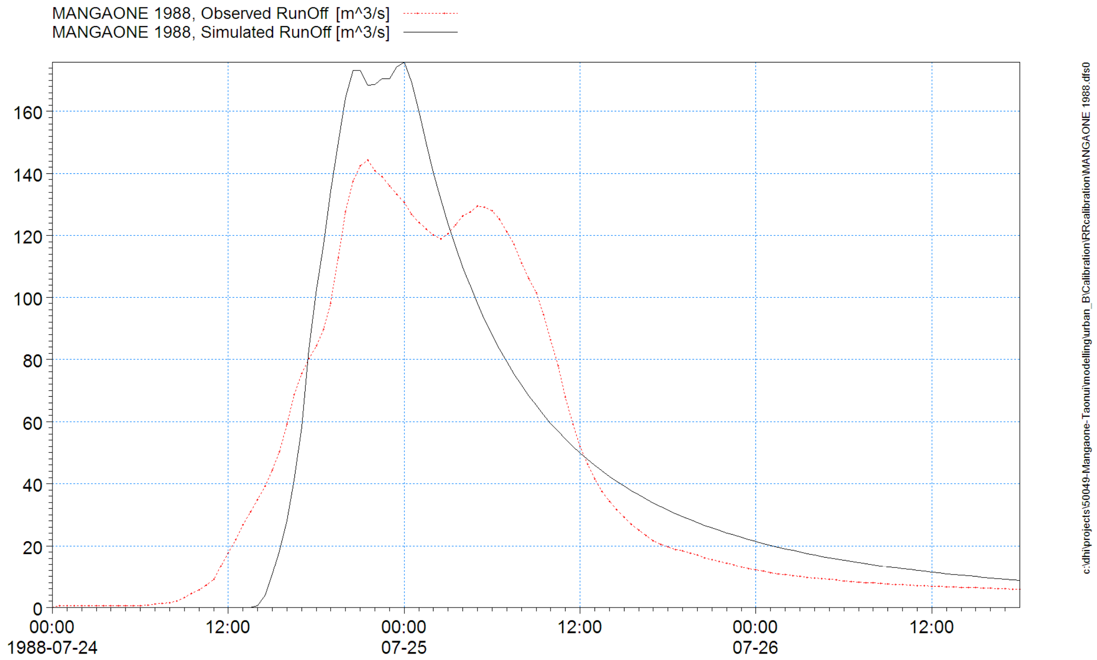
/6/. Wollongong City Council, *Conduit Blockage Policy 3.11*

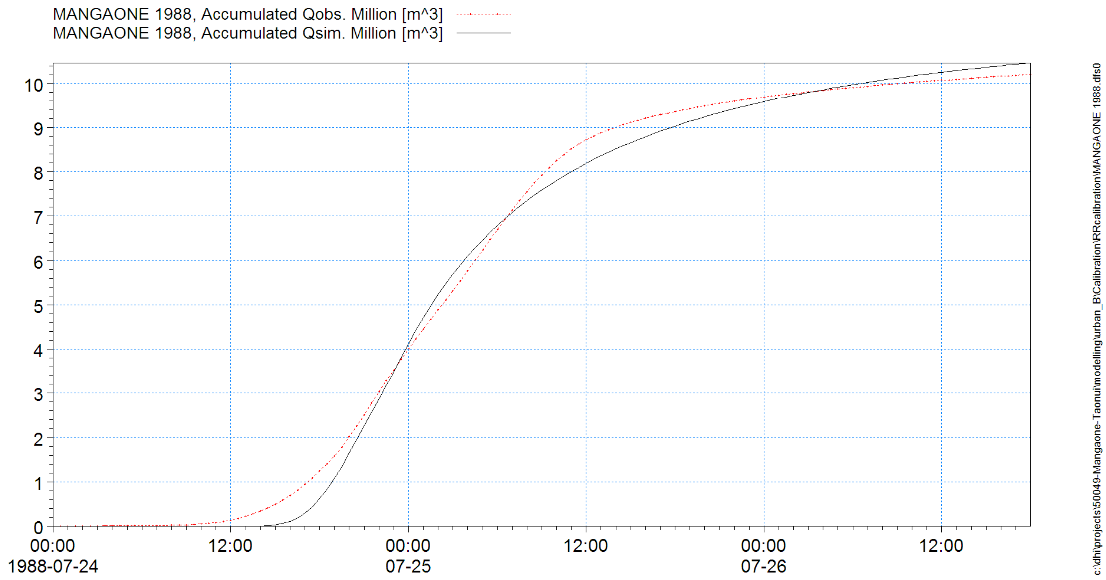
DRAWINGS

(Drawings 6 – 43 in separate volume)

APPENDIX A

Hydrological Model Calibration Results





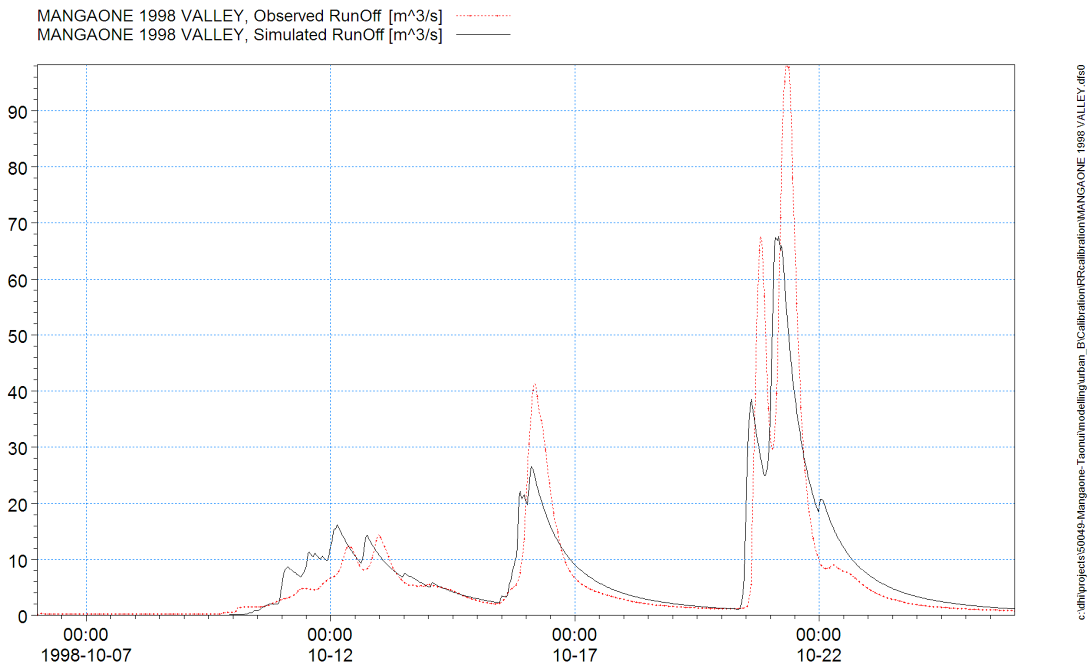
DHI WATER & ENVIRONMENT

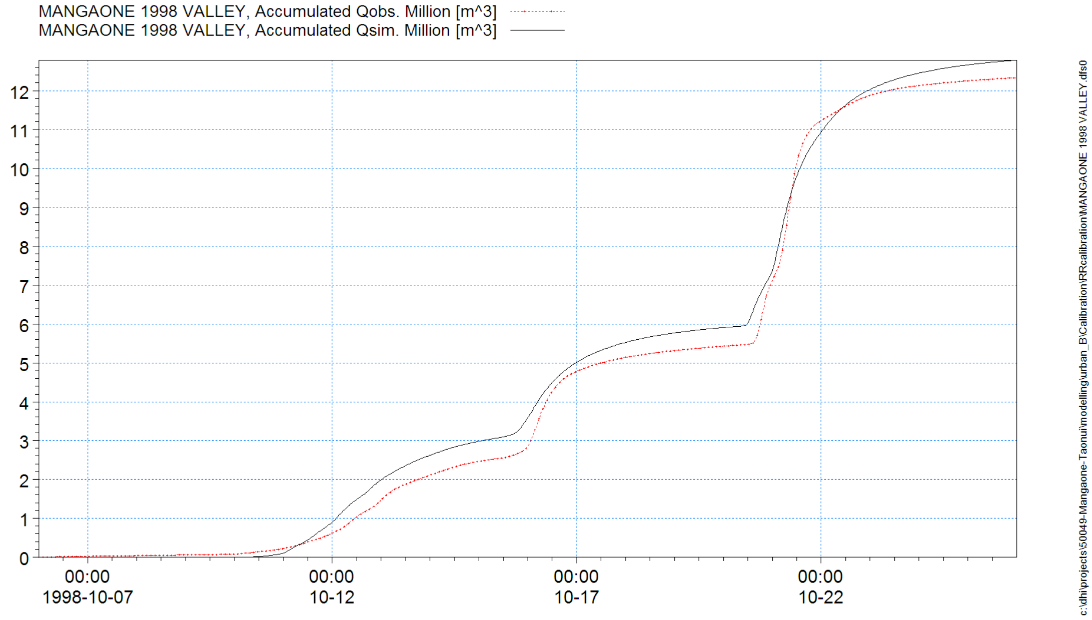
Client: Horizons Regional Council

Project: Mangaone-Taonui Flood Hazard

MIKE Zero

Calibration	Date:		Drawing no.
July 1988	25/ 7/2006 19:51	R2=0.841, WBL= -2.5% (obs=8622mm/y, sim=8841mm/y)	C-1
	Init:		





DHI WATER & ENVIRONMENT		Client: Horizons Regional Council	MIKE Zero
		Project: Mangaone-Taonui Flood Hazard	
Calibration October 1998	Date: 8/9/2006 20:51	R2=0.726, WBL= -3.7% (obs=1433mm/y, sim=1485mm/y)	Drawing no. C-2
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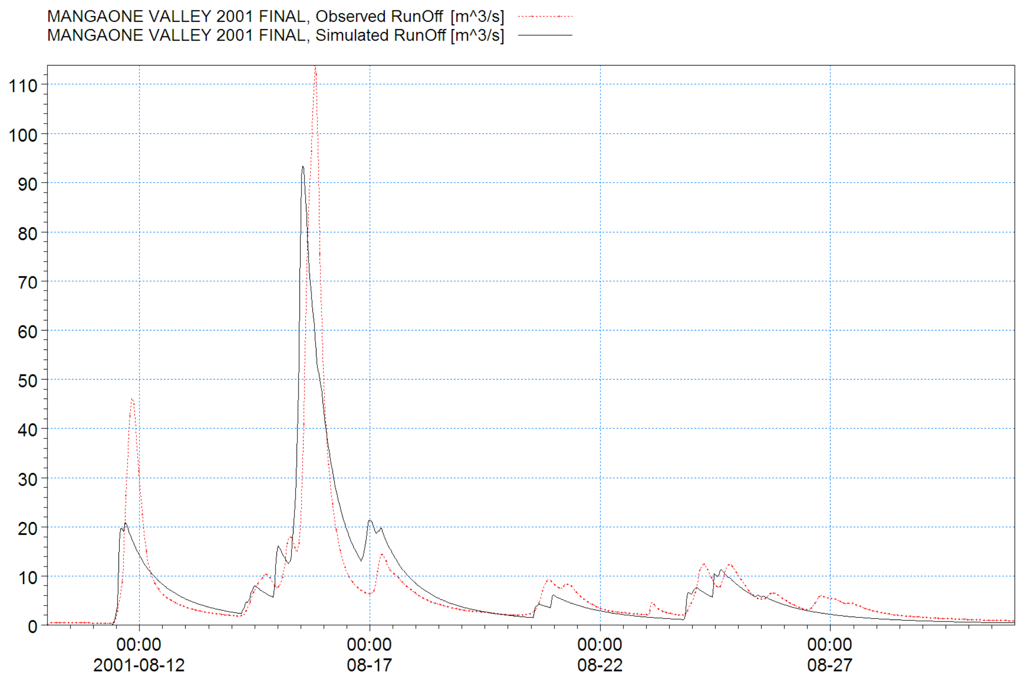

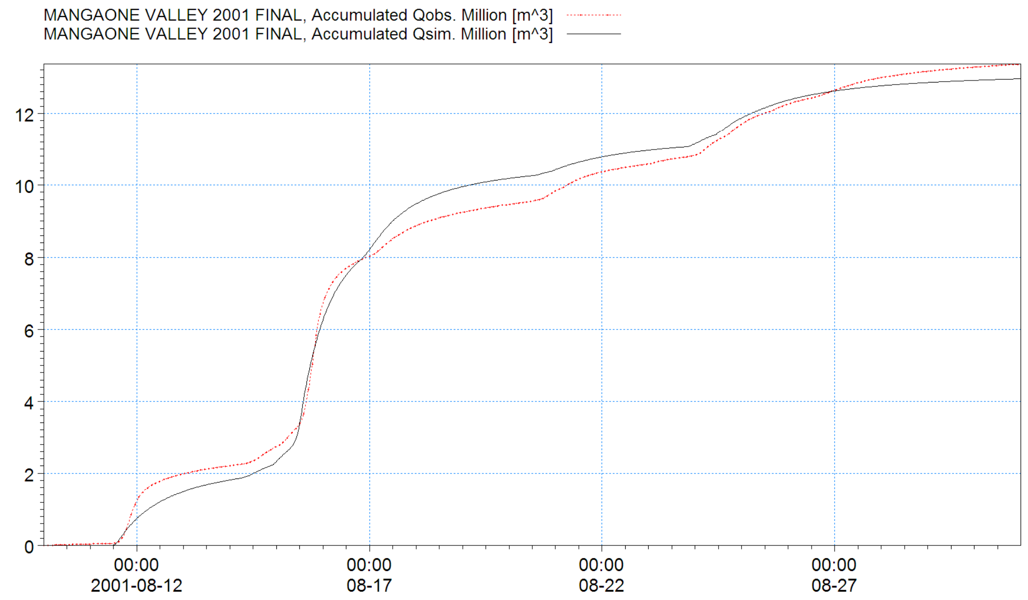

DHI WATER & ENVIRONMENT		Client: Horizons Regional Council Project: Mangaone-Taonui Flood Hazard	MIKE Zero
Calibration August 2001	Date: 4/5/2006	R2=0.665, WBL= 3.0% (obs=1479mm/y, sim=1434mm/y)	Drawing no. C-3
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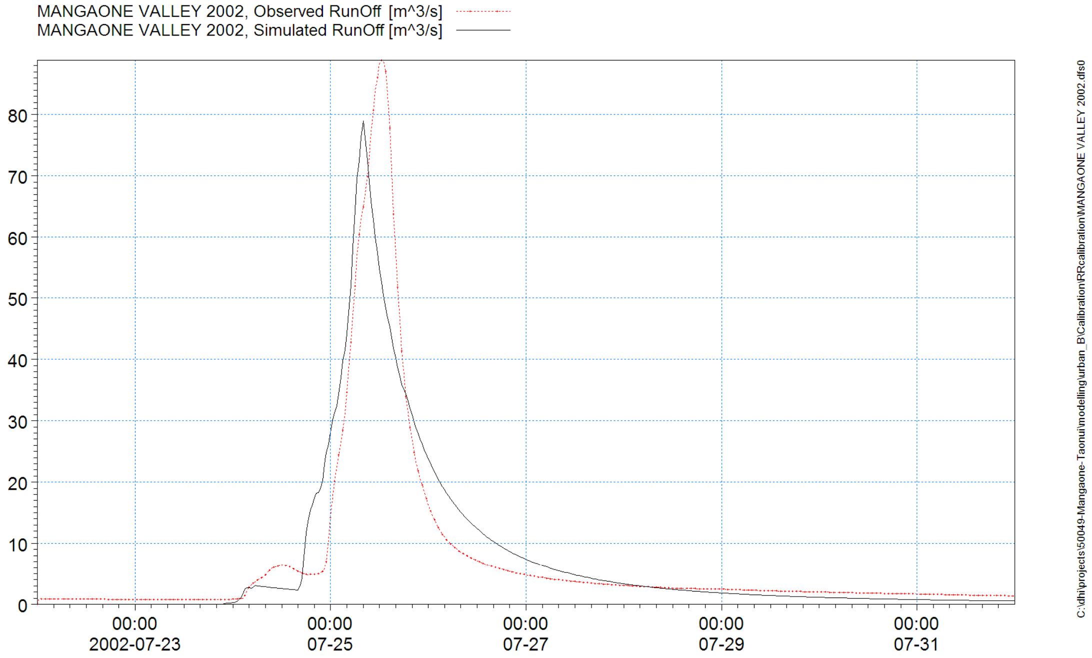
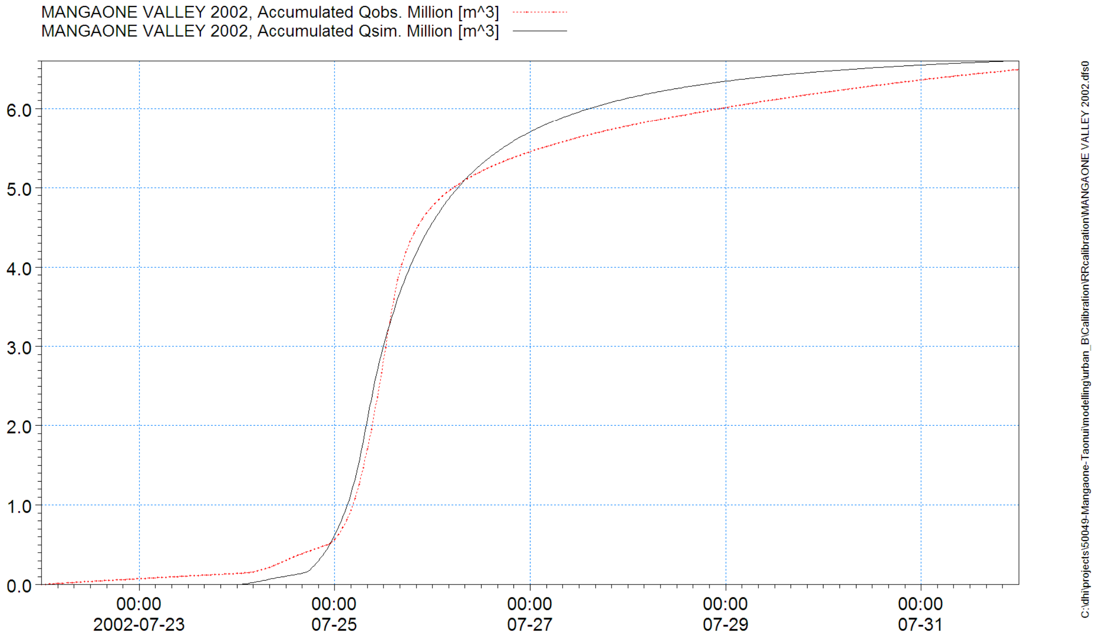




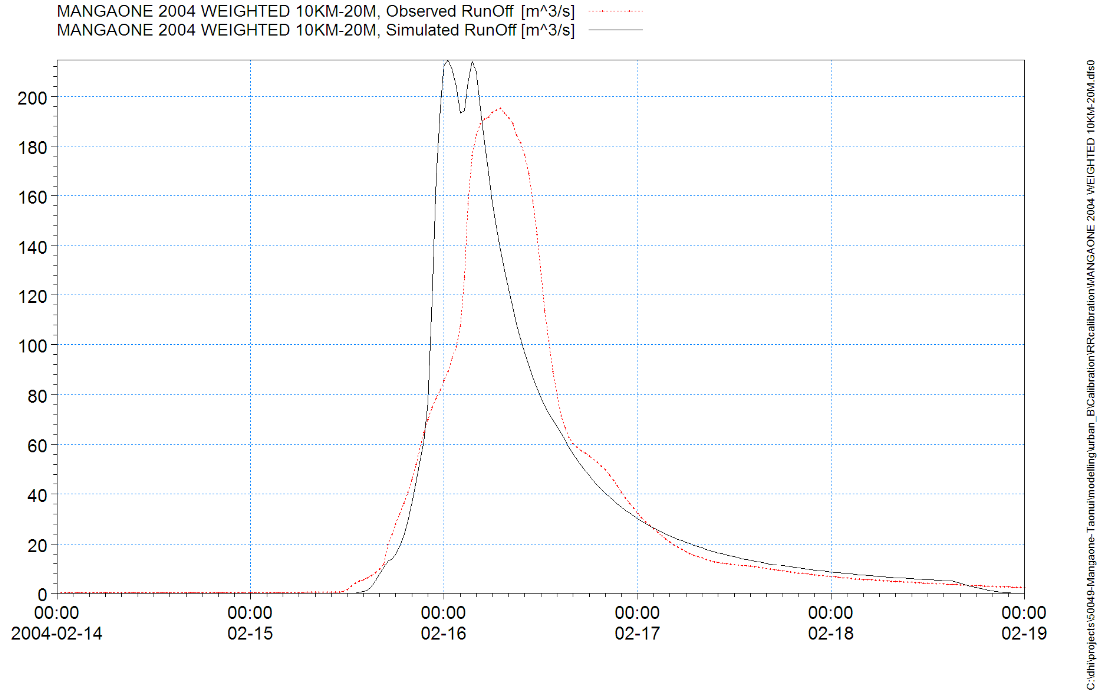
DHI WATER & ENVIRONMENT

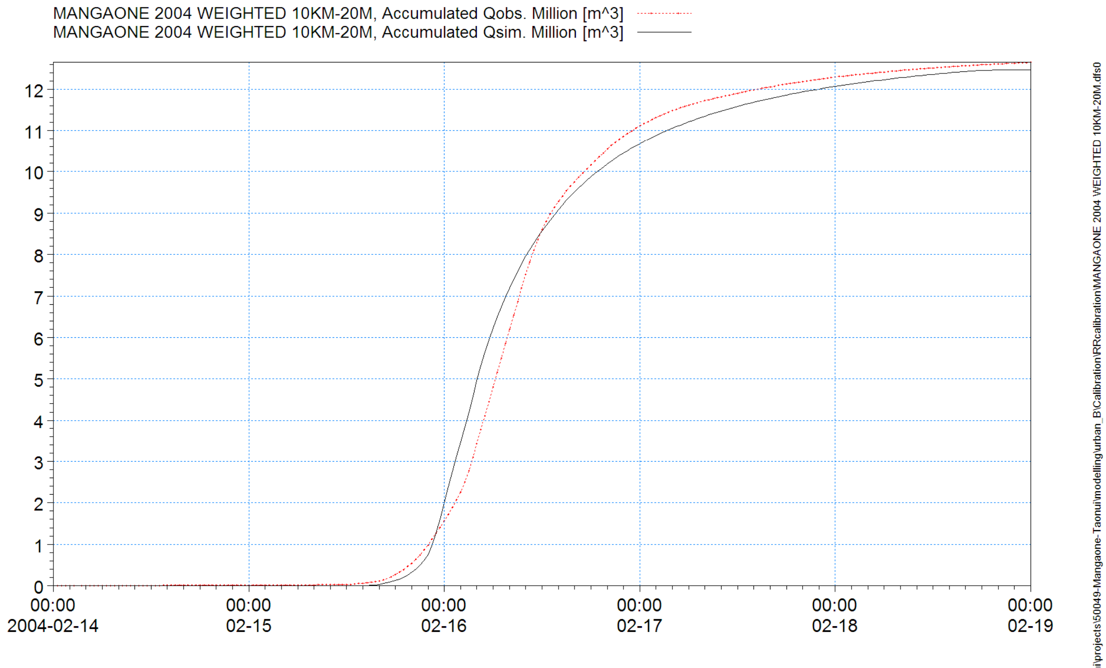
Client: Horizons Regional Council

Project: Mangaone-Taonui Flood Hazard

MIKE Zero

Calibration July 2002	Date: 4/5/2006	R2=0.849, WBL= -1.7% (obs=1509mm/y, sim=1534mm/y)	Drawing no. C-4
	Init:		





DHI WATER & ENVIRONMENT

Client: Horizons Regional Council

Project: Mangaone-Taonui Flood Hazard

MIKEZero

Calibration: February 2004

Date: 25/7/2006 18:55

Init:

R2=0.742, WBL= 1.4% (obs=5876mm/y, sim=5792mm/y)

Drawing no. C-5

APPENDIX B

Field Cross Section and Structure Surveys

Survey Brief

Cross Sections Surveys for Mangaone-Taonui Basin Flood Study

Cross sections locations

Cross sections to be surveyed are shown below, plus on following maps. Shape files (ESRI GIS compatible) are also supplied.

XS No.	LOCATION	Struc. No. (Dwg. 5)
1	Bottom of Main Drain at Rangiotu	-
2	Main Drain at Karere Rd	53
3	Main Drain on Lockwood Rd	54
4	Burkes Drain on Lockwood Rd	55
5	Taonui Stream near start of Burkes Drain	-
6	Whiskey Creek on Longburn-Rongotea Rd	51
7	Taonui Stream on Longburn-Rongtea Rd	59
8	Drain on Longburn-Rongotea Rd at Bunnythorpe-Kairanga Rd	50
9	Drain on Longburn-Rongotea Rd at Aranui Rd	-
10	Drain on Gillespies Line nr Bunnythorpe-Kairanga Rd	48
11	Whiskey Creek on Gillespies Line	47
12	Taonui Stream on Kauwhata-Arahuri Rd (Willowdene)	41
13	Taonui Stream at Milsons Line	40
14	Mangaone Stream at Richarsons Line near airport	30
15	Mangaone spillway channel at Flygers Line (under Flygers Line)	45a*
16	Mangaone spillway channel at Flygers Line (under Rangitikei Line)	45b
17n	Mangaone spillway channel upstream spillway on Milsons Line – north	34
17s	Mangaone spillway channel upstream spillway on Milsons Line –south	33
18	Mangaone at Roberts Line nr Clevely Line	23*
19	Taonui Stream at Taonui nr water tower	2*
20	Mangaone tributary upstream of railway near Richardsons Line	25*

* not included in model

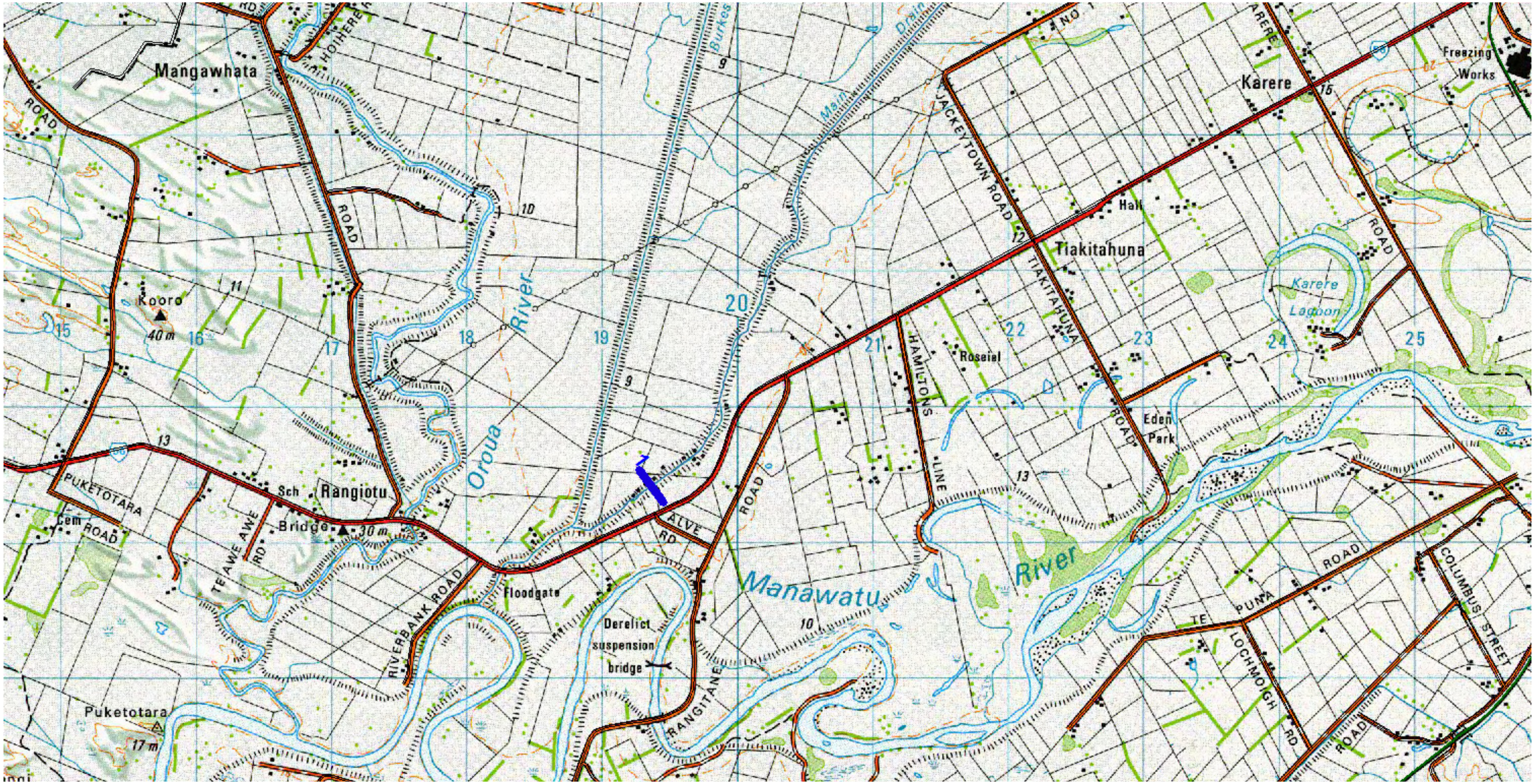
Extents

Cross sections are to extend as per the attached shape files. The section shall define fully the channel (including below water parts), stopbanks or natural banks, and the floodplain nominally for 100 m either side of the banks. In some cases longer extents have been defined where two channels are covered in the same section

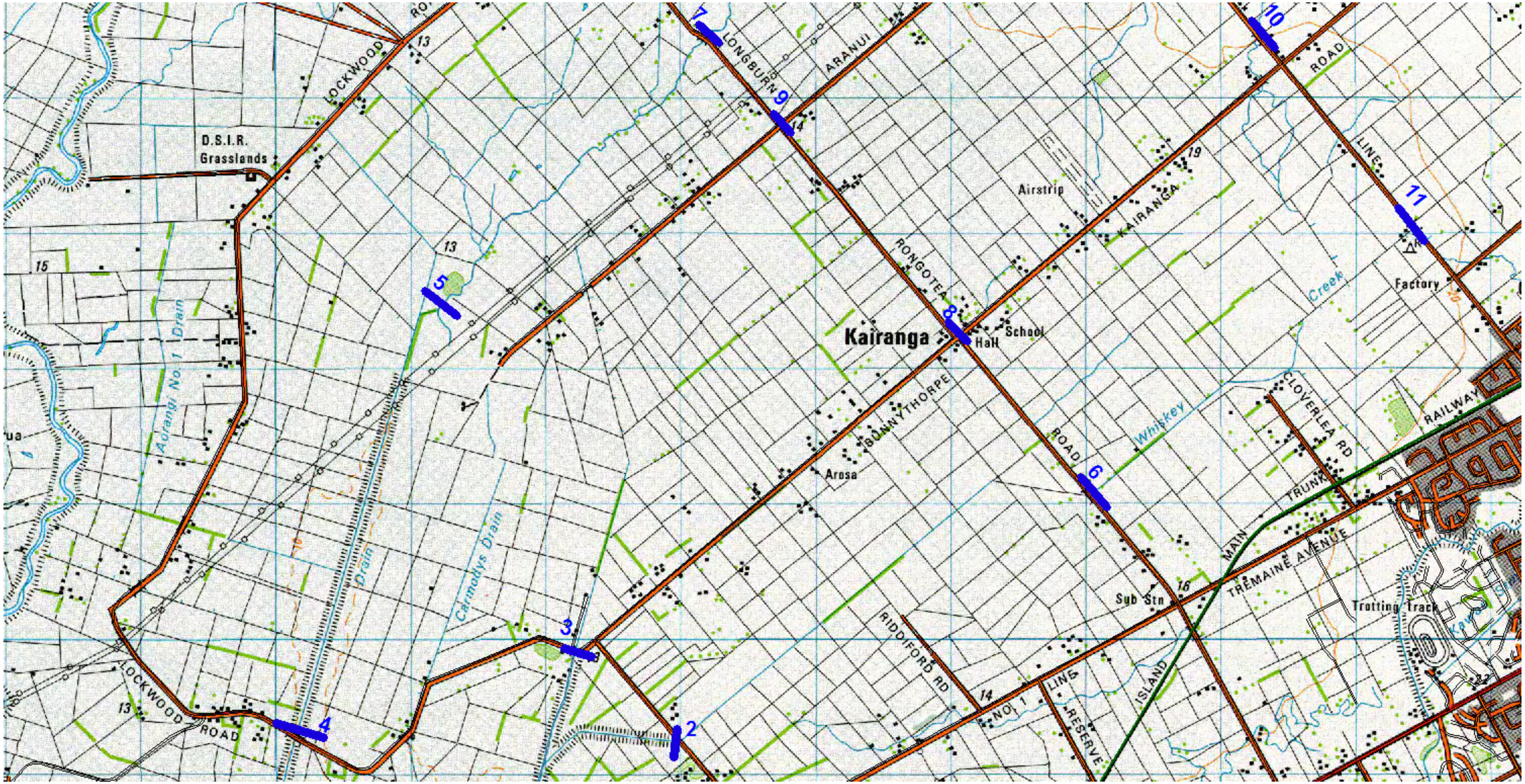
Drainage structures

Most cross sections are defined at channel road crossings. In these cases the approximate structure dimensions are also to be included. These would be typically:

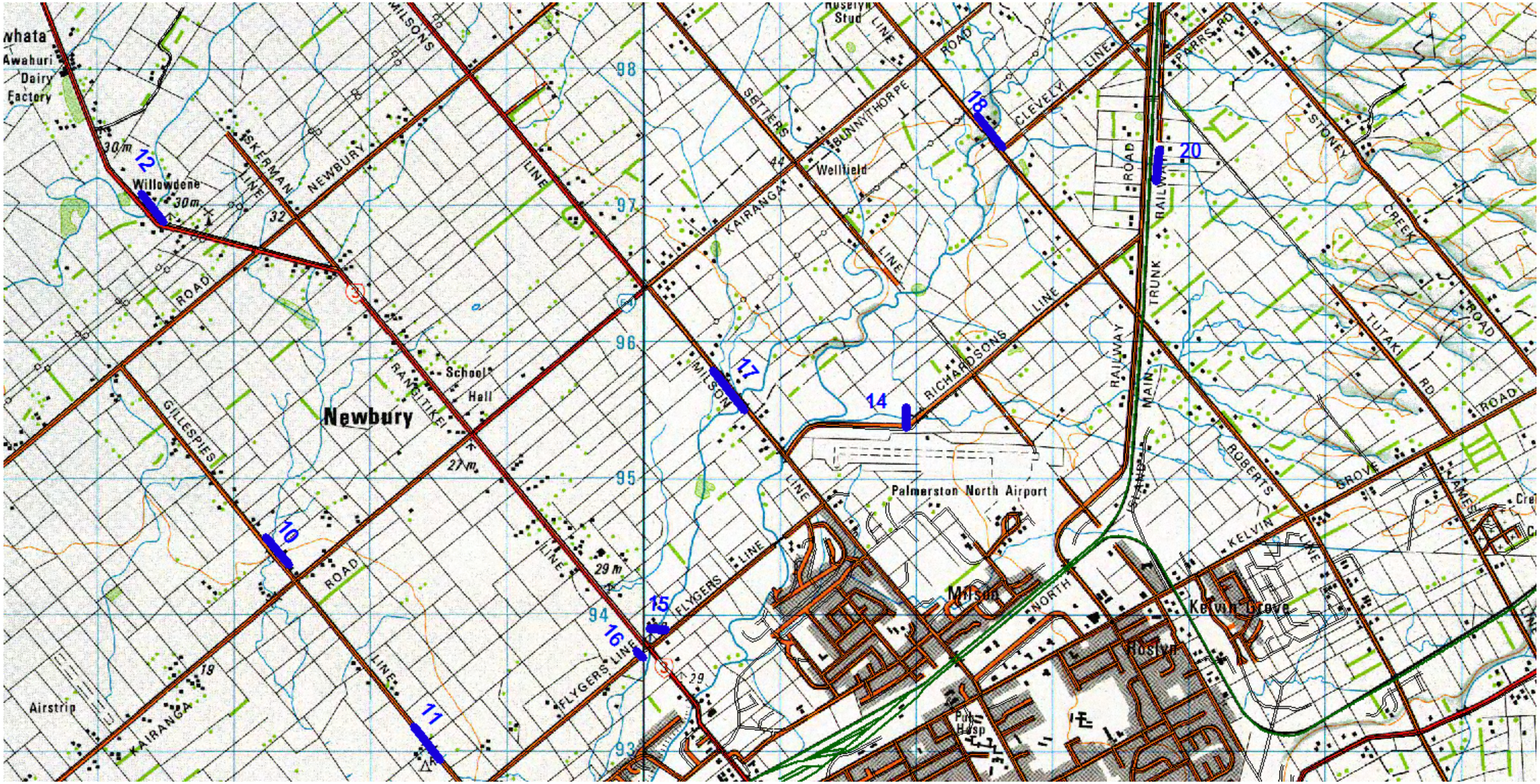
Circular culverts:	No. of culverts, invert level and diameter, and road deck level
Rectangular culverts:	Invert level, width and height and road deck level
Bridges:	Distance between abutments, level of soffit and road deck level. If piers are present, note number and approx width/diameter.



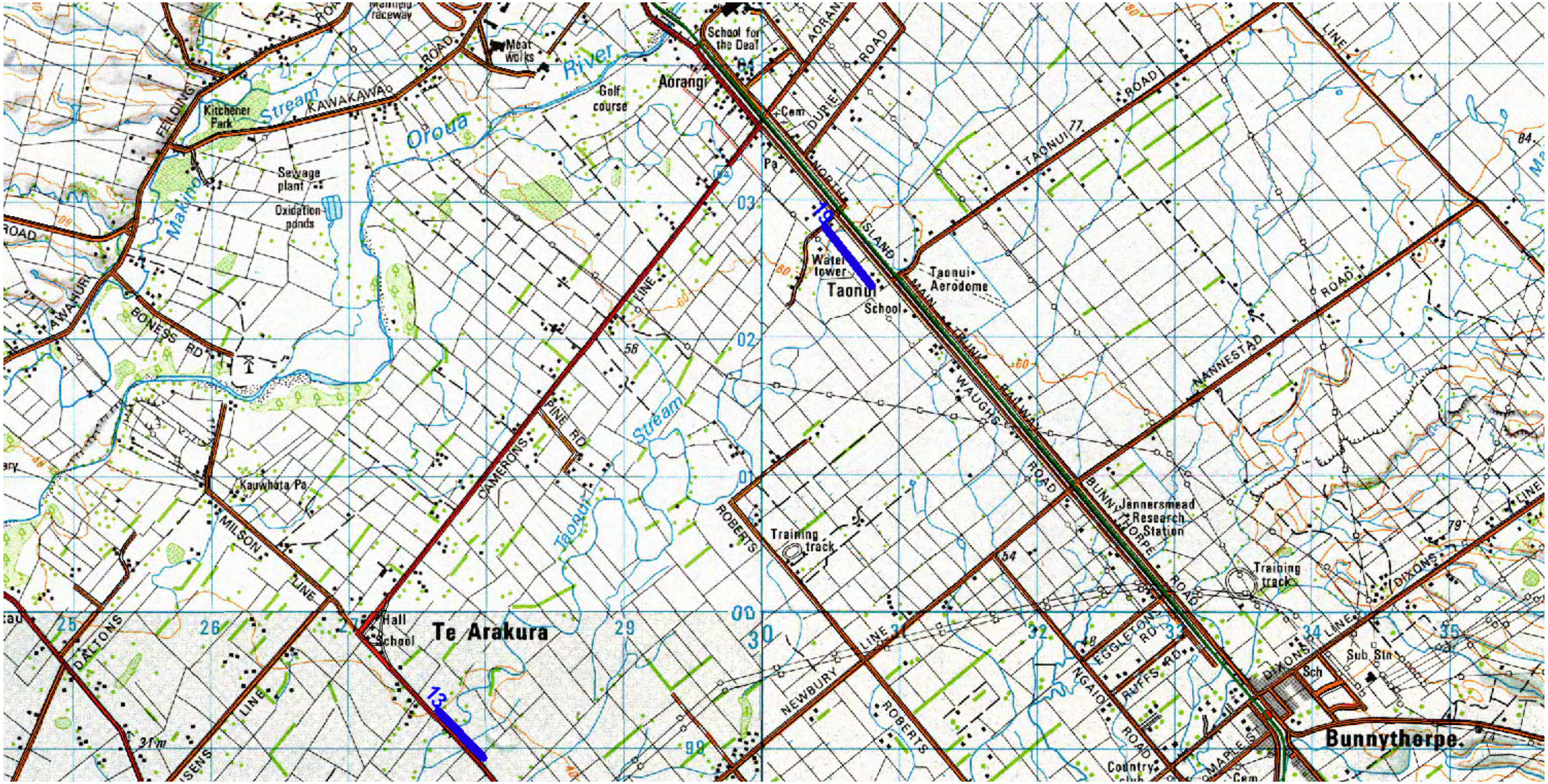
Location XS no. 1



Location XS 2,3,4,5,6,7,8,9,10 & 11



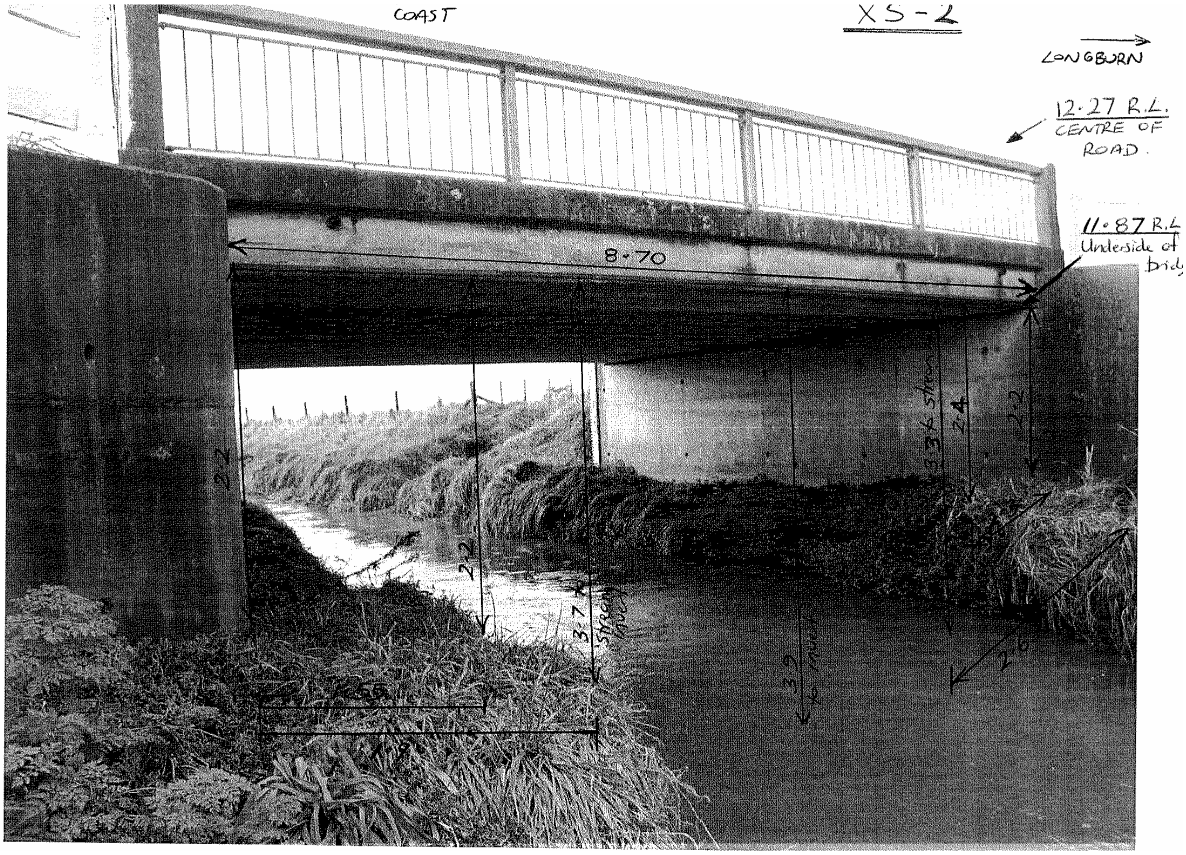
Location XS 10,11,12,14,15,16,17,18 & 20



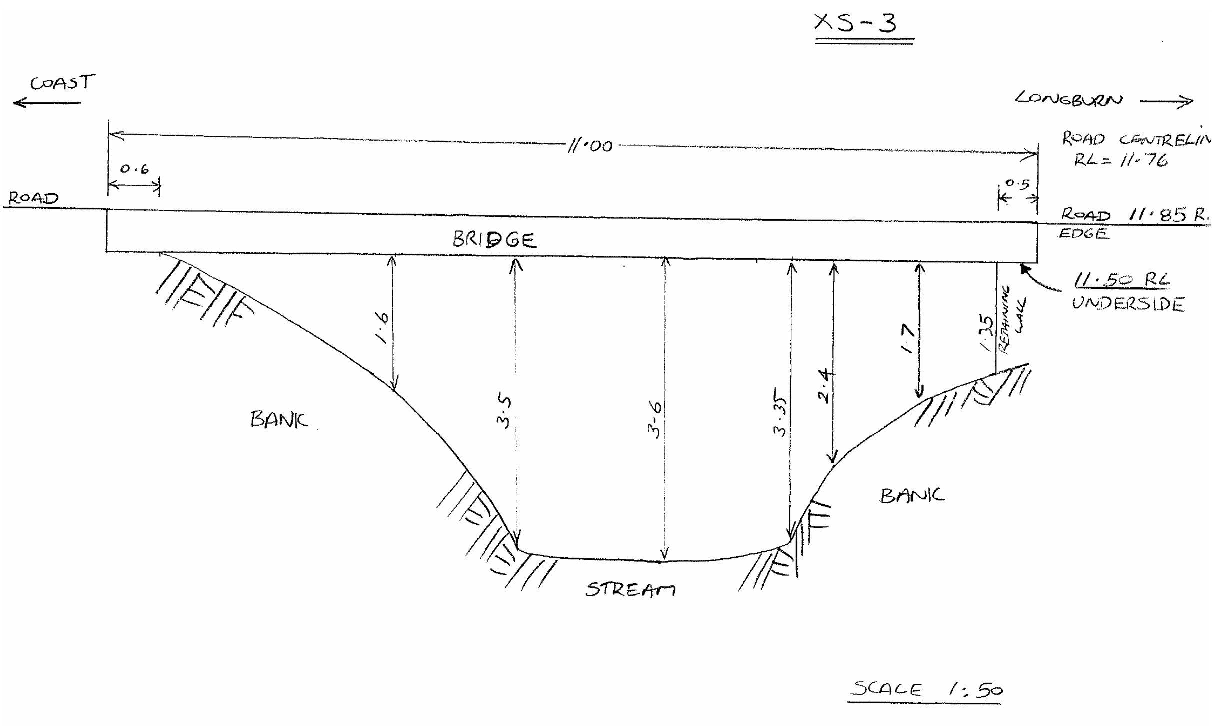
Location XS 13 and 19

Structure Surveys

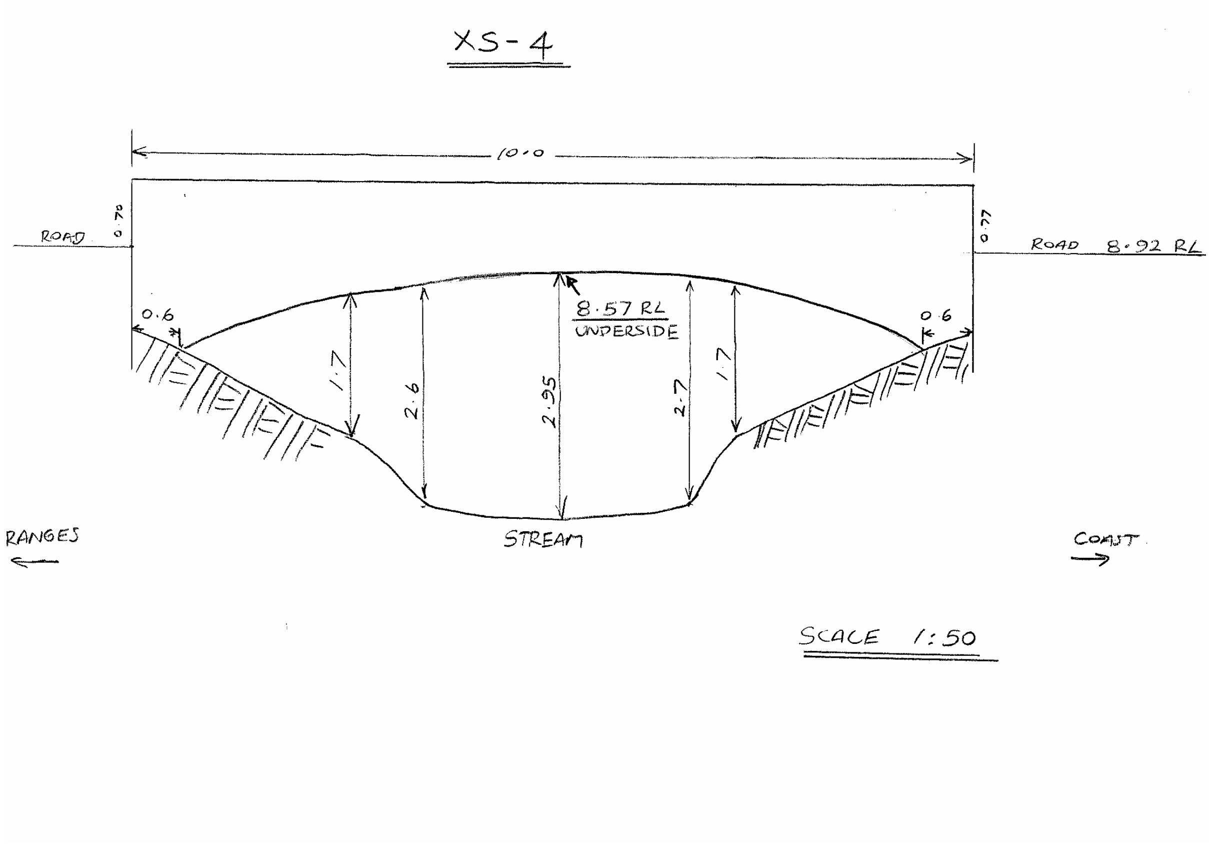
(Structure Numbers Refer to Drawing No. 5)



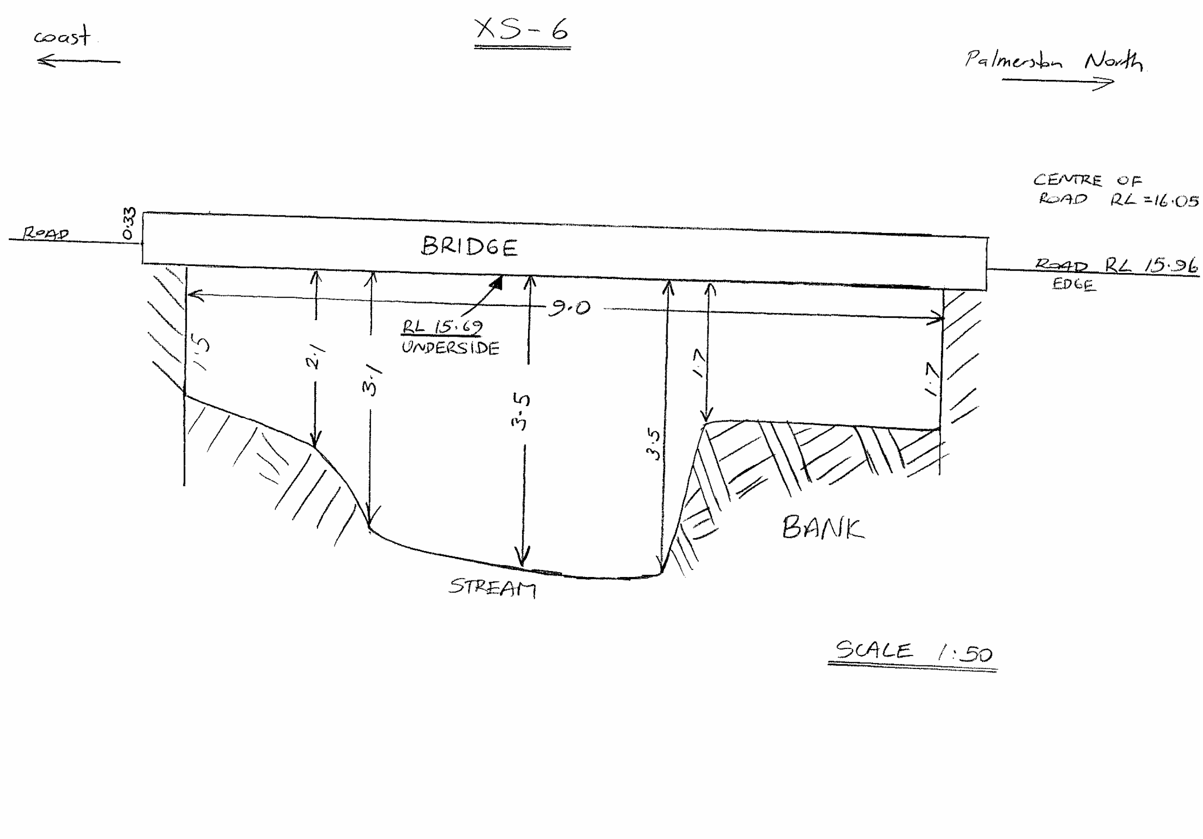
Structure No. 53, Main Drain at Karere Rd



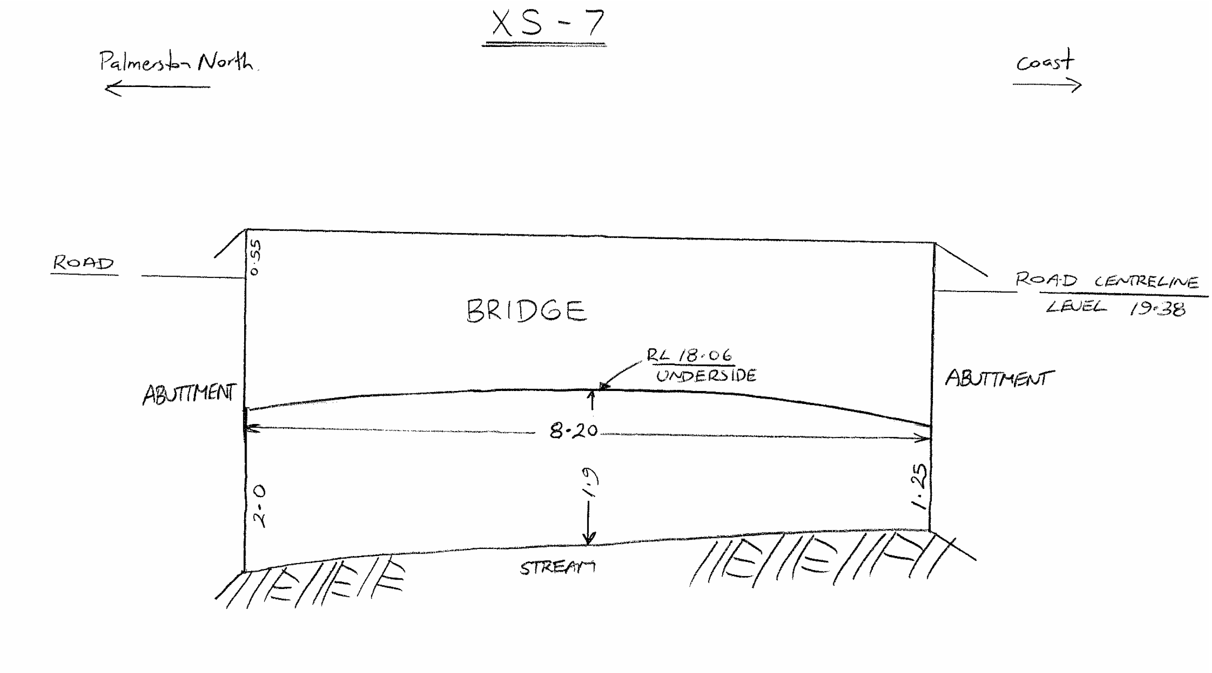
Structure No. 54, Main Drain on Lockwood Rd



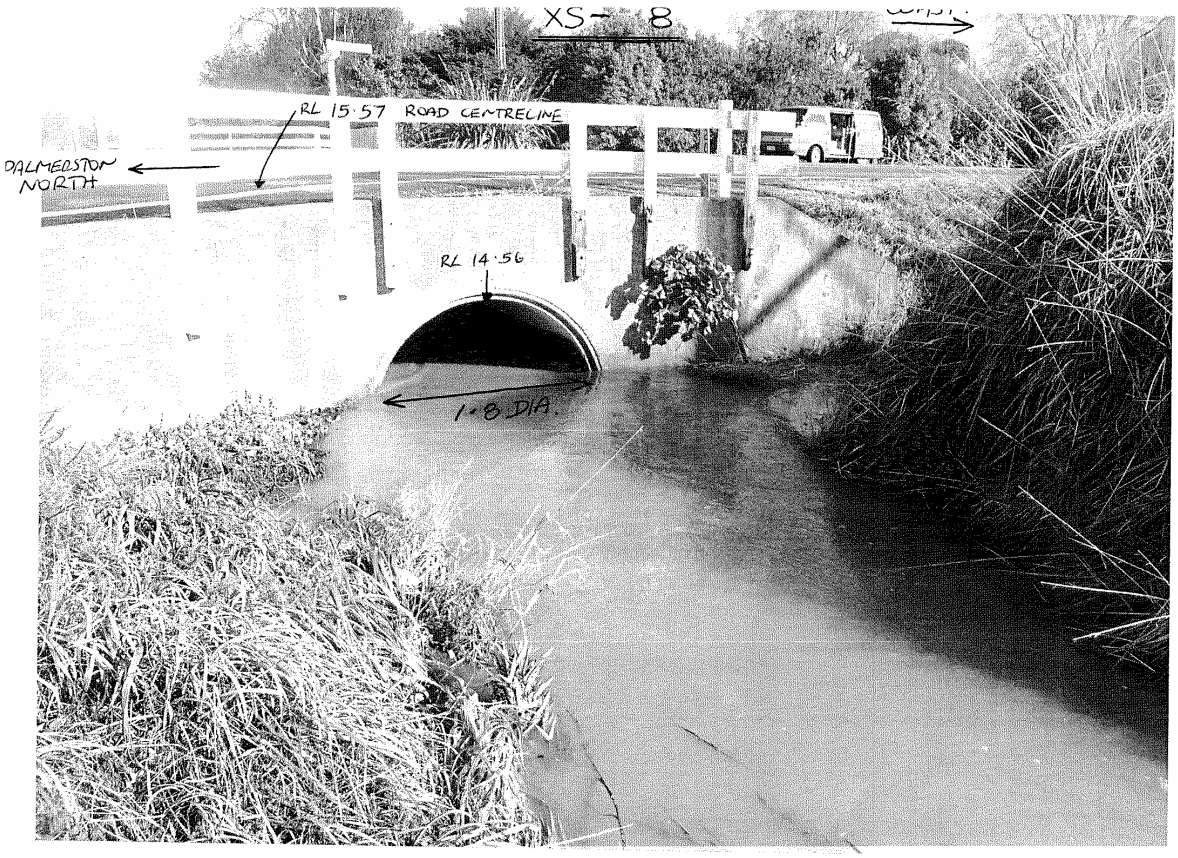
Structure No. 55, Burkes Drain on Lockwood Rd



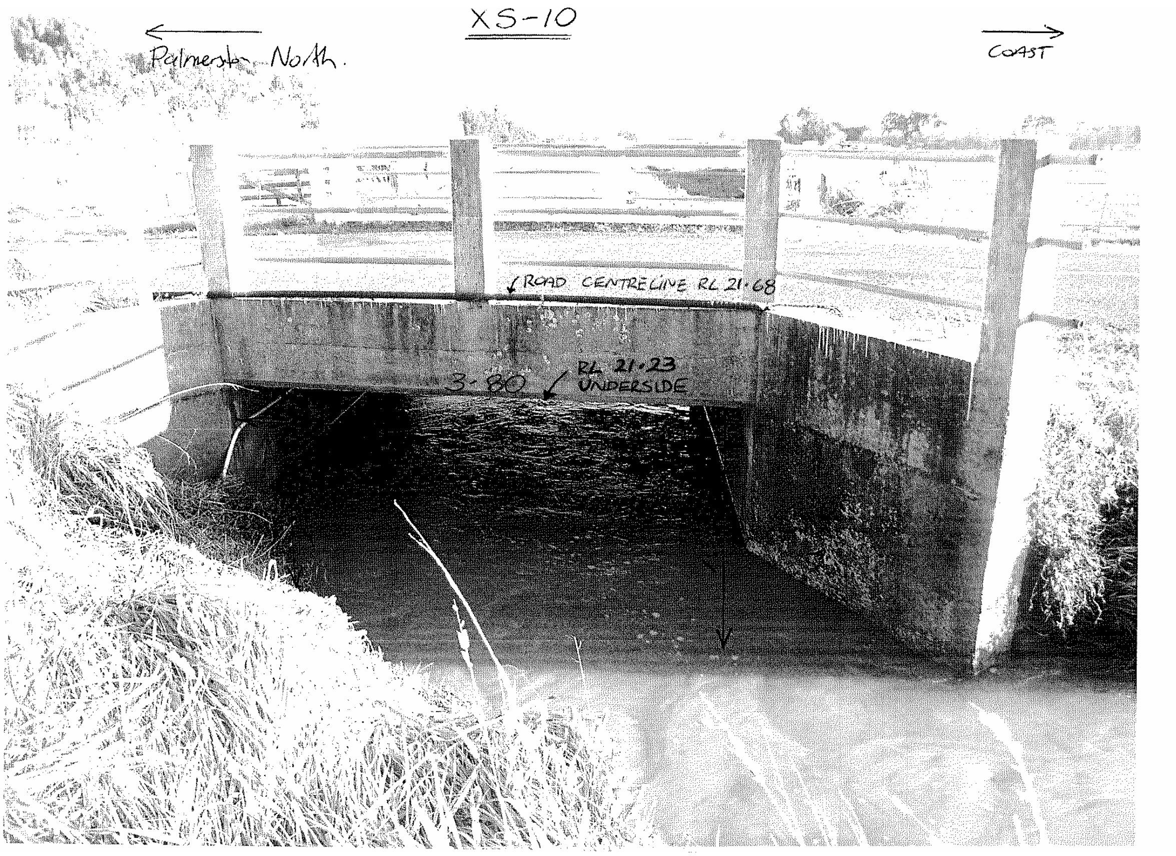
Structure No. 51, Whiskey Creek on Longburn-Rongotea Rd



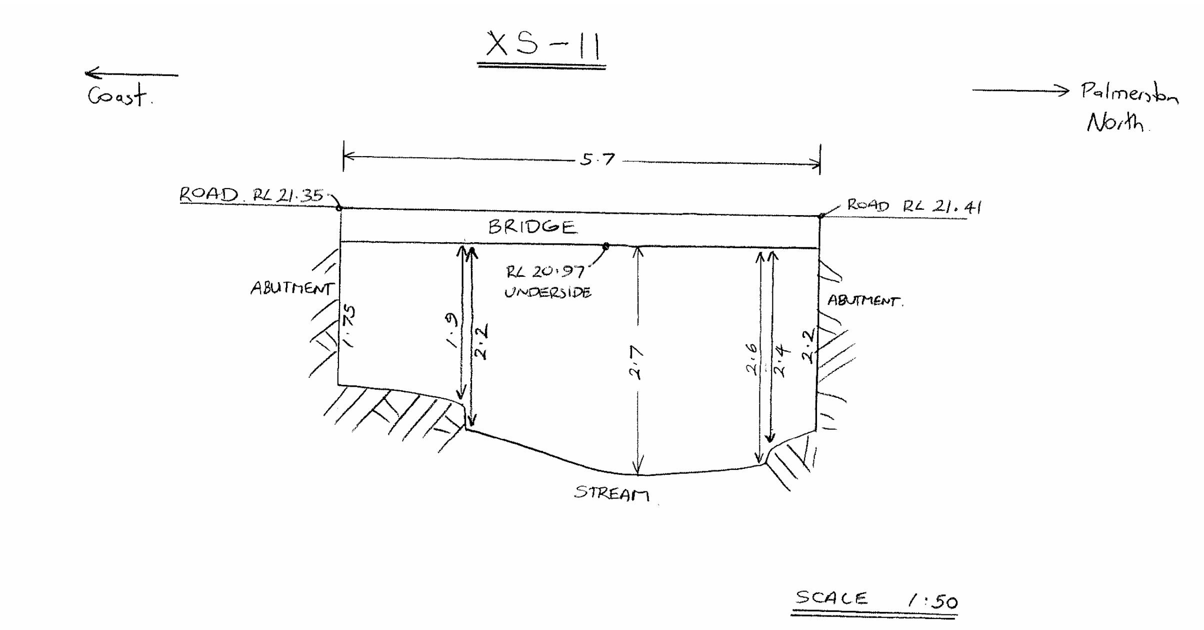
Structure No. 59, Taonui Stream on Longburn-Rongtea Rd



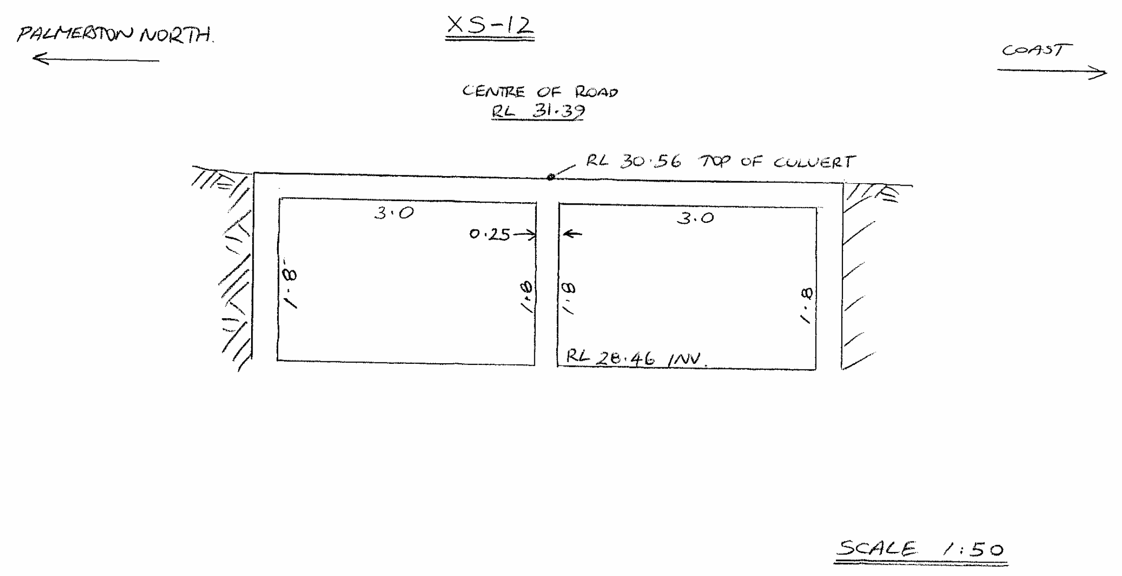
Structure No. 50, Drain on Longburn-Rongotea Rd at Bunnythorpe-Kairanga Rd



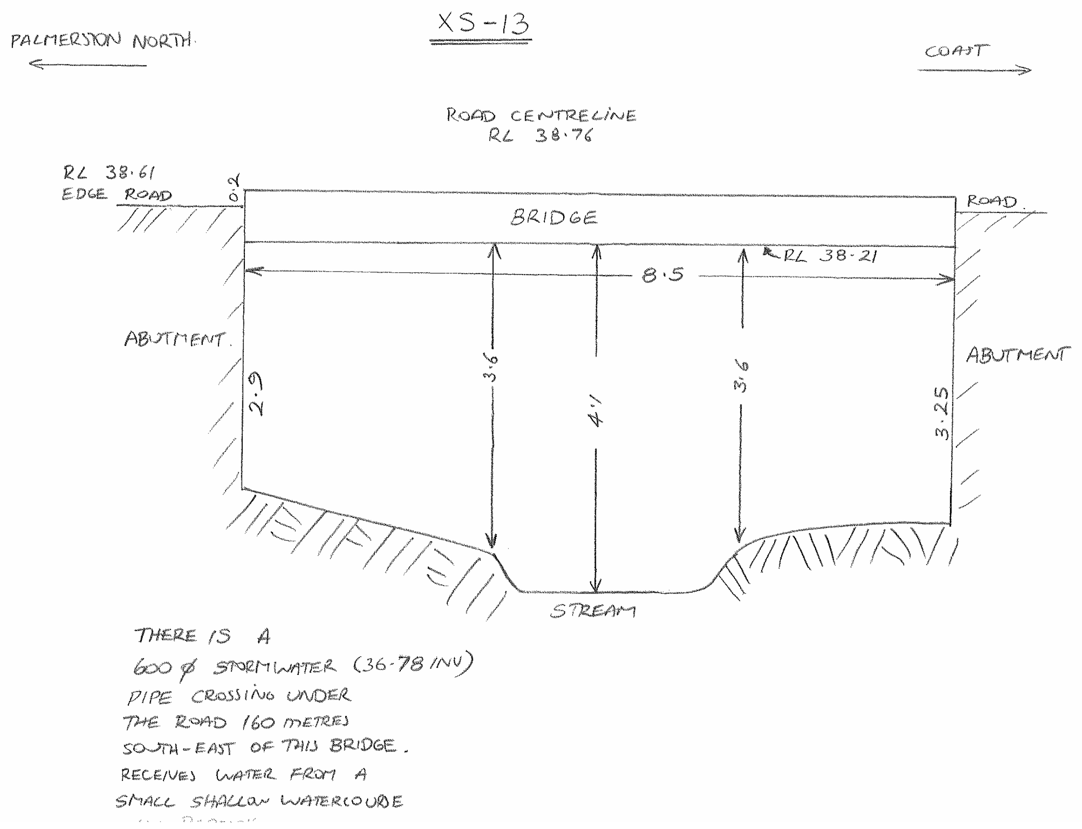
Structure No. 48, Drain on Gillespies Line near Bunnythorpe-Kairanga Rd



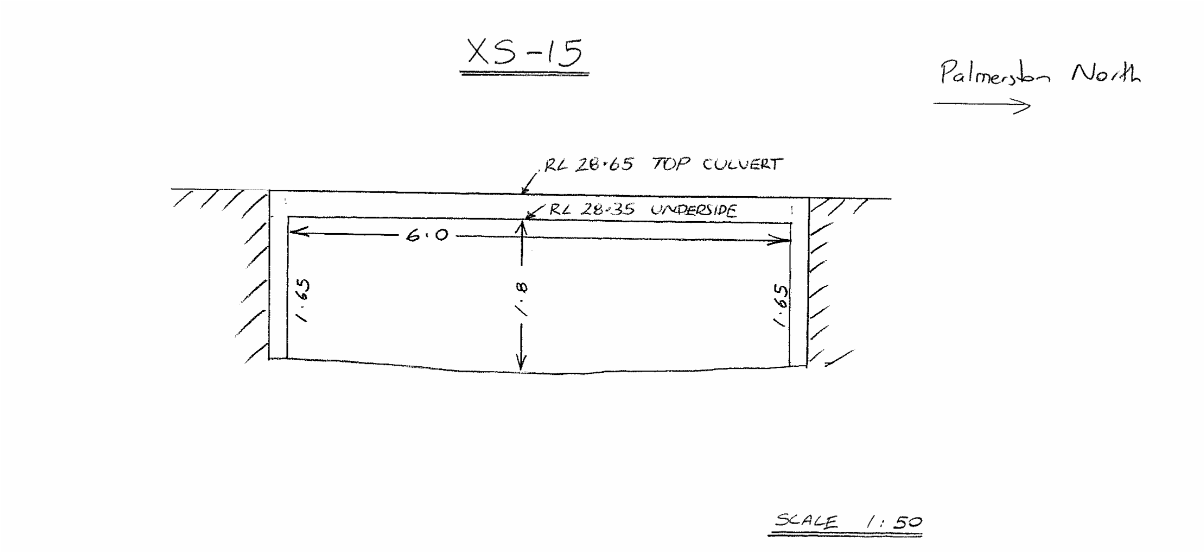
Structure No. 47, Whiskey Creek on Gillespies Line



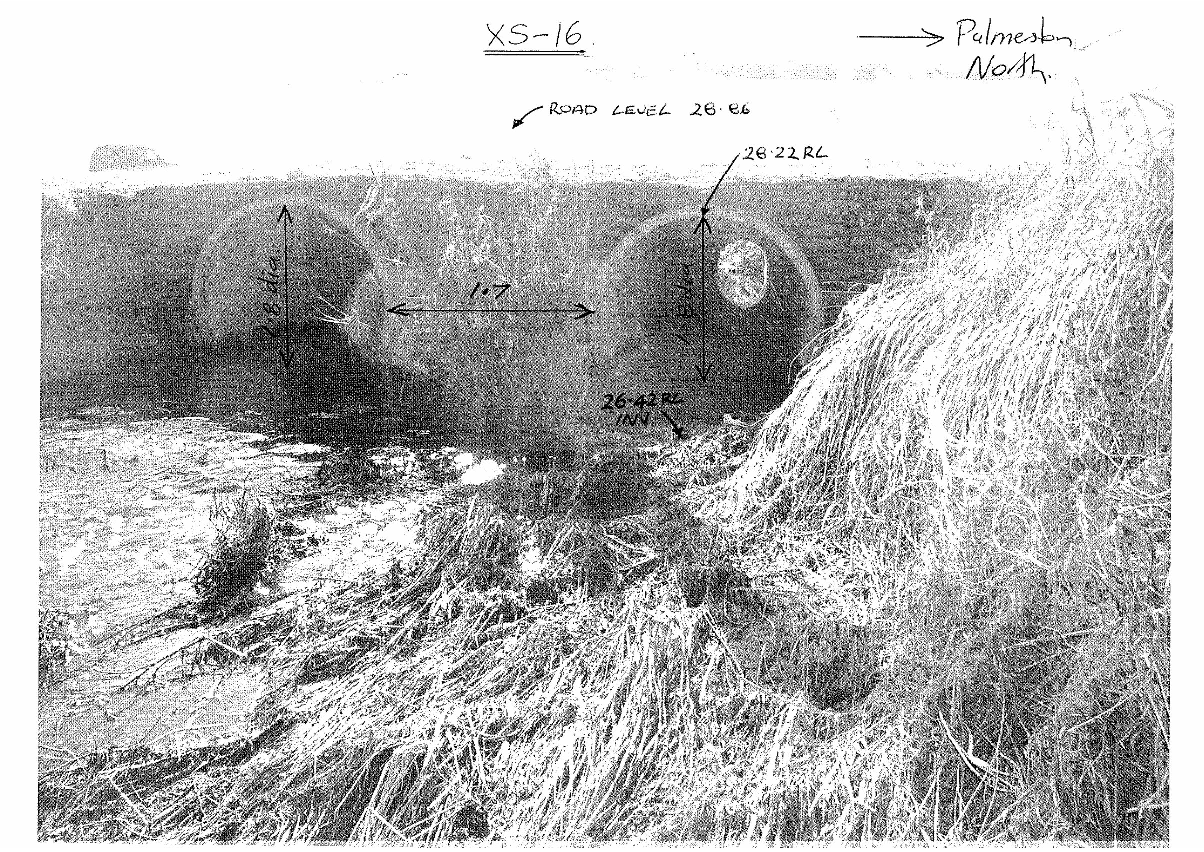
Structure No. 41, Taonui Stream on Kauwhata-Arahuri Rd (Willowdene)



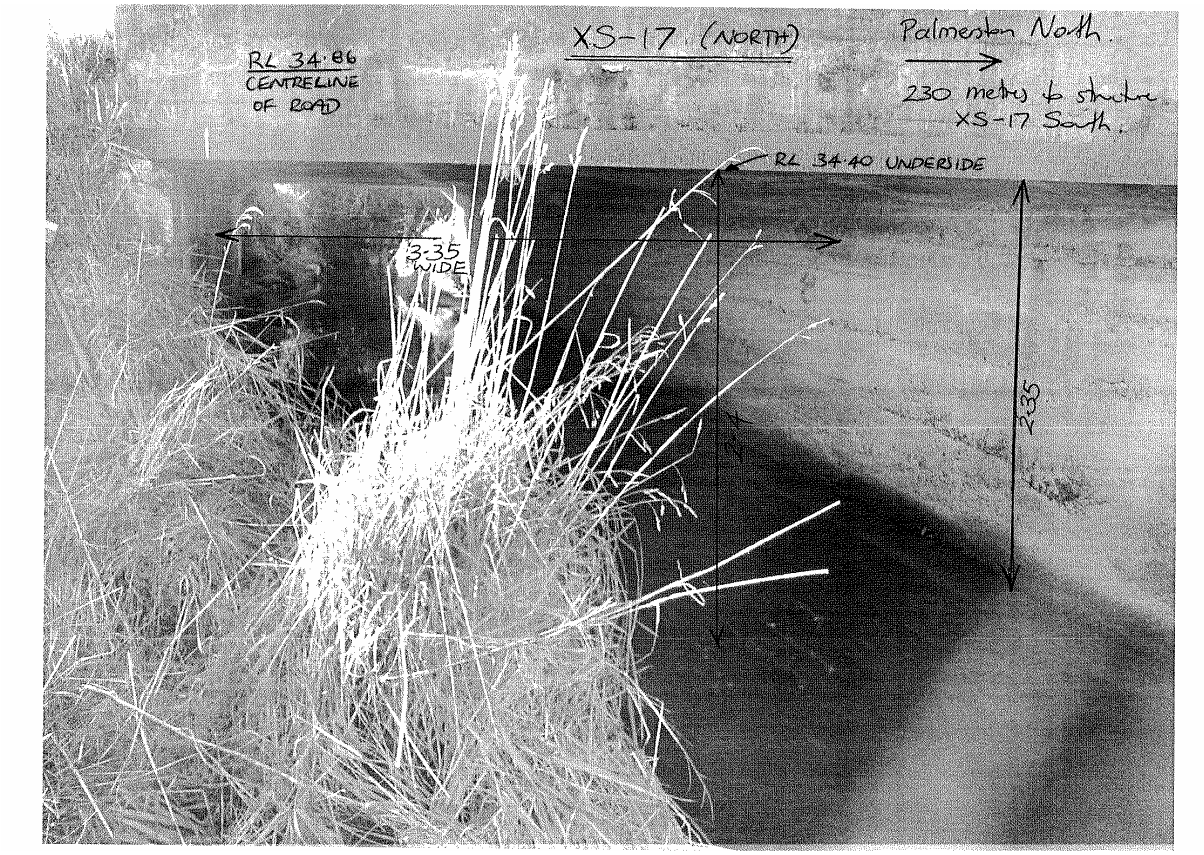
Structure No. 40, Taonui Stream at Milsons Line



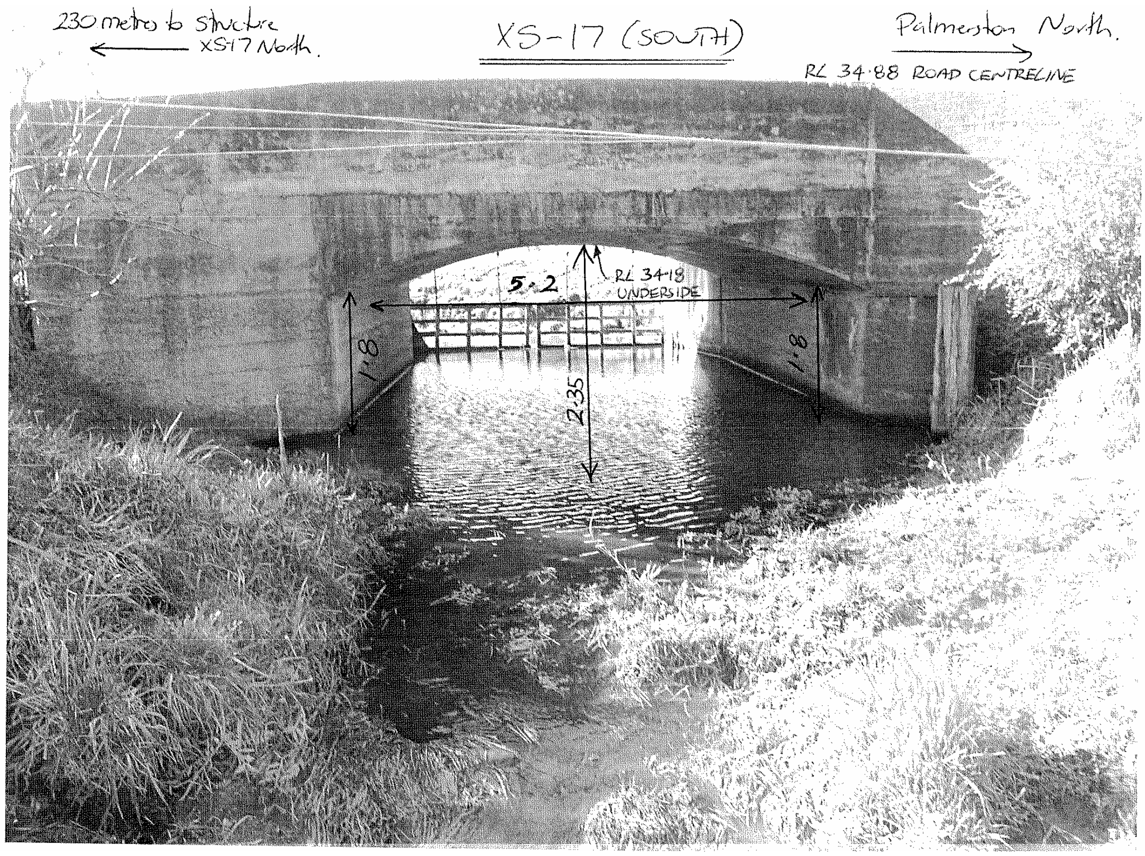
Structure No. 45a, Mangaone spillway channel at Flygers Line (under Flygers Line)



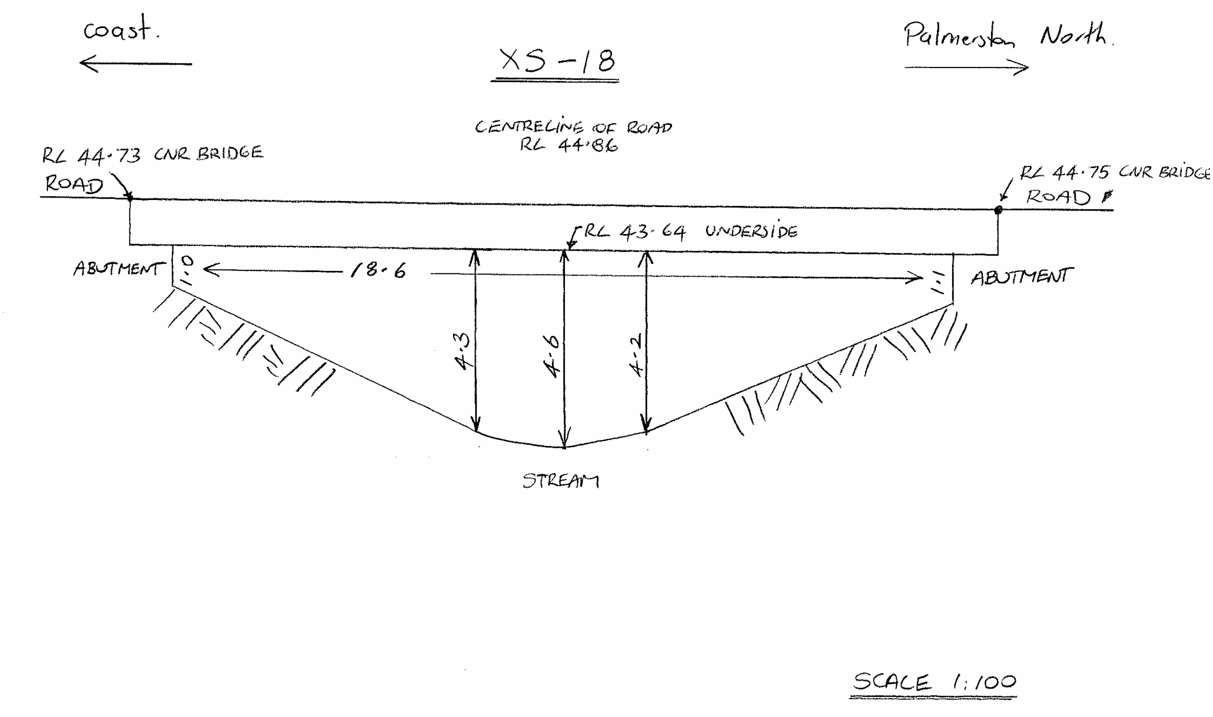
Structure No. 45b, Mangaone spillway channel at Flygers Line (under Rangitikei Line)



Structure No. 34, Mangaone spillway channel u/s spillway on Milsons Line

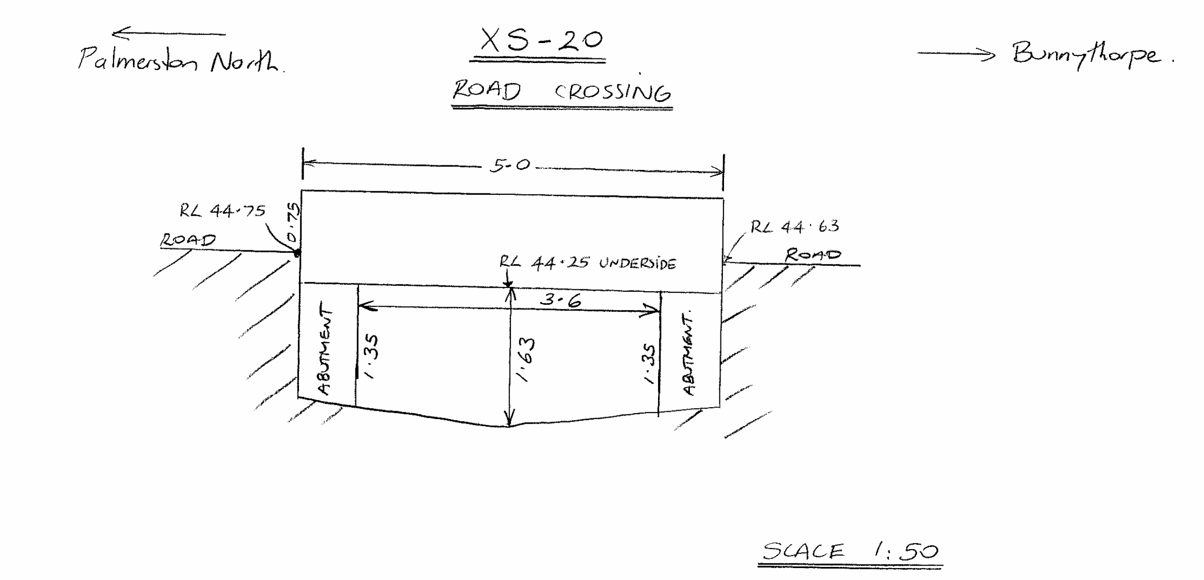


Structure No. 33, Mangaone spillway channel u/s spillway on Milsons Line

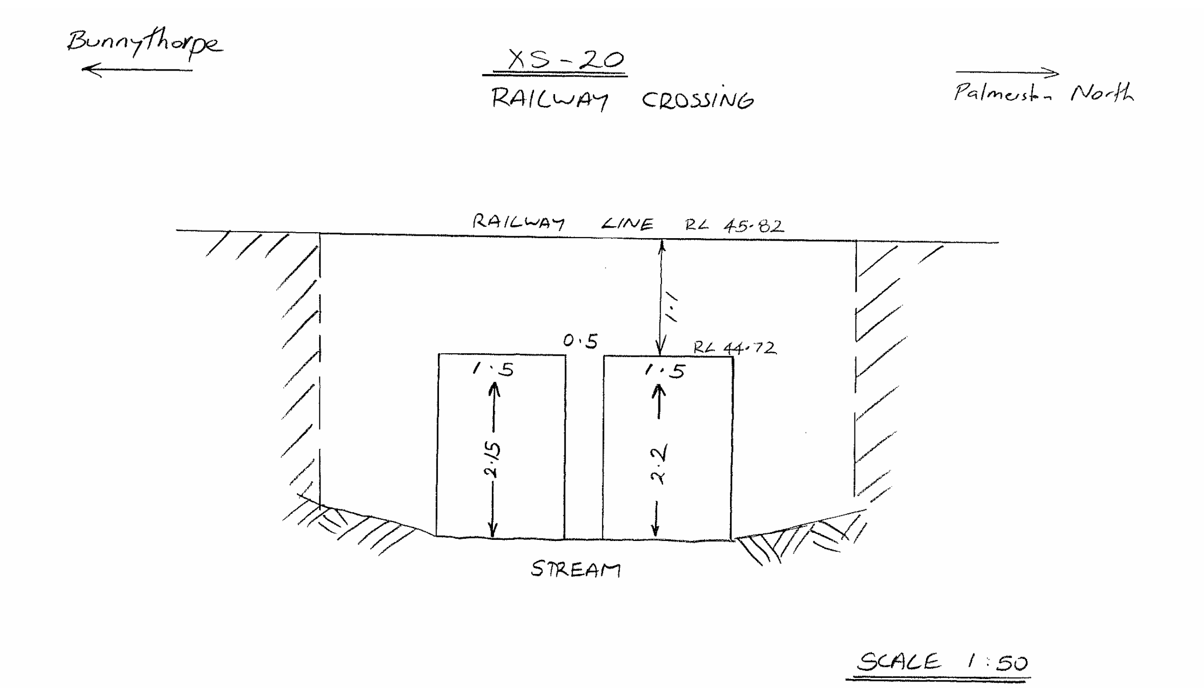


Structure No. 23, Mangaone at Roberts Line nr Clevely Line

Structure No. 2, Taonui Stream at Taonui nr water tower



Structure No. 25, Mangaone tributary upstream of railway near Richardsons Line



Structure No. 20, Mangaone tributary upstream of railway near Richardsons Line

Cross Section Surveys

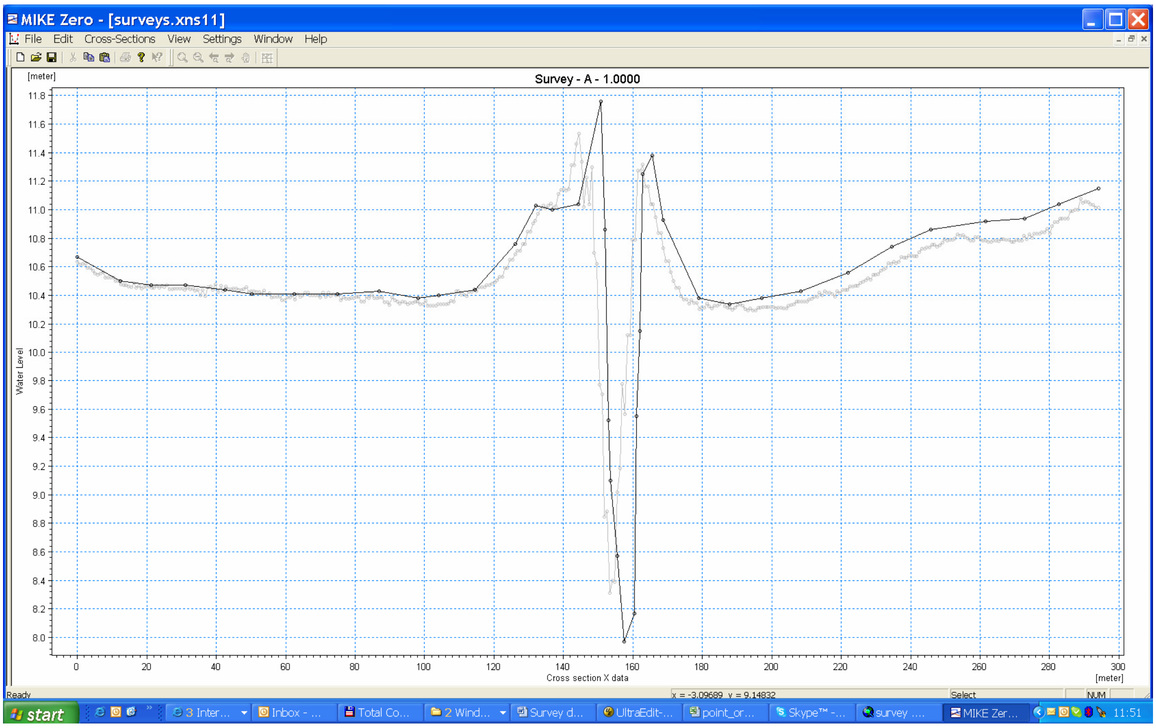
Survey Data Analysis

Cross sections from the surveys have been processed and plotted against the LiDAR for comparison.

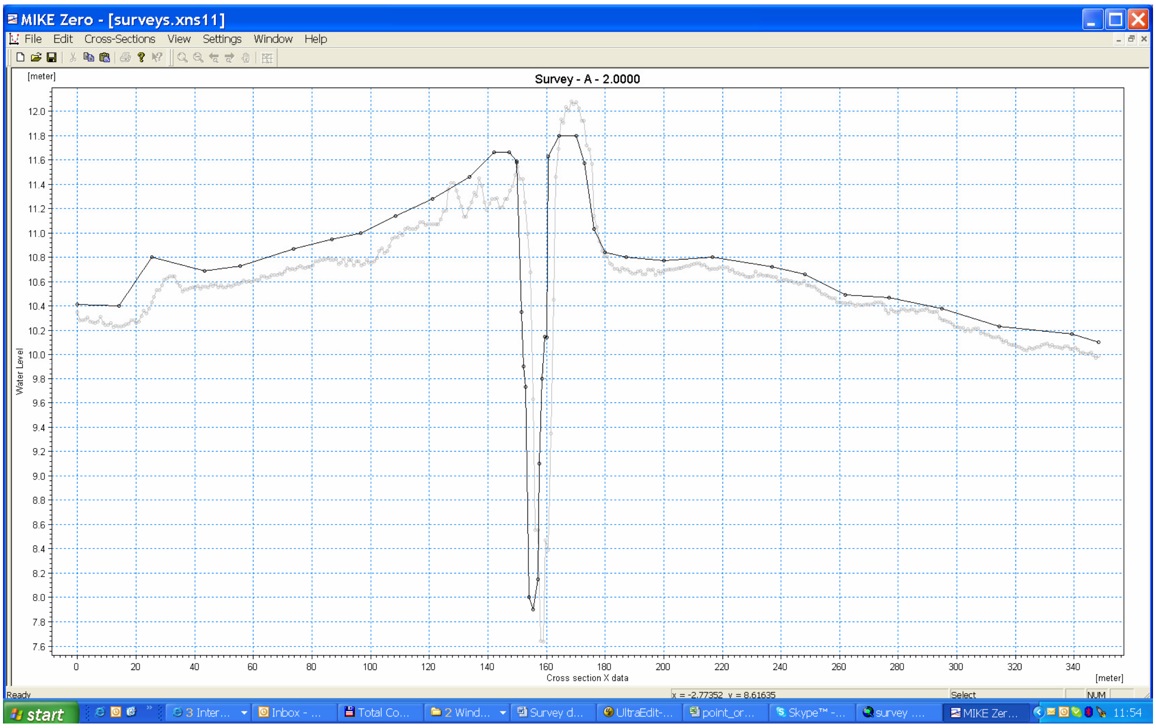
The locations of the cross sections and their ID are shown in the survey brief at the beginning of this appendix. Some difficulties were encountered in processing the survey points which were not taken in a continuous line across the channel. As such a number of sections could not be processed satisfactorily and these were omitted from the analysis. The remaining cross section s from both the surveys and the LiDAR data has been processed in the MIKE11 cross section database for comparison. The cross sections are plotted from the right to left bank (facing downstream). The following plots show the surveyed cross sections in solid lines and the LiDAR cross sections (in lighter lines).

The main aim of the surveys was to determine whether the LiDAR data was sufficient to enable cross sections to be extracted for the purposes of building the hydrodynamic model. It is clear from the field surveys that the LiDAR data has penetrated to the bed the main flow channels in most cases, therefore confirming the suitability of the LiDAR dataset for the cross section extraction.

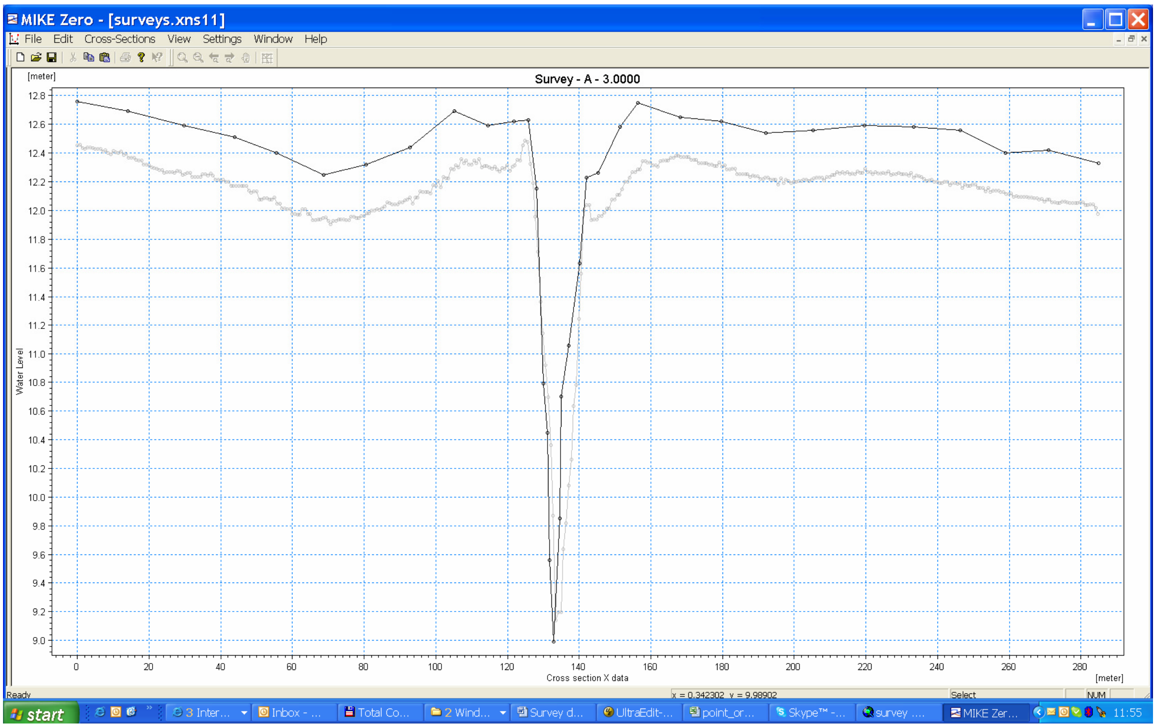
Differences are apparent in the floodplain levels in some cases, with the field survey levels mainly higher than the LiDAR levels by 20-50cm. The cause of these discrepancies has not been ascertained. However as mentioned above the field survey data was provided as a series of mass points which required significant processing and interpretation in order to finally derive the cross sections shown. Nevertheless, ground survey floodplain levels are consistently higher than the LiDAR levels, with the deviation increasing in the upstream direction. Additional ground level checks may be required to confirm the reasons for this.



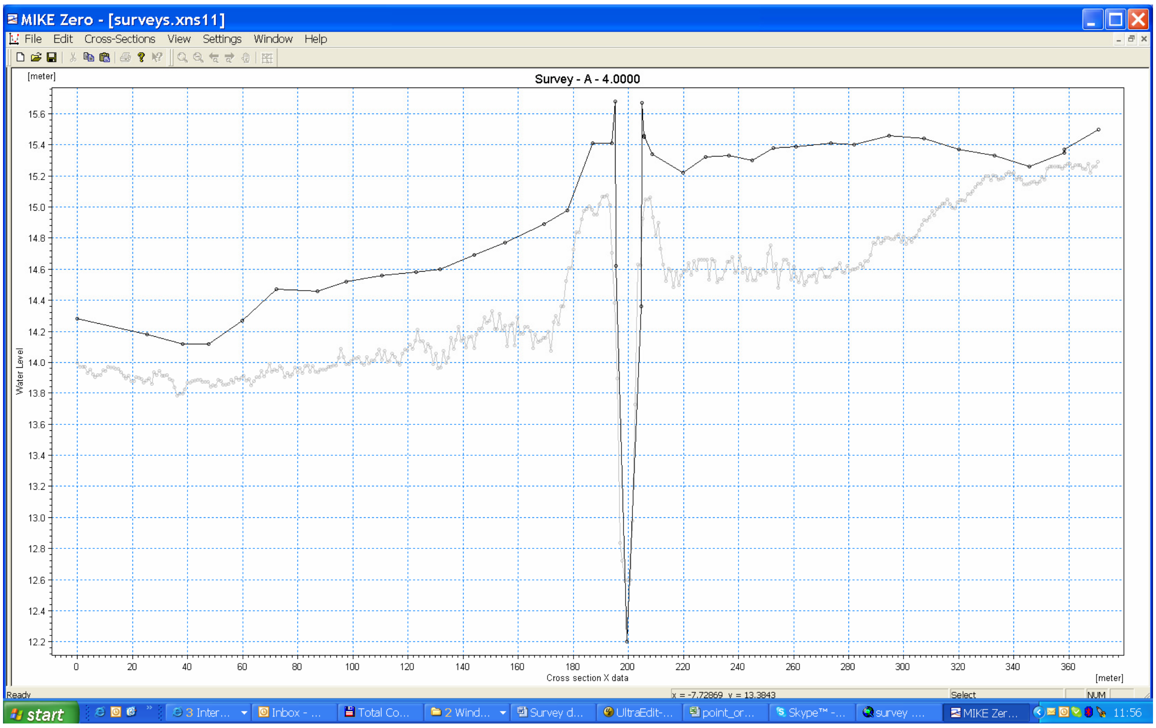
Cross Section No. 2: Main Drain at Karere Rd (ground survey dark line, LiDAR light line)



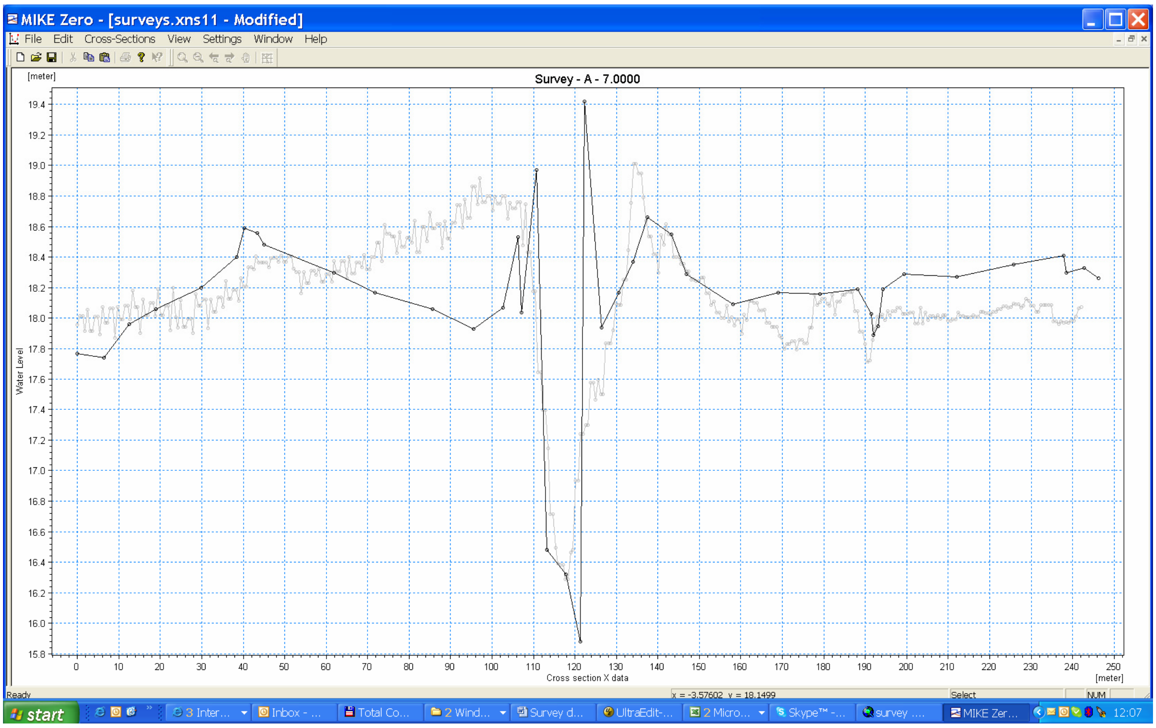
Cross Section No. 3: Main Drain on Lockwood Rd.



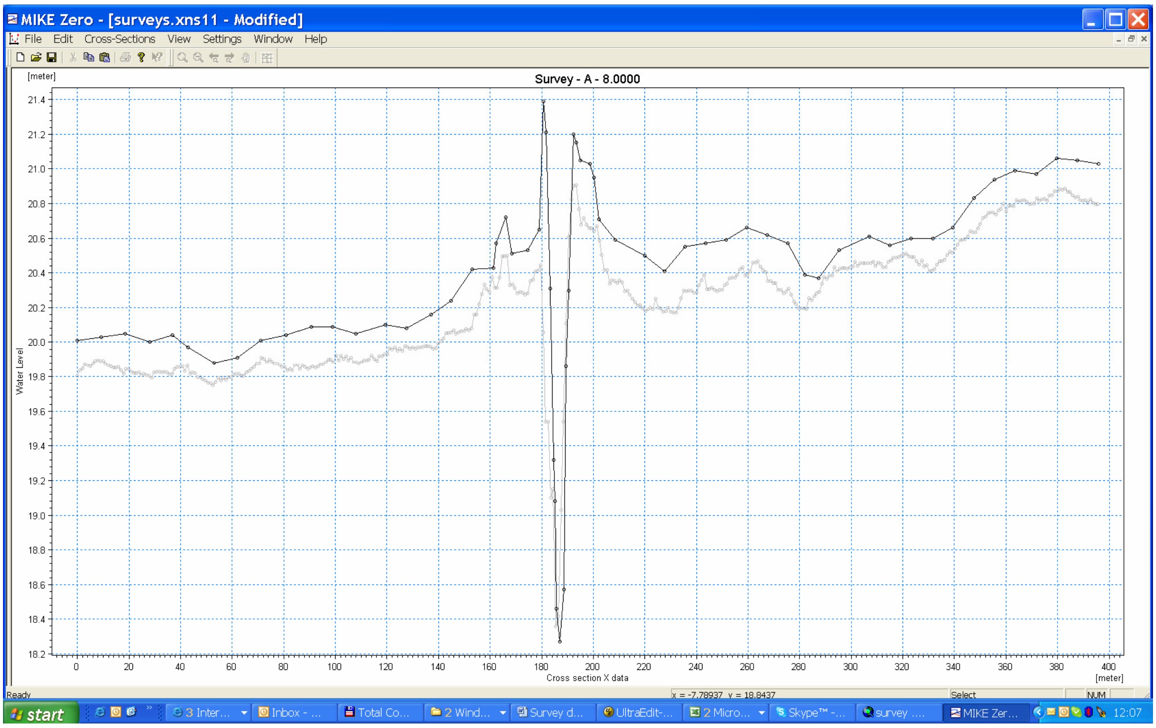
Cross Section No. 5: Taonui Stream near start of Burkes Drain



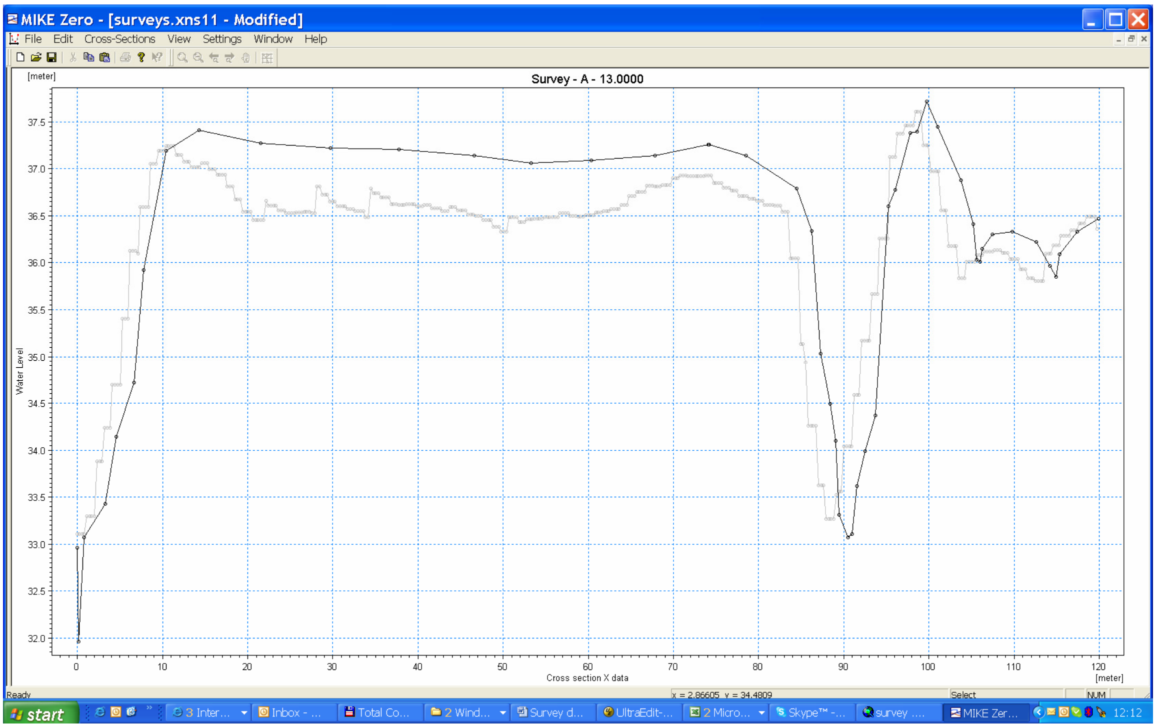
Cross Section No. 6: Whiskey Creek on Longburn-Rongotea Rd



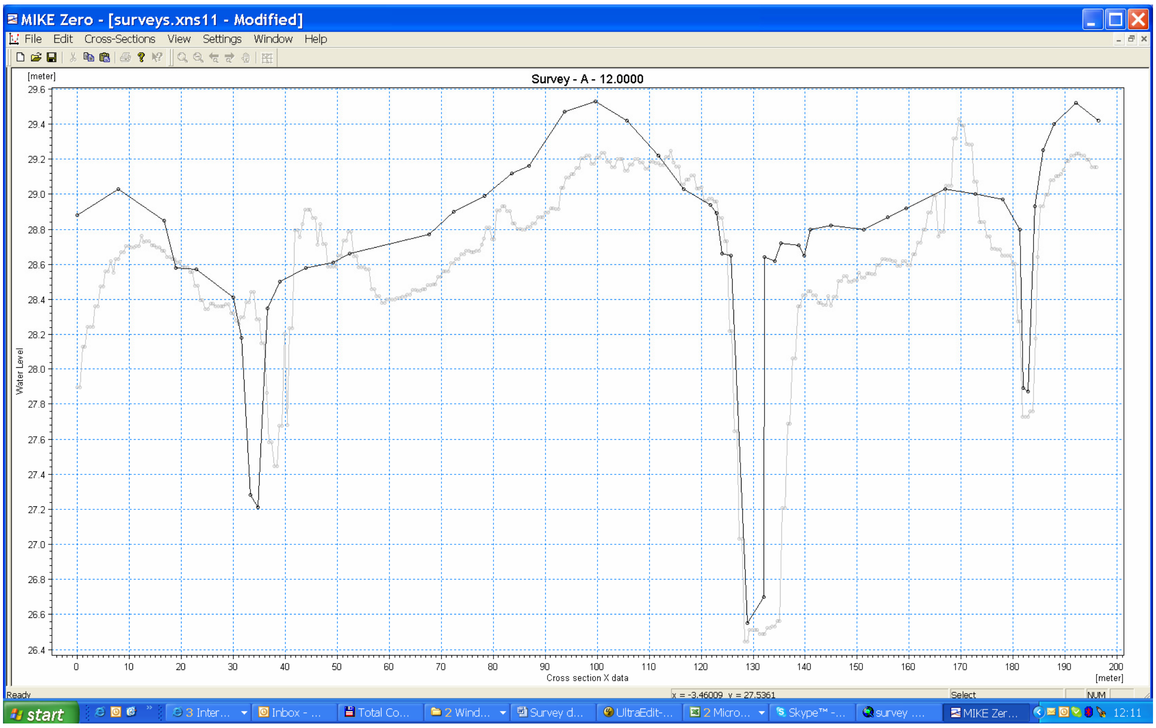
Cross Section No. 7: Taonui Stream on Longburn-Rongtea Rd



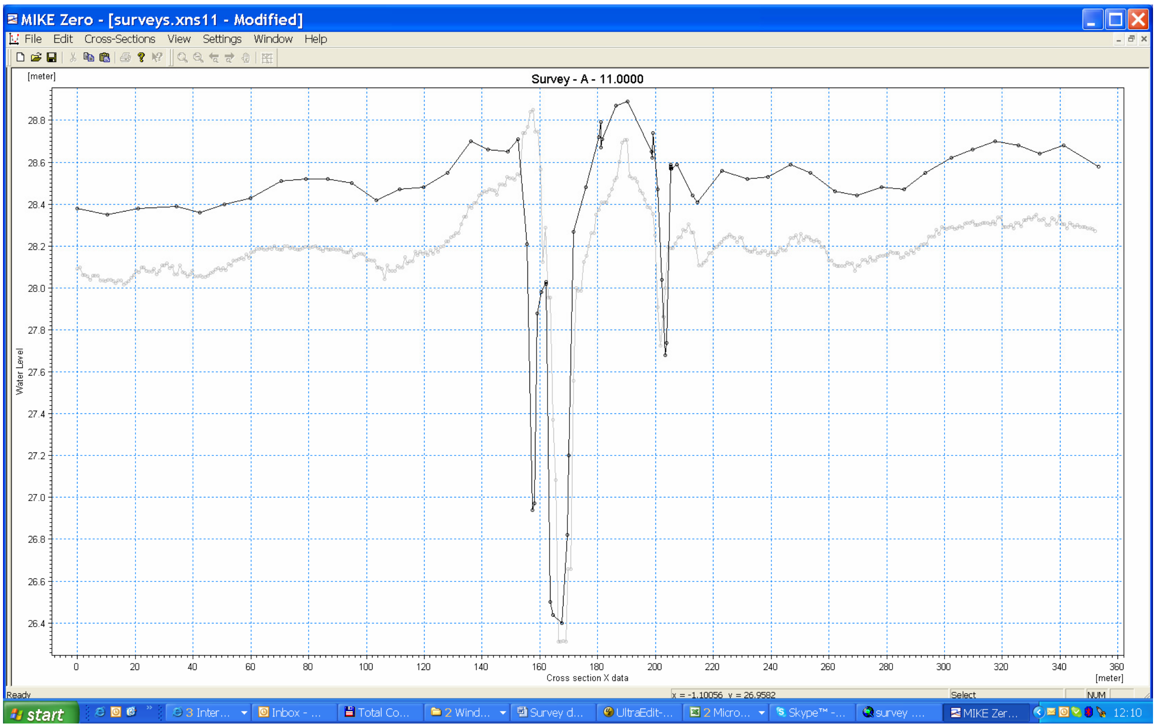
Cross Section No. 11: Whiskey Creek on Gillespies Line



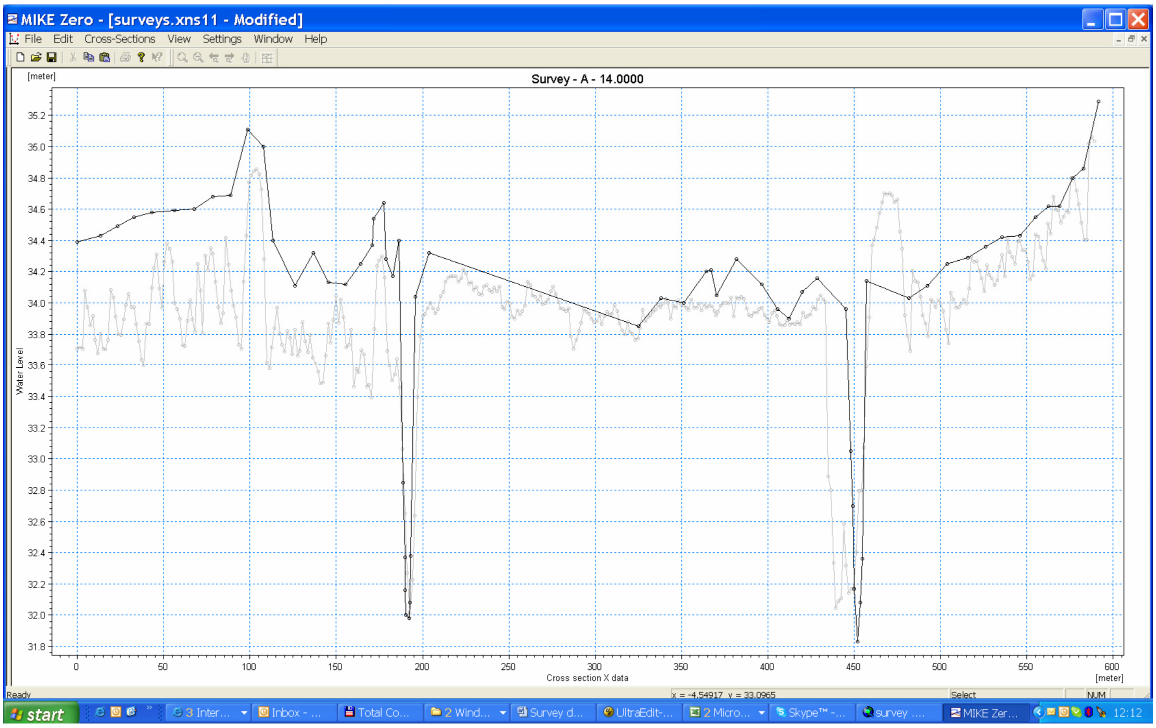
Cross Section No. 14: Mangaone Stream at Richarsons Line near airport



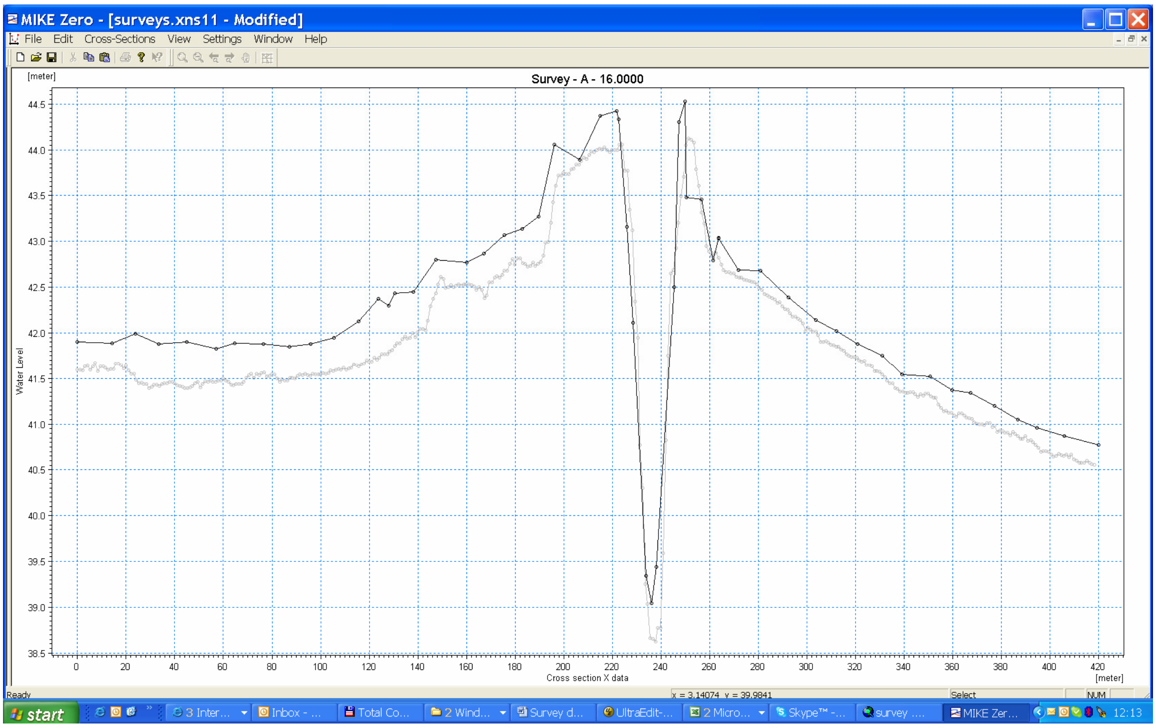
Cross Section No. 15: Mangaone spillway channel at Flygers Line #1



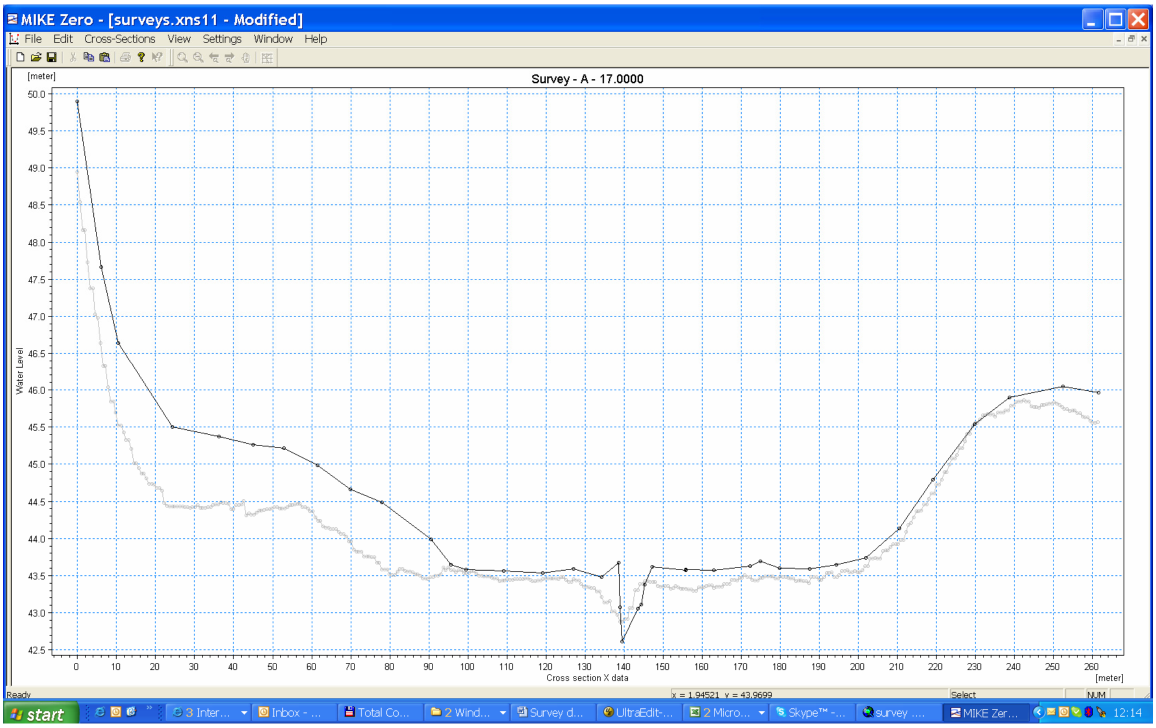
Cross Section No. 16: Mangaone spillway channel at Flygers Line #2



Cross Section No. 17: Mangaone spillway channel upstream spillway on Milsons Line



Cross Section No. 18: Mangaone at Roberts Line near Clevely Line



Cross Section No. 20: Mangaone tributary upstream of railway near Richardsons Line

APPENDIX C

2004 Flood Water Level Comparison

Ref. Point	Water Level (m)	
(Dwg. 8)	*Observed*	*Simulated*
1	54.51	-
2	54.41	-
3	54.38	-
4	51.29	-
5	50.32	49.77
6	50.28	49.77
7	50.26	-
8	50.25	-
9	43.81	43.10
10	43.43	43.09
11	43.01	-
12	42.39	-
13	38.97	38.27
14	36.13	36.04
15	34.99	34.83
16	34.24	33.44
17	31.18	-
18	28.85	27.69
19	28.40	-
20	27.52	27.47
21	26.80	26.43
22	26.28	25.68
23	24.15	23.68
24	23.38	22.84
25	23.35	-
26	23.33	22.84
27	20.98	-
28	16.88	16.59
29	16.04	-
30	15.18	14.21
31	13.38	-
32	13.33	-
33	11.68	11.52
34	10.24	-
35	10.19	-
36	10.05	-
37	9.98	9.59
38	9.94	9.83
39	9.94	-
40	9.82	9.61
41	9.79	-
42	9.76	9.61
43	9.76	-
44	9.69	9.59
45	9.63	9.61
46	9.62	-
47	9.58	-
48	9.53	9.61
49	9.52	9.59
50	9.48	-
51	9.40	9.61
52	9.38	9.61
53	9.36	9.61
54	9.35	9.61
55	9.23	9.61