# Waikawa and Manukau Streams

# Floodplain Hazard Assessment

### Hydraulic Modelling and Mapping

Final Report
November 2008

# Waikawa and Manukau Streams Floodplain Hazard Assessment

## Hydraulic Modelling and Mapping

PO Box 300-705
Albany
New Zealand

Tel: +64 9 912 9638
Fax: +64 9 912 9639
e-mail: dhi@dhihroup.com
Web: www.dhi.co.nz

| Client | Client's representative |
|---|---|
| Horizons Regional Council | Jeff Watson |

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## *DRAWINGS*



*Note Drawings 5-28 are provided in a separate A3 map book.*

## *APPENDICES*

# 1 INTRODUCTION

## 1.1 Background

Horizons Regional Council (HRC) requires information regarding the extent and depth of flood inundation occurring from floods in the Waikawa and Manukau Streams, Horowhenua District. This report details the work undertaken to develop hydrological and hydraulic models of the catchments and the subsequent flood risk assessment to identify the 100 and 200 year ARI flood event extents in the lower floodplain.

## 1.2 Physical Setting

The Waikawa and Manukau Streams are located in the Horowhenua District, and drain a combined area of approximately 70 square kilometres. The streams rise in the Tararua Ranges and drain westward to the Tasman Sea. The catchment topography varies enormously. The south eastern part of the catchment covers part of the Tararua Ranges and rises to over 900m within the Waikawa sub-catchment. The terrain falls rapidly to the sandy coastal lowlands, which are characterised by a range of sand dunes extending up to 6km inland. On the moderately steep slopes of the Tararua Range, the soils are thin, friable or granular silts loams. Much of the native forest has been cleared and replaced by low quality pasture and radiata pine plantations (Duguid, 1990).

Urban development is mainly centred around the townships of Manukau along SH1 and Waikawa Beach, although new developments are mooted in the coastal lowlands and both sides of SH1.

The ranges represent a region of intense rainfall and is amongst the wettest in the North Island. Annual rainfall along the centre of the range is estimated to be more than 5000mm (Riddell, 1981). Annual rainfall exceeds 3700mm at the Mangahao gauge high in the Tararuas and falls to around 1100mm at Levin on the lowlands.

Drawing 1 shows the study area.

## 1.3 Approach

DHI have developed both hydrological and hydraulic models to aid the assessment of the flood hazard. The hydrological models have been calibrated against recent flood events and are used to generate inflows to the hydraulic model. This comprises a dynamically linked 1D-2D model (MIKE FLOOD), which is used to both route the catchment runoff downstream of the headwaters and at the same time map the flood extent and depth. Details of the model development and calibration are provided in the following sections.

## 1.4 Projections and datum

The map projection adopted for the study is NZ Map Grid (NZMG) and the flood levels are referred to Wellington datum.

# 2 HYDROLOGICAL ASSESSMENT

The hydrological assessment of the Waikawa and Manukau streams was undertaken through a combination of model development and calibration, supported by a separate regional flood frequency estimate and analysis of the January 2008 flood event.

## 2.1 Catchment Description

The main sources of floods in the lower catchment foothills and coastal plains are the very steep headwater catchments associated with high intensity rainfall. The Waikawa and Manukau Streams exhibit somewhat different responses to rainfall events due to the differing nature of the headwater catchments. The Waikawa catchment (see Drawing 2) rises from the coastal plain to 930m in just over 18km of stream length. The steep valleys rapidly funnel the runoff to a single outlet at the base of the valley and onto the coastal floodplain. See Figure 2-1.

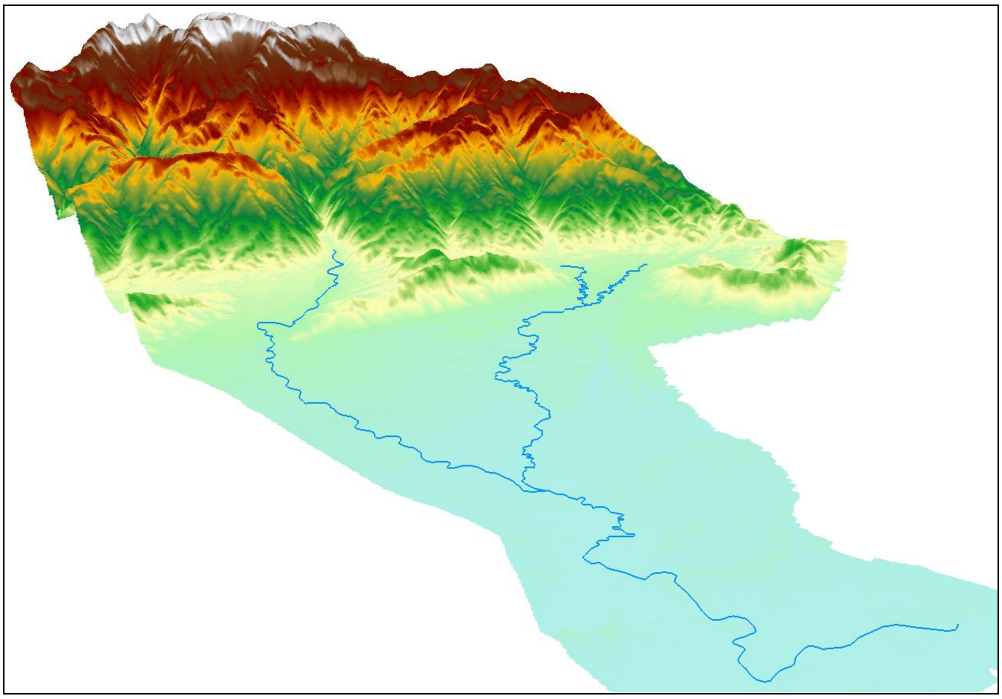

*Figure 2-1 3D Visualisation of the Catchment – Waikawa Stream to left, Manukau to right.*

In contrast the Manukau upper catchment comprises a number of smaller sub-catchments of differing characteristics. The highest part of the catchment reaches 680m, but the upper slopes are mainly confined to below 500m. The Waikawa catchment is expected to experience higher rainfall compared to the neighbouring Manukau catchment due to the higher elevation.

Land use in the upper catchments is mainly forest, which gives over to pasture in the foothills and grasses down in the coastal sand dunes. Urban areas at risk from flooding comprise mainly the township of Manukau, located between the two streams near SH1, and Waikawa Beach, located close to where the combined streams discharge to the sea.

## 2.2 Hydrometric Data Availability

HRC have provided hydrological and topographical data as shown in Table 2-1 and described below.

*Table 2-1 Hydrological data available for the study*

| Data | Availability | Comments |
|---|---|---|
| ***Rainfall*** | | |
| Jarvis | 3/6/77 – 1/1/87 | Daily data |
| Upper Mangahao | 2/6/77 – Present | Recording gauge |
| Levin (NIWA) | 2/1/86 – Present | Gap 1/2/91 – 27/10/91<br>6-hourly from 27/10/91 to1/1/95, hourly thereafter. |
| ***Discharge*** | | |
| Waikawa at Nth Manukau Rd | 18/5/06 – Present | |
| Manukau at Gleesons | 23/11/78 – 20/4/89 | Gauge was moved to SH1 in 2007, no data April 1989 – July 2007 |
| Manukau at SH1 | 1/7/07 – Present | |

### 2.2.1 Rainfall

Recording rainfall data are available from sites located at Upper Mangahao and Levin. The Upper Mangahao site at 375m elevation represents the closest site which can potentially capture the rainfall occurring in the stream headwaters in the Tararua Range, although this gauge is located approximately 20km to the north east from the upper catchments. The Levin gauge is more representative of lower catchment rainfall, and is located approximately 12km north of the catchment. The Jarvis gauge, located in the catchment near Manukau township, operated for 10 years from 1977 – 1987 but only recorded daily data.

The highest daily rainfall recorded at Upper Mangahao was during the January 2008 event, when 251mm fell in a 24 hour period. At the same time Levin recorded 86mm. The next highest daily totals at Upper Mangahao were 184mm on 10 March 1990 and 180mm on 4$^{th}$ Oct 1986. The latter event contributed to the highest flow in that year at Gleesons Road of 22.2m$^3$/s

Generally the correlation of Upper Mangahao rainfall to peak flows in the Manukau and Waikawa catchments is poor, except for major events such as occurred in January 2008. This is discussed further in Section 2.5.3.

### 2.2.2 Streamflow

Streamflow data is available on both the Waikawa and Manukau Streams. The Manukau has the longest record, from 1978 but with a 10 year gap between 1989–2007. The gauge was repositioned in July 2007 and a new gauge installed on the Waikawa Stream in May 2006. Table 2-2 shows the maximum flows recoded at each site. Note values for the Manukau Stream recorded up to 1988 are from the Gleesons Road gauge. The catchment areas upstream of the existing gauges is calculated to be 28.46km$^2$ for the Waikawa and 15.83km$^2$ on the Manukau.

The highest flow on record by far occurred in January 2008, when the Waikawa gauge recorded 81m$^3$/s and Manukau 49m$^3$/s. Significantly, these flows are also considered by HRC to be the highest flows to have occurred on either stream since gauging records commenced on the Manukau in 1979. The previous highest flow recorded on the Manukau at was at Gleesons Road in November 1984 when a peak flow of 27m$^3$/s was recorded.

*Table 2-2 Maximum Annual flows recorded on the Manukau and Waikawa Streams.*

| | **Max. Annual Discharge** (m$^3$/s) | |
|---|---|---|
| **Date and Year** | **Manukau** | **Waikawa** |
| 12 April 1979 | 13.7 | |
| 20 January 1980 | 20.9 | |
| 3 June 1981 | 10.4 | |
| 21 December 1982 | 22.2 | |
| 4 November 1983 | 11.3 | |
| 25 November 1984 | 27.2 | |
| 23 December 1985 | 20.2 | |
| 4 October 1986 | 22.2 | |
| 15 June 1987 | 6.3 | |
| 24 August 1988 | 11.8 | |
| 17 November 2006 | | 40.8* |
| 4 November 2007 | 14.1* | 32.3 |
| 8 January 2008 | 48.9* | 80.9* |

*Partial year record

## 2.3 Rainfall Analysis and Generation of Design Storms

An analysis of the available rainfall data at Levin and Upper Mangahao has been undertaken in order to generate suitable rainfall design hyetographs for the hydrological model. The analysis has not considered in detail the Jarvis gauge due to the daily resolution of the data. In addition its location in the lower part of the catchment where rainfall is less spatially variable means that the hourly data from the alternative site at Levin is likely to provide a suitable basis for analysing the lower catchment rainfall.

### 2.3.1 Gauge Analysis

A depth-duration-frequency analyses of the Levin and Upper Mangahao gauges has been undertaken using HIRDS. These values have been compared to the HRC values for Upper Mangahao as shown in Appendix A.

A summary shown in Table 2-3 indicates that at the Upper Mangahao gauge the HRC analysis generally predicts higher rainfall totals at lower ARI's and lower totals at higher ARI's compared to HIRDS.

*Table 2-3 HIRDS Depth-Duration-Frequency Analyses at Upper Mangahao and Levin Gauges**

| | **Upper Mangahao** | | | **Levin** | | |
|---|---|---|---|---|---|---|
| Duration (hrs) | ARI (Years) | | | | | |
| | 10 | 50 | 100 | 10 | 50 | 100 |
| 1 | 33.6 [38.6] | 47.0 [50.5] | 55.0 [55.5] | 16.8 | 26.2 | 33.2 |
| 2 | 48.4 [53.1] | 67.7 [65.5] | 79.1 [70.6] | 23.3 | 35.5 | 44.5 |
| 6 | 86.4 [103.7] | 120.6 [123.7] | 141.1 [131.3] | 39.2 | 57.6 | 70.7 |
| 12 | 124.6 [146.1 | 173.8 [176.2] | 203.1 [187.8] | 54.4 | 78.0 | 94.6 |
| 24 | 179.6 [212.4] | 250.4 [265.6] | 292.5 [286.4] | 75.6 | 105.8 | 126.6 |

*HRC Analysis in square brackets [ ]

The rainfall totals at the Upper Mangahao gauge can be seen to be more than twice those predicted for Levin, indicating the high spatial variability of rainfall in and near the catchment. Figure 2-2 shows the HIRDS predictions of 24 hour rainfall depth in the region. The effect of the Tararua Ranges is clearly seen.

### 2.3.2 Catchment Design Rainfall

Design rainfall hyetographs have been generated from the depth-duration-frequency (DDF) data. Hyetographs have been developed using Chicago storm approach, with storms of higher intensity and shorter duration nested inside longer duration events. The total duration of the hydrograph generated is 24 hours, with the smallest rainfall interval set at 10 minutes. Design storms have been generated using HIRDS rainfall depths both for the gauges at Levin and Upper Mangahao, and also at locations in the upper and lower catchments. The DDF tables are shown in Appendix A. The HIRDS data for Upper Mangahao has been chosen instead of the HRC gauge data as it is generally more conservative and it ensures consistency in the overall approach.

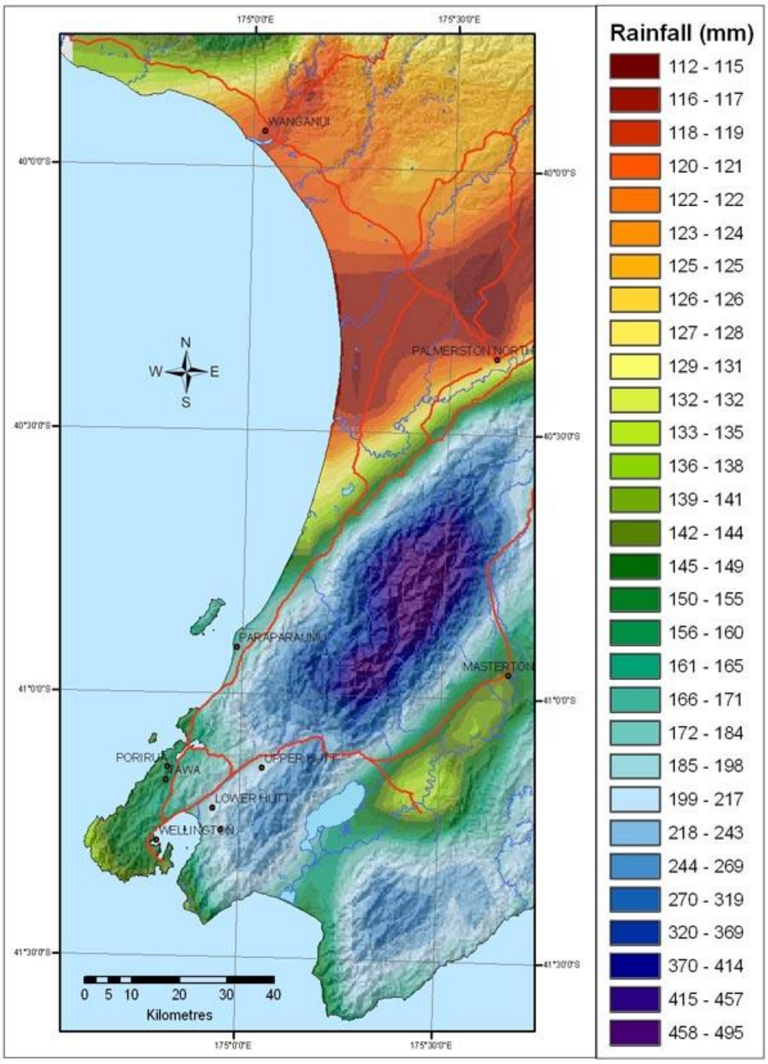


*Figure 2-2 Spatial variation of 24 hour rainfall totals in the region predicted by HIRDS (Courtesy NIWA)*

## 2.4 Flood Frequency Analysis

In order to quantify the range of flood magnitudes that can be expected, different methods have been applied. A gauge based analysis has been applied to the combined gauge record for the Manukau Stream, while the streamflow record for the Waikawa has been extended through use of a rainfall-runoff model. Finally a regional flood frequency analysis has been applied to each stream. An assessment of the January 2008 flood has been undertaken in light of these analyses.

### 2.4.1 Flood Frequency Analysis of Manukau Stream Flow Record

The Manukau Stream has been gauged since 1979, however a 17 year gap in the record exists between 1989 and 2006. The annual maxima are shown on Table 2-2. The January 2008 event is considered by HRC to be the largest event since gauging commenced in 1979.

The data have been subjected a statistical analysis by HRC and separately by DHI using the EVA (Extreme Value Analysis) software. A number of distributions have been tested, comprising Extreme Value Type 1 (EV1), Generalized Extreme Value (GEV) and Log-Pearson III. The record length (11 samples) is small compared to the statistical extremes (100 and 200 years) that need to be predicted. However the maximums recorded in November 2007 and January 2008 can be included in the record assuming the latter represents the highest flow since 1979. Figure 2-3 shows the results of the EV1 analysis (method of L-Moments) excluding the 2007 and 2008 flows with 95% confidence limits

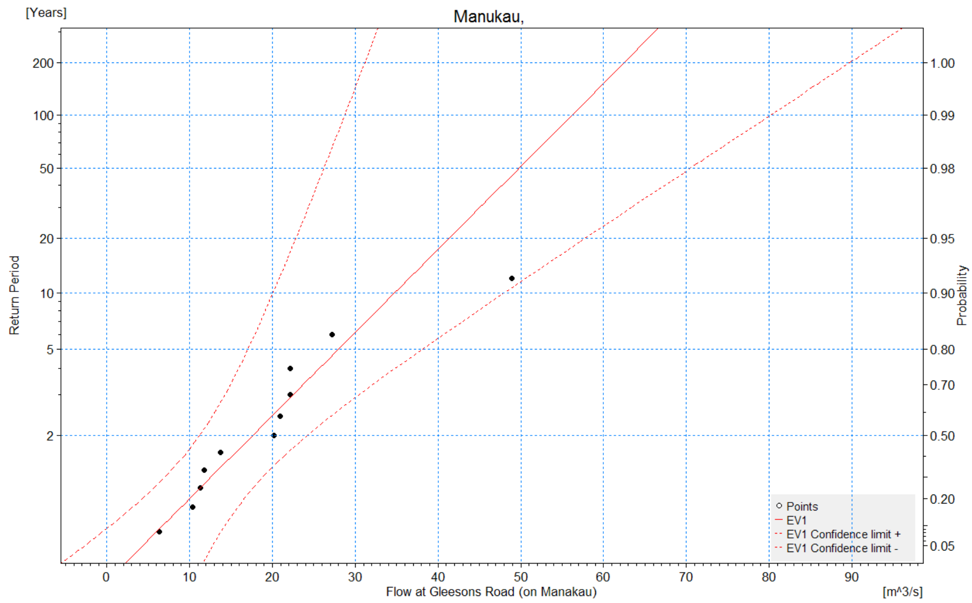


*Figure 2-3 EVA Analysis of Manukau Flow Gauge record, excluding 2007-2008*

Based on the existing gauge record, the 100 year peak flood discharge at the Manukau gauge is estimated by HRC and DHI to be between 53 – 66 $m^3/s$ and the 200 year between 59 - 79 $m^3/s$.

Taking into account the historical significance of the January 2008 event, the 100 year peak flood discharge is reduced to between 42-52 $m^3/s$ and the 200 year to between 45-60 $m^3/s$. The HRC estimates for these events are 52 and 58 m3/s for the 100 and 200 year events respectively.

### 2.4.2 Regional Flood Frequency Analysis – Manukau Stream

In view of the very limited flow record available for the two streams, a regional based flood frequency analysis has been undertaken by HRC utilizing a regional flood analyses developed by NIWA for the Region (pers. comm.. J. Watson).

Based on a regional analysis the 100 year flow for the Manukau Stream is estimated to be 2.4 times the average annual maxima of 18.8 $m^3/s$, yielding an estimate of 45 $m^3/s$. This is at the lower end of the range of the gauge based flow estimates (assuming a 30 year flow record) of 42-52 $m^3/s$ for the 100 year event.

Historical data concerning floods in the catchment is very sparse, and therefore validation of the predicted regional estimates is not directly possible.

### 2.4.3 *Flood Frequency Analysis of Waikawa Stream Record*

Flow gauging on the Waikawa has only been undertaken since May 2006, and therefore the gauge record does not form a suitable basis for a statistical analysis of annual flood peaks. In order to extend the flow record, a rainfall-runoff model has been setup for the Waikawa catchment upstream of the flow gauge and calibrated against the available flow record. DHI's NAM model, which is a continuous conceptual lumped model has been used for this analysis. NAM includes approximately 20 model parameters describing the surface and subsurface storage volumes and routing coefficients, which can be automatically calibrated using a built-in calibration module.

The model has been calibrated using an 80/20 weighted combination of Upper Mangahao and Levin rainfall, in addition to average monthly Levin evaporation data. The calibration was focussed on reproducing flood peaks above $20m^3/s$, rather than on smaller peaks and baseflow. The calibration was generally satisfactory, as shown in Figure 2-4, however it was unable to match the highest peak flow in January 2008.

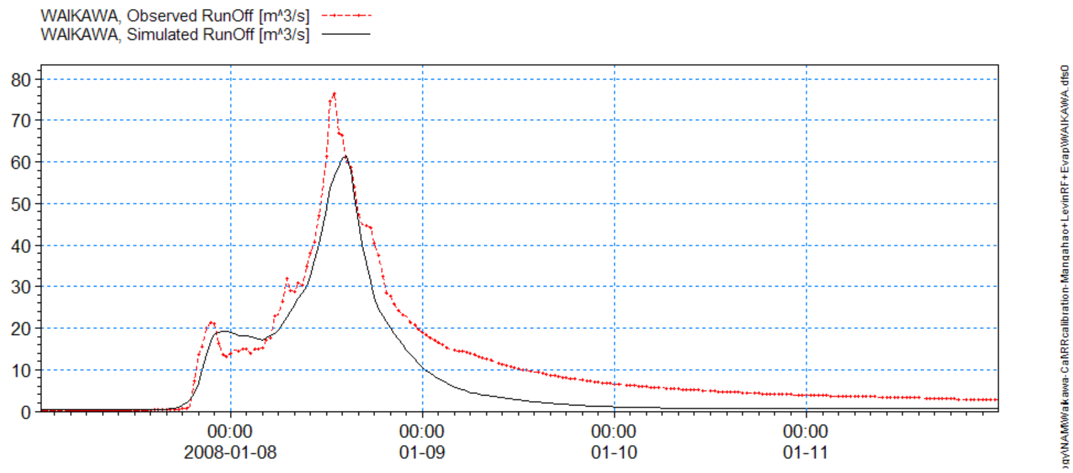


*Figure 2-4 NAM Rainfall Model calibration – detail around January 2008 event.*

Using the calibrated NAM model, a streamflow timeseries was generated for the period 1977-2005 using the weighted Upper Mangahao and Levin rainfall data, see Figure 2-5. The synthesised flows do not always appear realistic however, as for example the model predicts a large flood in January 2005, but there is no anecdotal evidence of a large flood at this time. HRC have records of floods occurring 25 Nov 1984 and 21 Dec 1982, however neither of these events stands out in the synthetic record. This illustrates the limitation in using the Upper Mangahao raingauge (located 20km from the catchment at 375m elevation) as a basis for both calibration and streamflow extension purposes at the Waikawa gauge.

It is interesting to observe however that using the Upper Mangahao gauge as input, the model does not produce a maximum flow over 70m3/s.

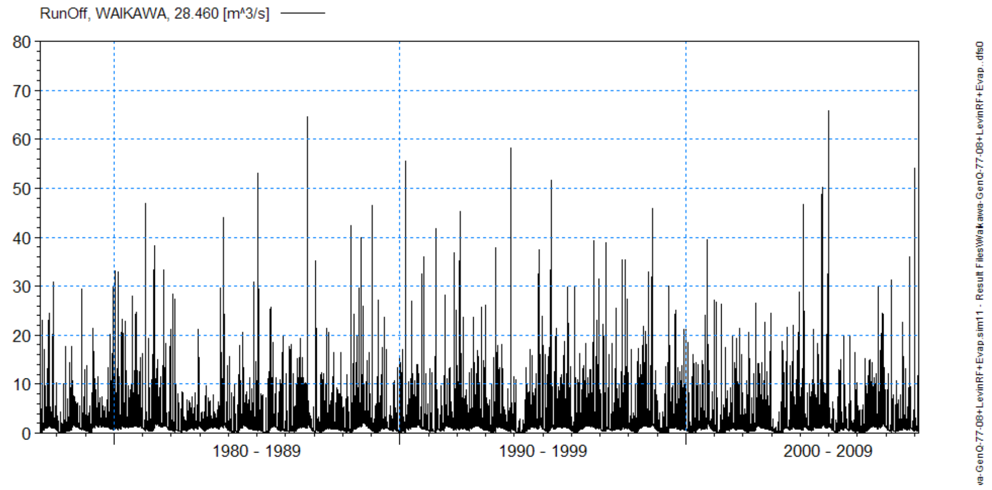


*Figure 2-5 Synthesised flow record for the Waikawa gauge based on Upper Mangahao rainfall 1977-2008*

Given the synthetic record may not be reliable, it was nevertheless useful to estimate the flood frequency. Annual peaks from the long term simulation were extracted, and the observed peaks from 2007-2008 were appended to the simulated record, which was then subjected to a statistical analysis.

Based on this composite record, the 100 year flow is predicted to be 88m$^3$/s for the 100 year event and 97m$^3$/s for the 200 year.

### *2.4.4 Analysis of January 2008 Storm*

It is applicable at this point to investigate the statistical relevance of the January 2008 storm event. This storm, which occurred on 8 January 2008 resulted in widespread flooding in the lower catchment, and led to the closure of SH1 and Waikawa Beach Road, see Appendix B.

The hourly rain recordings at Levin and Upper Mangahao, together with the recorded discharges on the Waikawa and Manukau gauges are shown in Figure 2-6.

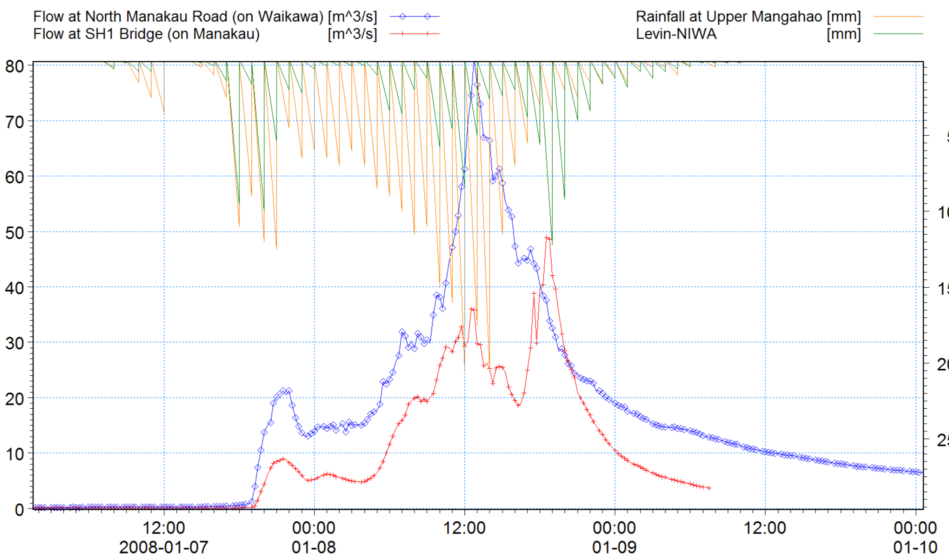


*Figure 2-6 Hourly rainfall and Discharges recorded during the January 2008 flood event.*

The catchment response to rainfall is very rapid, and is probably in the order of a few hours. The gauge comparison actually shows the peak flows in the catchment gauges occurring before the peak rainfall intensity at Upper Mangahao and Levin, indicating a possible northward movement of the storm. The Manukau gauge shows a different response compared to the Waikawa gauge and would appear to be influenced by both upper catchment rainfall represented by Upper Mangahao (first peak) and lowland rainfall represented by Levin (second peak). In contrast the Waikawa catchment discharge tracks closely with the Upper Mangahao rainfall in this event.

The maximum recorded depths for different durations during the storm and approximate return periods are shown in Table 2-4.

*Table 2-4 Maximum rainfall depths recorded during January 2008 storm and approximate ARI*

| | **Upper Mangahao** | | | **Levin** | |
|---|---|---|---|---|---|
| Period (hrs) | Max depth (mm) | ARI HRC | ARI HIRDS | Max depth (mm) | ARI HIRDS |
| 1 | 20.5 | <1 yr | <2 | 12.2 | 2 |
| 2 | 38.0 | <1yr | 5yr | 21.4 | 5yr |
| 3 | 58.5 | 4yr | 10yr | 27.0 | 10yr |
| 6 | 101.0 | 8yr | 20yr | 35.2 | 5yr |
| 12 | 158.0 | 20yr | 35yr | 65.6 | 25yr |
| 24 | 251.5 | 35yr | 50yr | 85.4 | 20yr |

From the rainfall analysis it may be surmised that the resulting flood peak discharge may have had a return period of between 10-20 years assuming a critical duration of less than 6 hours. The peak flows at Waikawa and Manukau were 80.9m$^3$/s and 48.9m$^3$/s respectively. Based on the historical gauge analysis and regional analysis, the Manukau peak flow is in the order of a 100 year flood event. The discrepancy with the apparent rainfall return period is not unusual, as the spatial variability of the rainfall leads to a great deal of uncertainty in the assessment of its probability.

It is possible that the rainfall recorded at Upper Mangahao and Levin is not representative of the actual rain that fell in the Waikawa and Manukau catchments. It is also likely that rainstorms of specific return periods do not result in floods of the same statistical frequency. This is a common situation but it is not possible to verify this for the Waikawa and Manukau catchments due to the short duration of the available flow record and the lack of rainfall stations in the upper catchment.

### 2.4.5 Final Estimates for 100 and 200 year Flood Event Peak Discharges

For the purposes of hydrologic design, it has been decided to adopt the HRC gauge based estimates of peak flows. For the Manukau catchment these are estimated as 52m$^3$/s and 58m$^3$/s for the 100 and 200 year events respectively.

The Waikawa and Manukau catchments are of a similar character and therefore the transposition of the 100 year flood estimate from Manukau to Waikawa may be based on standard techniques used in New Zealand, where the peak catchment discharge is scaled according to $A^{0.8}$, where A is the catchment area. Based on this, the January 2008 peak flood discharge for the Waikawa is estimated as 78.4 m$^3$/s, close to the gauged value of 80.9 $m^3$/s. Therefore applying this scaling factor to the Manukau 100 and 200 year flood peak discharges yields peak discharge values for the Waikawa catchment of 83 $m^3$/s and 93 $m^3$/s respectively. The values are summarised in Table 2-5.

*Table 2-5 Adopted Design Flood Peak Discharges ($m^3$/s)*

| ARI Event | Manukau | Waikawa |
|---|---|---|
| 100 year | 52 | 83 |
| 200 year | 58 | 93 |

The adopted Waikawa figures are not dissimilar to the values derived based on the extended streamflow records of 88$m^3$/s and 97$m^3$/s, see 2.4.3.

## 2.5 Hydrological Model Development and Calibration

A hydrological rainfall-runoff model was developed in order to generate catchment inflows using the design rainfall hyetographs generated as mentioned in Section 2.3.2.

### 2.5.1 Catchment Delineation

The entire catchment has been delineated using the land level (LiDAR and 20m contour) data supplied by HRC as shown in Drawing 2. The derived catchment properties are shown in Table 2-6.

*Table 2-6 Sub-Catchment Physical Properties*

| Catchment Name | Area ($km^2$) | Length (m) | Slope (m/km) |
|---|---|---|---|
| Up_Man_East1 | 3.13 | 3713 | 165.9 |
| Up_Man_East2 | 3.53 | 3266 | 153.1 |
| Up_Wai1 | 24.80 | 8308 | 99.9 |
| Up_Wai2 | 3.66 | 1465 | 92.2 |
| Up_Man_West1 | 5.43 | 2990 | 103.3 |
| Up_Man_West2 | 3.74 | 2267 | 176.9 |
| Wai1 | 3.31 | 4024 | 98.7 |
| Man1 | 4.34 | 3054 | 27.8 |
| Man2 | 4.51 | 4014 | 13.7 |
| Man3 | 1.36 | 648 | 20.8 |
| Man4 | 0.58 | 646 | 7.9 |
| Man5 | 4.15 | 4257 | 5.2 |
| Wai2 | 3.04 | 2323 | 4.3 |
| Wai3 | 3.75 | 1799 | 3.3 |

### 2.5.2 Model Development

The hydrological model used for the generation of design rainfall inflows is DHI's Model B. This is an event based model, the pervious component of which combines a Hortonian rainfall loss model with a kinematic overland flow routing model. An impervious component ignores infiltration losses. The model parameters include catchment slope and length, initial and continuing losses, and Manning number of overland flow. The model simulates fast response surface runoff only and does not account for interflow or baseflow. For design flood simulations these contributions can usually be ignored.

The model was initially set up with the catchments upstream of the flow gauges on the Manukau and Waikawa Streams, so that model parameters for the upper catchments could be calibrated. It is assumed the catchment is 100% pervious.

### 2.5.3 Model Calibration

There is a limited number of flood events available for calibration of the hydrological model, due to the relatively short duration of the flow record (particularly on the Waikawa) and the remoteness of the raingauges from the catchments, which means not all recorded rainfall events are reflected in the flow record..

The January 2008 event is an obvious selection as this is the highest flood on record. Two other events have been selected – June 2006 and November 2007. Only Manukau flow data is available for the 2006 event. The rainfall and flow response for the January 2008 event is shown in Figure 2-6.

The hydrological model was calibrated by varying the initial and continuous infiltration loss parameters in each contributing sub-catchment. The Waikawa catchments utilize the Upper Mangahao rainfall as the only input. After several trials, it was found that the calibration at the Manukau gauge was best achieved through weighting the rainfall as 0.80 to Upper Mangahao and 0.40 to Levin. The total weight of 1.2 means the recorded rainfall is scaled up by 20%, but this is justified as the Levin rainfall is lower than that falling in the lower catchments according to the HIRDS distributions (see Appendix A).

The model calibration results for all three events are shown in Appendix C. The results for the 2008 event are shown in Figure 2-8.

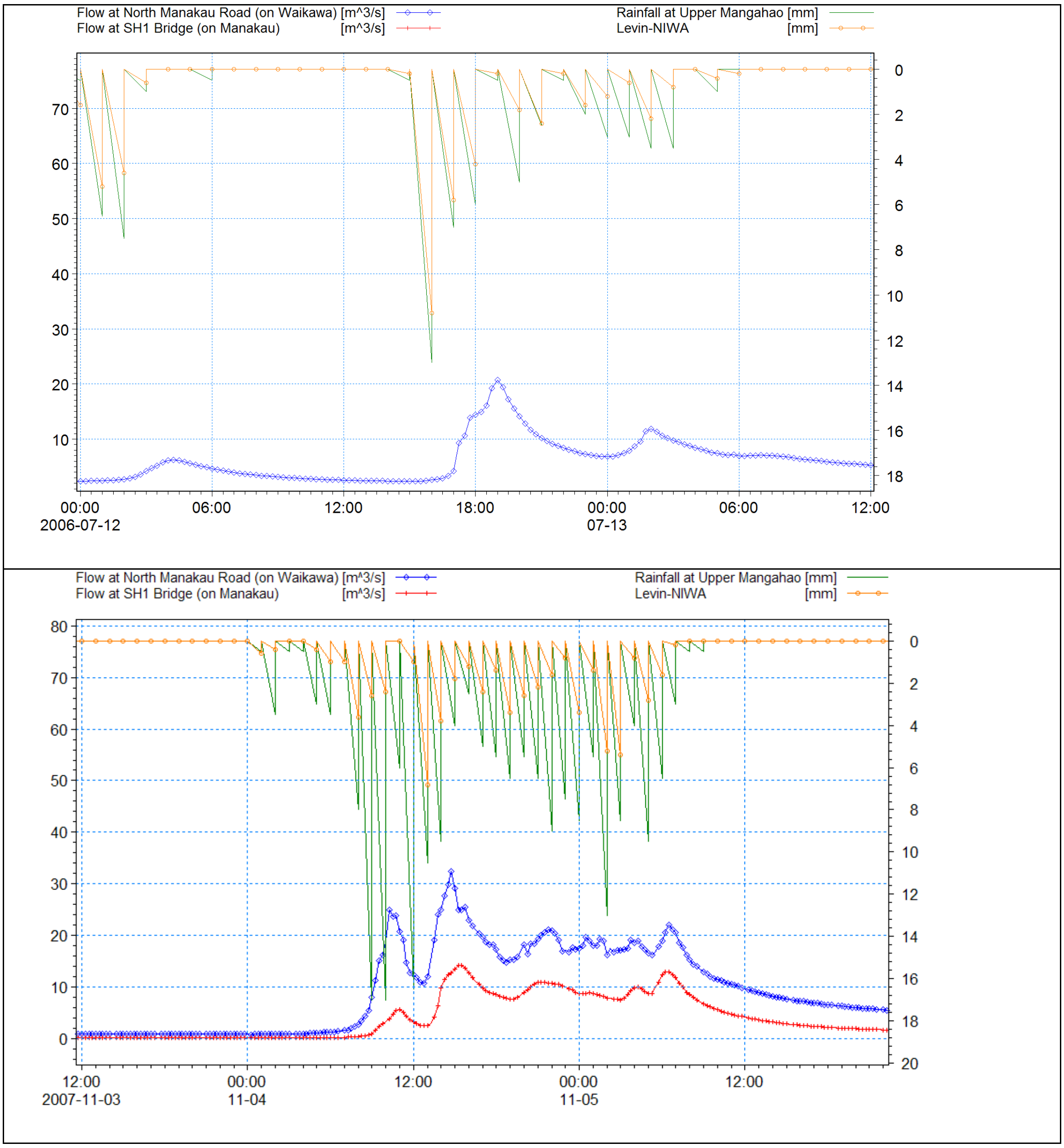


*Figure 2-7 Recorded rainfall and discharges for June 2006 flood (top) and November 2007 (bottom)*

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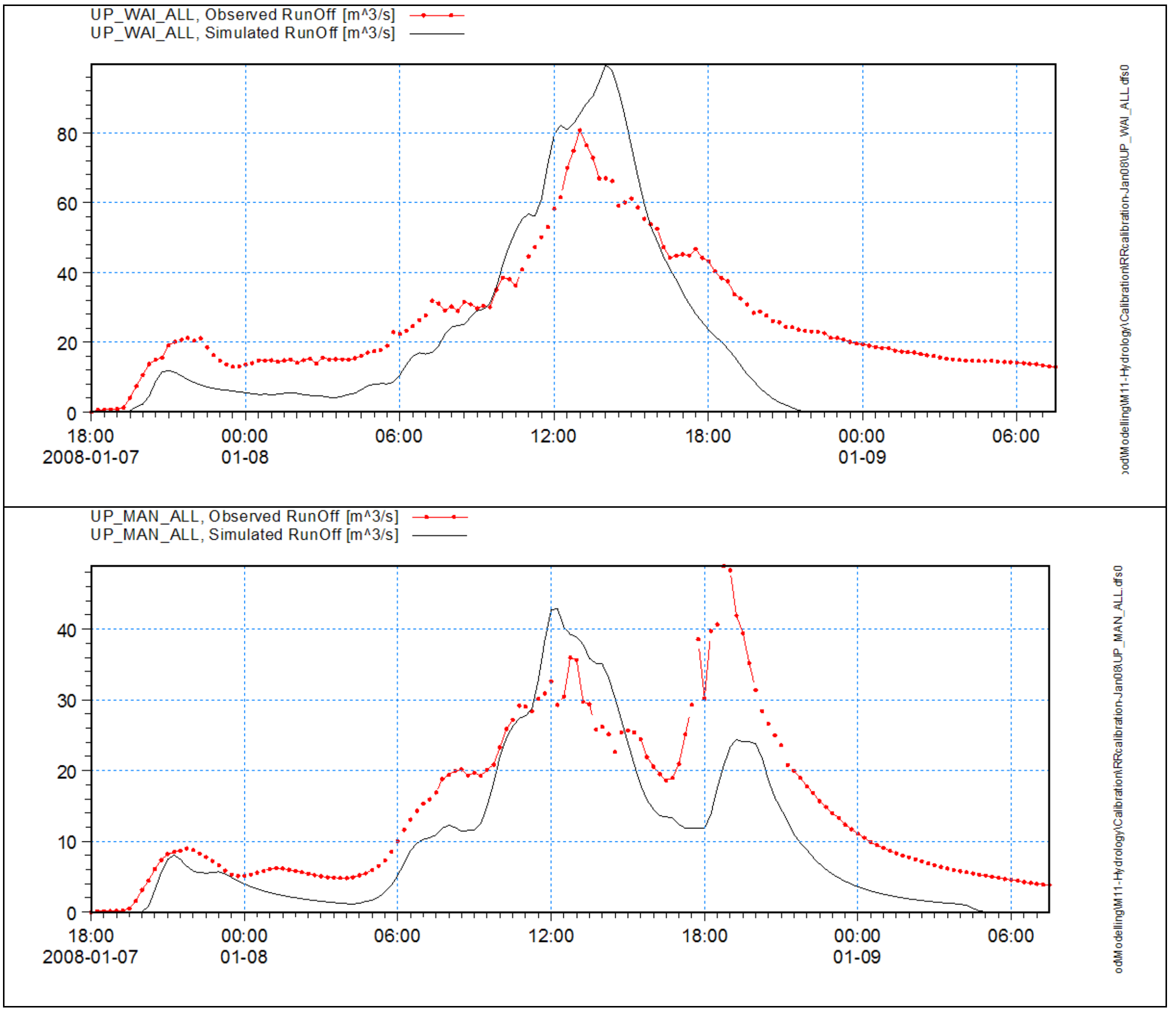


*Figure 2-8  Hydrological Model Calibration for January 2008 – Waikawa (top) and Manukau (bottom)*

Based on the calibration results, the following model parameters have been applied for the design simulations.

*Table 2-7  Applied Hydrological Model Parameters*

| Parameter | Value |
|---|---|
| Wetting Loss (mm) | 0.05 |
| Storage Loss (mm) | 10 |
| Initial Infiltration Rate (mm/hr) | 5 |
| Final Infiltration Rate (mm/hr) | 3 |
| Horton “k” exponent (/second) | 0.005 |
| Manning n | 0.05 |

## 2.6 Design Event Generation

The calibrated catchment parameters were applied to the remaining lower sub-catchments. A 20% impervious area was applied to catchment *Wai3* to account for the urbanisation at Waikawa Beach. The design rainfall hyetographs were applied to the calibrated hydrological model to generate runoff hydrographs for each sub-catchment. The runoff from the upper catchments was compared to the design flood peaks derived from the flood frequency analysis. Two sets of simulations were undertaken. One set of simulations was made using the design hyetographs derived from the HIRDS rainfall in the upper and lower catchments. The assignment of upper and lower catchment rainfall is shown in Table 2-8. A second set of simulations was made using HIRDS data generated at the Upper Mangahao and Levin gauges. The rainfall inputs for the Manukau catchment in this case were scaled in the same way as the calibration (see section 2.5.3)

*Table 2-8 Assignment of HIRDS catchment based rainfall for 50 and 100 year ARI Design Events*

| Catchment Name | Catchment Rainfall applied |
|---|---|
| Up_Man_East1 | Upper |
| Up_Man_East2 | Upper |
| Up_Wai1 | Upper |
| Up_Wai2 | Upper |
| Up_Man_West1 | Upper |
| Up_Man_West2 | Lower |
| Wai1 | Lower |
| Man1 | Lower |
| Man2 | Lower |
| Man3 | Lower |
| Man4 | Lower |
| Man5 | Lower |
| Wai2 | Lower |
| Wai3 | Lower |

The calibrated hydrological model predicts flows far in excess of any previous gauging. The design rainfall hyetographs represent more intense rainfall than has occurred in the historical record at the Upper Mangahao or Levin gauges. For example the 100 year design rainfall hyetograph for the Upper Mangahao catchment is compared to the January 2008 hyetographs at Upper Mangahao and Levin in Figure 2-9 as hourly totals.

It is evident that in the 31 years since rainfall recordings commenced at the Upper Mangahao gauge a flood event comparable to that predicted by the hydrologic design model has not yet taken place. This may be due to the fact that rainfall of the intensities observed at Upper Mangahao, or predicted by HIRDS in the catchment, overestimate the actual situation in the Waikawa-Manukau catchment due orthographic or other effects. Alternatively it is statistically possible that a storm of the critical duration and sufficiently high rainfall intensity has not occurred over the catchment in recent history.

Following discussions with HRC it was decided to adopt the gauge based flow estimates (shown in Table 2-5) for the flood hazard mapping as the hydrological model predictions were considered to be too conservative.

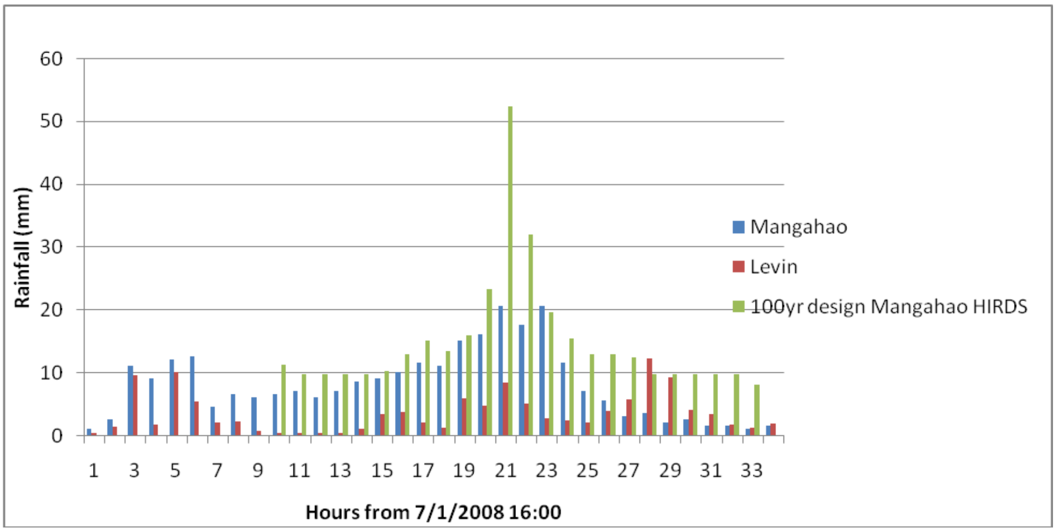


*Figure 2-9  100 year design hyetograph at Upper Mangahao compared to January 2008 record*

Table 2-9 summarises the results of the simulations in terms of the peak discharge and compares these to the flood frequency assessment described in section 2.4.2.

*Table 2-9  Comparison of predicted peak catchment discharges*

| ARI (years) | Waikawa | | | Manukau | | |
|---|---|---|---|---|---|---|
| | Model Qpeak | | Gauge Assess-ment | Model Qpeak | | Gauge Assess-ment |
| | Gauge HIRDS | Catchment HIRDS | | Gauge HIRDS | Catchment HIRDS | |
| 100 | 284 | 317 | **52** | 179 | 203 | **83** |
| 200 | 347 | 401 | **58** | 231 | 262 | **93** |

The gauge based assessments (shown in bold above) have been used to scale the January 2008 hydrographs recorded at each site to provide inflow boundary conditions to the hydraulic model. The 2008 hydrograph at Manukau has been "reshaped" so as to provide a single peak event, as shown in Figure 2-10. The Waikawa hydrograph has been scaled without modification. Inflows from other contributing sub-catchments have also been scaled based on these two hydrographs directly in relation to the contributing sub-catchment area, as shown in Table 2-10.

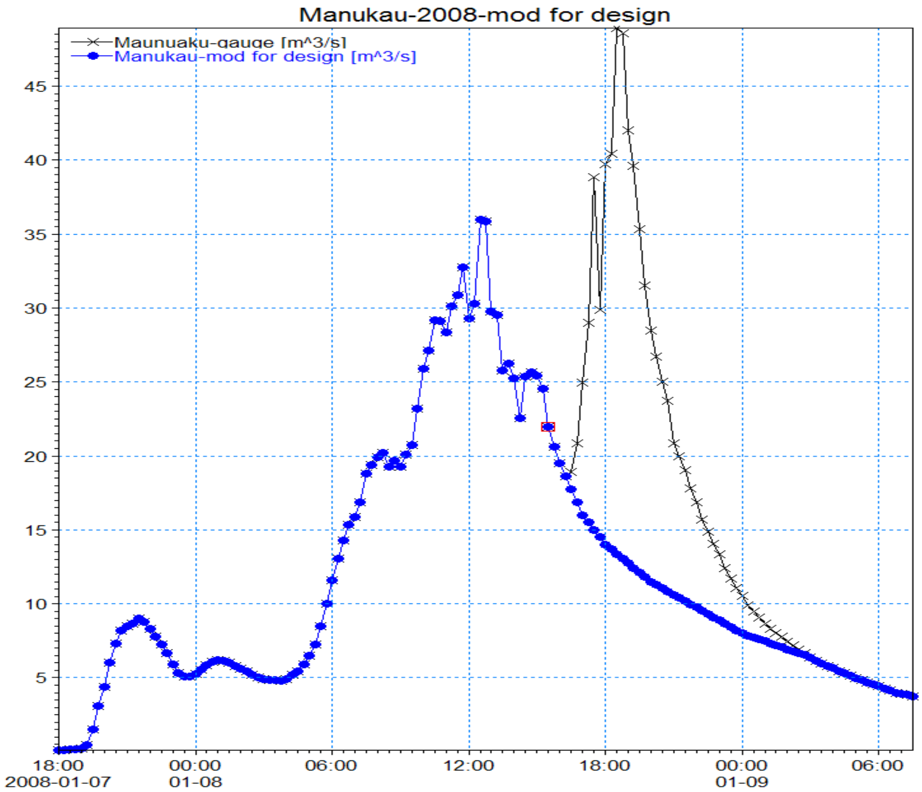


*Figure 2-10 Manukau January 2008 hydrograph "reshaped" (blue line) for flood hazard modelling*

*Table 2-10 Scaling Factor Applied to January 2008 Gauged Flows for Model Sub-Catchments*

| Catchment | Area ($km^2$) | Scaled to - | Scaling factor to Gauged flows | Peak Discharge ($m^3/s$) | |
|---|---|---|---|---|---|
| | | | | 100 year | 200 year |
| Up_Wai1 | 24.80 | Waikawa@Gauge | 0.87 | 91.5 | 104.6 |
| Up_Wai2 | 3.66 | Waikawa@Gauge | 0.13 | 13.5 | 15.4 |
| Up_Man_East1 | 3.13 | Manukau@Gauge | 0.20 | 11.9 | 13.8 |
| Up_Man_East2 | 3.53 | Manukau@Gauge | 0.22 | 13.4 | 15.6 |
| Up_Man_West1 | 5.43 | Manukau@Gauge | 0.34 | 20.6 | 24.0 |
| Up_Man_West2 | 3.74 | Manukau@Gauge | 0.24 | 14.2 | 16.5 |
| Wai1 | 3.31 | Manukau@Gauge | 0.21 | 12.6 | 14.7 |
| Man1 | 4.34 | Manukau@Gauge | 0.27 | 16.4 | 19.2 |
| Man2 | 4.51 | Manukau@Gauge | 0.28 | 17.1 | 19.9 |
| Man3 | 1.36 | Manukau@Gauge | 0.09 | 5.2 | 6.0 |
| Man4 | 0.58 | Manukau@Gauge | 0.04 | 2.2 | 2.6 |
| Man5 | 4.15 | Manukau@Gauge | 0.26 | 15.7 | 18.4 |
| Wai2 | 3.04 | Manukau@Gauge | 0.19 | 11.5 | 13.4 |
| Wai3 | 3.75 | Manukau@Gauge | 0.24 | 14.2 | 16.6 |

# 3 HYDRAULIC MODEL DEVELOPMENT AND CALIBRATION

## 3.1 Model Description

The hydraulic 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 DHI 2008.

## 3.2 Physical Description of Manukau and Waikawa Streams

The Manukau and Waikawa streams have their headwaters high in the Tararua catchment and emerge onto the coastal floodplain east of SH1 at elevations of between 60-100m.From here the two streams pass through arable pasture land, crossing SH1 and the North Island Truck Railway either side of the township of Manukau. The ground elevation at SH1 on both streams is around 55m, and from here the streams drop around 50m over the next 4km to the confluence. From the confluence the stream meanders through sandhills past the township of Waikawa Beach before discharging via a morphologically active outlet to the sea. The lower reaches of the stream are influenced by the tide.

Major cross drainage structures exist on both streams where they cross SH1 and the railway. A number of lesser structures exist both upstream and downstream the SH1. The main structures have been surveyed by HRC and the features included in the model.

## 3.3 Data Availability

The following paragraphs list the data made available for the hydraulic model development.

### 3.3.1 Land Levels (LiDAR )

HRC supplied detailed land level data in the form of airborne laser survey (ALS, or LiDAR) data in GIS format. The extent of the LiDAR data is shown in Drawing 3. A 1m grid digital elevation model (DEM) of the LiDAR has been created and resampled to a 10m grid for use in the MIKE 21 model. The 10m grid has been extended east into the Tararua Ranges using 20m contour data supplied by HRC. The LiDAR extent runs close to the Waikawa river right bank floodplain and therefore the 10m model grid has also been extended north using the 20m contour data set, supplemented by some spot levels supplied by HRC.

### 3.3.2 Cross Sections and Topography

HRC undertook a bathymetric and topographic survey of the lower reaches of the Waikawa stream and river mouth in September 2007. Cross sections surveys of the Manukau Stream upstream of the confluence were additionally undertaken at in December 2007, see Drawing 3.

Additional cross sections for use in the MIKE 11 1D model were extracted from the 1m LiDAR grid as shown in Drawing 3.

### 3.3.3 Bridges and Culverts

The main bridges in the study area are represented by the SH1 and railway structures which cross both the Waikawa and Manukau Streams. The road and rail bridges on the Manukau are closely aligned, and the road bridge (representing the most severe constriction) was surveyed along with the stream cross sections in September 2007. A number of smaller bridges spanning the Manukau Stream were also included in this survey, these are on Waikawa Beach Road, Takapu Road and Gleesons Road (site of the old flow gauge).

The Waikawa SH1 road bridge is located approximately 200m upstream of the rail bridge. Both these structures were surveyed by HRC in May 2008.

### 3.3.4 Flood levels and Extents

The January 2008 flood was recorded by HRC who documented the flood extent from a helicopter during the event. HRC have provided DHI with the photographic record of the flood as well as a GIS layer indicating the extent. This data has been used to validate the MIKE FLOOD model. No flood level data is available within the catchment.


*Figure 3-1 Photographs of January 2008 flood event from HRC aerial survey*

## 3.4 Model Extent and Development

### 3.4.1 Model Extent

The 2D floodplain component of the MIKE FLOOD model extends from close to the upstream limits of the LiDAR down to the sea. The 1D MIKE 11 model component extends from the SH1 bridge on the Manukau and the North Manukau road bridge on the Waikawa, down to approximately 1200m upstream of the river mouth. Upstream of the MIKE 11 model extent, the floodplain and stream flows are simulated using the 2D model only. In this area the stream channel provides only a small proportion of the total floodplain conveyance and therefore a pure 2D description is appropriate. The last 1200m of the stream is also modelled in 2D only, as the width and depth of the stream channel at this point allows it to be described with adequate resolution in the 10m MIKE 21 model. The entire MIKE 11 model is dynamically linked to the 2D grid via MIKE FLOOD.

### 3.4.2 1D MIKE 11 Model

The 1D MIKE 11 model has been developed of the Manukau and Waikawa Streams using cross sections surveyed by HRC, supplemented by approximately 90 additional cross sections extracted from the LiDAR at representative locations at 100-150m centres.

All major bridge structures have been included in the model. The large SH1 and rail bridges on the Waikawa have been accounted for through a local narrowing of the model cross sections to account for the contraction due to abutments and bridge piers. The cross sections have been “sealed” so that flows above the bridge soffits are forced to pressurised a state, and allowance has been made in the MIKE 21 model for overflows that make take place over these bridge decks.

All bridges on the Manukau Stream (SH1, Waikawa Beach Road, Takapu Road and Gleesons Road) have been included in the MIKE 11 model as culvert structures. These allow for flow under the road while bridge overtopping is handled in the MIKE 21 model.

Numerous access road culverts in the lower part of the study area - typically 1m diameter with 200mm concrete deck – have been ignored in this analysis as they are unlikely to affect overall flood levels or flows.

A constant Manning “n” of 0.025has been specified throughout the MIKE 11 model. The downstream water level boundary has been specified as mean sea level (at Wellington Port, 0.165m) for all design simulations, and 0.8m for the January 2008 simulation, which corresponded to the approximate maximum tide level at the time of the flood.

Hydrological model runoff hydrographs are introduced into the MIKE 11 model according to the sub-catchment contribution areas and extents as shown in Drawing 2.

### 3.4.3 2D MIKE 21 Model

The 2D model bathymetry is based on the 1m LiDAR grid supplied by HRC. This has been blended with 20m contour data plus some spot level information from HRC to produce a 10m grid DEM for use in the model. The 20m contour data has been used to extend the model domain north of the Waikawa Stream, as initial model simulations indicated that out of bank flows are directed north toward the Ohau catchment. The model bathymetry in this area is therefore highly uncertain.

All important topographical features have been "burnt in" into the 10m grid, including SH1, the railway and all sealed roads in the study area. Low level stopbanks, where identified from the 1m DEM, have also been "burnt" back into the 10m grid. The "burning in" process sets the 10m model land levels to the true levels as determined from the 1m grid. These fine scale features may have otherwise been filtered out in the resampling process. The HRC survey of the river mouth was included in the downstream extent of the MIKE 21 grid to ensure an adequate representation of the channel conveyance is included in the model in this final reach.

A 0.8m tide constant water level boundary has been applied for the January 2008 simulations and MSL (0.165m) all design runs. The combined effects of flood flows and storm surge have therefore not been taken into account in the modelling.

A 2D hydraulic resistance map has been derived from the MfE Land Classification Database GIS layer. 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 3-1. 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.

### 3.4.4 MIKE FLOOD Coupling

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.

In the current model, standard and lateral links have been employed. Lateral links are used to connect the MIKE 11 branches to the 2D domain along the river alignment, which accounts for overbank spilling and flow exchange between the river and floodplain. Generally centreline linkages have been used – whereby the flow exchange is initiated when water reaches bankfull conditions in MIKE 11. Once water enters the MIKE 21 domain it is free to flow "across" the top of the MIKE 11 model. The stream channel is infilled in MIKE 21 to reduce the double counting of stream conveyance.

A more rigorous 2-sided linkage has been used in sections along the Waikawa where low level stopbanking has been detected from the LiDAR. Separate lateral linkages are defined for both left and right river banks, and the river channel itself is blocked out (set to land value) to avoid double accounting of the channel capacity.

Table 3-1 Adopted hydraulic resistance based on land use types

| Description (LCDB2) | Code | n | M |
|---|---|---|---|
| High Producing Exotic Grassland | 40 | 0.05 | 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 | 0.01 | 10 |
| Short-rotation Cropland | 30 | 0.05 | 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 | 0.02 | 50 |
| River and Lakeshore Gravel and Rock | 11 | 0.02 | 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 | 0.02 | 50 |
| Major Shelterbelts | 61 | 0.125 | 8 |
| Surface Mine | 3 | 0.05 | 20 |
| Transport Infrastructure | 5 | 0.1 | 10 |
| Afforestation (not imaged) | 62 | 0.125 | 8 |
| Low Producing Grassland | 41 | 0.05 | 20 |
| Mixed Exotic Shrubland | 56 | 0.05 | 20 |
| Forest Harvested | 64 | 0.125 | 8 |

Standard links have been used at the upstream extent of the MIKE 11 model to allow hydrograph inflows from MIKE 21 to MIKE 11 to take place, and at the downstream end to allow flows from the MIKE 11 model to the river mouth.

A long artificial drainage channel has been included along the model northern extent to drain away overland flows heading toward the Ohau catchment. Inflows from the Ohau are not represented in the model.

## 3.5 Model Validation

The MIKE FLOOD hydraulic model has been validated against the January 2008 flood event, by comparing simulated flood extents to those observed and digitized from the HRC aerial survey. The model has been run by introducing the observed flows at the gauge locations. This provide the most accurate boundary inflow conditions on which to assess the overall model performance. Areas upstream of these gauges are consequently not mapped in this simulation.

The simulated flood extent is shown in Drawing 4. The red hatched outline indicates the observed flood extent. HRC have advised that the flood extent mapped immediately east of the river mouth was the most accurately mapped and this area shows a good match to the simulation. The model also shows some shallow flooding occurred across SH1 near the Manukau SH1 bridge and this has also been confirmed by HRC.

The simulation indicates shallow flooding occurs north of the Waikawa Stream toward the Ohau catchment. The largest breakout occurs just upstream of the confluence while a smaller breakout can be seen just upstream of the Waikawa Beach township. The bathymetry in these areas has been derived from the 20m contours supplemented by additional spot survey data from HRC. The simulated flood extent outside the LiDAR extent has not been shown as it is unreliable.

Northbound (Ohau) outflows at the largest breakout location during the January 2008 event are simulated by the model to be around $35m^3/s$. Although this figure appears high, it is consistent with a 500m wide breakout channel with 15cm depth of water flowing at 0.5m/s. There may be some indication that the model is simulating excessive outflows at this point as the flood extent downstream is slightly less than that observed. In order to improve the model in this area, additional land level data long the overflow channel needs to be collected to determine the threshold level for flows. Unless extensive land level data for the area north of the Waikawa is obtained considerable uncertainty will remain for higher flood events.

Generally the model provides a satisfactory match to the observed flood extents for the January 2008 event.

Following discussions with HRC, the breakout north or Waikawa Beach has been "sealed" for the design event simulations so that no net outflows from the model occur in this area. The Ohau outflows have however been retained. Some additional refinement of the bathymetry in this area has been undertaken prior to the design event simulations to ensure that excessive outflows do not occur in this area.

# 4 FLOOD RISK ASSESSMENT

## 4.1 Design Events

The MIKE FLOOD models have been used to simulate the 100 and 200 year ARI events. Catchment inflows have been generated from the calibrated hydrological model as described in Section 2. The models have been used to determine flood extent, depth, level, flow speed and flood hazard.

The results are shown on Drawings 5 – 12. Flood hazard has been classified according to the NSW Floodplain Development Manual (NSW DIPNR, 2005)) as shown in Figure 4-1. 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.

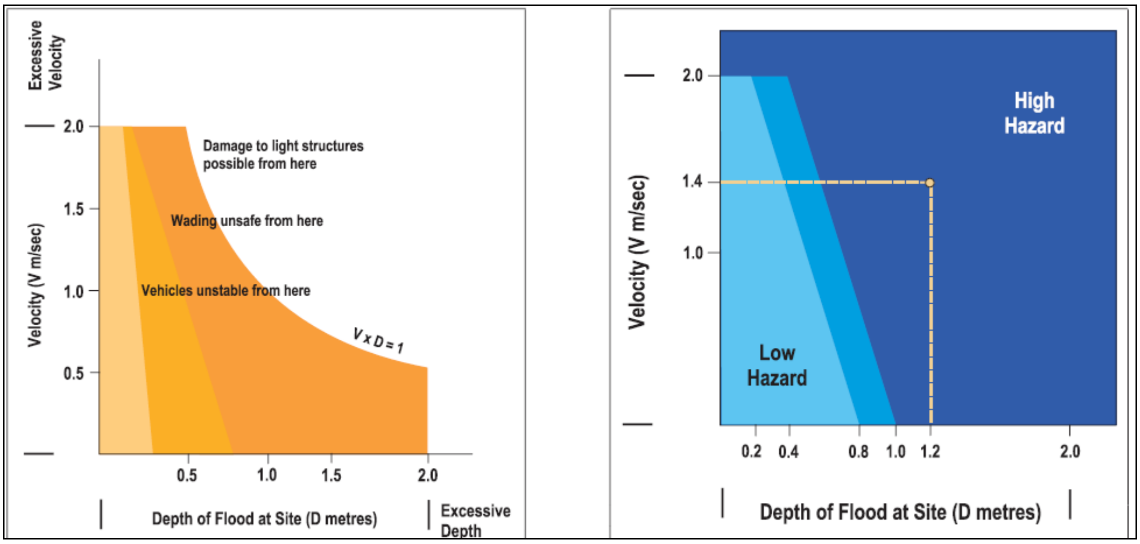


*Figure 4-1 Floodplain Hazard Categories (Source: NSW Floodplain Development Manual, App. L)*

### 4.1.1 Ohau Trans-Catchment Flows

The flood extents in the upper to middle catchments are contained within the floodplain terraces. Outflows to the north (Ohau) are significant in both events and account for approximately one third of the total catchment, as shown in Figure 4-2. This shown that in the 100 year event a peak breakout flow of 60m$^3$/s occurs just upstream of the confluence heading toward the Ohau catchment, while the peak flow entering the Waikawa estuary is 124m$^3$/s. In the 200 year event the peak flow entering the confluence is 137m$^3$/s, with 74m$^3$/s breaking out at the confluence.

The proportion of flow breaking out at the confluence is significant and is determined by the land levels in the area which are somewhat uncertain, as the LiDAR coverage does not extend fully into the spill region. Consequently flows and flood extents downstream of the confluence are subject to some uncertainty.

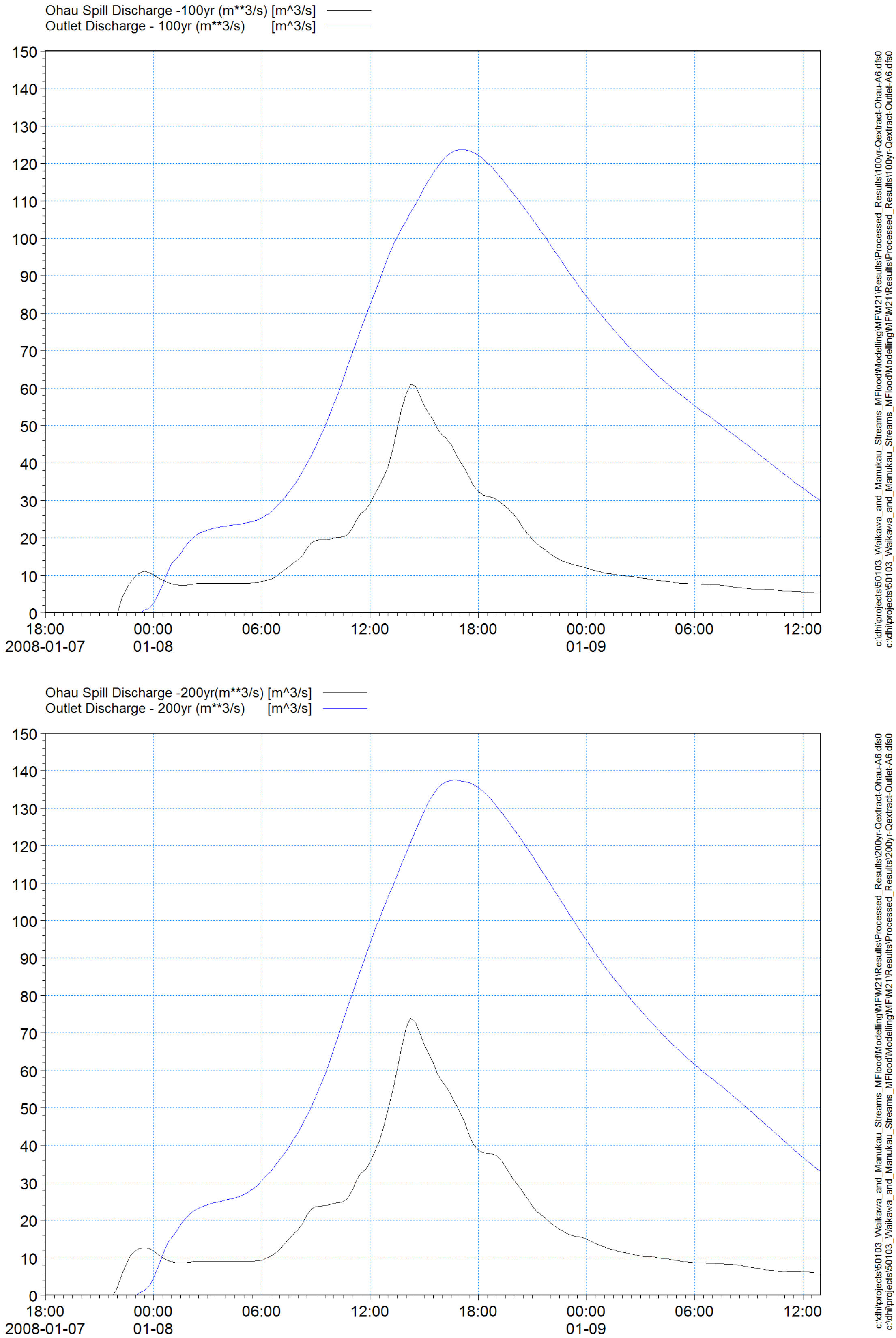


*Figure 4-2 Simulated Ohau outflows and total catchment flows for 100 and 200 year flood events*

Flood extents do not change noticeably between the two scenarios, as the topography in the upper catchments constrains the flow, and downstream of the confluence there is little difference between the two peak flows due to spills occurring at the confluence.

It should also be noted that catchment inflows from the Ohau are not considered in the present analysis. An increased level of flood risk may be possible if both Ohau and Waikawa-Manukau catchments were to flood simultaneously, in which spill flows to the north may be impeded or at worst reversed. Ongoing stopbanking construction on the Ohau by HRC will decrease the risk of a combined flood event occurring in future.

### 4.1.2 Cross-Railway Flows near Manukau Township

The models predict widespread but shallow flooding upstream of the main railway line crossing just south of Manukau township. The flooding originates from a breakout on the right bank of the right branch of the Manukau Stream as it emerges from the upstream gorge, and ponds against the railway embankment. Although some flooding in the general area was observed in the 2008 flood event is was not as widespread as predicted by the model. The model does not include any cross drainage structures under the railway embankment, however investigations have revealed that although a number of culverts exist in this area, these did not play an important role in surface drainage in the 2008 flood event.

Hence the current model reflects this lack of effective drainage across the railway line, and predicts that overflows will occur at the main Manukau Stream Bridge and at a second location further north, see Figure 4-3 which shows the situation for the 200 year ARI event. The corresponding overflows are shown in Figure 4-4, which show the overflow at the bridge is approximately 1.5m$^3$/s while a much larger overflow occurs at the northern spill location of almost 10m$^3$/s.

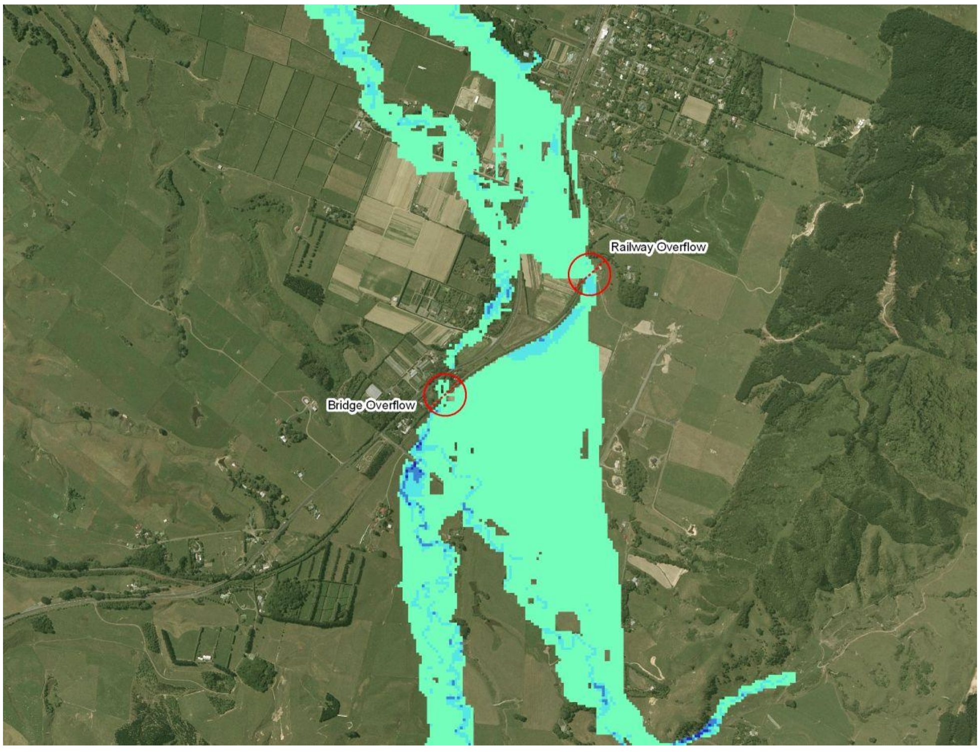


*Figure 4-3 Location of Railway overflows – 200 year ARI event*

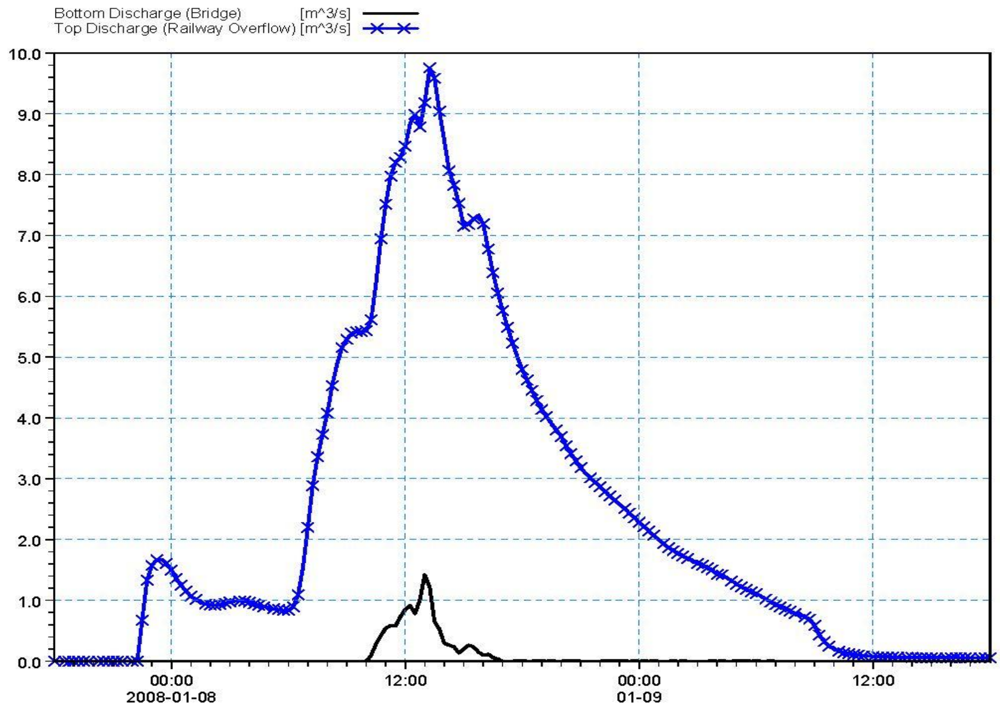


*Figure 4-4 Railway overflows – 200 year event.*

### 4.1.3 *Flood Hazard*

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 4-1. High hazard areas are mainly associated with areas of deep water, for example upstream of the Waikawa Road gauge and downstream of the Manukau confluence to the river mouth.

## 4.2 *Climate Change and Storm Surge Events*

Following the mapping of the design event floodmaps, HRC requested DHI to undertake additional runs taking into account storm surge conditions and climate change. Subsequently, the model boundaries were modified as shown in Table 4-1 below.

The storm surge levels are consistent with those applied elsewhere in the region (HRC, 2007)

*Table 4-1 Storm Surge and Climate Change Boundary Conditions*

| Boundary Condition | Storm Surge | Storm Surge plus Climate Change to 2080 |
|---|---|---|
| Inflows | No change | Increase by 20% |
| Sea Level (Moturiki Datum) | 2.3m | 2.6m |

Each of the two scenarios above have been applied to 100 year and 200 year flood events. The flood depth, level, speed and hazard maps are presented in Drawings 13-28.

The modelling indicates only a small sensitivity to the applied downstream boundary, as peak water levels rise reasonably quickly upstream of the estuary.

# 5 SUMMARY AND RECOMMENDATIONS

## 5.1 Summary

A hydrological and hydraulic flood risk assessment has been carried out for the Manukau and Waikawa Streams in Horowhenua District.

The hydrological assessment, aimed at quantifying the magnitude of 100 and 200 year ARI flood events in each stream, has been based on an analysis of gauged flows, hydrological model predictions and a regional analysis.

The gauge based flood estimates are associated with some uncertainty due to limited period of the flow record – approximately 12 years on the Manukau Stream and just 18 months on the Waikawa. However the January 2008 flood has been designated the highest flood since records began in 1979, and therefore the highest in 30 years. This provides some additional confidence in the flood estimates using this event.

A hydrological model was developed for the entire catchment and calibrated to 3 flood events – July 2006, June 2007 and the highest flood on record which occurred in January 2008. The hydrological model was used to generate flood hydrographs for each subcatchments 100 and 200 year design rainfall events developed from HIRDS rainfall data. The rainfall depths and intensities in the design rainstorms are higher than values in the historical record at the rainfall stations which are closest to the catchment. There is some uncertainty as to whether the design rainfall depths and intensities could occur in the catchment.

The hydrological model predicts 100 year peak flows at the Waikawa and Manukau flow gauges of 317 $m^3/s$ and 203 $m^3/s$ respectively. These are significantly higher than the gauged based flood frequency estimates and are approximately four times higher than the highest flow on record. A pragmatic approach has therefore been adopted for the study in which the gauge based estimates have been used, and applied to the January 2008 inflow hydrographs in order to provide design inflows for the hydraulic model.

The hydraulic floodplain model comprises a coupled 1D-2D description using MIKE FLOOD. The 1D MIKE 11 model extends from the flow gauge on the Waikawa and SH1 on the Manukau to the sea. The 2D model domain covers virtually the entire LiDAR data extent. The two models are fully coupled allowing flow exchanges between the 1D channel and 2D floodplain components. Rainfall-runoff inflow hydrographs are introduced into MIKE 11 model, apart from small catchment areas upstream of the MIKE 11 boundaries where the flows are included as source point inflows to the MIKE 21 model.

The MIKE FLOOD model has been successfully validated against the January 2008 flood extent. The validated model has been used to simulate the 50, 100 and 200 year flood events and generate flood extents, depths and flood hazard.

During high flood events it is evident that large catchment outflows to the north can take place both near the confluence and possibly upstream of Waikawa Beach. The existing LiDAR extent does not cover this area and therefore flood levels and flows in the lower part of the model area downstream of the confluence may be underestimated.

The model does not take into interactions with the Ohau catchment. Simulations taking into effect changes in the sea level boundary due to surge, as well as climate change effects have also been undertaken.

## 5.2 Recommendations

### 5.2.1 Uncertainties and Freeboard

Two main areas of uncertainties are inherent in the models. These are the design inflows used in the hydrological model, and the magnitude of the out-of-model spills occurring on the right bank of the Waikawa.

The hydrological uncertainty can only be overcome through long term gauging in the catchment, both in the upper catchment areas and down on the floodplain. Further analyses could however also be undertaken by comparing the findings of this study to neighbouring catchments where longer term gauging is available.

Flood flows which exit the model area to the north need are somewhat uncertain as these will be dependent on land levels in this area, some of which have been obtained by ground based GPS surveys as the area in question lies outside the LiDAR extent. If LiDAR can be obtained in this area these uncertainties could be eliminated. The possibility of Ohau catchment inflows during large combined flood events should also be considered.

Despite these uncertainties it can be seen that the simulated flood extents within the catchment are constrained by the topography, and therefore the extent is not overly sensitive to changes in catchment flows or downstream sea levels.

Given the current uncertainties in the model, it is recommended that freeboard allowances in the catchment are set to a minimum of 0.5m, until additional investigation can be undertaken to refine the model accuracy.

### 5.2.2 Model Improvements

The following recommendations are made in order to reduce the uncertainty in the model predictions, in reducing order of priority:

1. Additional LiDAR surveys are required to extend the model domain northwards so that catchment outflows can be accurately assessed and taken into account.

2. Effects of hydrological and hydraulic interactions with the neighbouring Ohau catchment are assessed.

3. Further hydrological investigations are undertaken to assess whether the adopted design rainfall events are consistent with neighbouring catchment records.

4. Jarvis raingauge is reinstated and converted to a recording station and a new station is located in or close to the upper catchment headwaters

# 6 REFERENCES


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Riddell, D.C., (1981): "Review of Mangahao Power Scheme hydrology", Report to Power Division, Ministry of Works and Development.

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# D R A W I N G S

## *Drawings 1-4*

(Drawings 5-28 are provided in a separate A3 map book)

# A P P E N D I C E S

# A P P E N D I X   A

## *Depth Duration Frequency Rainfall Tables*

**HRC- Upper Mangahao at No.1 Dam**
**2-Jun-1977 13:42:00 to 4-Jun-2008 14:15:00**

| | **Duration** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **ARI (year)** | 30min | 60min | 2 hr | 3 hr | 6 hr | 12 hr | 24 hr | 48 hr | 72 hr |
| 1 | 18.7 | 26.9 | 39.7 | 51.4 | 79.3 | 109.3 | 149.9 | 189.1 | 208.1 |
| 5 | 24.2 | 33.2 | 47.2 | 61.0 | 93.5 | 130.69 | 185.6 | 234.5 | 256.3 |
| 10 | 28.8 | 38.6 | 53.1 | 68.4 | 103.7 | 146.1 | 212.4 | 269.2 | 294.7 |
| 20 | 33.2 | 43.8 | 58.6 | 75.1 | 112.8 | 159.8 | 236.4 | 300.8 | 330.5 |
| 50 | 38.8 | 50.5 | 65.6 | 83.4 | 123.7 | 176.2 | 265.6 | 339.7 | 375.4 |
| 100 | 42.9 | 55.5 | 70.6 | 89.4 | 131.3 | 187.8 | 286.4 | 367.5 | 408.1 |
| 200 | 47.0 | 60.4 | 75.5 | 95.1 | 138.5 | 198.8 | 306.3 | 394.5 | 440.0 |

| **High Intensity Rainfall Design System (HIRDS) - Upper Mangahao at No.1 Dam (mm)** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Duration** | | | | | | | | | | |
| **ARI (year)** | 10m | 20m | 30m | 60m | 2h | 3hr* | 6h | 12h | 24h | 48h | 72h |
| 2 | 8.1 | 12.4 | 15.8 | 24.2 | 34.9 | 41.8 | 62.4 | 90.0 | 129.8 | 160.6 | 181.9 |
| 10 | 12.1 | 18.0 | 22.6 | 33.6 | 48.4 | 57.9 | 86.4 | 124.6 | 179.6 | 217.0 | 242.5 |
| 20 | 14.4 | 21.1 | 26.4 | 38.6 | 55.7 | 66.6 | 99.4 | 143.2 | 206.3 | 246.9 | 274.3 |
| 30 | 16.0 | 23.2 | 28.9 | 42.1 | 60.6 | 72.5 | 108.1 | 155.8 | 224.4 | 266.9 | 295.5 |
| 40 | 17.3 | 24.9 | 31.0 | 44.7 | 64.4 | 77.0 | 114.9 | 165.6 | 238.6 | 282.5 | 311.9 |
| 50 | 18.4 | 26.4 | 32.6 | 47.0 | 67.7 | 80.9 | 120.6 | 173.8 | 250.4 | 295.5 | 325.5 |
| 100 | 22.3 | 31.6 | 38.7 | 55.0 | 79.1 | 94.6 | 141.1 | 203.1 | 292.5 | 341.4 | 373.7 |
| 150 | 25.1 | 35.2 | 43.0 | 60.5 | 87.1 | 104.1 | 155.2 | 223.5 | 321.8 | 373.0 | 406.6 |
| 200* | 26.4 | 36.9 | 45.0 | 63.1 | 90.8 | 108.6 | 161.8 | 233.0 | 335.4 | 387.7 | 421.9 |

*Upper Mangahao Dam – Rainfall Analyses; HRC (top) and HIRDS (Bottom)*

*Note HIRDS 3hr and 200 year values are interpolation and extrapolated respectively from existing data

| High Intensity Rainfall Design System (HIRDS) - Levin | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Duration | | | | | | | | | | |
| **ARI (year)** | 10m | 20m | 30m | 60m | 2h | 3hr* | 6h | 12h | 24h | 48h | 72h |
| 2 | 3.6 | 5.7 | 7.5 | 11.8 | 16.7 | 19.8 | 28.9 | 40.9 | 57.8 | 68.0 | 74.8 |
| 10 | 5.7 | 8.6 | 11.0 | 16.8 | 23.3 | 27.3 | 39.2 | 54.5 | 75.6 | 89.6 | 99.0 |
| 20 | 7.1 | 10.6 | 13.4 | 20.0 | 27.5 | 32.0 | 45.6 | 62.8 | 86.3 | 102.7 | 113.7 |
| 30 | 8.2 | 12.1 | 15.2 | 22.4 | 30.7 | 35.6 | 50.3 | 68.8 | 94.0 | 112.1 | 124.3 |
| 40 | 9.1 | 13.4 | 16.7 | 24.4 | 33.3 | 38.5 | 54.2 | 73.7 | 100.3 | 119.9 | 133.0 |
| 50 | 10.0 | 14.5 | 18.0 | 26.2 | 35.5 | 41.0 | 57.6 | 78.0 | 105.8 | 126.6 | 140.6 |
| 60 | 10.8 | 15.5 | 19.3 | 27.8 | 37.6 | 43.4 | 60.6 | 81.9 | 110.7 | 132.6 | 147.3 |
| 100 | 13.5 | 19.1 | 23.5 | 33.2 | 44.5 | 51.1 | 70.7 | 94.6 | 126.6 | 152.3 | 169.6 |
| 150 | 16.5 | 22.9 | 27.9 | 38.8 | 51.5 | 58.8 | 80.8 | 107.2 | 142.4 | 171.8 | 191.7 |
| 200* | 17.9 | 24.7 | 30.1 | 41.5 | 54.8 | 62.5 | 85.7 | 113.2 | 149.9 | 181.1 | 202.2 |

*Levin –HIRDS rainfall analysis*

*Note HIRDS 3hr and 200 year values are interpolation and extrapolated respectively from existing data

| | Waikawa Upper: Northing 6047900, Easting 2704500 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Duration | | | | | | | |
| ARI (year) | 10m | 20m | 30m | 60m | 2h | 6h | 12h | 24h |
| 2 | 8.3 | 12.8 | 16.4 | 25.3 | 37.7 | 70.7 | 105.2 | 156.6 |
| 10 | 12.2 | 18.3 | 23.2 | 34.9 | 52.0 | 97.7 | 145.5 | 216.6 |
| 50 | 18.0 | 26.4 | 33.1 | 48.5 | 72.3 | 136.0 | 202.5 | 301.7 |
| 100 | 21.6 | 31.3 | 39.0 | 56.6 | 84.3 | 158.7 | 236.4 | 352.3 |
| 150 | 24.2 | 34.8 | 43.2 | 62.2 | 92.7 | 174.4 | 259.9 | 387.3 |
| 200* | 24.5 | 38.0 | 48.0 | 68.0 | 100.0 | 187.0 | 285.0 | 420.0 |

| | Waikawa Lower: Northing 6047900, Easting 2704500 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Duration | | | | | | | |
| ARI (year) | 10m | 20m | 30m | 60m | 2h | 6h | 12h | 24h |
| 2 | 7.1 | 9.9 | 12.1 | 16.9 | 22.5 | 35.5 | 47.2 | 62.9 |
| 10 | 10.4 | 14.2 | 17.0 | 23.3 | 31.0 | 48.9 | 65.1 | 86.8 |
| 50 | 15.4 | 20.4 | 24.2 | 32.3 | 43.0 | 67.9 | 90.5 | 120.7 |
| 100 | 18.4 | 24.3 | 28.5 | 37.6 | 50.2 | 79.2 | 105.6 | 140.8 |
| 150 | 20.6 | 26.9 | 31.5 | 41.3 | 55.1 | 87.0 | 116.0 | 154.7 |
| 200* | 23.0 | 29.0 | 34.0 | 44.0 | 59.0 | 93.0 | 125.0 | 165.0 |

*HIRDS Rainfall Estimates for Upper (top) and Lower(bottom) catchments*

*Note  200 year values extrapolated from existing data

# A P P E N D I X   B

## NZ Herald Report of January 2008 Flood

# Flooding hits lower N Island roads

*This picture from a reader shows how heavily roads in Horowhenua have been hit by the poor weather.*

**9:10AM Wednesday January 09, 2008**

Torrential rain in the lower North Island last night closed State Highway 1, cut off a beach settlement and caused widespread flooding.

One farm had lost power and Levin's water treatment plant was shut down when flood debris overloaded its filter system.

The road between Levin and Otaki was closed for two hours. The Ohau stopbanks breached at Muhunoa West Rd, with water reported to be rising at 10cm an hour before 6pm.

A record 259mm of rain fell in the Tararua Ranges in the 24 hours to 3pm, swelling rivers and streams. The previous 24-hour record for rainfall in the area was 162.5mm. The heavy rain was due to ease off overnight.

"The Otaki [river] has gone from an absolute minimum flow to up near 800 cubic metres a second and the Waitohu has gone from virtually a dribble up to around 80 cubic metres a second," said Sergeant Noel Bigwood.

Te Horo Beach Rd was also flooded after the Mangaone Stream overflowed, and Mr Bigwood said the stream had gone from a flow of about three cubic metres a second to nearly 30.

He said Waikawa Beach Rd was closed near SH1 - isolating residents and holidaymakers.

But the Metservice has now lifted it's heavy rain warning for northern Auckland and Northland.

Earlier the forecaster had warned that areas between the Bay of Islands and Orewa could get up to 80mm of rain overnight.

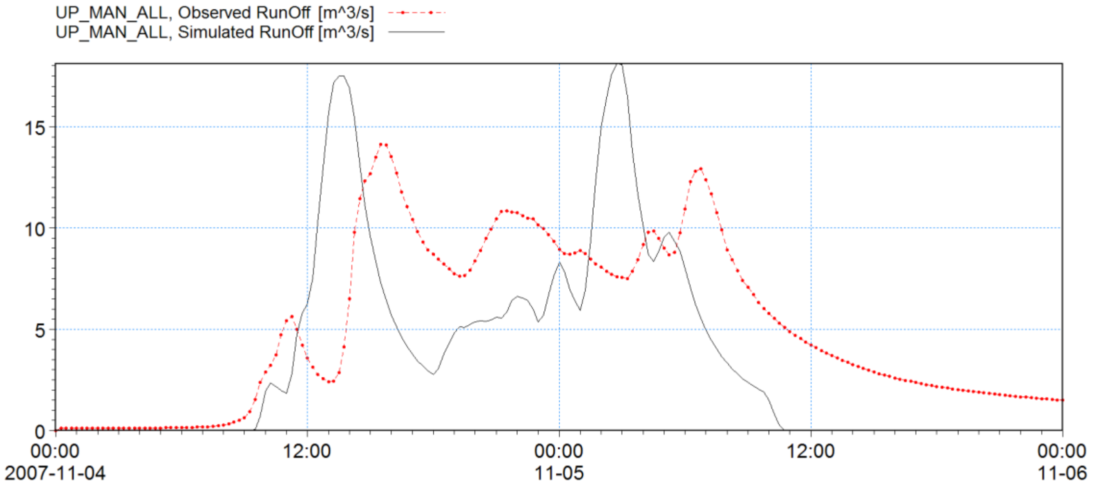
Weather ambassador Bob McDavitt said that has now been downgraded and the drizzle in Auckland is clearing up.

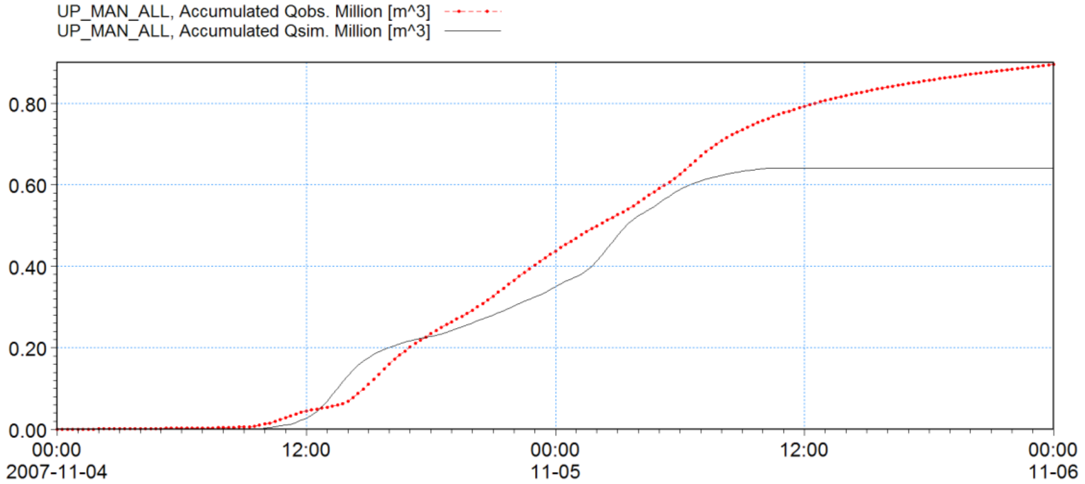
"It looks as though it's moving east. I don't know if it is going to come back to us, I don't think so, it looks as though the front is on its way," Mr McDavitt said.

He said the rain clouds over Horowhenua have also cleared and the North Island could expect a fine weekend.    - NZPA, NZ HERALD STAFF

# A P P E N D I X   B

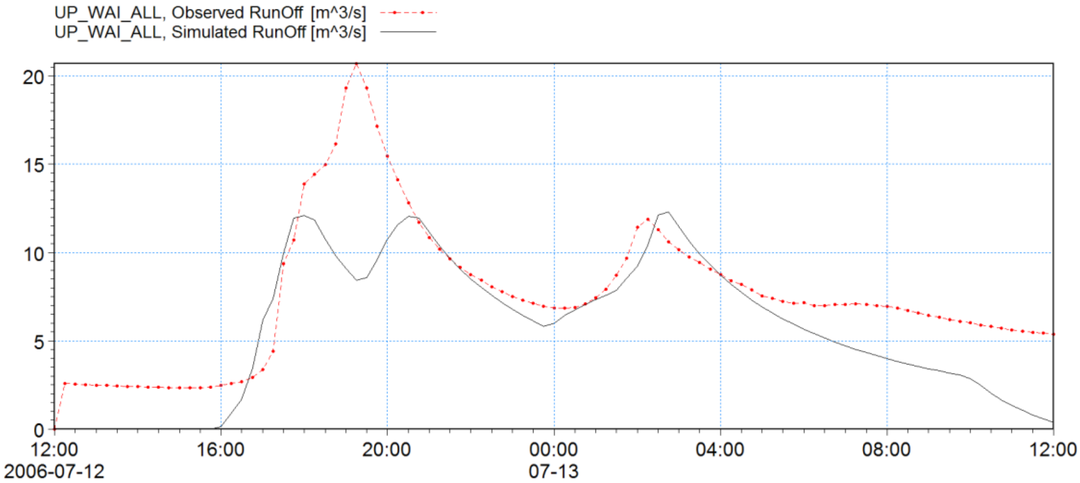
## *Hydrological Model Calibration*

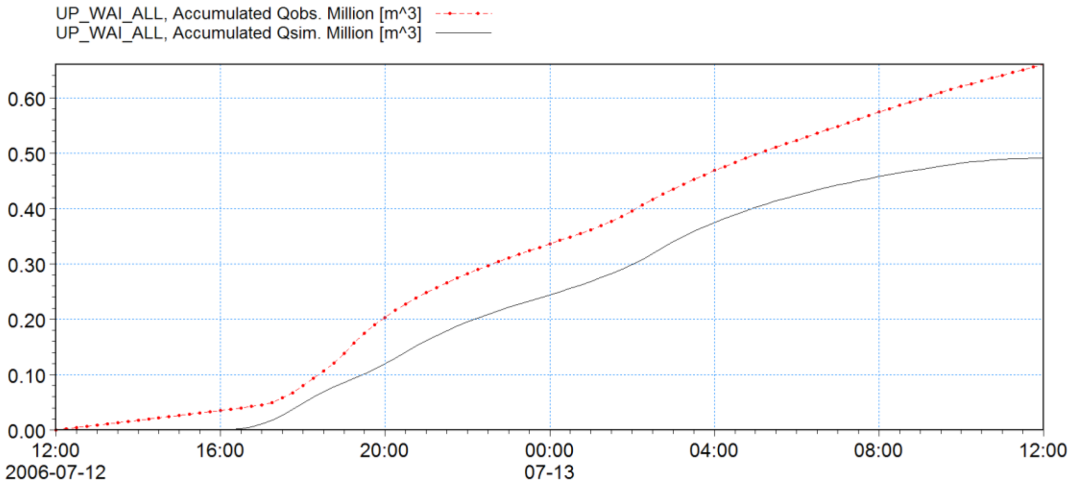



c:\dhi\projects\50103_Waikawa_and_Manukau_Streams_MFlood\Modelling\M11-Hydrology\Calibration\RRcalibration-Jul06\UP_MAN_ALL.dfs0

| DHI | Client: Combined catchment<br>Project: Results | MIKE Zero |
|---|---|---|
| Parameterfile: C1_WaiManCal-Nov2007.rr11 | Date: 08 1:33 | R2=-0.151, WBL= 28.4% (obs=10327mm/y, sim=7392mm/y) | Drawing no. |
| | Init: | | |

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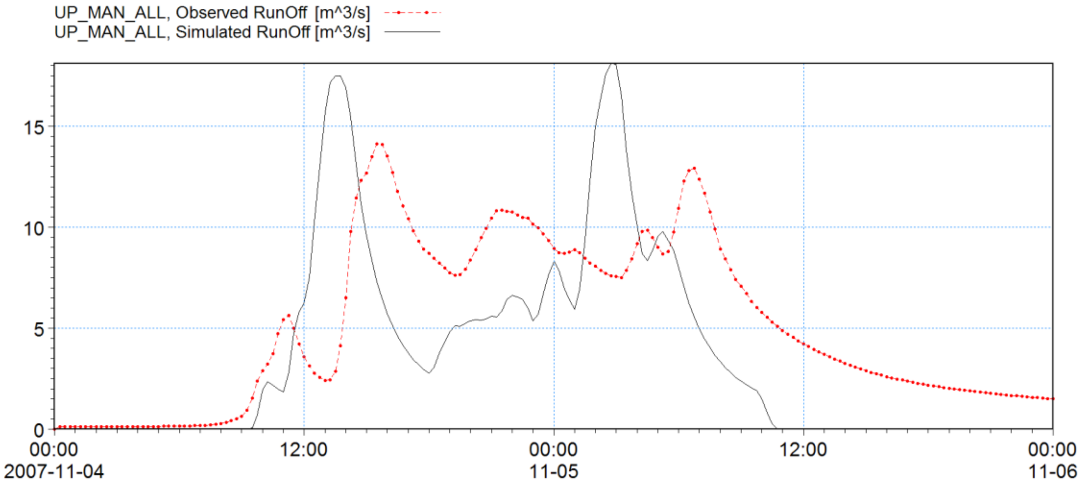
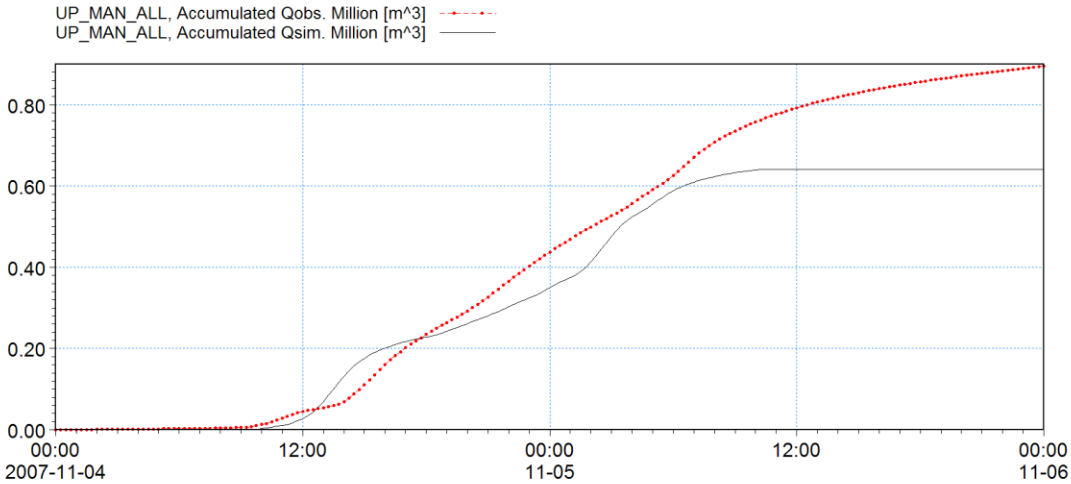
| DHI | Client: Combined catchment | MIKE Zero |
|---|---|---|
| | Project: Results | |

| Parameterfile | Date: | | Drawing no. |
|---|---|---|---|
| C2_WaiManCal-Jun2006.rr11 | 0)08 14:19 | R2=0.424, WBL= 25.7% (obs=8474mm/y, sim=6299mm/y) | |
| | Init: | | |

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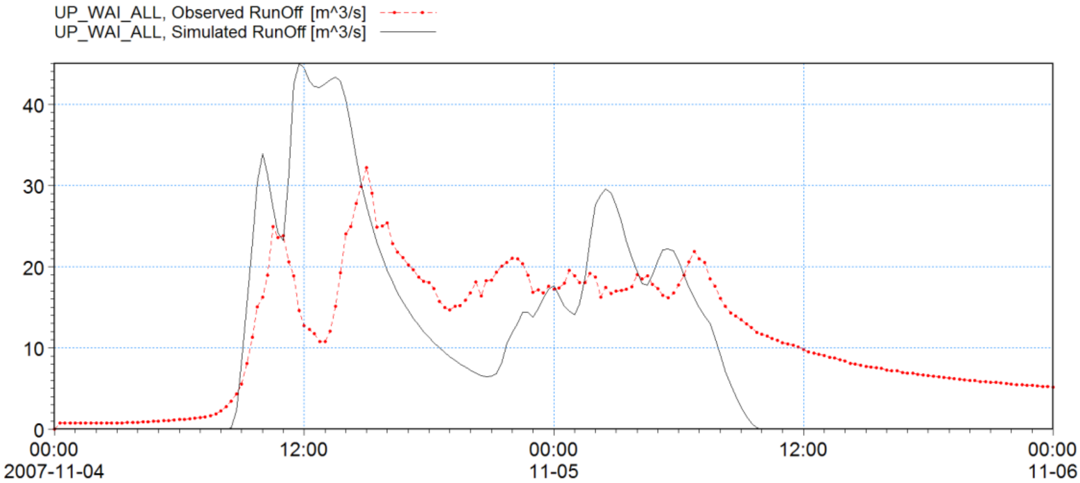
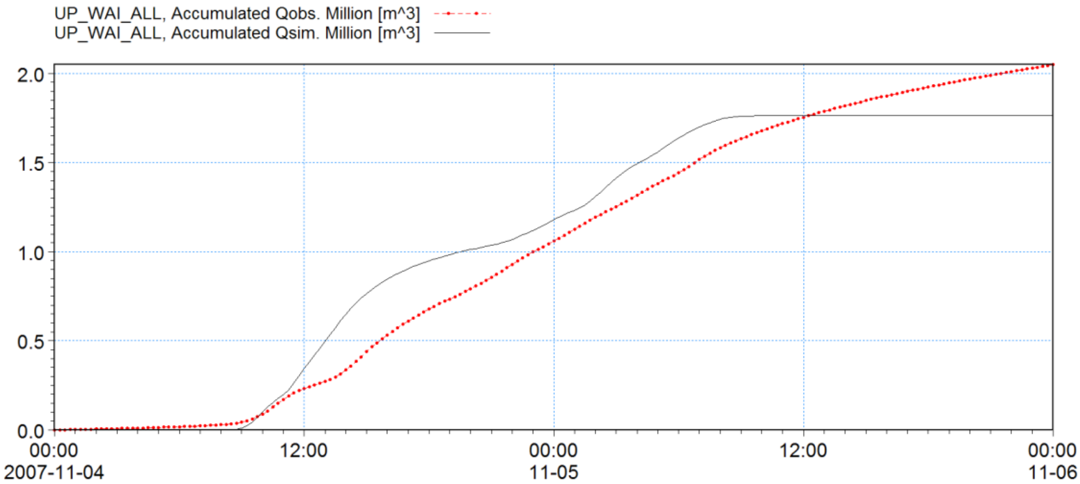
| Parameterfile | Date: | Client: Combined catchment | |
|---|---|---|---|
| | | Project: Results | |
| C1_WaiManCal-Nov2007.rr11 | 08 1:33 | R2=-0.151, WBL= 28.4% (obs=10327mm/y, sim=7392mm/y) | Drawing no. |
| | Init: | | |

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Project: Results

Parameterfile: C1_WaiManCal-Nov2007.rr11

Date: 08 1:33

Init:

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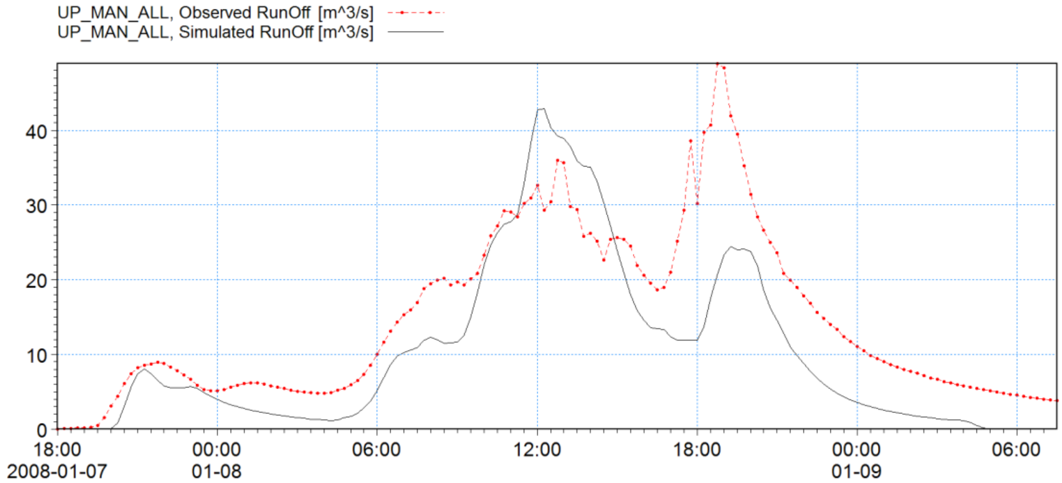
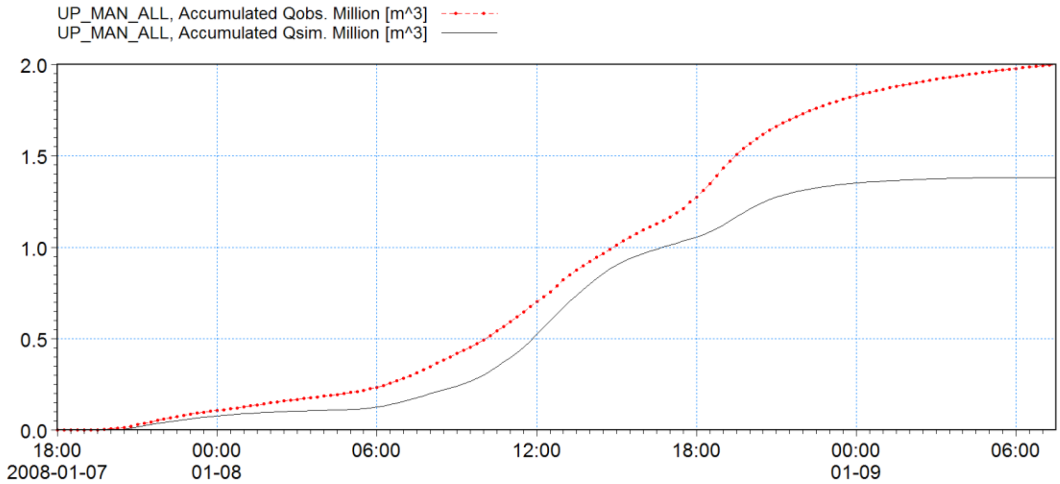
Drawing no.




| | | |
|---|---|---|
| DHI | Client: Combined catchment | MIKE Zero |
| | Project: Results | |
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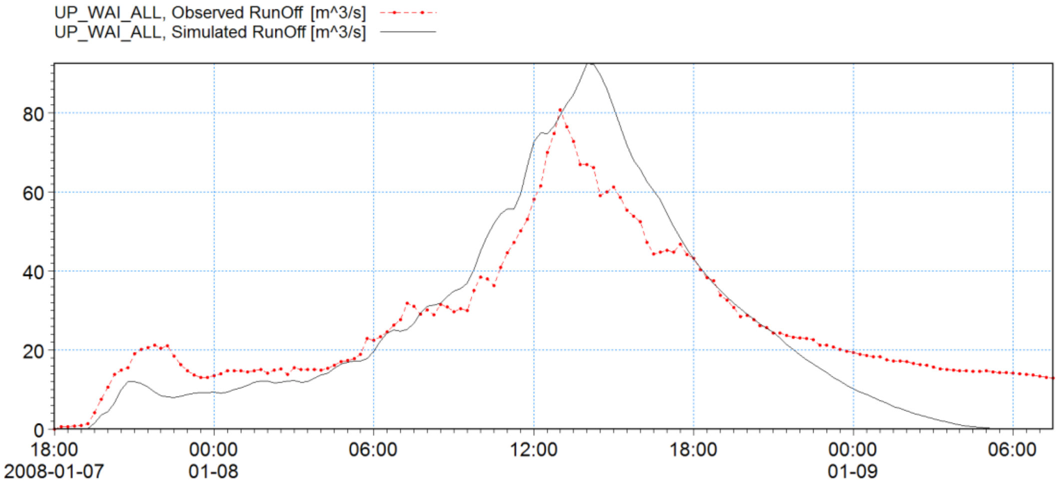
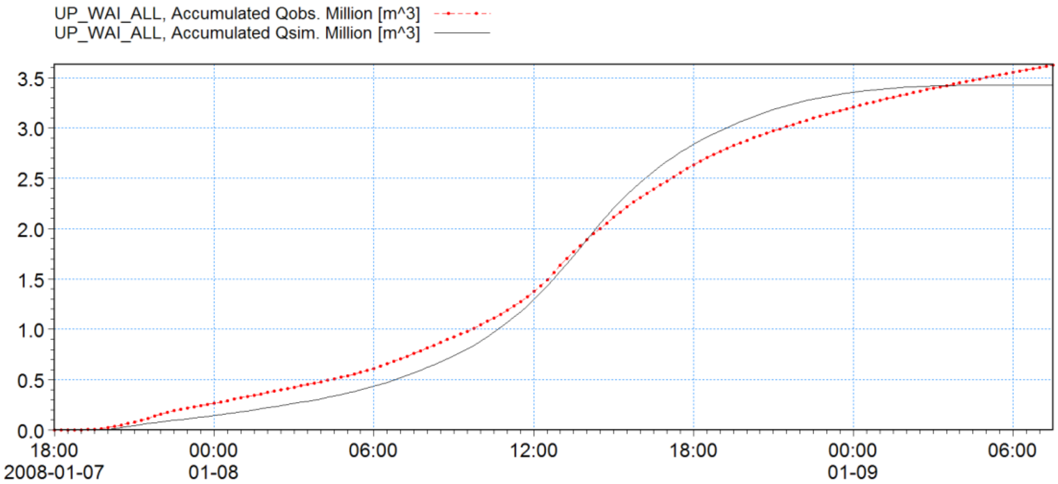
| | Init: | |

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| | | |
|---|---|---|
| DHI | Client: Combined catchment | MIKEZero |
| | Project: Results | |
| Parameterfile C5_WaiManCal-Jan2008.rr11 | Date: )08 15:15 | R2=0.681, WBL= 5.6% (obs=29775mm/y, sim=28120mm/y) | Drawing no. |
| | Init: | | |