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Quantifying the Performance of a Post-Earthquake, Post-Rebuild Wastewater Network using Hydraulic Models

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Abstract

Objectives: This paper demonstrates how hydraulic models were built and calibrated for the 2018 post-rebuild hydraulic model and the 2018 no-earthquake hydraulic model for Christchurch's wastewater network to evaluate the success of the post-earthquake rebuild work in returning the Level of Service (LoS) of the wastewater network to the no-earthquake level. **Methods**: Info works ICM (Integrated Catchment Management) and Infonet hydraulic modeling tools were used for this investigation. The models were developed taking Christchurch's sewer network information such as the network survey files, GIS sewer network files, Closed Circuit Television (CCTV) inspection information and flow-monitoring data. **Findings**: Wastewater network hydraulic models were found to be very powerful tools that can combine different network information (GIS, CCTV inspection data, surveys and flow-monitoring data) into a meaningful platform and predict the performance of the network for different development scenarios. This paper successfully demonstrates how hydraulic models were developed and used to assess and compare the performance of the rebuilt sewer network with the no-earthquake sewer network of Christchurch. As per the model simulation results, there will be less wastewater overflow in the post-rebuild network when compared with the no-earthquake network. **Application/Innovation:** Sewer network hydraulic modelling is traditionally used for concept design and future planning, or programming for wastewater network. In this research, hydraulic models were developed and used in an innovative way to assess the success of multimillion dollar rebuild works.

Keywords: Earthquake, Rebuild, Sewer Network, Sewer Performance, Wastewater Network, Hydraulic Model

1. Introduction

Christchurch was devastated by a series of major earthquakes in 2010 and 2011[1-3]. The government, via the Canterbury Earthquake Recovery Authority (CERA), together with Christchurch City Council (CCC), funded millions of dollars' worth of earthquake-damage repairs and rebuilding as part of the rebuild to restore the performance of the wastewater network[4-6]. Some of the well-established methods to assess the performance of a wastewater network are Closed Circuit Television (CCTV), inspections, network surveys, asset condition assessments and flow monitoring[7-9]. Each of these methods has its limitations. Hydraulic models can collate all these relevant survey and assessment information into a meaningful platform and predict the performance of the network.

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Hydraulic modelling is normally used for concept design and future planning, or programming for water and wastewater networks[10-3]. In these assessments, hydraulic models were used to assess and compare the performance of the 2018 post-rebuild Christchurch wastewater network and the 2018 no-earthquake Christchurch sewer network. Christchurch's pre-earthquake wastewater network consisted of approximately 1,650 kilometres of sewer mains, 91 key pump stations, around 27,000 manholes and a treatment plant[14,15]. The 2018 Christchurch no-earthquake model was developed using Christchurch's pre-earthquake wastewater network information with some further adjustments due to capital works projects, future growth areas and pipe age. As shown in figure 1, the no earthquake network mainly consists of gravity sewer network.

The post-rebuild Christchurch wastewater network includes 124 key pump stations, pressure and vacuum sewer systems, 1,770 kilometres of sewer mains, around 30,000 manholes and a treatment plant[4,14,15]. (Figure 2).

This paper summarizes how hydraulic models were developed and used to assess the performance of Christchurch's rebuilt wastewater network. This paper compares the performance of the 2018 post-rebuild wastewater network with the performance of the 2018 no-earthquake wastewater network and assesses whether the rebuild work will be able to restore the Level of Service

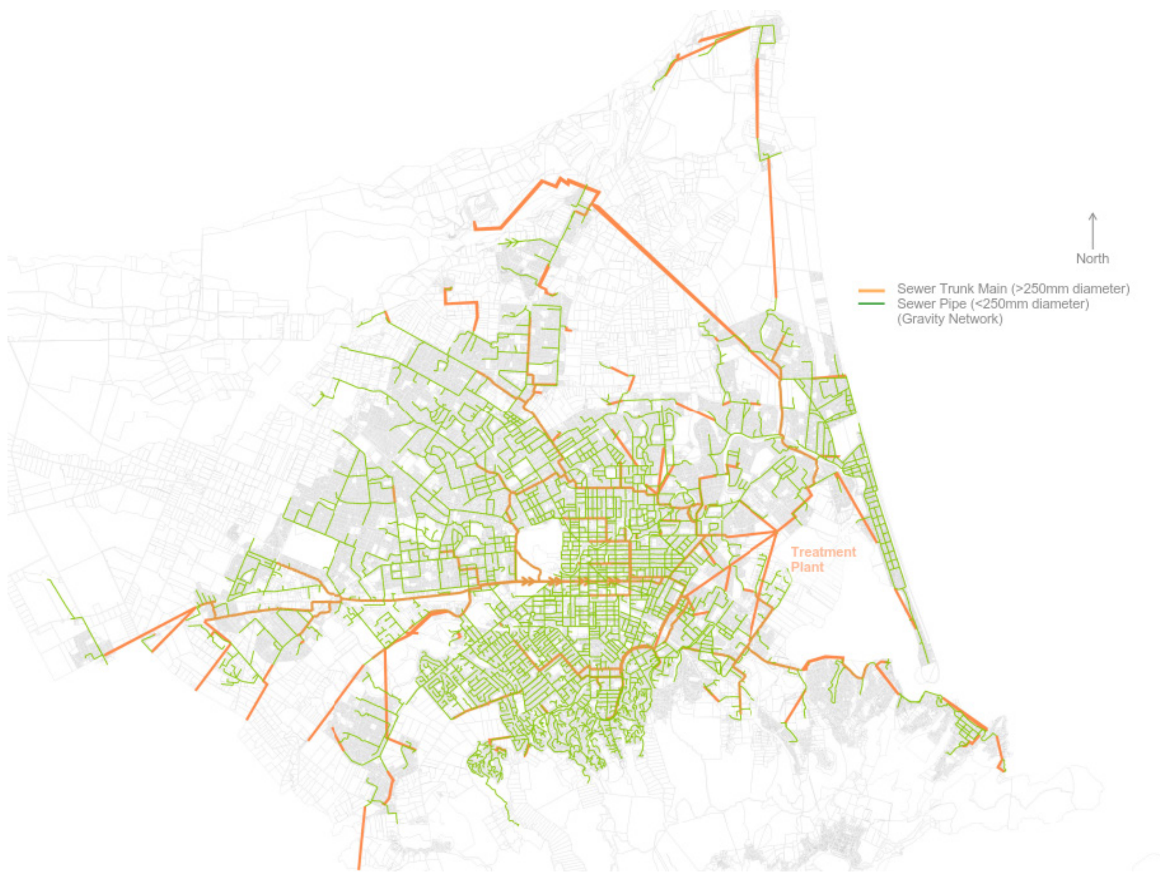

Figure 1. The 2018 no-earthquake network.

Figure 2. The 2018 post-rebuild network.

(LoS) of the wastewater network to the no-earthquake level or not.

2. Methodology

The performance of the wastewater network can be assessed using different methods: engineering condition surveys, CCTV, visual inspections, and constructed overflow monitoring and sewer network flow-monitoring[8,9,16]. Hydraulic models and GIS database are powerful tools that can combine different network information files into a meaningful platform and predict the performance of the network.

Two hydraulic models were developed for this investigation. The two 2018 models (the 2018 no-quake model and the 2018 post-rebuild model) were used to evaluate the success of the rebuild at returning LoS to a no-earthquake level. The 2018 no-earthquake model predicts the performance of the wastewater network in 2018–2019 assuming there is no earthquake in Christchurch. The 2018 post-rebuild model predicts the performance of the post-earthquake, post-rebuild network in 2018–2019 after completion of all the rebuild works. Infoworks ICM and Infonet modeling tools were used for hydraulic modelling.

3. The 2018 Post-Rebuild Hydraulic Model

The model was developed taking post-earthquake, post-rebuild information such as the post-earthquake network survey files (2015-2016), and post-rebuild GIS network files, CCTV information and recent post-earthquake flow-monitoring data (2016-2017). The 2018 post-rebuild model included post-quake population growth predicted to 2018-2019 (based on the 2013 census)[14,17]; it also included post-earthquake rebuild projects. After including the rebuild data, the model was calibrated in 2015–2016[5,6]. The model was further validated in 2016–2017 using long-term flow-monitoring data from 13 long-term flow-monitors.

3.1 Model Inputs and Parameters

The 2018 post-rebuild model parameters and input information is outlined in table 1.

Table 1. The 2018 post-rebuild hydraulic model inputs and parameters

Input Description	The 2018 Post-rebuild Hydraulic Model
Ground Level	This information was extracted from the Info Net GIS model which incorporated the latest post-rebuild survey information (2014–2015). If no data were available post-earthquake, LiDAR (airborne light detection and ranging) levels were used.
Network Data	Pipe inverts were based on recent network surveys (2014, 2015, and 2016) and as-builds information files. Inferred-level data was re-inferred based on updated post-rebuild levels in many areas. Pressure and vacuum sewer systems were included in the model. Data from numerous wastewater reticulation upgrades and renewal projects were incorporated into the model.
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 was used unless otherwise identified by operators during site visits, from condition assessments, from calibration or as proposed by construction designers and surveyors.
Sediment in Pipe	No sediment assumed unless identified by operators or seen during flow-monitoring.

Table 1 Continued

Population	Population as per 2018–2019 (population data projected from the 2013 Canterbury census data)[14,17]. Major population growth areas were identified in the north, north-west and south-west areas of Christchurch and these were added to the model.
Baseflow (DWF Infiltration)	The baseflow was based on flow-monitoring done in 2015–2016 from 102 short-term and 13 long-term flow-monitoring sites.
Infiltration (WWF)	Infiltration was primarily based on area and land use patterns which were updated based on post-rebuild calibration flow-monitoring data.
Rebuild Projects	Wastewater reticulation upgrade and renewal projects were included in the model.

3.2 Model Calibration and Validation

The post-rebuild sewer model was calibrated in 2015–2016 with an extensive flow-monitoring programme involving 102 short-term and 13 long-term flow monitors[5]. The model was again validated in 2016–2017 with data from 13 long-term flow monitors.

4. The 2018 No-Earthquake Hydraulic Model

This model was developed to understand the performance of Christchurch's wastewater network 2018–2019. It assumed there was no earthquakes in Christchurch and took account of non-earthquake related previously planned (planned before September 2010 earthquake) repair and renewal projects. The model included 2018–2019 population figures that were predicted prior to the September 2010 earthquake, along with major CCC capital work projects that were proposed to be completed by 2018–2019.

4.1 Model Inputs and Parameters

The 2018 no-earthquake model parameters and input information are outlined in table 2.

Table 2. The 2018 no-earthquake hydraulic model inputs and parameters

Input Description	The 2018 No-Earthquake Model
Ground Level	Extracted from pre-earthquake LiDAR (airborne light detection and ranging) or as-builds.
Network Data	Pipe inverts were based on pre-earthquake survey files, pre- earthquake GIS database and as-builds information. In some cases, if data were missing, it was inferred or interpolated from known points. The model also incorporated any of capital work projects proposed to be completed by 2018 or 2019.
Pipe Roughness	Default top roughness was 1.5 mm (Colebrook-White). Default bottom roughness was 3.0 mm (Colebrook-White) and 25 mm for brick barrel pipes. Standard roughness data was used unless otherwise identified by operators during site visits, from condition assessments, or from calibration.
Sediment in Pipe	No sediment assumed unless identified by operators or seen during pre-earthquake flow-monitoring.
Population	Population as per 2018–2019 (population data projected from the 2006 pre-quake census)[14,17]. Major population growth areas were identified in the north-east and south-west areas of Christchurch.
Baseflow (DWF Infiltration)	The baseflow was based on flow-monitoring done in 2010 before the September 2010 earthquake from approximately 20 short-term and 13 long-term flow-monitoring sites. If there was no flow-monitoring data for any pump station catchment area, pump station flow data were used for baseflow assessments. Further adjustments were made to account for capital work projects and changes in pipe roughness due to pipe age as per CCC's design guidelines[18,19].
Infiltration (WWF)	Infiltration was based primarily on area and land use patterns which were updated based on pre-earthquake flow-monitoring data.

4.2 Model Calibration

The 2018 no-quake model was calibrated with flow-monitoring completed before the September 2010 earthquake. The 2010 pre-quake, flow-monitoring data were used for the 2018 no-quake model with some adjustments made to account for capital upgrades planned to have been commissioned by 2018–2019. There was no pre earthquake flow monitoring for a few pump station sub-catchment areas. In these cases, pump station flow data were used for calibration and base flow assessments.

5. Results and Discussion

The no-earthquake and the post-earthquake, post-rebuild models were run for three different scenarios to compare the performance of these networks. The models were run for dry and wet weather periods.

- Dry Weather Flow (DWF) Simulation Run: The simulation was run for two standard dry weather days (with no rainfall).
- Wet Weather Flow (WWF) 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 (2002–2016).

The rainfall events were derived and assessed using Christchurch City Council's "Waterways, *Wetlands and Drainage Guide*"[18]. The hydraulic models included Christchurch's sewer network adding all the constructed overflow sites, sewer trunk mains (>150 mm diameter pipes), pump stations, manholes, other relevant assets etc so that they replicated the reality. A number of performance indicators were used in this assessment such as DWF infiltration, the hydraulic capacity of pipes, manhole surcharging, and self-cleaning potential during DWF periods and wastewater overflow volume from manholes and constructed overflow points.

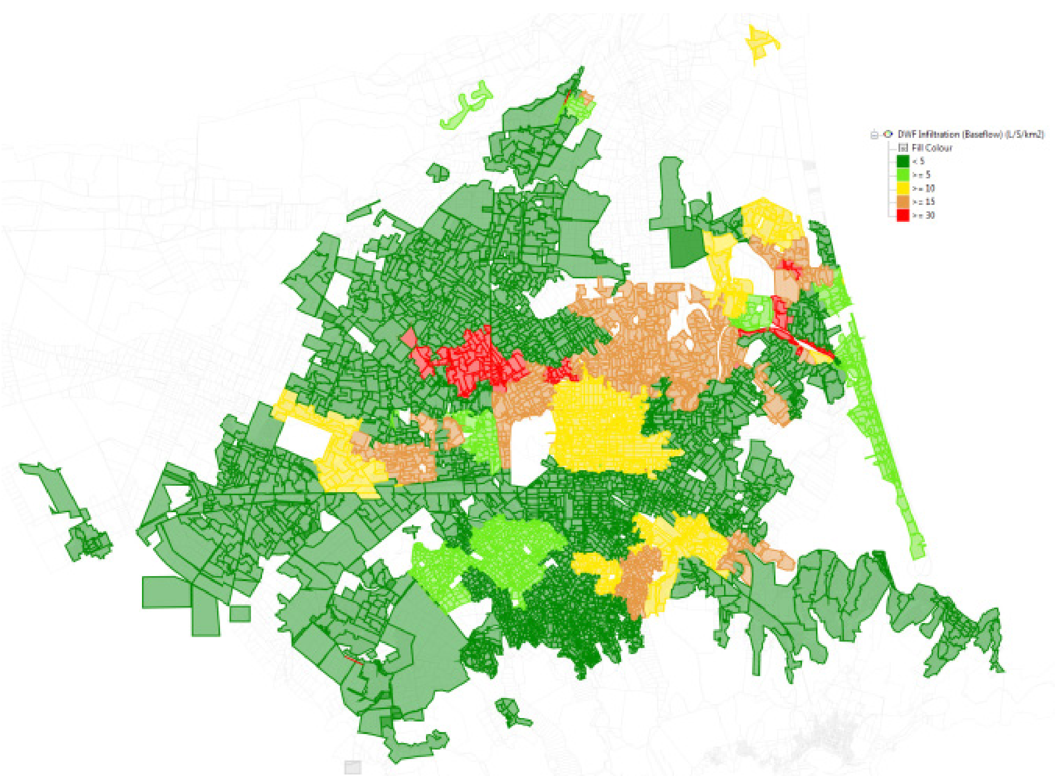

Figure 3. The 2018 no-earthquake model – DWF infiltration.

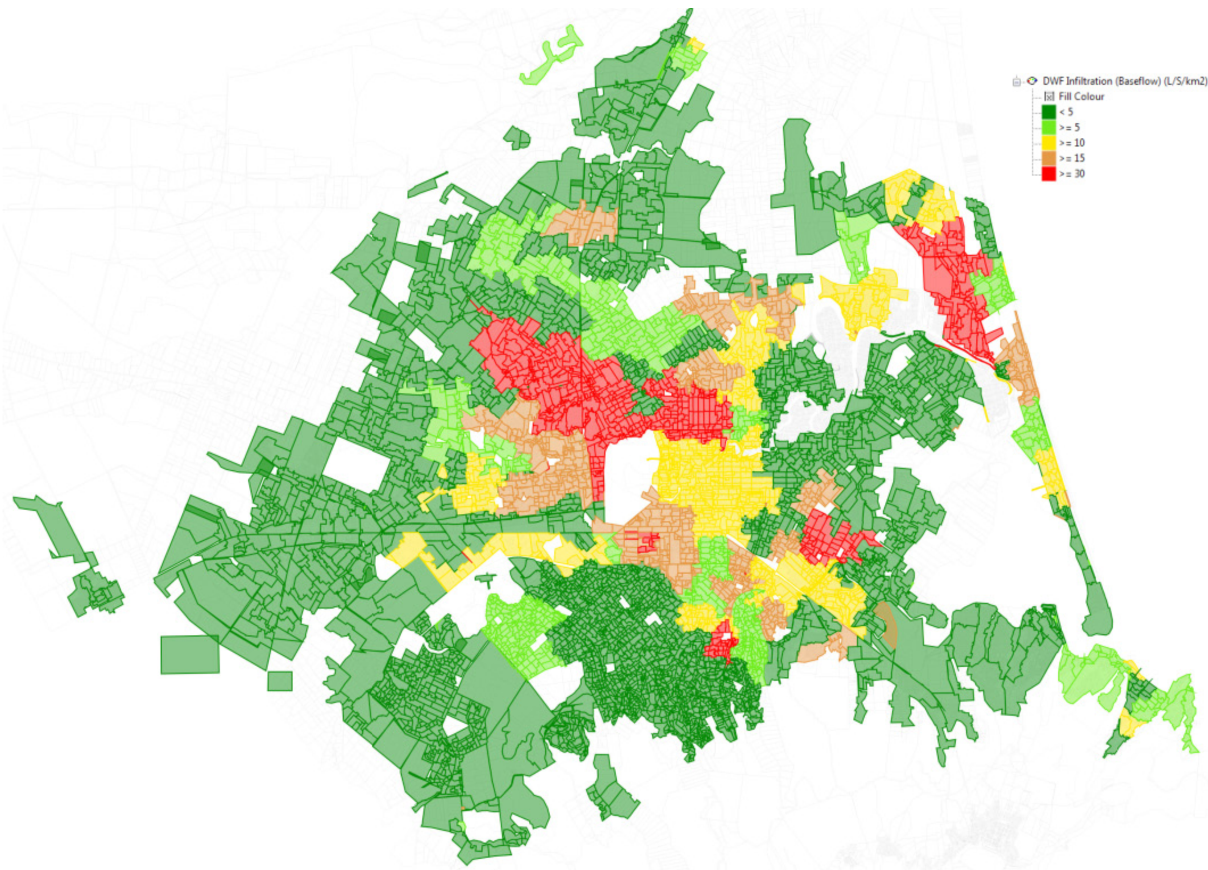

Figure 4. The 2018 post-rebuild model – DWF infiltration.

5.1 DWF Infiltration

A detailed flow-monitoring programme – using data from 102 short-term and 13 long-term flow monitors – for the post-rebuild model calibration helped to quantify DWF infiltration efficiently and effectively whereas a small number of flow monitors (20 short-term and 13 long-term flow monitors) were used for calibrating the 2018 no-earthquake model. In some areas, further calibration was done for the 2018 no-earthquake model using pre-earthquake pump station flow data. DWF infiltration data were extracted from hydraulic model files (Figure 3 and Figure 4).

As shown in Figure 3 and Figure 4, there are some areas where the 2018 post-rebuild model shows higher DWF infiltration than the 2018 no-earthquake model. This may be due to decreased rebuild expenditure in the area and decisions to maintain the earthquake-damaged asset rather than rebuilding the asset. In both network, some areas (red colour) in the north-west corner of the city centre were found to have very high DWF infiltration. Figure 3 Figure 4 In this part of the city, the pipe network is under the groundwater level. A high infiltration rate was also observed in the north-east of the city.

The earthquakes caused a significant increase in DWF infiltration especially in the east of the city. When compared with the no-earthquake model, the post-rebuild model showed less DWF infiltration in the west of the city. In some areas in the east, the post-rebuild network showed higher DWF infiltration than the no-earthquake model. No detailed assessments have been done for the pressure and vacuum sewer systems at this stage. It is assumed that there will be negligible DWF infiltration from these areas as the network is monitored using a smart control system to prevent inflow or infiltration.

5.2 Hydraulic Capacity

Assessment of the system's performance indicated good DWF capacity in general. In summary, during dry weather periods, there was around a 3.5% increase in pipe surcharging in the post-rebuild network but manhole surcharging had decreased notably in the post-rebuild network when compared with the no-earthquake network (Figure 5 and Figure 6).

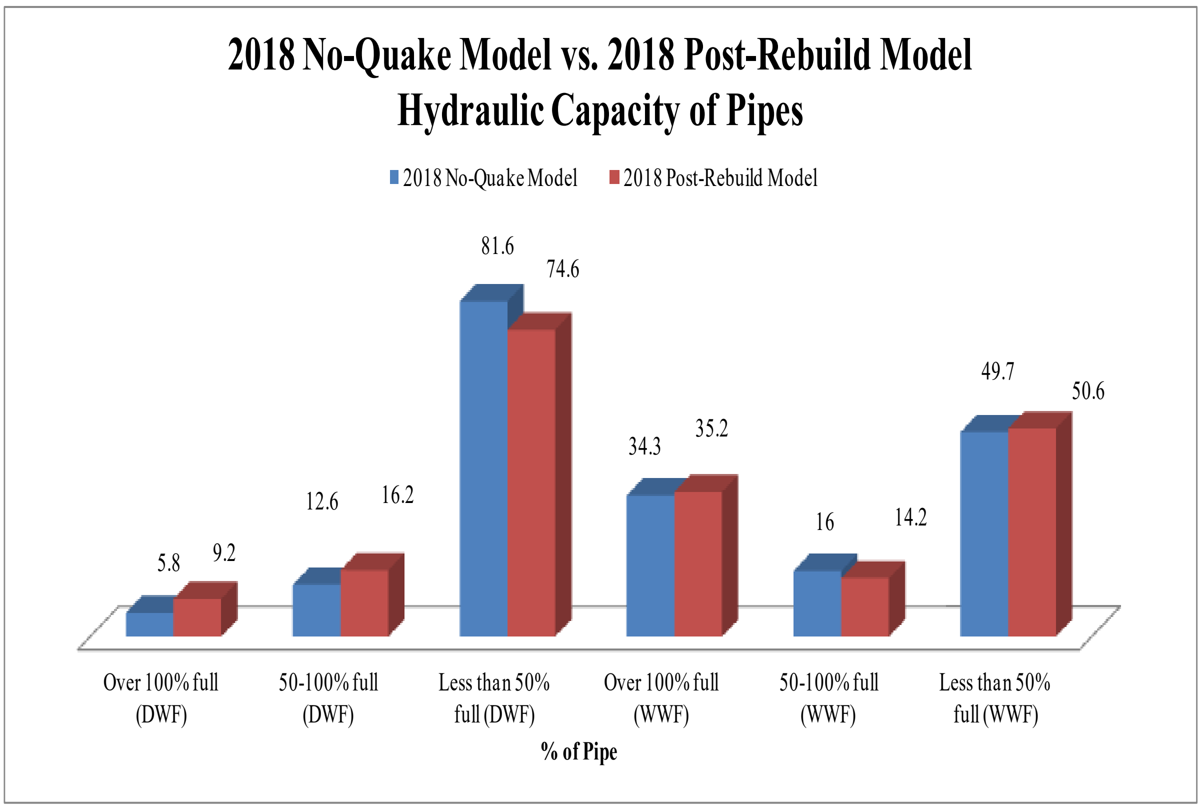

Figure 5. Hydraulic capacity of pipe (the 2018 no-earthquake network versus the 2018 post-rebuild network).

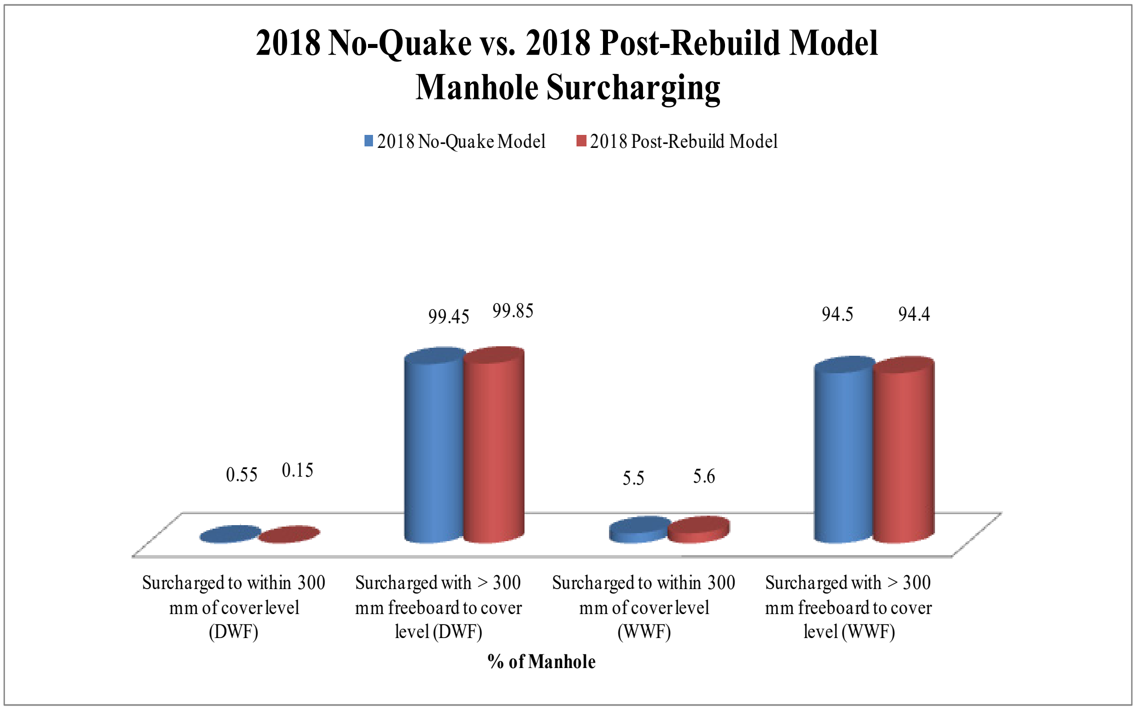

Figure 6. Manhole surcharging (the 2018 no-earthquake network versus the 2018 post-rebuild network).

During wet weather events, as shown in Figure 5 and Figure 6, there was no major difference in surcharging between these two network models. As part of the rebuild works, in some cases, the upstream network was used as storage so that wastewater overflow cannot occur in the downstream network during peak time. This may be the reason for increased pipe surcharging in the post-rebuild network during DWF periods.

5.3 Self-Cleansing Potential (Maximum DWF Velocity)

Self-cleansing is important during DWF conditions whereas self-cleansing is not an important parameter during WWF events. A self-cleansing network needs to have a minimum 0.55 m/s wastewater velocity[18,19]. Self-cleansing was found to have increased in the post-rebuild gravity network (Figure 7).

5.4 Overflow Performance and Frequency

In the post-rebuild model there were 128 constructed overflow pipes, whereas in the no-earthquake model there were 102 constructed overflow points. In summary, constructed overflow volume had increased by around 25% in the post-rebuild network (Table 3). This is suspected (anecdotally) to be due to increased areas of network capacity without downstream improvement (reduced flow

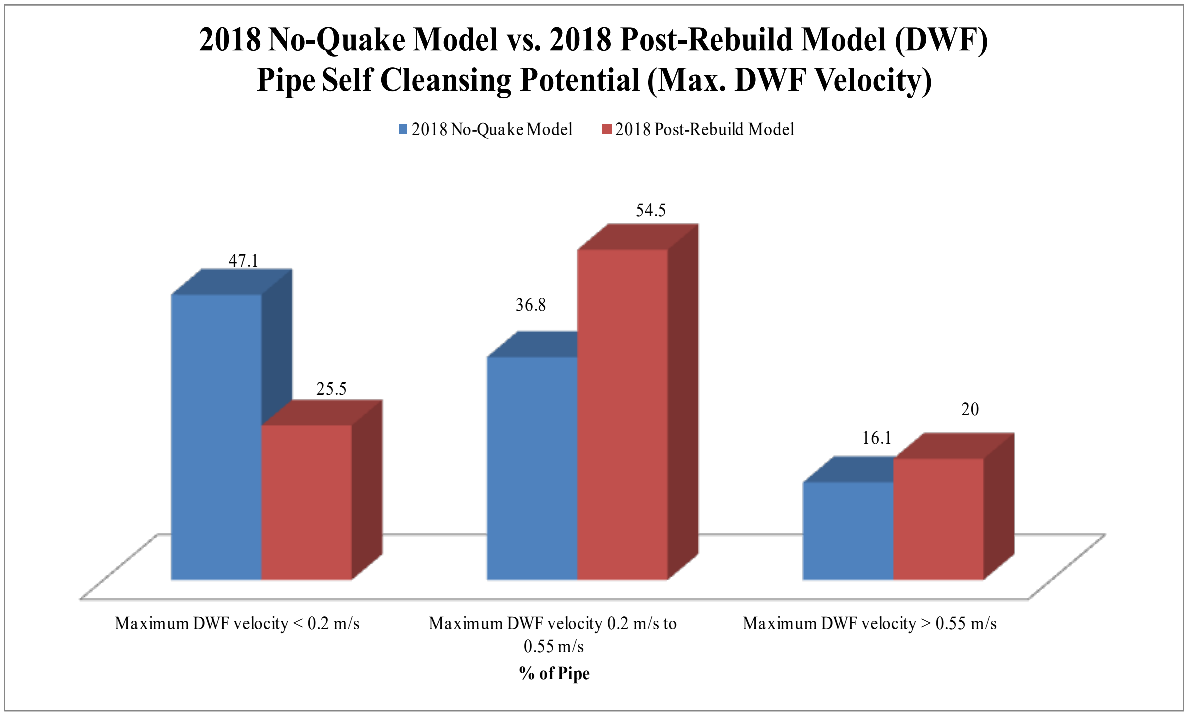

Figure 7. Self-cleansing potential (the 2018 no-earthquake network versus the 2018 post-rebuild network).

Table 3. Sewer overflow (the 2018 post-rebuild model versus 2018 no-earthquake model)

Level of Service (LOS) Target	The 2018 No-earthquake Hydraulic Model vs. the 2018 Post-rebuild Hydraulic Model
Volume of constructed overflow spilt during 15 years of storms	Constructed overflow volume increased by around 25% in the post-rebuild wastewater network.
Volume of manhole overflow spilt during 15 years storms	Manhole overflow volume decreased by around 15% in the post-rebuild wastewater network.
Total overflow volume (constructed overflow points and manhole overflow)	Total wastewater overflow volume decreased by around 2% in the post-rebuild wastewater network.

attenuation) and the introduction of additional pump stations or lift stations (creating new overflow points).

Though wastewater overflow using constructed overflow points increased in the post-rebuild model, manhole overflow volume decreased considerably (15%) in the post-rebuild network. Overall, there was approximately a 2% decrease in sewer overflows in the post-rebuild network (Table 3).

6. Conclusions

Wastewater network hydraulic models were found to be very powerful tools that can combine different network information (GIS, CCTV inspection data, surveys and flow-monitoring data) into a meaningful platform and predict the performance of the network for different development scenarios. This paper demonstrates how hydraulic models were used to assess and compare the performance of the rebuilt sewer network with the no-earthquake sewer network of Christchurch. The performance of the rebuilt network showed a mixed result. In some areas the performance of the no-earthquake model was better than the post-rebuild model and, in some areas, the post-rebuild network showed a better result. There will be less wastewater overflow in the post-rebuild network when compared with the no-earthquake network. In 2019–2020, further flow-monitoring and calibration of the post-rebuild model will give further detailed information on the performance of the post-rebuild network.

7. Acknowledgement

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8. References

1. Biswas RR. Importance of Smart Monitoring Systems for Efficient Vacuum Sewer Performance and Modelling the Network. International Journal of Computer Sciences and Engineering. 2017 August; 5 (8): 247-251. Crossref.
2. Biswas RR. Biswas TR. Modelling Seismic Effects on a Stormwater Network and Post-earthquake Recovery. International Journal of Computer Sciences and Engineering. 2017 September; 5 (9): 63-69. Crossref.
3. Christchurch Quake Live. [cited 2017 July 07]. Available from: http://www.canterburyquakelive.co.nz/Browse/
4. Biswas RR. Biswas TR. Testing the Performance of Pressure Sewer Systems to Reduce Wastewater Overflow. Research Journal of Engineering and Technology. A & V Publications. ISSN: 0976-2973. in press.
5. Biswas RR. Calibrating wastewater hydraulic model during post-earthquake rapid rebuild works. International Journal for Research in Applied Science and Engineering Technology. 2017 June; 5 (6): 461–470.
6. Biswas RR. Biswas TR. Hydraulic and Hydrologic Model Calibration and Validation for an Earthquake-Prone Three Waters Network. Unpublished.
7. Ngien S. Yap H. Flow Design of Sewerage System – A Case Study in Taman Pandan Damai, Kuantan. Indian Journal of Science And Technology. 2017; 10(2). Crossref.
8. Johnson D. O'Neill E. Using hydraulic models to aid the earthquake recovery. Paper presented at: Water New Zealand Annual Conference, 2012 September 26-28; Rotorua, New Zealand.
9. Liu M. Decision Support Framework for Post-earthquake Restoration of Sewerage Pipelines and Systems [PhD thesis]. Christchurch, New Zealand: University of Canterbury; 2016.
10. Machell J. Mounce SR. Boxall JB. Online modeling of water distribution systems: a UK case study. Drinking Water Engineering and Science. 2010; 3:21–7.
11. Boulos P.F. Smart water network modeling for sustainable and resilient infrastructure. Journal of Water Resources Management. 2017 August; 31(10): 3177-3188. Crossref.
12. Sourghali V. Pugh A. The vision and the journey for predictive modelling. In Proceedings of the Australia's international water conference & exhibition (Ozwater'16), 2016 May 10-12; Melbourne, Australia.
13. Boulos P.F. Andrew A.T. Fixing the future of wastewater systems with smart network modeling. Journal of American Water Works Association, 2015 April; 107(4): 72-80. Crossref.
14. Christchurch City Council (CCC). Water and Sanitary Services Pre and Post-earthquake GIS Network Files.

15. Christchurch City Council (CCC). Wastewater facts and figures. [cited 2016 November 10]. Available from: https://ccc.govt.nz/services/wastewater/about-wastewater/facts-andfigures/
16. Yap HT. Ngien SK. Analysis of flow characteristics in sewerage system. Applied Mechanics and Materials. 2015; 802(1):599-60.
17. Stats NZ. Canterbury Census Data. [cited 2016 March 9]. Available from: http://www.stats.govt.nz/Census/2013-census/profile-and-summary-reports/quick-stats-about-aplace.aspx?request_value=14703&tabname=.
18. Christchurch City Council (CCC). Waterways, Wetlands and Drainage Guide. 2011 December; Part B. Chapter 21. [cited 2016 March 14]. Available from: https://www.ccc.govt.nz/environment/water/water-policy-and-strategy/waterwayswetlands-and-drainage-guide
19. Christchurch City Council (CCC). Infrastructure Design Standard. 2016 September; Part 6 – Wastewater Drainage. [cited 2016 March 14]. Available from: https://ccc.govt.nz/consentsand-licences/construction-requirements/infra-structure-designstandards/download-the-ids/