REPORT

Chapman Tripp on behalf of the Earthquake Commission (EQC)

Canterbury Earthquake Sequence: Increased Flooding Vulnerability River Modelling and Coastal Extensions Report
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Report prepared for:
Chapman Tripp on behalf of the Earthquake Commission (EQC)

Report prepared by:
Tonkin & Taylor Ltd

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Executive summary

This report documents the sources, use, documentation and limitations of the river and coastal extension flood models used to define Increased Flooding Vulnerability (IFV) as caused by the Canterbury Earthquakes.

The river flood models are those used by Christchurch City Council (CCC) for flood management purposes. These models exist for the Avon, Heathcote and Styx catchments. The models have been commissioned by CCC, and have been constructed by the following organisations:

- DHI – Avon catchment;
- NIWA – Heathcote catchment; and
- GHD – Styx catchment.

The river models represent the main river and stream channels, but differ in the extent to which they represent the stormwater systems away from the main channels. The models are MIKE FLOOD models with MIKE 11 sub-models for the main rivers/streams and MIKE 21 sub-models for the terrain away from the rivers. For the purposes of IFV these models are used to assess flooding adjacent to the main rivers and stream channels. The river models are supplemented by overland flow models that assess flooding away from the main floodplains.

The coastal extension model represents flooding from the sea in areas surrounding the Avon-Heathcote estuary. This model is a projection of the extreme sea levels over the adjacent low-lying areas of land.

This report documents the key assumptions in developing the river models and the coastal extensions. It also notes the key limitations of these models, but is unable to quantify the effect of these limitations.

It is considered that the use of the river flood, coastal extensions and overland flood models together represents the best available information for assessing flooding and identifying potential IFV across the whole of Christchurch. It is acknowledged that there may be more detailed models for local areas, however it is not practical to consider the use of these across the whole city.
1 Introduction

The report is written for Chapman Tripp acting on behalf of the Earthquake Commission (EQC) to document the river models used for the engineering assessment of Increased Flooding Vulnerability (IFV) land damage due to the earthquake sequence in Christchurch.

**Increased Flooding Vulnerability** is a physical change to residential land\(^1\) as a result of an earthquake which adversely affects the use and amenity that could otherwise be associated with the land by increasing the vulnerability of that land to flooding events.

Other reports have been supplied to EQC from Tonkin & Taylor (T&T). These reports are the ‘Increased Flooding Vulnerability Assessment Methodology’ (T&T, Volume 1, April 2014), the ‘Increased Flooding Vulnerability Overland Flow Model Build Report’ (T&T, Volume 3, August 2014), and the ‘Peer Review report’ (Benn et al, 2014), and are referred to as such for the remainder of this report.

The Assessment Methodology (T&T, Volume 1, April 2014) sets out the background and methodology for the engineering assessment of IFV. It details the criteria and thresholds that are part of this process.

The Overland Flow Model Build report (T&T, Volume 3, August 2014) documents the construction of the TUFLOW overland flow model. A TUFLOW overland flow model is used as part of the assessment of properties for potential IFV. The report documents the model selection and build, as well as sensitivity analyses and calibration.

The Peer Review report (Benn et al, 2014) is a summary of the recommendations of the peer reviewers. T&T has taken these recommendations into account in the development of IFV methodology, flood models and implementation.

The objective of this report is to outline the river and coastal extension models used to assessment IFV caused by (fluvial) river and tidal flooding, respectively.

This report is Volume 2 in a suite of five reports describing IFV and its implementation for EQC. The report titles are provided below and should be read in conjunction with this report:

- Volume 1: Increased Flood Vulnerability: Assessment Methodology Report;
- Volume 2: Increased Flood Vulnerability: River Modelling and Coastal Extensions Report;
- Volume 3: Increased Flood Vulnerability: Overland Flow Model Build Report;
- Volume 4: Increased Flood Vulnerability: Implementation Report; and
- Volume 5: Increased Flood Vulnerability: Geological Processes Causing Increased Flood Vulnerability.

The report is organised into the following sections:

- Section 2 describes the relevant background to the Canterbury earthquake sequence resulting in flooding;
- Section 3 provides details of the flood models used in the assessment;

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\(^{1}\) “Residential land” is used in this assessment methodology as it is defined in the Earthquake Commission Act 1993, s2(1).
• Section 4 provides a summary of the coastal extensions used to model tidal flooding; and
• Section 5 provides the conclusions and recommendation of this report.
2 Background

The majority of background information regarding the Canterbury earthquake sequence and IFV are found in the Assessment Methodology report (T&T, Volume 1, April 2014). The most relevant background information to this report is as follows.

2.1 Canterbury earthquake sequence and flood scenarios

The Canterbury area has been affected by a large number of seismic events following a major earthquake on 4 September 2010. Collectively, these seismic events are known as the Canterbury earthquake sequence. Four major earthquakes caused measurable ground surface subsidence, on:

- 4 September 2010;
- 22 February 2011;
- 13 June 2011; and
- 23 December 2011.

Land damage assessment by EQC is based on the damage caused by individual events. Therefore, the IFV assessment needs to consider each earthquake independently to the extent possible. This requires five flood models for before and after each of four major earthquakes. The five model scenarios are:

- Pre-September 2010;
- Post-September 2010;
- Post-February 2011;
- Post-June 2011; and
- Post-December 2011.

2.2 Flooding in Christchurch

The Canterbury earthquake sequence has caused changes to the topography of the land in Christchurch (T&T, Volume 5, August 2014). This has changed the flood vulnerability for a large number of properties. Figure 2-1 is an illustration of the types of flooding that commonly occur in Christchurch. Flooding can also be caused by a change in groundwater level relative to the ground surface.

Where the groundwater is higher than the ground surface, water may pond either seasonally, for example in winter when the water table is high, or in some cases indefinitely creating a permanent pond. IFV does not recognise groundwater ponding or flooding caused by earthquakes because this is an observable form of damage covered under a separate category of land damage.

The three flooding mechanisms that cause flooding are listed below with explanations of how the earthquake has modified these mechanisms.

- Pluvial flooding is caused by rainfall runoff that exceeds the capacity of the stormwater system causing overland flow. It may also be caused where rainfall exceeds the infiltration capacity of the ground. It can be exacerbated in situations where settlement has occurred due to changes overland flow paths or reduction of
hydraulic gradients to stream/rivers. Pluvial flooding is simulated by the overland flow model, described in T&T (Volume 3, August 2014).

- **Fluvial flooding** is caused by flow in streams/rivers that exceed the capacity of the channel and cause flooding of adjacent land. The earthquakes have reduced the capacity of some stream/river due to lateral spreading and bed heave, which has reduced widths and increased bed levels and bed siltation due to changed river gradients and accumulation of liquefaction sediments. Ground subsidence can increase the overflow from streams/rivers onto land vulnerable to flooding, and can also result in inundation of land previously not vulnerable to flooding. Where river gradients have flattened due to the earthquakes this can also cause greater flooding. Fluvial flooding is simulated by the river models described in this report.

- **Tidal flooding** results from higher than normal water levels in coastal areas and lower reaches of river catchments, caused by extreme tide levels or storm surges. Land subsidence can make areas more prone to tidal flooding where the land settles to a level below normal tide levels if not protected. Tidal flooding is simulated by the coastal extension models described in this report.

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Figure 2-1 Types of flooding in Christchurch (Tidal – top, Pluvial (overland) – middle, and Fluvial (River) – bottom)
3 River Flood Models

3.1 General

The river flood models are the models used by Christchurch City Council (CCC) for flood management purposes. These models exist for the Avon, Heathcote, and Styx catchments. Figure 3-1 shows the location of the rivers and their approximate catchment extents. The models have been commissioned by CCC and have been constructed by the following organisations:

- DHI – Avon catchment;
- NIWA – Heathcote catchment; and
- GHD – Styx catchment.

The river flood models are detailed in Table 3-1. All models represent the main river and stream channels, but differ in the extent to which they model the stormwater systems away from the main channels. The models are MIKE FLOOD models with MIKE 11 sub-models for the main rivers/streams and MIKE 21 sub-models for the terrain away from the rivers. In addition, the Styx and the Avon models incorporate MIKE URBAN sub-models to represent parts of the stormwater pipe networks (the Heathcote model does not).

Figure 3-1 Styx, Avon and Heathcote river catchments
Table 3-1  River Flood Models

<table>
<thead>
<tr>
<th>Model</th>
<th>Version</th>
<th>Author</th>
<th>Model type</th>
<th>Model description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avon catchment</td>
<td>D13</td>
<td>DHI</td>
<td>MIKE FLOOD model coupling MIKE 11, MIKE 21 and MIKE URBAN.</td>
<td>River, floodplain and stormwater networks represented. Stormwater network less extensive than for Styx.</td>
</tr>
<tr>
<td>Heathcote catchment</td>
<td>N/A</td>
<td>NIWA</td>
<td>MIKE FLOOD model coupling MIKE 11 and MIKE 21.</td>
<td>River and floodplain. No stormwater network modelled.</td>
</tr>
<tr>
<td>Styx catchment</td>
<td>N/A</td>
<td>GHD</td>
<td>MIKE FLOOD model coupling MIKE 11 (1D rivers), MIKE 21 (2D terrain) and MIKE URBAN (pipe network).</td>
<td>River, floodplain and stormwater networks represented.</td>
</tr>
</tbody>
</table>

The models have been constructed according to CCC modelling guidelines (GHD, 16 July 2012).

The river flood models use the kinematic wave routing method, with lumped subcatchment loading at nodes. Hydrographs for each sub-catchment are calculated using a MOUSE Model B hydrological model in MIKE URBAN, with initial and continuing losses. Some catchments have additional inflows not from rainfall (baseflow from outside the model boundary).

The models use the New Zealand Map Grid (NZMG) co-ordinates, on 10 m x 10 m grids for the Avon and Heathcote, and 8 m x 8 m grids for the Styx. These have been re-projected to a 5 m x 5 m grid in New Zealand Transverse Mercator format (NZTM), using bilinear interpolation to resample cells. GHD (27 August 2012) reported that the three river flood models have been developed to various levels of accuracy and completeness for each catchment, with different ultimate objectives. Different modelling approaches have been used within the river flood models and some still require updating to represent post-earthquake changes in channel cross-sections and infrastructure. CCC are undertaking a process of consolidating and documenting the river flood models because the flood levels (that are determined by the models) provide important information not just to EQC, but also for setting building floor levels required for the Christchurch rebuild.

We understand from correspondence with CCC and its consultants that the three river models are regularly updated. The updates are carried out to reflect new survey data, recent construction works and local sub-catchment model upgrades. The model versions used are the most current available at the time of use.
3.2 River flood model documentation

The documentation for the CCC flood models which the River Flood models are based on is shown in Table 3-2. While models have had some updates since the writing of the documentation, the documentation provides sufficient detail into the basis of the models.

Table 3-2 CCC river flood model documentation

<table>
<thead>
<tr>
<th>Author</th>
<th>Date</th>
<th>Title</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model Consolidation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PDP</td>
<td>August 2012</td>
<td>CCC Model Consolidation</td>
<td>PowerPoint presentation summarising the model consolidation process.</td>
</tr>
<tr>
<td>Guidelines</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GHD</td>
<td>24 August 2012</td>
<td>Stormwater Modelling Consolidation – Guideline for using Stormwater Modelling Results in Statutory Processes (Draft)</td>
<td>Document to assist CCC to fulfil statutory requirement to set flood levels when processing resource consents and building consent applications.</td>
</tr>
<tr>
<td>Peer Review</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PDP</td>
<td>3 August 2012</td>
<td>Peer Review of Floor Level Data: Styx and Avon Catchments</td>
<td>Peer review of Styx and Avon models.</td>
</tr>
</tbody>
</table>

3.3 Application of models to IFV

In this section the application of the river flood models to the assessment of potential IFV is described.
3.3.1 IFV criteria

The CCC river flood models were run with the IFV criteria, for the five topographical scenarios, before and after each major earthquake in the Canterbury earthquake sequence (Pre-September 2010, post-September 2010, post-February 2011, post-June 2011 and post-December 2011), (refer Table 3-3).

The criteria outlined in Assessment Methodology report (T&T, Volume 1, April 2014) for the modelling of IFV is as follows:

- For a storm with a 1% Annual Exceedance Probability (AEP);
- Without temporary stop banks;
- Without an assumption for the effects of future climate change; and
- For existing development.

The criteria are applied to flood modelling to produce maximum flood depth maps.

3.3.2 Digital Elevation Model

The Digital Elevation Model (DEM) used to model the changes in ground level for the five different topographical scenarios is based on a 5 m grid resolution for the river model, derived from LiDAR which was gathered by Australian Aerial Mapping (AAM), and New Zealand Aerial Mapping (NZAM). This is described in detail in the Assessment Methodology report (Appendix A, T&T, April 2014). The sources and commissioning agencies of the LiDAR surveys are summarised in Table 3-3.

Table 3-3 LiDAR information

<table>
<thead>
<tr>
<th>DEM</th>
<th>Source LiDAR</th>
<th>Commissioning Agencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Sept 2010</td>
<td>AAM, 6-9 Jul 2003</td>
<td>Christchurch City Council</td>
</tr>
<tr>
<td></td>
<td>AAM, 21-24 Jul 2005</td>
<td>Environment Canterbury &amp; Waimakariri District Council</td>
</tr>
<tr>
<td></td>
<td>AAM, 6-11 Feb 2008</td>
<td>Environment Canterbury &amp; Selwyn District Council</td>
</tr>
<tr>
<td>Post-Sept 2010</td>
<td>NZAM, 5 Sep 2010</td>
<td>Ministry of Civil Defence and Emergency Management</td>
</tr>
<tr>
<td>Post-Feb 2011</td>
<td>NZAM, 8-10 Mar 2011</td>
<td>Ministry of Civil Defence and Emergency Management</td>
</tr>
<tr>
<td></td>
<td>AAM, 20-30 May 2011</td>
<td>Christchurch City Council</td>
</tr>
<tr>
<td>Post-Dec 2011</td>
<td>NZAM 17-18 Feb, 2012</td>
<td>Earthquake Commission</td>
</tr>
</tbody>
</table>

The river models are created using a 10 m rectilinear grids for the Heathcote and the Avon catchments; and an 8 m grid for the Styx.

The LiDAR data used to build the DEM does not provide full coverage of all of the modelling areas for some topographical scenarios. Where this is the case, the LiDAR for the previous topographical scenario, is used as a substitute. This is relevant for the post-September 2010 and post-December 2011 sets, which are supplemented by the pre-September 2010 and
post-June 2011 LiDAR data, respectively. LiDAR coverage is shown in Figures A3 – A7 of T&T (Appendix A, Volume 1, April 2014).

3.3.3 **Input rainfall hyetographs**

The input rainfall hyetographs used for the models is the triangular hyetograph with the peak at 70% of storm duration, as described in Section 21.4 of the CCC Waterways, Wetlands, and Drainage Guide (CCC WWDG). The 1% AEP rainfall depths are summarised in Table 3-3.

3.3.4 **Downstream boundaries**

The downstream boundaries used in the models are dynamic tidal time series, with the peak matching the peak water level at the outflow point. These are described in Section 5.3.2 of the CCC Stormwater Modelling Specification for Flood Studies (GHD, 2012). This specification states that the downstream condition of the 2D model is a tidally influenced water level, and “the ratio of the AEP for the tidal event to that of the rainfall event shall be 10 (e.g. 10% AEP tidal event and 1% AEP rainfall event and vice versa)”. Section 5.2.2 of the specification states that the boundary conditions of the 1D model are similar to the 2D model. The tidal boundary water levels are summarised in Table 3-4.

The result of this boundary condition is that there are two models run for any one AEP event. For the 1% AEP event, used for the IFV assessment, the model runs are:

- The 1% AEP rainfall event with the 10% AEP tidal event; and
- The 10% AEP rainfall event with the 1% AEP tide.

The maximum flood depths reported from the modelling are the maximum of the levels from these combinations as illustrated in Figure 3-2.

![Figure 3-2 Maximum 1% AEP flood depths for conceptual flood profile for a Christchurch river](image-url)
Temporary stop banks constructed after the earthquakes in the Avon catchment are removed by tracing the extent of the stop banks into a GIS layer and adjusting the levels of this area based on the ground level at the edge of the stop bank.
<table>
<thead>
<tr>
<th>Type</th>
<th>Model</th>
<th>Source</th>
<th>Version</th>
<th>File Name</th>
<th>Date Received (yyyy/mm/dd)</th>
<th>Rainfall</th>
<th>Downstream Boundary</th>
<th>Topography (LiDAR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>River Flood models</td>
<td>Avon Pre-Sept</td>
<td>DHI</td>
<td>D13</td>
<td>avon_d13_100yr_0slr_preeq_nosb_rr_depth avon_d13_10yr_0slr_preeq_nosb_rr_depth</td>
<td>2013/10/24</td>
<td>Maximum of 1% AEP rainfall paired with 10% AEP sea level and 10% AEP rainfall paired with 1% AEP sea level</td>
<td>10% AEP peak of 10.829 mRL Christchurch Drainage Datum (CDD). 1% AEP peak of 10.936 mRL Christchurch Drainage Datum (CDD).</td>
<td>Pre-Earthquake</td>
</tr>
<tr>
<td></td>
<td>Avon Post-Sept</td>
<td>DHI</td>
<td>D13</td>
<td>Avon_D13_100yr_0SLR_PostSepEQ_NoSB_RR_Depth Avon_D13_10yr_0SLR_PostSepEQ_NoSB_RR_Depth</td>
<td>2014/04/17</td>
<td>1% AEP with 3 durations at different points of the catchment, 9, 18 and 24 hours, with total depths of 81.5 mm, 117.0 mm and 136.1 mm respectively</td>
<td></td>
<td>Post-September 2010</td>
</tr>
<tr>
<td></td>
<td>Avon Post-Feb</td>
<td>DHI</td>
<td>D13</td>
<td>avon_d13_100yr_0slr_postfebeq_nosb_rr_depth avon_d13_10yr_0slr_postfebeq_nosb_rr_depth</td>
<td>2013/10/24</td>
<td>1% AEP with 3 durations at different points of the catchment, 9, 18 and 24 hours, with total depths of 50.1 mm, 72.0 mm and 83.8 mm respectively</td>
<td></td>
<td>Post-February 2011</td>
</tr>
<tr>
<td></td>
<td>Avon Post-June</td>
<td>DHI</td>
<td>D13</td>
<td>Avon_D13_100yr_0SLR_PostAugEQ_NoSB_RR_Depth Avon_D13_10yr_0SLR_PostAugEQ_NoSB_RR_Depth</td>
<td>2014/04/17</td>
<td>1% AEP with 3 durations at different points of the catchment, 9, 18 and 24 hours, with total depths of 50.1 mm, 72.0 mm and 83.8 mm respectively</td>
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<td>Post-June 2011</td>
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<td>Avon Post-Dec</td>
<td>DHI</td>
<td>D13</td>
<td>avon_d13_100yr_0slr_postdeceq_nosb_rr_depth avon_d13_10yr_0slr_postdeceq_nosb_rr_depth</td>
<td>2013/10/24</td>
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<td>Post-December 2011</td>
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<tr>
<td></td>
<td>Heathcote Pre-Sept</td>
<td>NIWA</td>
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<td>Heathcote_Base_PreSep2010_100yST_NoMPD_MaxDepth0 Heathcote_Base_PreSep2010_100yFL_NoMPD_MaxDepth0</td>
<td>2012/11/05</td>
<td>Maximum of 1% AEP rainfall paired with 10% AEP sea level and 10% AEP rainfall paired with 10% AEP sea level</td>
<td></td>
<td>Pre-Earthquake</td>
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<tr>
<td>Location</td>
<td>Agency</td>
<td>Model Name</td>
<td>Date</td>
<td>Description</td>
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<td>Heathcote</td>
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<td>2014/04/08</td>
<td>AEP rainfall paired with 1% AEP sea level and 1% AEP with duration of 30 hours. Three depths of 158.4 mm on “flats”, 139.7 mm on “subcatchment 14”, and 180.6 mm on “hills”. 10% AEP with duration of 30 hours. Three depths of 97.2 mm on “flats”, 85.5 mm on “subcatchment 14”, and 111.0 mm on “hills”.</td>
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<td>Heathcote</td>
<td>NIWA</td>
<td>Heathcote_Base_PostFeb2011_100yST_NoMPD_MaxDepth0</td>
<td>2012/11/05</td>
<td>1% AEP peak of 10.768 mRL CDD. 1% AEP peak of 10.894 mRL CDD.</td>
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<td>Heathcote</td>
<td>NIWA</td>
<td>Heathcote_Base_PostJun2011_100yST_NoMPD_MaxDepth0</td>
<td>2014/04/08</td>
<td>Maximum of 1% AEP rainfall paired with 10% AEP sea level and 10% AEP rainfall paired with 1% AEP sea level and 1% AEP with rainfall duration of 48h, with total rainfall depth of 168.48mm. 10% AEP with rainfall duration of 48h, with total rainfall depth of 103.2 mm.</td>
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<td>Heathcote</td>
<td>NIWA</td>
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<td>2012/11/05</td>
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<td>2014/07/22</td>
<td>Post-September 2010 overlaid on Pre-Earthquake</td>
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<td>Post-February 2011</td>
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<td>Styx</td>
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<td>Styx Post-June</td>
<td>GHD</td>
<td>EQ_Q100_10T_No_SLR_No_16%_ED_48hr_June11_v95_MAX_DEPTH0</td>
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<td>Post-June 2011</td>
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<tr>
<td>Styx Post-Dec</td>
<td>GHD</td>
<td>EQ_Q10_100T_No_SLR_No_16%_ED_48hr_June11_v96_MAX_DEPTH0</td>
<td>2013/12/11</td>
<td>Post-December 2011 (February 2012 overlaid on post-June with 0.05 m drop in dunes)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### 3.4 Limitations

The limitations of the river flood models are detailed below (Table 3-5) based on model documentation, discussion with CCC’s modelling consultants and consideration of the application of the models to assess potential IFV. Where the limitations of the river flood model have been addressed, the management of the limitations are described.

#### Table 3-5 River flood model limitations

<table>
<thead>
<tr>
<th>Description of limitation</th>
<th>Description of management</th>
</tr>
</thead>
<tbody>
<tr>
<td>The river flood models have been developed over time by different consultants. The specification for each model is different, which is most obvious in the extent to which the models include stormwater networks. CCC has undertaken work to standardise the models and now have a Stormwater Modelling Specification for Flood Studies (GHD, July 2012). The compliance with this specification is detailed in the Peer Review (PDP, August 2012).</td>
<td>For the assessment of IFV this limitation is partially overcome because the river flood models are used in conjunction with the overland flow models, which simulate larger elements in the stormwater networks on a consistent and city-wide basis (refer T&amp;T Volume 3, August 2014).</td>
</tr>
<tr>
<td>The models include only partial updates for the changes in ground levels caused by the earthquakes (GHD, 27 August 2012). The models use mixed LiDAR data sets for terrain. Figures depicting the extents of the various LiDAR data sets are found in Appendix A of T&amp;T April 2014.</td>
<td>This same limitation applies to the overland flow models and coastal extension models. The LiDAR surveys that were flown post-earthquakes targeted the areas with land damage, so the majority of changes to land damage should have been recorded (refer Section 3.3.2).</td>
</tr>
<tr>
<td>The 8 and 10 m grids do not resolve features that are smaller than the grid cell size. These may include some roads, footpaths and gaps between buildings.</td>
<td>This limitation would be most significant in the overland flow areas, which are not covered by the river flood models. The limitation is partially overcome by requiring that the centroid of the derived 5 m cell be in the property for potential IFV, refer T&amp;T (Volume 1, April 2014) for rules for pixel centroid. This reduces effects of cells that are predominantly over the road, but have corners that impinge onto a property at a level higher than the road. Furthermore, the development of the overland flow models that use a 5m cell has provided better resolution of overland flow areas and the assessment of potential IFV in these areas (refer T&amp;T Volume 3, August 2014).</td>
</tr>
<tr>
<td>The maximum flood extents used in this report are restricted by the 2D model extents. Flooding outside the 2D modelling extents is not assessed. The assessment border is shown in Figure A2 T&amp;T Volume 1 Appendix A.</td>
<td>This limitation is overcome by the use of overland flow models, which includes larger areas and models rain-on grid that enables flooding to be simulated away from rivers and channels (refer T&amp;T Volume 3, August 2014).</td>
</tr>
<tr>
<td>The calibration or validation for pre-earthquake events has been undertaken to different degrees for each model and is not well documented. In addition there is a lack of calibration of flood models for post-earthquake events, due to limited data availability and the short hydrometric record. We understand that CCC is currently validating the</td>
<td>This limitation is partially overcome as the river flood models are supplemented by the overland flow models (refer T&amp;T Volume 3 August 2014), which have been extensively sensitivity tested and calibrated to the recent 4/5 March 2014 flood event.</td>
</tr>
</tbody>
</table>
river model(s) for the recent 4 and 5 March event. A re-calibrated model was not available at the time of site specific engineering assessments commencing.

The flood models use post-earthquake cross-section survey for lower branches of channels/rivers, but pre-earthquake survey cross-sections for upper branches of channels/rivers. As a result, the post-earthquake models may not account for all post-earthquake changes in flood level, especially in the upper catchments.

Overland flow paths away from the main floodplain are resolved to different degrees by the different River Flood models. Issues affecting the modelling of overland flow paths include:

- Styx flood model includes extensive pipe networks;
- Avon flood model has some areas with no pipes;
- Heathcote flood model has no pipe networks; and
- The flood models use different schemes to load hydrological inputs to the hydraulic model.

The river flood models assume for time of concentrations that favour longer duration rainfall events that maximise the flood depths in the lower catchment. Therefore, the flood depths predicted by the flood models for the upper catchments away from the lower main channels may be non-conservative (i.e. actual flood depths could be greater than predicted).

The higher frequency floods (i.e. more frequent that the 10% AEP) are more influenced by the local drainage network (which is typically designed for a 20% to 10% AEP) than the 1% AEP. We understand that CCC’s local drainage networks including those being reinstated by SCIRT (who are responsible for repairing earthquake damage to the stormwater infrastructure) operates at a 20% AEP level of service. Because there is limited local drainage infrastructure included in the river models (and none in the Heathcote), the 10% AEP and to a lesser extent the 2% AEP flood model results should be treated as indicative only and not used for IFV qualification.

The LiDAR and the model grids have limitations that affect the accuracy of the modelling. Refer to Appendix E of T&T (Volume 1, April 2014) for details. The model grids reduce the resolution of

This is not a limitation as the assessment of IFV is for the changes in flooding due to on-site effects, so it does not need to consider the change in capacity of the channels/rivers.

In these areas the limitations of the river models are overcome with the use of the overland flow models (refer T&T Volume 3, August 2014).

This limitation has been overcome by the overland flow modelling, which uses an embedded hyetograph approach to account for different time of concentrations at different locations in the catchment (refer T&T Volume 3, August 2014).

The inconsistency aspect of this limitation is partially overcome by the use of overland flow models that have an extensive network of minor channels and simulates pipes over 600 mm diameter. However the reliability of the overland flow models is still reduced for flooding that approaches the 20% AEP rainfall event as the primary piped stormwater system becomes more influential.

T&T (Volume 3, August 2014) concluded for the overland flow modelling that a 5 m grid size was the minimum that could be used because of the
<table>
<thead>
<tr>
<th>Ground Features, with the Styx Model Using an 8 m Grid and the Avon and Heathcote Models Using 10 m Grids with a Single Elevation Applied to Each Cell in the Model. The Vertical Accuracy Is Dependent on the Range of Elevations Across the Grid Cell, But May Be Larger Than 0.1 m. The Smaller the Grid Cell the More Accurate the Representation Is Likely to Be. For Example the Specifications for Hydraulic Models Used for Flood Hazard Mapping by Auckland Council Requires a Maximum 2 m Grid Resolution. However, Small Grid Cells Significantly Increase Model Run Times.</th>
<th>Relatively Few Bare Earth Ground Returns for the July 2003 LiDAR.</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-the-Ground Features May Significantly Affect the Pathway of Overland Flow and Cause Local Flooding and These Are Not Simulated by the Flood Models (PDP, August 2012). This Is Because the LiDAR Digital Elevation Models Exclude Features Such as Houses and Fences That Affect Flow Paths, and the Grids Used for Modelling Cannot Resolve These Features.</td>
<td>Flood Models Would Not Normally Consider These.</td>
</tr>
<tr>
<td>The Catchment Boundaries (Heathcote-Avon-Styx) and Sub-Catchment Boundaries Within Each of the River Flood Models Are Based on the Pre-Earthquake Terrain and Have Not Been Updated to Consider the Post-Earthquake Terrain. PDP (3 August 2012) Consider That This Should Not Have Major Effect on Large Rainfall Events, Such as the 1% AEP Flood Event.</td>
<td>This Limitation Is Overcome by the Use of the Overland Flow Model That Is a City-Wide Model and Does Not Have Sub-Catchment Boundaries.</td>
</tr>
<tr>
<td>The Effects of the Earthquakes on Rainfall-Runoff Characteristics, Such as Infiltration, Have Not Been Considered and Are Not Yet Understood. Pre-Earthquake Parameters Are Used for These Rainfall-Runoff Characteristics. We Consider This to Be Acceptable Since Measures of Changes Would Be Difficult to Achieve and Are Unlikely to Change Flood Levels, Particularly for Large Storm Events Such as the 1% AEP.</td>
<td>We Note That the Overland Flow Model Uses the 85th Percentile Post-Earthquake Groundwater Level to Cap the Infiltration to Ground (T&amp;T, Volume 3 August 2014). Therefore, the Overland Flow Models Include Reduction of Groundwater Depth Due to Ground Subsidence That Will Change the Infiltration in Some Areas, But Have Assumed a Post-Earthquake Groundwater Level for This.</td>
</tr>
<tr>
<td>Blockages to the Stormwater Network Are Not Considered, Nor Are the Changes to the Performance of These Systems for Various Scenarios, and These Are Contributors to Surface Flooding in Many Areas (PDP, August 2012).</td>
<td>Flood Hazard Models Do Not Normally Consider Blockages.</td>
</tr>
<tr>
<td>The Extent and Level of Flooding Is Based on the Accuracy of the Data Available (PDP, August 2012). The Actual Conditions on the Ground May Be Different to What Is Modelled E.g. Stormwater Systems May Be Impaired Until They Are Repaired to Pre-Earthquake Condition.</td>
<td>Note.</td>
</tr>
<tr>
<td>The Flood Simulations Are Based on a Hypothetical Design Storm in Accordance with CCC Guidelines. Actual Flood Events Will Behave Differently Depending on the Actual Temporal and Spatial Patterns of Rainfall, Tidal Boundary Conditions</td>
<td>Typically, the Design Storm Provides a More Conservative Estimate of Flood Depth Than an Actual Rainstorm.</td>
</tr>
</tbody>
</table>
(which will not necessarily be related to the rainfall by a factor of 10), antecedent conditions (the relative wetness of the catchment preceding the flood event), and the performance of the drainage network (e.g. blockages).

| The modelling consultants express professional limitations in the modelling documentation. | These limitations limit the modelling consultants being liable for the use of the models (i.e. the modelling has been undertaken for CCC with no direct contractual arrangement between EQC and the consultants. |

While acknowledging those limitations, T&T consider that the use of the river flood models represents the best available information for assessing fluvial flooding across the whole of Christchurch. We consider that the river models, coastal extensions used together with the overland models (T&T, Volume 3, August 2014) address the majority of the limitations described in Table I. It is acknowledged that there may be more detailed models for local areas, however it is not practical to consider the use of these across the whole city.
4 Coastal and Sumner extensions

4.1 General

In addition to the models shown in Figure 3-1, the coastal areas around Southshore, Ferrymead, Bromley, South New Brighton, and Sumner are at risk of flooding due to high sea levels. The CCC WWDG shows that the maximum 1% AEP tide level is 10.894 mRL CDD at Ferrymead. This is equivalent to 1.851 mRL Lyttelton Vertical Datum (LVD). For the Sumner area, the level is 10.856 mRL CDD (1.813 mRL LVD).

These levels are used as flood levels for the 1% AEP event for coastal areas outside the Avon, Heathcote, and Styx models. The location of the coastal and Sumner extensions are shown in Appendix A (T&T Volume 1 April 2014) and Figure 3-1.

The coastal and Sumner extensions models were run for the five topographical scenarios, before and after each major earthquake in the Canterbury earthquake sequence (Pre-September 2010, post-September 2010, post-February 2011, post-June 2011 and post-December 2011). The models use 5 m x 5 m grids with New Zealand Transverse Mercator format (NZTM). The extensions are applied using the GIS software Global Mapper v13.1.3 published by Blue Marble Geographics.

The coastal extensions are not part of the river flood models and have been added by T&T to assess potential IFV for those areas that surround the Avon-Heathcote Estuary and Sumner coast. In some places, the coastal extensions overlap the Avon and Heathcote river flood models. Where this is the case, the maximum flood depth of the two overlapping points is adopted. The maximum flood depths from the river flood models and coastal extensions are combined for subsequent analysis and referred to as the “river flood model”.

The boundary conditions that have been applied to the overland flow model for the assessment of IFV are summarised in Table 4.1.

4.2 Limitations

The coastal extension models give a simplistic representation of extreme tide levels. As such the following limitations apply:

- The models do not consider the local drainage network;
- The models do not consider the effectiveness of any seawalls, flapgates or tide gates;
- The models do not specifically consider the effect of wind setup or wave run-up causing flooding; and
- Where the ground levels (pre- or post-earthquake) is above the extreme tide level; then the models do not capture any flooding that may occur as a result of overland or river flooding.
## Table 4-1 Coastal and Sumner extension boundary conditions

<table>
<thead>
<tr>
<th>Type</th>
<th>Model</th>
<th>Source</th>
<th>Version</th>
<th>File Name</th>
<th>Date Received (yyyy/mm/dd)</th>
<th>Rainfall</th>
<th>Downstream Boundary</th>
<th>Topography (LiDAR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastal extension</td>
<td>Pre-Sept</td>
<td>T&amp;T</td>
<td>01 Coastal Extension PreSept 100Y NZTM</td>
<td>2013/10/14</td>
<td></td>
<td>None</td>
<td>10.894 mRL overlaid on DEM (bathtub model)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-Sept</td>
<td>T&amp;T</td>
<td>02 Coastal Extension PostSept 100Y NZTM</td>
<td>2014/04/08</td>
<td></td>
<td>None</td>
<td>Post-September 2010 overlaid on pre-Earthquake</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-Feb</td>
<td>T&amp;T</td>
<td>03 Coastal Extension PostFeb 100Y NZTM</td>
<td>2013/10/14</td>
<td></td>
<td>None</td>
<td>Post-February (Combined March 2011 and May 2011)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-June</td>
<td>T&amp;T</td>
<td>04 Coastal Extension PostJune 100Y NZTM</td>
<td>2014/04/08</td>
<td></td>
<td>None</td>
<td>Post-June (September 2011)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-Dec</td>
<td>T&amp;T</td>
<td>05 Coastal Extension PostDec 100Y NZTM</td>
<td>2013/10/14</td>
<td></td>
<td>None</td>
<td>Post-December (February 2012 overlaid on post-June)</td>
<td></td>
</tr>
<tr>
<td>Sumner extension</td>
<td>Pre-Sept</td>
<td>T&amp;T</td>
<td>01 Sumner Extension PreSept 100Y NZTM</td>
<td>2013/10/18</td>
<td></td>
<td>None</td>
<td>10.856 mRL CDD overlaid on DEM (bathtub model)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-Sept</td>
<td>T&amp;T</td>
<td>02 Sumner Extension PostSept 100Y NZTM</td>
<td>2014/04/08</td>
<td></td>
<td>None</td>
<td>Post-September 2010 overlaid on pre-Earthquake</td>
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<tr>
<td></td>
<td>Post-Feb</td>
<td>T&amp;T</td>
<td>03 Sumner Extension PostFeb 100Y NZTM</td>
<td>2013/10/18</td>
<td></td>
<td>None</td>
<td>Post-February (Combined March 2011 and May 2011)</td>
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</tr>
<tr>
<td></td>
<td>Post-June</td>
<td>T&amp;T</td>
<td>04 Sumner Extension PostJune 100Y NZTM</td>
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<td>None</td>
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<tr>
<td></td>
<td>Post-Dec</td>
<td>T&amp;T</td>
<td>05 Sumner Extension PostDec 100Y NZTM</td>
<td>2013/10/18</td>
<td></td>
<td>None</td>
<td>Post-December (February 2012 overlaid on post-June)</td>
<td></td>
</tr>
</tbody>
</table>
5 Conclusions

River flood and coastal extension models are used for the engineering assessment of IFV land damage due to the earthquake sequence in Christchurch. These models are supplemented by overland flow models, refer T&T (Volume 3, August 2014).

The river flood models are those used by CCC for flood management purposes. These models exist for the Avon, Heathcote, and Styx catchments. The river models represent the main river and stream channels, but differ in the extent to which they represent the stormwater systems away from the main channels. The models are MIKE FLOOD models with MIKE 11 sub-models for the main rivers/streams and MIKE 21 sub-models for the terrain away from the rivers. For the purposes of IFV these models are applied to assess flooding adjacent to the main rivers and stream channels.

The coastal extension model represents flooding from the sea in areas surrounding the Avon-Heathcote estuary. This model is a projection of the extreme sea levels over the adjacent low-lying areas of land.

This report documents the key assumptions in developing the river models and the coastal extensions. It also notes the key limitations of these models and the mitigation of these limitations, which in many cases is the supplementary use of the overland flow models.

The application of the models to assess IFV requires the models to be run for specific criteria and scenarios. The relevant boundary conditions for criteria and topography for scenarios are summarised in this report.

It is considered that the use of the river flood, coastal extensions and overland flood models together represents the best available information for assessing flooding and identifying potential IFV across the whole of Christchurch. It is acknowledged that there may be more detailed models for local areas, however it is not practical to consider the use of these across the whole city.
6 References

Benn, J, Smart, G, Syme, W, 5 May 2014. EQC Increased Flooding Vulnerability Damage Peer Review Final Report Part 1 (Draft 4)


PDP, 3 August 2012, “Peer Review of Floor Level Data: Styx and Avon Catchments.”

PDP, August 2012, “Christchurch City Council Model Consolidation.”

T&T April 2014 Volume 1: Increased Flood Vulnerability: Assessment Methodology Report

T&T August 2014 Volume 2: Increased Flood Vulnerability: River Modelling and Coastal Extensions Report


T&T August 2014 Volume 4: Increased Flood Vulnerability: Assessment Implementation

T&T August 2014 Volume 5: Increased Flood Vulnerability: Geological Processes Causing Increased Flood Vulnerability
7 Applicability

This report has been prepared for the benefit of Chapman Tripp on behalf of Earthquake Commission with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.

Tonkin & Taylor Ltd
Environmental and Engineering Consultants

Report prepared by: 
Authorised for Tonkin & Taylor Ltd by:

[Signatures]
Kevin Ng
Water Engineer

Tim Fisher
Project Director

Mark Taylor
Senior Water Engineer