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Modelling Seismic effects on a Sewer Network using Infoworks ICM

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Abstract

Objectives: The effects of earthquakes on a sewer network can be assessed using different well established methods such as flow monitoring, visual inspection, condition assessments and engineering survey. The main objective of this study is to investigate how hydraulic models were developed and used to assess the immediate devastating impacts of seismic activities on Christchurch's sewer network. **Methods:** Infoworks ICM (Integrated Catchment Management) and InfoNet hydraulic modeling tools were used for this investigation. Two hydraulic models (2010 pre-quake model and 2011 post-quake model) were developed for Christchurch's sewer network as part of this assessment. **Findings:** Hydraulic modelling was found to be a very powerful tool engineers can use to assess the impact of an earthquake and quantify the performance of sewer network. In Christchurch earthquakes caused significant damage to the waste water network. In post-earthquake Christchurch, there was an increase of 33% in the flows to the treatment plant due to earthquake related damage in the network. **Application/Innovation:** This paper summarizes hydraulic-model building and calibration works for pre-earthquake and post-earthquake Christchurch to evaluate the impacts of seismic activities on the sewer network. This paper suggests that any modern water authority could implement appropriate hydraulic modelling tools to prepare for any unforeseen situation.

Keywords: Earthquake, Infoworks ICM, Modelling, Seismic Effects, Sewer Network

1. Introduction

Hydraulic modelling is considered one of the most powerful tools saving millions of dollars during the concept design stage by accepting or rejecting different project proposals[1-4]. In this research, hydraulic models were developed to assess seismic effects on Christchurch's wastewater network.

The pre-earthquake wastewater network in Christchurch consisted of approximately 1,650 km sewer mains, 91 key pump stations, around 27,000 manholes and a treatment plant[5,6]. The September 2010 and February 2011 earthquakes had a devastating effect on Christchurch[7-9]. The wastewater network of the city was damaged significantly due to these two major earthquakes. The eastern suburbs of the city were significantly damaged and many properties were disconnected from the sewer network (Figure 1).

Temporary sewer systems such as portable toilets were installed in many areas. The cracks and breaks in the pipes, and the failure of many, caused a significant increase in Dry Weather Flow (DWF) infiltration causing the wastewater treatment plant to work overtime and break down on some occasions.

This paper summarizes how hydraulic models were developed and used to assess the immediate, devastating effects of the February 2011 earthquake on Christchurch's wastewater network. It compares the performance of the pre-earthquake (before September 2010 earthquake) wastewater network with the post-earthquake (after February 2011 earthquake) wastewater network performance.

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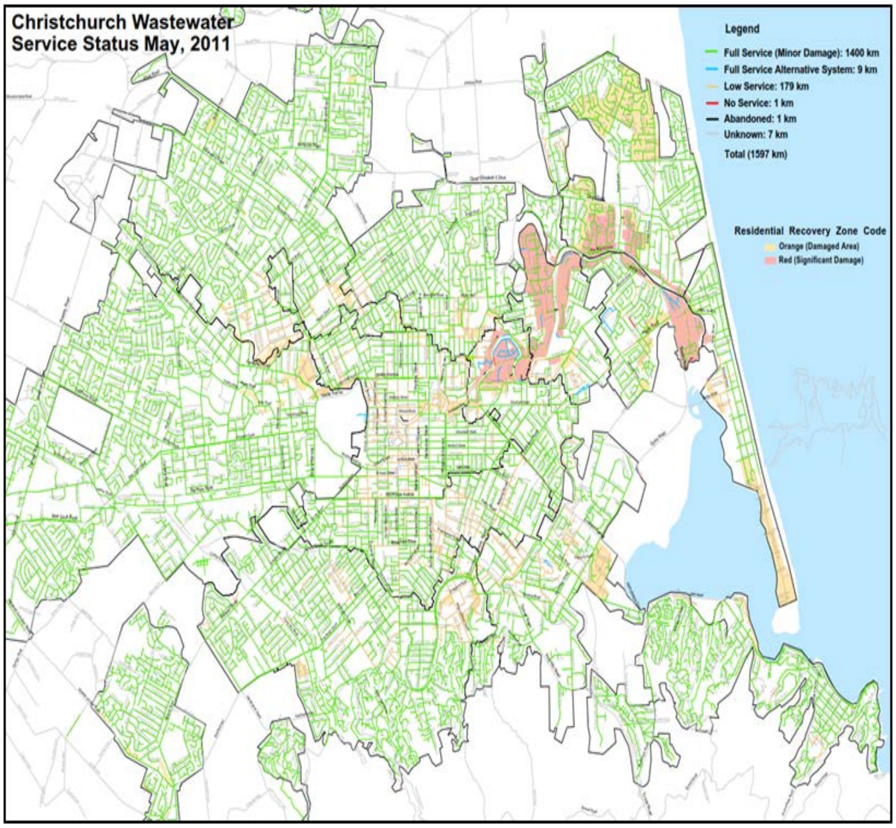

Figure 1. Christchurch Wastewater Service Status after the February 2011 Earthquake.

2. Post-earthquake versus Pre-earthquake Performance Assessment

The performance of a wastewater network can be assessed using different methods. Some of the well-established methods are Closed Circuit Television (CCTV), inspections, network surveys, asset-condition assessments and flow-monitoring[9,10]. Each of these methods has its own limitations.

2.1 Engineering Survey/CCTV Inspection

Engineers can collect information on a wastewater network using different survey instruments and visual aids[9-11]. CCTV instruments can be installed to assess pipe conditions and an appropriate damage rating can be applied based on visual inspection. Christchurch's wastewater network is a complex system. In 2011 it used to serve around 360,000 people[12] and consisted of approximately 1,650 km sewer mains and around 27,000 manholes. Surveying such a big network is time consuming and may not be economically feasible. Only selective assessment can be done using this method.

2.2 Constructed Overflow Monitoring

If flow monitors are installed at the constructed overflow sites, then flow-monitoring data help us to understand the extent of damage in different parts of the wastewater network[13,14]. There were around 102 constructed overflow sites in Christchurch's wastewater network and only 17 of them were monitored. This could not give adequate information on the area-wise wastewater network performance.

2.3 Wastewater Treatment Plant Flow-Monitoring

An increase in DWF to the treatment plant meant more groundwater infiltration due to broken and cracked pipes[14-16]. In Christchurch, a flow meter was installed upstream of the treatment plant. This flow-monitoring data gave us an overall picture of the performance of the sewer network. But it did not give detailed information about the wastewater network performance such as manhole overflow, overflow from constructed overflow points, and area-specific variations in network performance.

2.4 Network Flow-Monitoring

Thirteen long-term flow monitors were installed in different parts of the network. The data they provided were useful to understand the sewer network performance. But this method also failed to give engineers a detailed picture on wastewater network performance. Interpretation of flow-monitoring data and replicating the reality is a big challenge unless hydraulic modelling and GIS tools are used.

All of the above assessment results needed to be combined into a meaningful system. A GIS database such as the Info Net model database can be made by adding all the information into a single database platform. Appropriate hydraulic models fit perfectly in this situation. Since they can collate all the relevant survey and assessment information into a meaningful platform and predict the performance of the network for different development or design scenarios, this powerful tool can help engineers assess the impact of an earthquake and quantify the performance of the sewer network.

Two hydraulic models were developed for this investigation:

- The 2010 pre-earthquake hydraulic model, and
- The 2011 post-earthquake hydraulic model.

The 2010 pre-earthquake model predicted the performance of the wastewater network before the September 2010 earthquake whereas the 2011 post-earthquake model predicted the performance of the network just after the February 2011 earthquake. These two models helped engineers understand the immediate effects of the earthquakes on the performance of the wastewater network. A number of design and development solutions were created using the hydraulic modelling tools to return the level of service of the network to the pre-earthquake level. In this research article, Infoworks ICM and InfoNet modelling tools were used for sewer network modelling.

3. The 2010 Pre-earthquake Hydraulic Model

This model was developed to understand the performance of Christchurch's wastewater network before the September 2010 earthquake. The model was developed in 2011 by taking pre-earthquake information such as network survey files, GIS files, CCTV information, and flow-monitoring data and as build files.

3.1 Model Inputs and Parameters

The 2010 pre-earthquake model parameters and input information included various sewer network files and flow-monitoring data that were available from before the earthquake (Table 1).

Table 1. The 2010 Pre-earthquake Hydraulic Model Inputs and Parameters

Input Description	2010 Pre-earthquake Model
Ground Level	Extracted from pre-earthquake LiDAR (airborne light detection and ranging) and as-builds information files.
Network Data	Pipe inverts based on pre-earthquake Christchurch City Council (CCC) GIS files and available as-build data. If data was missing, it was inferred or interpolated from known points.
Pipe Roughness	Default top roughness was 1.5 mm (Colebrook-White). Default bottom roughness was 3.0 mm (Colebrook-White), or 25 mm for brick barrel pipes. Standard roughness data were used unless otherwise identified by operators from condition assessment or calibration.
Sediment in Pipe	No sediment depth was assumed unless identified by operators or seen during flow monitoring.
Population	Population as per 2010–2011. (Population data projected from 2006 Canterbury census) [5,12].
Baseflow (DWF Infiltration)	The baseflow was based on flow monitoring done before September 2010 from 13 long-term and approximately 20 short-term flow-monitoring sites. There was no flow monitoring for a few pump station sub-catchment areas. In these cases, pump station flow data was used for baseflow assessments.
Infiltration (WWF)	Infiltration was based on area and land use data which was the same in pre and post-earthquake models.

3.2 Model Calibration and Validation

The 2010 pre-quake model was calibrated to the pre-earthquake flow-monitoring data from 13 long-term and approximately 20 short-term flow monitors. It was validated to a rainfall event in May 2010. Where there was no pre-earthquake flow monitoring data, pump station flow data were used for calibration and baseflow assessments.

4. The 2011 Post-earthquake Hydraulic Model

This model was developed to understand the performance of Christchurch's wastewater network immediately after the February 2011 earthquake. The model was developed in 2011 after February 2011 earthquake taking post-earthquake information such as network survey files, GIS files, CCTV information and flow-monitoring data.

4.1 Model Inputs and Parameters

The 2011 post-earthquake model parameters and input information were extracted from various post-earthquake sewer network files and flow-monitoring data (Table 2).

The true response of the network to rainfall-derived infiltration is often limited by the carrying capacity of the network and soil conductivity. As infiltration is based on area and land use data, which was the same in the pre- and post-earthquake models, in wet weather situations there is often no visible change between peak flows from pre-quake and post-quake models.

Table 2. The 2011 Post-earthquake Hydraulic Model Inputs and Parameters.

Input Description	2011 Post-earthquake Model
Ground Level	Extracted from post-February 2011 earthquake LiDAR (airborne light detection and ranging) or as-builds information files.
Network Data	Pipe inverts were based on post-earthquake survey data. Pre-earthquake invert and cover levels were retained if post-earthquake levels were unavailable. Pre-quake inferred level data was re-inferred based on updated post-quake levels.
Pipe roughness	Default top roughness was 1.5 mm (Colebrook-White); Default bottom roughness was 3.0 mm (Colebrook-White), or 25 mm for brick barrel pipes. Standard roughness data were used unless otherwise identified by operators from condition assessment or calibration.
Sediment in Pipe	No sediment assumed unless identified by operators, post-earthquake condition assessments, or seen during flow monitoring.
Population	Population as per 2010– 2011. (Population data projected from 2006 Canterbury census)[5,12].
Baseflow (DWF Infiltration)	The model was calibrated to actual flow data dated August–September 2011. In some areas, flow data was found to be considerably higher than the pre-earthquake flow data.
Infiltration (WWF)	Infiltration was based on area and land use data which was the same in pre and post-earthquake models.

4.2 Model Calibration

The 2011 post-quake model was calibrated to the post-earthquake flow-monitoring data from 13 long-term and 42-short term flow monitors in September 2011. It was validated to a rainfall event in October 2011.

5. Results and Discussion

The pre- and post-earthquake models were run for three different scenarios to compare the performance of the network pre-earthquake versus post-earthquake. The models were run for dry and wet weather periods.

- DWF (Dry Weather Flow) Simulation Run: The simulation was run for two standard dry weather days (no rainfall)
- WWF (Wet Weather Flow) Simulation Run: The simulation was run for two days with a one-in-three year's rainfall event.
- Long Time Simulation Run (DWF and WWF): The simulation was run for the last 15 years' storm events (1997–2011).

The rainfall return periods were assessed using the Christchurch City Council publication Waterways, Wetlands and Drainage Guide[17]. Both hydraulic models (pre- and post-quake) included Christchurch's sewer network including all the constructed overflow sites, manholes, pump stations and main trunk network (pipes >150 mm diameter).

The following performance indicators were investigated:

- DWF infiltration,
- hydraulic capacity for DWF and WWF simulation runs,
- self-cleansing potential (maximum DWF velocity),
- wastewater overflow performance for 15 years of storm events, and

- dry weather night-time flow to wastewater treatment plant.

5.1 DWF Infiltration

In Christchurch, the earthquakes caused significant damage to pipes (cracks, collapse, and joint breakage), pumps and the treatment plant. They also caused pipe blockage due to liquefaction in many areas[8,18]. DWF infiltration maps were extracted from the calibrated hydraulic model files.

As shown in figure 2, in the 2010 pre-earthquake network, a small area (red colour) in the north-west corner of city centre was found to have very high DWF infiltration. In this area, the pipe network was under the groundwater level. This caused high infiltration. In the 2010 pre-earthquake network, a high infiltration rate was also observed on the north-eastern part of the city.

As shown in figure 3, as the pipes are under the groundwater level in the north-western corner of the city, this caused very high DWF infiltration due to post-earthquake pipe cracking and breakage.

Due to earthquake damage in the city centre, many buildings were unoccupied and this caused a decrease in wastewater flows in the network but, in reality, the area will be occupied in the future with a large number of business and commercial activities increasing the wastewater discharge into the network. Overall, the earthquakes caused a significant increase in DWF infiltration especially in the east of the city. The red and orange colours show the areas with high earthquake damage. It helped engineers to target the rebuild areas and allocate funding for the area with high earthquake damage.

5.2 Hydraulic Capacity

Assessment of the system's performance indicated good DWF capacity in general. In post-earthquake Christchurch, widespread surcharging was observed in many areas.

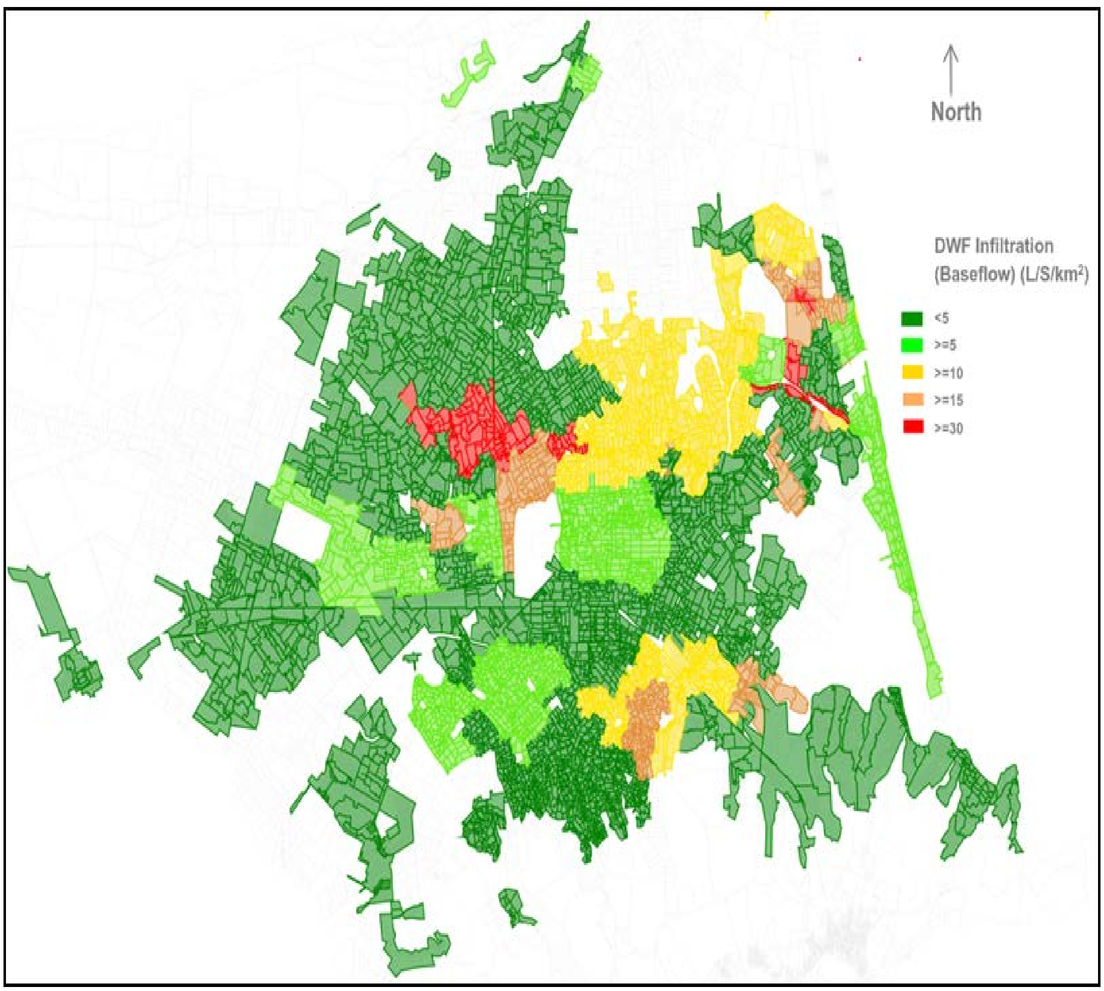

Figure 2. The 2010 Pre-earthquake Model – DWF Infiltration.

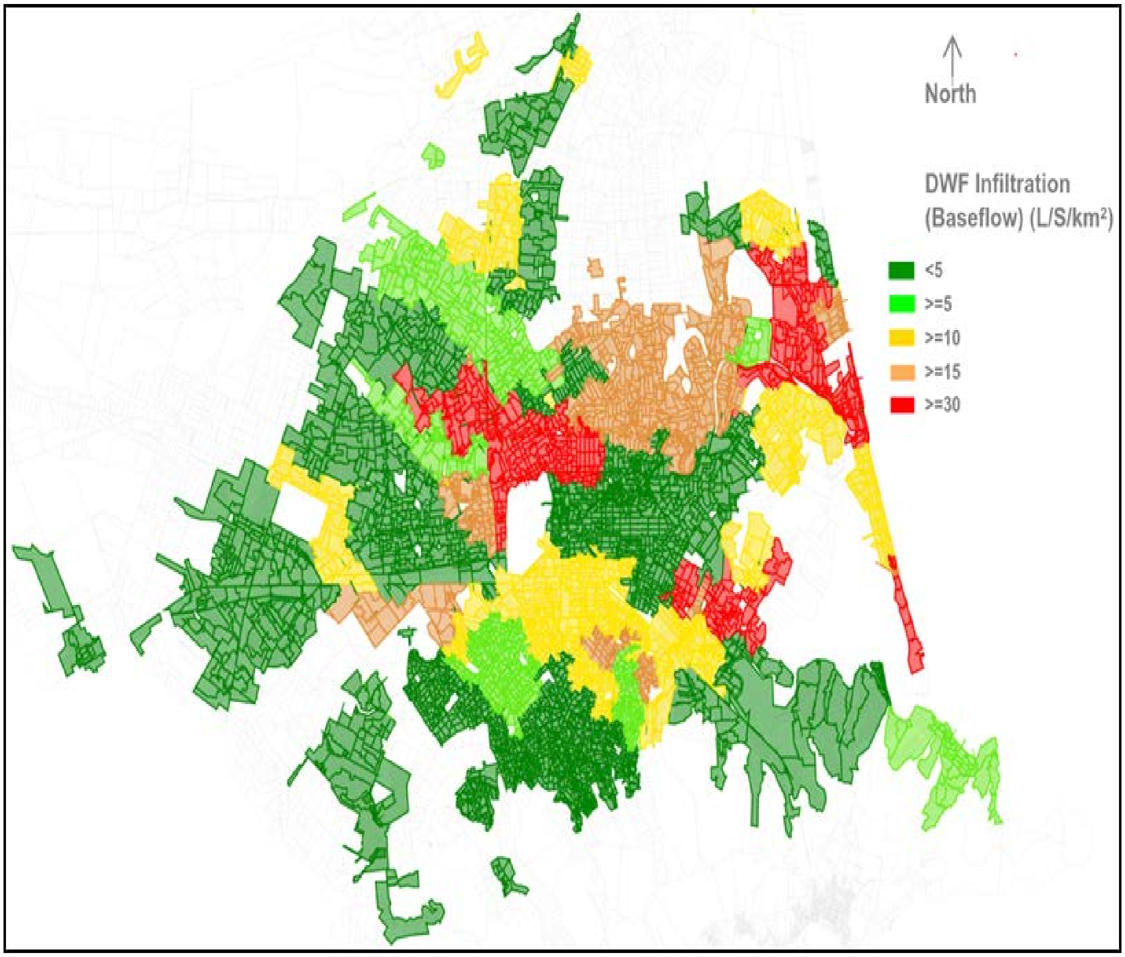

Figure 3. The 2011 Post-earthquake Model – DWF Infiltration.

During WWF widespread surcharging occurred across the system, which was further exacerbated by increased DWF infiltration in the postearthquake network (Figure 4, Figure 5). In WWF conditions, as shown in figure 4, there was approximately a 7% increase in pipe surcharging in the post-earthquake sewer network. As outlined in figure 5, manhole surcharging also increased considerably (approximately a 2% increase) due to the earthquakes.

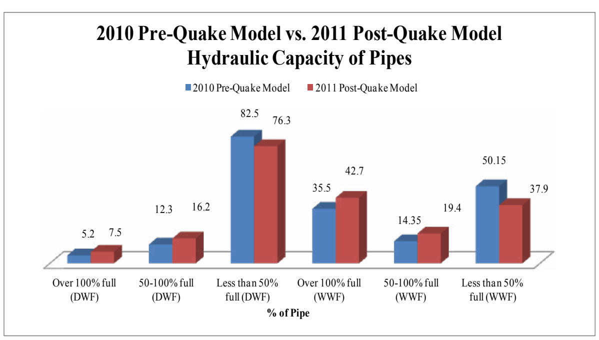

Figure 4. Hydraulic Capacity of Pipe (pre-earthquake versus post-earthquake).

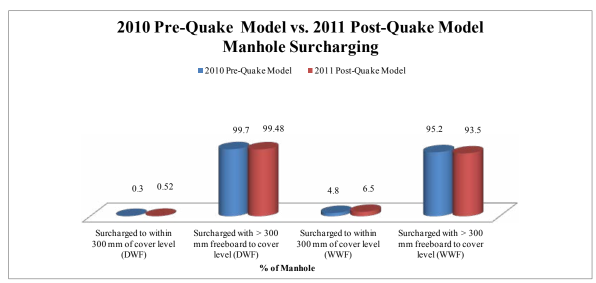

Figure 5. Manhole Surcharging (pre-earthquake versus. post-earthquake).

5.3 Self-Cleansing Potential (maximum DWF velocity)

During DWF, the large-diameter trunk mains were able to self-cleanse even at relatively flat grades, while the smaller diameter trunk system had only limited self-cleansing potential. During WWF, the velocity of the wastewater flow was not an important parameter as self-cleansing is not an issue during such events. According to post earthquake customer complaints, wastewater became stagnant in many areas[9]. In some areas, the residents were unable to flush their toilets due to liquefaction-related blockage and network damage. If the wastewater velocity is more than 0.55 m/s then it is called a self-cleansing network[16]. As shown in figure 6, Self-cleansing potential decreased in the post-earthquake network since the network was having very low DWF velocity in many areas due to the earthquakes.

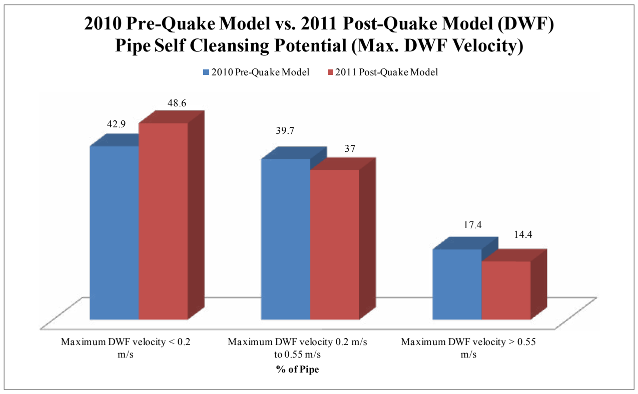

Figure 6. Self-Cleansing Potential (pre-earthquake versus post-earthquake).

5.4 Overflow Performance and Frequency

Increased DWF infiltration through the system as a result of earthquake damage, not only reduced the network's capacity, but also increased overflow discharge frequency. Analysis of the 15-year Time Series Rainfall (TSR) (1997-2011) model simulation runs identified a number of overflows which were predicted to be operating. There were 102 constructed overflow points in the sewer network. In summary, as shown in table 3, total wastewater overflow volume increased by around 22% in post-earthquake Christchurch.

Table 3. Sewer Overflows during 15 Years Storms Pre-Quake versus Post-Quake.

Level of Service (LOS) Target	2010 Pre-Quake Hydraulic Model vs. 2011 Post-Quake Hydraulic Model
Total overflow volume spilled during 15-year storms (overflow from constructed overflow points and manholes)	Total wastewater overflow volume increased by around 22% in the post earthquake wastewater network.

5.5 DWF Night-time flow to Wastewater Treatment Plant

An analysis was done to compare flows to the wastewater treatment plant. As shown in figure 7, there was around a 33% increase in flow into the wastewater treatment plant due to the earthquakes.

As shown in Figure 7, The flow rate predicted by the model and the observed data matched well. Successful calibration of the model increased confidence in the model's predicted results and enabled correct decision makings. WaPug calibration criteria were applied to make the hydraulic models fit for purpose[14,15].

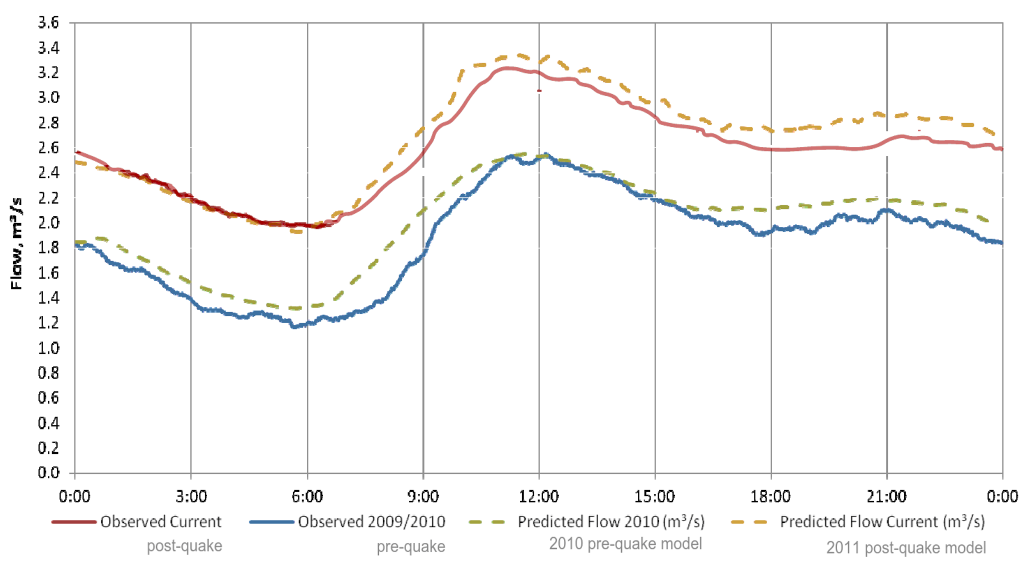

Figure 7. Wastewater Flow to the Wastewater Treatment Plant Pre-Quake versus Post-Quake.

6. Conclusions

This paper demonstrates that hydraulic models can be used to assess the immediate effects of an earthquake on a sewer network. The model was useful for accurate decision making in real time saving millions of dollars during rebuild works. This paper suggests that any modern water authority could implement appropriate hydraulic modelling strategies and modelling tools to prepare for any unforeseen situation. The 2010 pre-earthquake model and the 2011 post-earthquake models were extensively used for prioritizing rebuild works and for understanding the extent of the damage in different parts of the network. Fortunately, Christchurch City Council has a good hydraulic modelling programme that ensured successful hydraulic modelling supported the rebuild.

In summary, earthquakes caused significant damage to the wastewater network of Christchurch. Some of the key impacts of the earthquakes are summarized below:

- There was a significant increase of DWF infiltration, especially in the east of the city.
- In WWF conditions a 7% increase in pipe surcharging was observed whereas manhole surcharging (wastewater surcharged within 300 mm of cover level) increased by around 2%.
- There was a notable decrease in the self-cleaning potential in pipes due to the earthquakes. In many areas pipes were blocked due to liquefaction. This caused a decrease in velocity during dry weather flow periods.
- In post-earthquake Christchurch, there was an increase of 33% in the flows to the treatment plant. This caused the treatment plant to work overtime and fail on some occasions.

7. Acknowledgement

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