Hydraulic and Hydrologic Model Calibration and Validation for an Earthquake-prone Three-Waters Network

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Abstract: ***This paper summarises the three-waters network (water, wastewater, storm water) model calibration and validation work undertaken in Christchurch after the devastating 2010–2011 earthquakes. The paper outlines some unusual and unique challenges during model calibration due to continual earthquakes in the region and the post-earthquake rebuild work. In case of water supply network model, the validation peak summer date was chosen carefully so that earthquake-related damage and associated rebuild works would have minimal impact on the captured data. The wastewater network was damaged significantly due to the earthquakes. Wastewater flow data were influenced by earthquake damage and post-earthquake major construction activities. Christchurch's storm water network faced a number of changes – changes in topography, ground levels, river channels and liquefaction – due to the earthquakes. Ongoing model maintenance and updating was a big challenge during model calibration, and an effective collaboration among various teams – GIS, construction contractors, network operations and survey – was important for data collection, data interpretation, model calibration and validation work.***

Keywords: Hydraulic model calibration, Hydraulic model validation, Hydrologic model, Stormwater, Surface water, Water supply, Waste water.

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I. INTRODUCTION

Adequate safe water supply is essential for human existence [1, 2]. Managing water supply network efficiently and effectively is very important for any water authority. Sewer network is essential to keep a city clean and safe. It is important for human health and safety. Surface water network is important for managing flooding and related impacts on human beings [3]. Safe surface water network allows adequate recreation facility for the local community. Recent advances in technology allows engineers to visualize the performance of the three waters network (water, wastewater, stormwater) in real time [4, 5]. Hydraulic and hydrologic models are very important tools to investigate the performance of three-waters network (water supply, wastewater, stormwater).

Hydraulic models must be adequately calibrated and then validated so that the models represent the actual operation of the network [6, 7]. The model must include up-to-date infrastructure, the correct level of demand, and replicate different ancillary structures and operational sites accurately [6, 7].

After the devastating earthquakes in 2010–2011, earthquake related aftershocks have become a common feature of daily life in the Canterbury region of New Zealand. Approximately 20,000 earthquakes and aftershocks occurred in the Canterbury region following the first earthquake on 4 September 2010 [8].Three-waters hydraulic and hydrologic models have been used extensively in Christchurch to investigate earthquake damage and also to help in earthquake recovery and restoration work [9, 10]. It is a challenge to calibrate hydraulic models because of the continual earthquakes and earthquake-related rebuild work [6].

This paper summarizes the three-water network hydraulic and hydrologic model calibration and validation work undertaken in Christchurch following the 2010–2011 earthquakes. The paper outlines some unusual and unique challenges during calibration work due to continual earthquakes in the region and the post-earthquake rebuild works.

II. WATER SUPPLY NETWORK MODELLING

Infoworks WS (Water Supply), SCADA (Supervisory Control and Data Acquisition), Infonet GIS (Geographic Information System) tools were used for calibration and validation of the water supply network models in Christchurch. The original water supply model was built and calibrated in 2009–2010 just before the September 2010 earthquake. The model was calibrated to a peak summer day in 2009. The model was again rebuilt in 2016-2017 using post-earthquake, post-rebuild information and GIS network files [12]. The post-rebuild water supply model was validated with a peak summer day in 2015.

The water supply model includes seven major pressure zones which are relatively big in area and largely open in nature [12, 13]. Many pump stations within the water supply network are managed manually by the shift controllers [13]. The combined water-supply model of Christchurch includes each and every asset of the water supply network including around 3,500 km pipes (mains and sub-mains), 92 reservoirs and suction tanks, 65 key pump station sites (includes 228 pumps), around 15,000 hydrants, all the nodes (connectors, junctions and valves) and wells.

The new water supply model for Christchurch was built in 2016–2017 as the previous pre-earthquake model was out of date. The new model had to replicate the post-rebuild water supply network for accurate decision making. SCADA data were extracted for 65 different pump station sites. Flow data, pump operational patterns and pressure data in different parts of the network were extracted for model validation. Data were extracted and matched with the results predicted by the model.

Limited calibration actions were undertaken where the validation of model failed. The validation specification required extensive validation of different pressure and flow logging sites. Table 1 outlines criteria used for water supply model calibration and validation works.

TABLE 1: CRITERIA USED FOR CALIBRATION/ VALIDATION OF WATER SUPPLY MODEL

Criteria	*Acceptable calibration/validation range (observed versus predicted)*
Pressure (Lowest)	Predicted minimum pressure within 10% of measured minimum pressure
Pressure (Peak)	Predicted peak pressure within 10% of measured Peak pressure
Volume	Predicted daily flow volume within 5 % of measured daily volume
Flow	Predicted peak flows within 5% of observed peak

III. WASTEWATER NETWORK MODELLING

Infoworks CS (Collection System), SCADA, Infonet GIS, and MapInfo tools were used for wastewater model calibration and validation. The original wastewater model was built and calibrated in 2010–2011. The model was further updated with up-to-date network information in 2013–2014, calibrated in 2014–2015 and validated in 2016–2017 [6, 10]. The model includes around 26,000 manholes, around 1,600 km sewer mains, all the key pump stations, and pressure and vacuum sewer systems.

The sewer hydraulic model is a trunk main model and in some areas the smaller reticulation (<DN225) is not included in the model. As shown in figure 1, flow data for model calibration were accessed from a massive flow-monitoring programme. Approximately 102 short-term flow monitors and 13 long-term flow monitors were used for calibration. Long-term flow monitors were monitors which are installed permanently in different parts of the trunk main network whereas each of the short-term flow monitors were installed for a period of approximately three to four weeks [10, 11].

Figure 1 shows location of different flow monitors in Christchurch's wastewater network.

Figure 1: Christchurch wastewater network flow monitoring in 2013–2014

Wastewater Planning User Group (WaPUG) criteria were used for wastewater model calibration works [10, 14]. Table 2 outlines criteria used for wastewater model calibration and validation works.

TABLE 2: CRITERIA USED FOR THE CALIBRATION/ VALIDATION OF WASTEWATER MODEL

Criteria	*Acceptable calibration/validation range (observed versus predicted)*
Depth	Maximum DWF (Dry Weather Flow) flow depth within 100 mm of observed maximum flow depth for DWF. Maximum WWF (Wet Weather Flow) depth within 100 mm of observed maximum flow depth when not surcharged, and depth within +500 mm or −100 mm when surcharged.
Volume	Predicted daily DWF flow volume within 10 % of measured daily volume for DWF. Predicted daily WWF volume within +20 % or −10 % of measured volume.
Flow	Predicted peak DWF flows within 10 % of observed peak. Predicted WWF peak flow within +25 % or −15 % of observed peak.
Minimum Night-time Flow	Predicted minimum DWF night flows within 20 % of observed minimum flow or ± 2 l/s, whichever is greater (for DWF).

The calibration specification requires extensive calibration using flow, volume and depth criteria. The flow monitors which captured a response to a wet weather event (45 short-term flow monitors and 13 long-term flow monitors) were calibrated for dry and wet weather events whereas the remaining flow monitors were used for calibration for dry weather events only. To capture the most conservative snapshot of the system's operation, the model was calibrated for the winter season (when the ground water level is high), first with the short-term flow monitors, and then further adjustments were done for long-term sites.

IV. SURFACE WATER NETWORK MODELLING

The local government organization has a large stock of different storm water models [9, 15]. But there is no city-wide model for Christchurch yet. The models were mainly built in DHI MIKE software platform; some of them were built in Infoworks ICM and some were built in TUFLOW. The local Council is currently building city-wide flood models that will include multiple models covering the whole of Christchurch [15]. A number of small models have already been made and calibrated with post-earthquake information. In this report, challenges during model calibration and validation for a storm water catchment (Lyttelton) within Christchurch are discussed.

Lyttelton is an area situated in the south-east of the city. The Infoworks ICM (Integrated Catchment Management/Modelling) tool was used to build the Lyttelton surface water model. The model was successfully validated with two real time rainfall events (both 1 in 50 year's rainfall). The results predicted by the model were compared and matched with customer complaints (related to flooding) as part of validation works. Impervious and pervious areas were allocated based on planning zones, road parcel boundaries and aerial imagery. The parameters of the model were allocated in accordance with Chapter 21 of Council's Waterways, Wetlands and Drainage Guide [16].

TABLE 3: CRITERIA USED FOR THE CALIBRATION AND VALIDATION OF LYTTELTON STORMWATER MODEL

Criteria	*Acceptable calibration/validation range (observed versus predicted)*
Depth	Model predicted maximum flood depth within 50 mm of observed maximum flood depth.
Flood extent visual match	The model-predicted flood extent was also visually matched with the observed data.
Flow data	No calibration actions were undertaken to match flow data due to lack of reliable information.

V. DISCUSSION

The earthquakes caused a number of changes in the three-water network. Further, ongoing post-earthquake rebuild works caused the network to perform differently at different points of time.

In case of the water supply network, the earthquakes caused an increase in MNF (minimum night-time flow) due to cracked and broken pipes [12]. In the water-supply network model calibration and validation work, the earthquakes had minimal impact as the network was less damaged than the wastewater and storm water network [9, 12]. The validation date for the water supply model was chosen carefully so that earthquake-related damage and associated rebuild work would have minimal impact on the captured data.

The wastewater network was damaged significantly due to earthquakes. Flow data were influenced by earthquake damage and major construction activities [10, 17]. In case of the wastewater hydraulic models, as part of the calibration work, the model was run for a prolonged period (dry weather and wet weather) ensuring a good match between observed and predicted data. Monitoring wastewater flow in Christchurch was influenced by post-earthquake groundwater infiltration, massive ongoing rebuild works and other unusual sewage discharge. Figures 2 and 3 show observed flow data for two flow monitoring sites to illustrate typical challenges during interpretation of unusual flow data. Figure 2 shows low observed wastewater flow due to upstream pipe bung off and rebuild works. In figure 3, occasional discharge of wastewater (construction vehicle wash-down) was evident in the observed flow data. Ongoing maintenance and updating of the hydraulic model was a big challenge during model calibration and continuous communication with construction contractors, operation engineers and the GIS team was important to keep the model up to date and useful for calibration at different points of time.

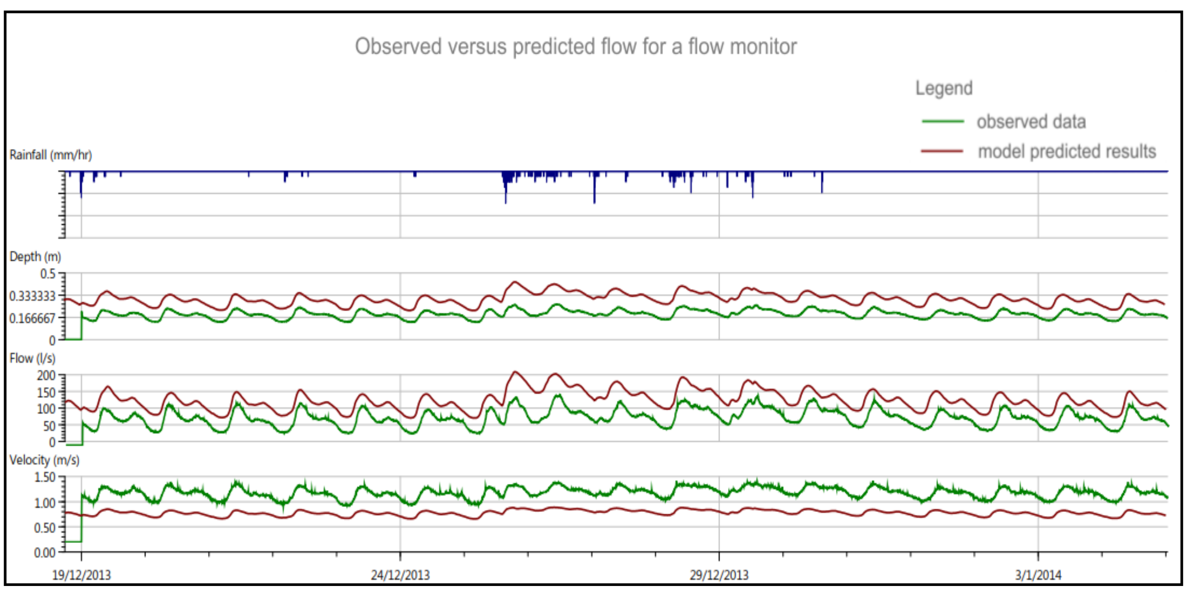

Figure 2: Observed versus predicted flow for a flow monitor (unusually low observed flow due to upstream pipe bung off and rebuild works)

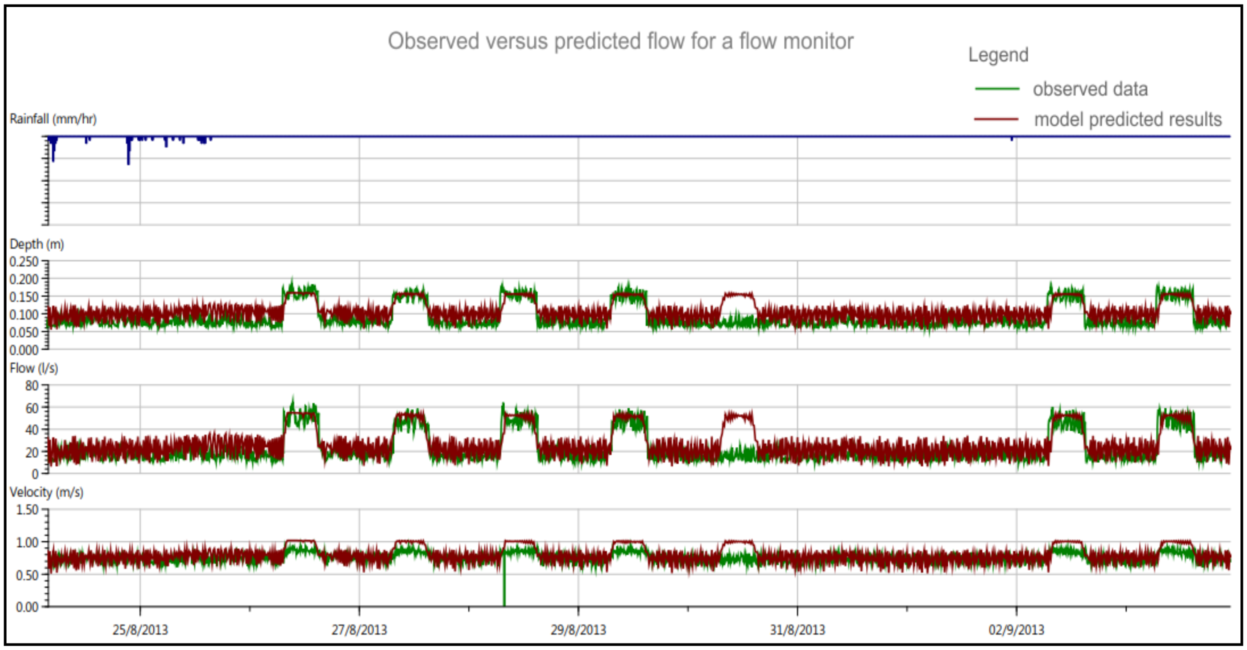

Figure 3: Observed versus predicted flow for a flow monitor (occasional discharge of 35 l/s due to temporary construction vehicle wash-down)

The sewer system and surface water network share some critical aspects of surface hydrology [6]. As shown in figure 4, after the ground is saturated with rainfall, water infiltrates into the sewer network through pervious areas and surface flooding. Pervious surface area was incorporated in the wastewater catchment hydrology and contributes rainfall to the unsaturated zone which is represented within the model using the Ground Infiltration Module (GIM).

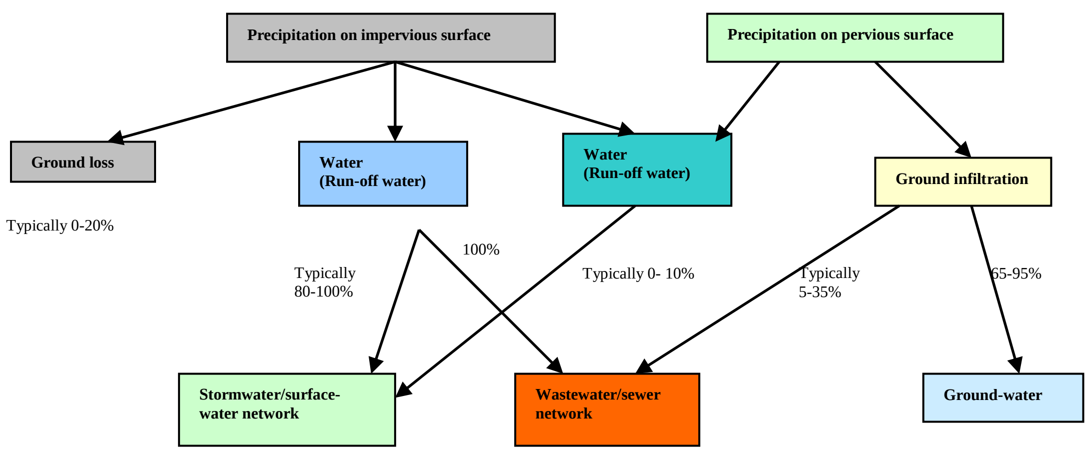

Figure 4: Precipitation distribution and interactions in the wastewater and storm water models

The storm water network faces a number of changes due to the earthquakes. These changes include changes in topography, ground levels, river channels, liquefaction and other storm water network damage [9]. Rapidly changing topography and the storm water network pose a number of challenges for a hydraulic modeller [9]. With an earthquake in excess of magnitude six, it is important to get the latest LiDAR (Light Detection and Ranging) information to update the model so that it replicates reality. Again, finding a calibration event after the earthquakes posed additional challenges. In many cases, engineering judgment and decision making were key to keep the model up to date [9, 15]. Lyttelton is a small town situated in the south-east coastal part of Christchurch. The Lyttelton storm water model predicted the extent and severity of flooding differently after major earthquakes. In some cases the change was minor but in others it was major. It is not easy to predict this until an appropriate network survey is done and LiDAR information is collected. Three different Lidar data sets have been used to model Lyttelton stormwater network to understand the impact of earthquakes on stormwater network. Figure 5, 6 and 7 show flood extent and severity in Lyttelton at different points of time.

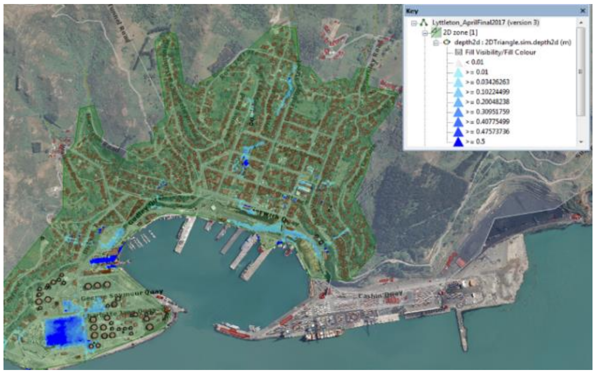

Figure 5: Lyttelton Pre-quake (before earthquake) flood modelling results

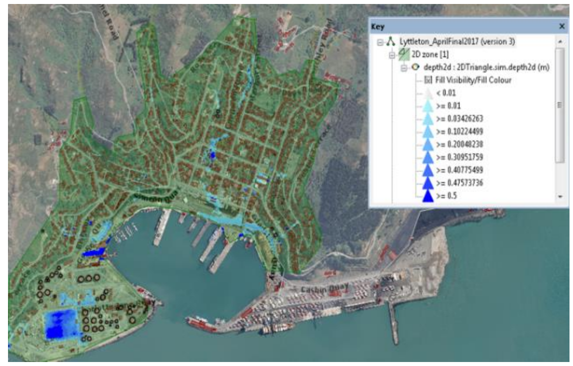

Figure 6: Lyttelton Post-quake (after February 2011 earthquake) flood modelling results

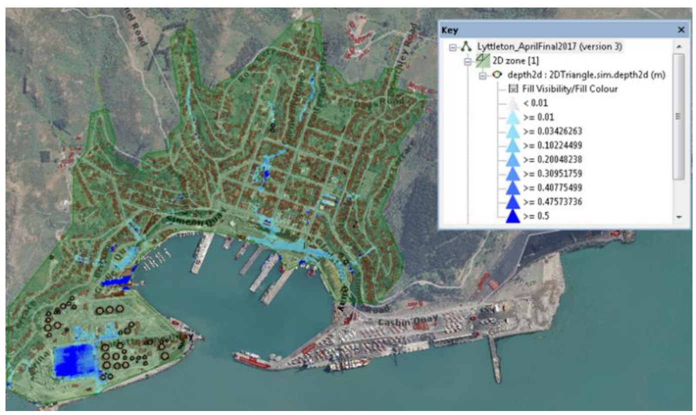

Figure 7: Lyttelton Post-quake (after June 2014 earthquake) flood modelling results

In Christchurch, there have been a total of around 20,000 earthquakes and aftershocks since September 2010 [8]. Of these, around 20 were greater than magnitude five [8]. These earthquakes are continually changing the topography of the network [9]. There is no magic tool to automatically update and calibrate the storm water model continuously with the changes in the network.

VI. CONCLUSIONS

Water models are very powerful tools that are being used for concept design and multimillion dollar decision making in the modern world [18]. In Christchurch, it is a challenge to keep the water models up to date due to earthquake-related changes in the performance of the water networks (water supply, wastewater and storm water), rapidly completed construction projects, and changes in ground conditions and geotechnical mechanisms. In case of water supply model, the calibration and validation of the model was not notably influenced by earthquakes as the calibration/validation peak summer date was chosen carefully. Wastewater flow monitoring data were influenced by post-earthquake geotechnical mechanisms and rapid construction works. Christchurch's storm water network faced a number of changes in topography, ground levels, river channels, and liquefaction due to the earthquakes. The ongoing maintenance and updating of the water models was a big challenge during model calibration and an effective collaboration among construction contractors and various teams

(GIS, network operations, and survey) was important for data collection, data interpretations and water model calibration work.

VII. Acknowledgement

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