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Calibrating Wastewater Hydraulic Model during Post Earthquake Rapid Rebuild Works

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Abstract*: Any modern water authority's capital works program, operational/maintenance decisions, compliance with environmental consenting, future planning and programming works highly depend on the hydraulic modelling results. There are significant risks with this if the available models are not calibrated properly and if the model is not fit for purpose. As part of the post-earthquake rebuild process, 120 short-term and 13 long-term flow monitors were installed across different parts of Christchurch's wastewater system. All these monitoring points needed to be calibrated to validate the wastewater network model and also to understand and assess the performance of wastewater network moving forward. Rapid changes in wastewater network configuration due to the fast tracked rebuild process created some unusual and unique challenges during calibration and validation works as the flow monitoring was done during different time periods and rebuild works forced the network to perform quite differently from time to time. This paper summarizes the challenges faced during model calibration and highlights the approaches adopted to address different calibration challenges and out-of-the-box scenarios.

***Keywords*: calibration, hydraulic, model, rebuild, flow, monitors**

I. INTRODUCTION

Hydraulic models have become a very powerful tool to assess the performance of wastewater network. To be suitable for use the hydraulic models must be sufficiently current and accurate to be a good representation of the actual operation of the wastewater system. The model must include up to date infrastructure, current demand, and represent operational sites correctly. Model calibration is very import to make the model useful for concept designing, planning and operational decision making. Hydraulic models have extensively been used in Christchurch to assess earthquake damage and to aid in earthquake recovery. [2]

Christchurch was devastated by a series of major earthquakes in 2010/2011. In 2013/2014, as part of post earthquake rebuild works a massive flow monitoring program was launched to calibrate the wastewater hydraulic model and also to understand the performance of the network. As part of the post-quake (PostQ) calibration, 120 short-term (ST) and 13 long-term (LT) flow monitors were installed across different parts of Christchurch's wastewater system.

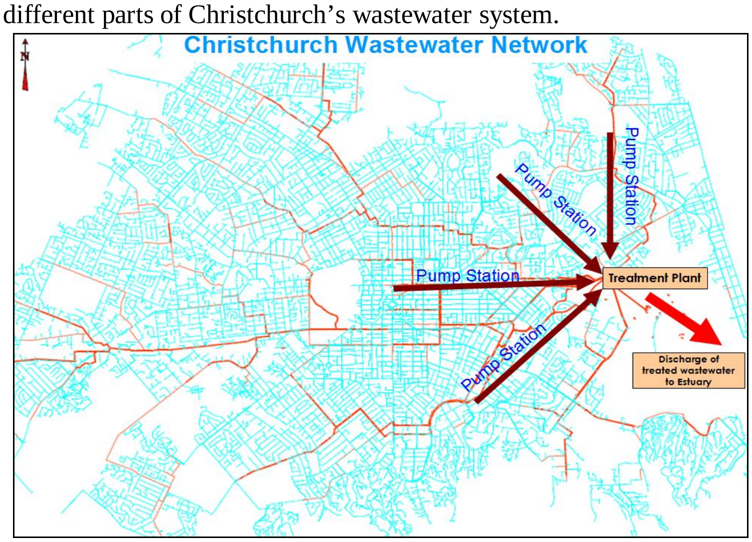

Fig. 1 Christchurch Wastewater Network

All these monitoring points needed to be calibrated to validate the post quake wastewater network model and also to understand and assess the performance of wastewater network. Rapid changes in wastewater network configuration due to the fast tracked rebuild

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process created some unusual and unique challenges during calibration and validation works as the flow monitoring was done during different time periods and rebuild works forced the network to perform quite differently from time to time.

This paper summarizes wastewater hydraulic model calibration works undertaken in Christchurch after devastating 2010/2011 Canterbury earthquakes. The paper outlines some unusual and unique challenges during calibration due to post earthquake rapid rebuild works. The document highlights the approaches adopted to address different calibration challenges and out-of-the-box scenarios.

II. MODELLING & SIMULATION

The Christchurch post earthquake Infoworks ICM wastewater hydraulic model was used for calibration. The Christchurch wastewater model was previously developed in 2011. In 2013/2014 the model was further rebuilt with additional network information and survey data and numerous changes were made to capture network upgrades as part of post-earthquake rebuild works. The model includes around 23000 manholes, around 1300 km sewer mains, all the key pump stations, pressure and vacuum sewer systems. The wastewater hydraulic model is a trunk main model and in some cases the smaller reticulation (<DN225) is not included in the model.

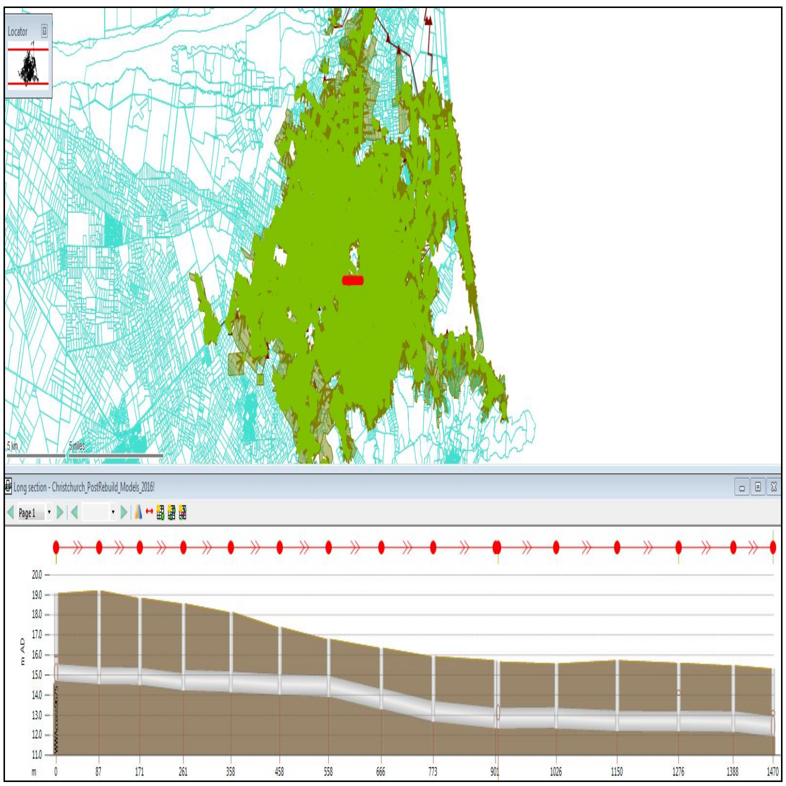

Fig. 2 Christchurch Wastewater Network Hydraulic Model Extent

III.FLOW MONITORING

Flow data for this project was accessed from 120 short term (ST01 to ST120) flow monitors installed by SCIRT (Stronger Christchurch Infrastructure Rebuild Team) and bolstered by data from 13 long term (LT01 to LT13) monitoring sites operated by AWT (Association of Water Technologies, New Zealand) on behalf of the Christchurch City Council (CCC), New Zealand. Each of the short term flow monitors were installed for a period of approximately 3-4 weeks whereas long term flow monitors are permanent flow monitors installed in different parts of trunk main network.

The 120 short term flow monitoring sites were spread across the city, with emphasis placed on areas with little previous data and/or where infiltration and inflow (I & I) were suspected to be an issue. Due to the large number of flow monitoring sites, the flow monitoring program was spread over a period from August 2013 to February 2014. Out of 120 short term flow monitoring sites, 102 sites were used for calibration. 18 short term flow monitors were either faulty as per flow monitoring report or removed/withdrawn due to on-site constraints.

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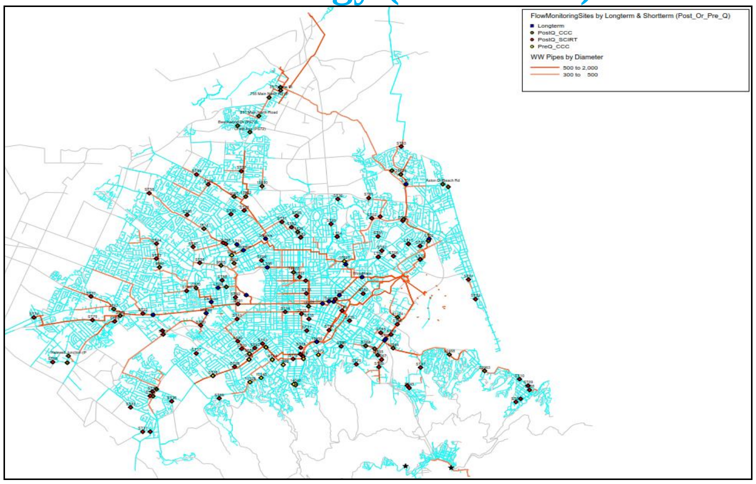

Fig. 3 Wastewater Network Flow Monitoring

IV. MODEL CALIBRATION METHOD

The calibration approach adopted was to run a prolonged acceptable period of dry weather and wet weather flow ensuring that a good match with observed data is attained at all times. Calibration over a prolonged period of Time Series Rainfall (TSR) provides the highest level of confidence and ensures the model is correctly accounting for antecedent conditions and soil saturation. But, as the short term flow monitoring was done for short time periods over an extended flow monitoring programme, this limits our ability to calibrate the model for a long time periods and multiple wet weather events.

A. Calibration Criteria

WaPUG (Wastewater Planning User Group, United Kingdom) criteria are internationally recognized as best practice for calibration works and this has been adopted for calibrating the wastewater network model. The calibration specification as per the WaPUG Code of Practice requires extensive calibration of the flow monitoring sites including flow, volume and depth criteria. [4]

Dry Weather Flow (DWF) calibration has been carried out as per WaPUG dry weather calibration standards. [4] Visual assessment of calibration is also undertaken relative to timing of peaks, noise and visual match.

TABLE I

DRY WEATHER FLOW (DWF) CALIBRATION CRITERIA [4]

Calibration Criteria	Calibration Range ("Observed" vs. "Predicted")
Depth	Maximum DWF flow depth within 100 mm of observed maximum flow depth
Volume	Predicted daily DWF flow volume within 10 % of measured daily volume
Flow	Predicted peak DWF flows within 10 % 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.

In the observed flow data rainfall induced infiltration was apparent for some of the flow monitors. Only those flow monitors which captured a response to a wet weather were calibrated for wet weather event. There were limited numbers of rainfall events captured during the flow monitoring period and in some cases this prevented the use of several rainfall events over a defined period for wet weather calibration as suggested by WaPUG. 45 flow monitors were identified to be suitable for wet weather calibration. In spite of different limitations, catchment response to rainfall and soil saturation is properly represented in the model by a good visual fit and similar timing of peak in the "Observed" vs. "Predicted" graph.

For the wet weather calibration works, observed data was compared against model predicted data and assessed against the WaPUG criteria. WaPUG criteria for wet weather calibration are outlined below:

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TABLE II
WET WEATHER FLOW (WWF) CALIBRATION CRITERIA [4]

Calibration Criteria	Calibration Range ("Observed" vs. "Predicted")
Depth	Maximum WWF 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 WWF volume within +20 % or -10 % of measured volume
Flow	Predicted WWF peak flow within +25 % or -15 % of observed peak

B. Calibration Approach

All model adjustments made in order to achieve calibration were based on observation or logical parameter adjustments with some justifiable basis.

As part of the calibration process pipe roughness or silt depth was occasionally adjusted at the flow monitor site or in other parts of the system where inspections had identified this. Some changes to key structures were also made within the model as per the latest operational data. Representative days with good coverage were selected for DWF and WWF calibration.

In order to ensure calibration represents the most conservative snap shot of the system's operation, the model was calibrated mainly for the winter season (as minimum DWF varies seasonally in areas), at first with the short term flow monitors, and then further adjustments were done for long term sites. There were a limited number of rainfall events during the flow monitoring period. Therefore, wet weather calibration adjustment was done only for 45 short term flow monitors, where suitable data for wet weather response was captured.

C. Flow Pattern

During this calibration numerous flow profiles were added into the model based on the observed flow data. The weekday profiles were adapted to create weekend profiles which typically consisted of a delayed and more pronounced morning peak. For this work, baseflow is defined as the flow rate observed during minimum DWF flow when the diurnal element is accounted for. Trade waste flow is also accounted as per latest available information provided by the Christchurch City Council (CCC).

D. Rainfall Hydrology

The wastewater system and stormwater network share some critical aspects of surface hydrology. Once the ground is saturated due to rainfall, some water infiltrates into the sewer system 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).

The pervious areas of the wastewater catchments were set to represent surface infiltration to ground only and the Ground Infiltration Module (GIM) accounts for soil saturation and infiltration to the wastewater system.

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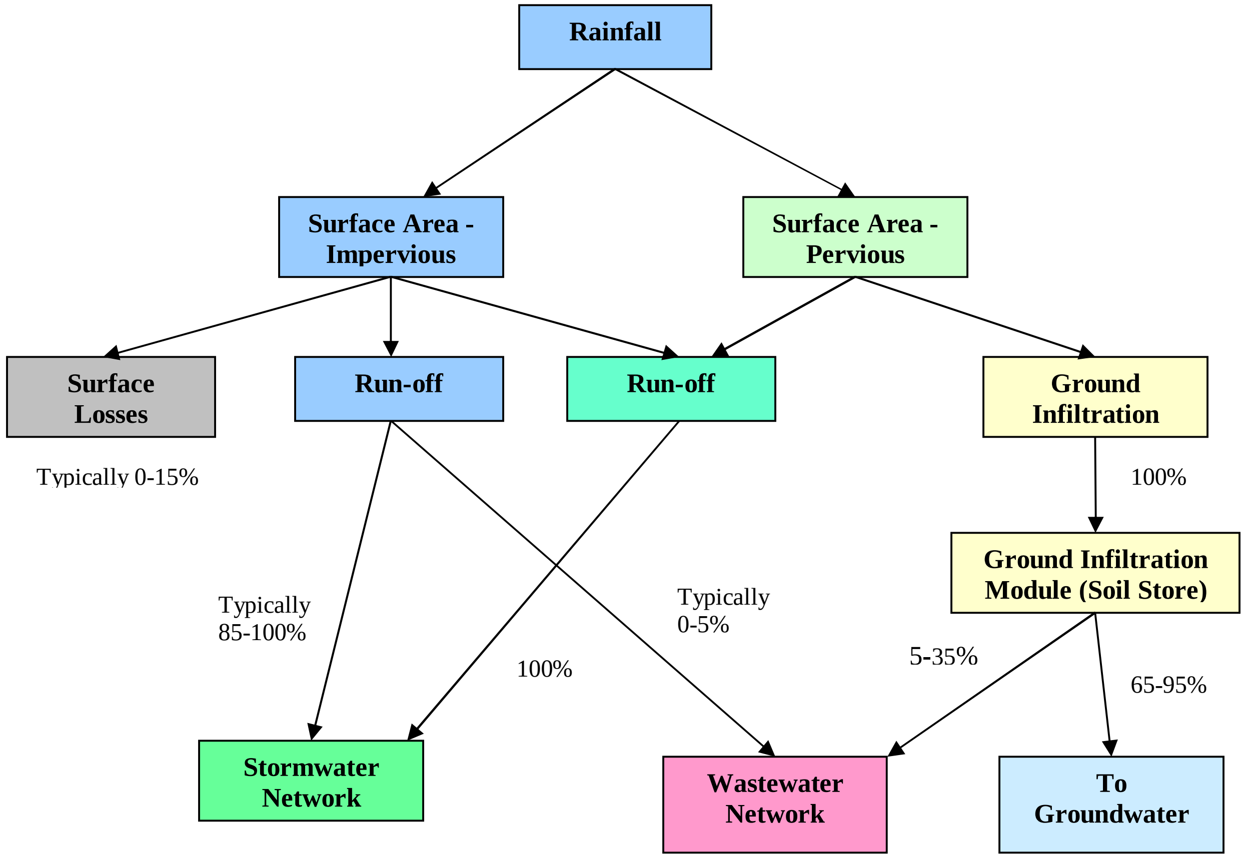

Fig. 4 Rainfall Distributions in the Model

Penman evapotranspiration rates for Christchurch were accessed from New Zealand's National Climate Database managed by NIWA (National Institute of Water and Atmospheric Research, New Zealand). This data was incorporated into the rainfall data in order to more accurately account for antecedent conditions when running Time Series Rainfall.

V. RESULTS & DISCUSSION

Flow monitoring is normally done during standard dry and wet weather periods for calibrating a wastewater model. In ideal situation, flow data is not influenced by major construction activities as the selection of monitoring period is carefully chosen to avoid unusual surprises.

In post-earthquake Christchurch due to unavoidable circumstances such as rapid construction works, funding constraints, rapid decision makings on project design and completions, many flow monitors were installed during the construction works. Flow monitoring done in Christchurch was highly influenced by massive ongoing rebuild works, post-earthquake unusual wastewater discharge and groundwater infiltrations. This caused surprising data pattern in different areas of the network.

It was very important to take out-of--box approaches to address different calibration challenges.

As part of model calibration work, a model calibration team was formed to understand what was happening in the network during the flow monitoring periods. Construction workers, contactors, designers, and asset engineers were part of this team.

A separate team of network operation engineers was consulted to understand wastewater network response. The network engineers helped in reviewing the flow monitoring data and calibration of model.

Ongoing hydraulic model maintenance and updating was a big challenge during model calibration. Continuous communication with GIS team, construction contractors, designers and surveyors was very important to keep the model current and up-to-date at different points of time.

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A. Construction Works & Dewatering

As part of rebuild works, a lot of construction works were going on during the flow monitoring program. This caused flow monitoring instrument to record unusual flow pattern for 11 flow monitoring sites. A few case studies are outlined below:

1) Case 01: Occasional Discharge of 30 l/s: An occasional discharge of 30 l/s was observed at flow monitoring site ST03 (Short Term Flow Monitor 03).

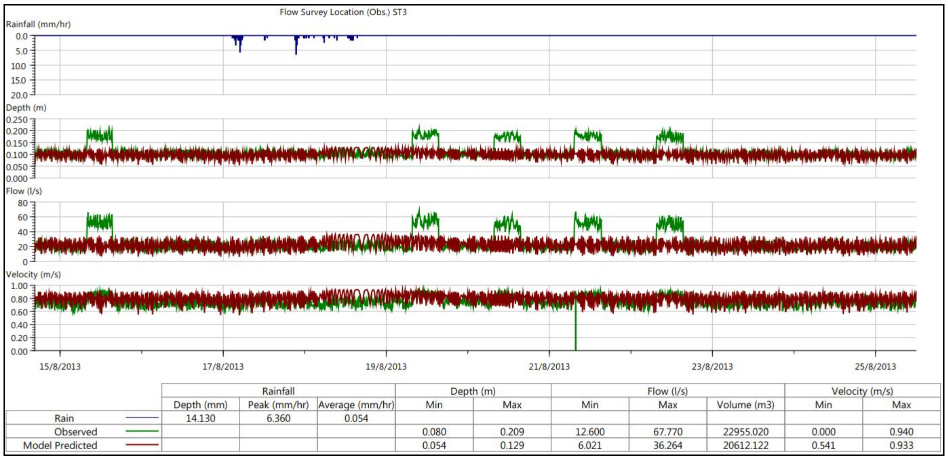

Fig. 5 ST03 Observed vs. Predicted Flow (Post Calibration)

It was confirmed by the construction contractors that truck wash down in a nearby construction site was occasionally discharging around 30 l/s during morning peak time. This additional flow rate was not added in the model as this is an unusual discharge due to ongoing construction and construction related dewatering.

2) Case 02: Gradual Decrease of Flow & Depth: As per observed data, flow and depth was found to decrease day by day at short term flow monitor 38 (ST38).

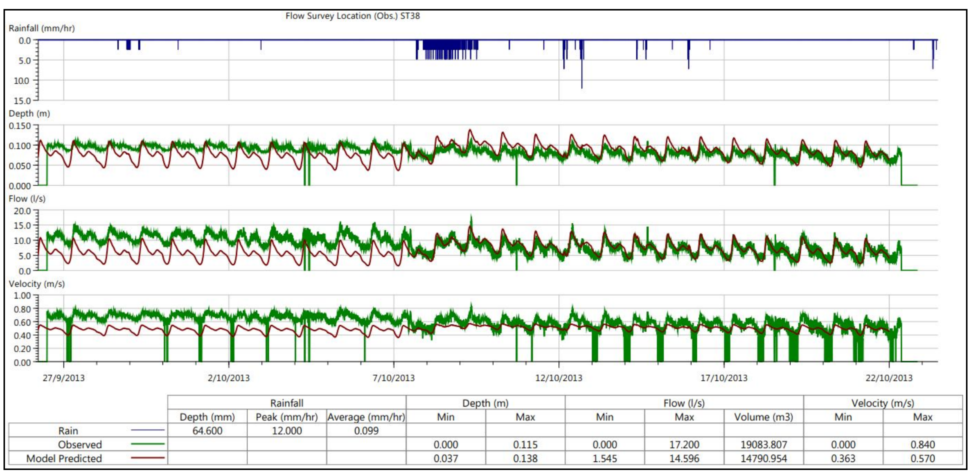

Fig. 6 ST38 Observed vs. Predicted Flow (Post Calibration)

The construction contractors confirmed that upstream flow control device and pipe bunging during construction works caused this unusual data pattern. Historical long term flow monitoring data was analysed and advice from network operation engineers were taken into consideration for calibration.

B. Project Completion & Network Change

As part of rebuild works, network configuration and flow directions changed rapidly time to time. Flow diversion, new rebuilt network and new pump station set up caused changes in flow pattern in different parts of wastewater network. Around 14 flow monitors recorded unusual flow data due to rapid changes in network configuration. A few case studies are outlined below:

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1) *Case 01: Low Flow Rates for a Big Catchment Area*: Short Term Flow Monitor 29 (ST29) was installed downstream of a big catchment area and it was located upstream of Pump Station 40 (PS40). The network operation engineers confirmed very high flow rates and surcharging in the network upstream of PS40.

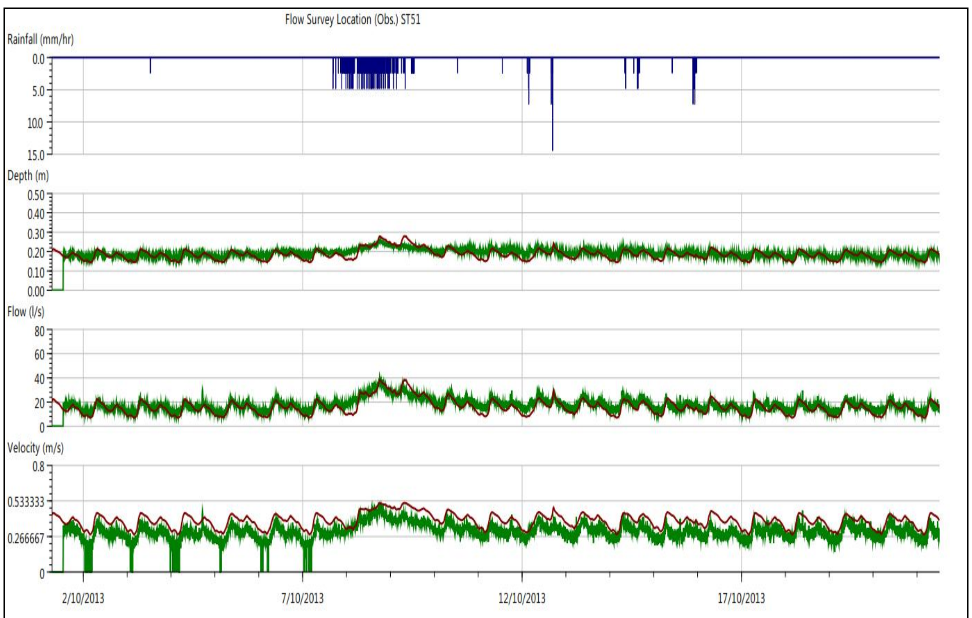
Historical pump operation data (PS40) suggested that surcharging was observed at this location in past. But, flow monitoring data showed no surcharging in the network.

	Rainfall			Depth (m)		Flow (l/s)			Velocity (m/s)	
	Depth (mm)	Peak (mm/hr)	Average (mm/hr)	Min	Max	Min	Max	Volume (m3)	Min	Max
Rain	27.090	4.800	0.046							
Observed				0.121	0.151	6.830	11.680	16953.644	0.000	0.480
Model Predicted				0.111	0.139	6.615	9.903	17030.300	0.446	0.471

Fig. 7 ST29 Observed vs. Predicted Flow (Post Calibration)

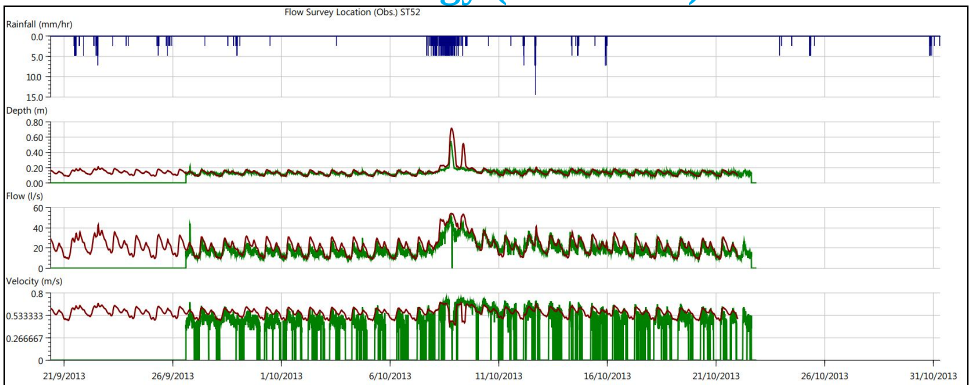
The designers and contractors suggested a number of updates including changes in pipe network and flow directions due to rapid completion of a few projects. This caused decrease in catchment area for flow monitor ST29. Calibration of flow monitor ST29 was done after readjusting the network configuration.

2) Case 02: Downstream & Upstream Flow Monitor Data Mismatch: Short Term flow monitor ST52 was installed at a location downstream of another short term flow monitor ST51. The observed wastewater flow and volume at ST52 was found to be less than the observed data at ST51.



	Rainfall			Depth (m)		Flow (l/s)			Velocity (m/s)	
	Depth (mm)	Peak (mm/hr)	Average (mm/hr)	Min	Max	Min	Max	Volume (m3)	Min	Max
Rain	47.600	14.400	0.098							
Observed				0.000	0.257	0.000	40.440	30516.740	0.000	0.510
Model Predicted				0.145	0.279	7.078	38.375	27803.291	0.283	0.519

Fig. 8 ST51 Observed vs. Predicted Flow (Post Calibration)

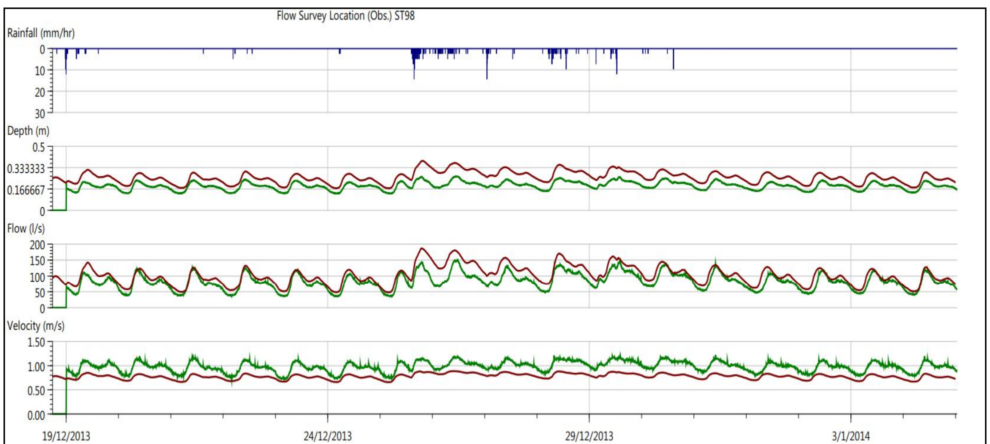


		Rainfall			Depth (m)		Flow (l/s)			Velocity (m/s)	
		Depth (mm)	Peak (mm/hr)	Average (mm/hr)	Min	Max	Min	Max	Volume (m3)	Min	Max
Rain		71.600	14.400	0.073							
Observed					0.000	0.542	0.000	51.770	41809.851	0.000	0.740
Model Predicted					0.086	0.717	8.920	54.236	59825.020	0.417	0.689

Fig. 9 ST52 Observed vs. Predicted Flow (Post Calibration)

The construction contractors proposed that exfiltration could be the main cause of this mismatch. The network operation engineers did not agree with this based on their network knowledge. The model was calibrated with ST51 only. The calibration mismatch at ST52 was taken as an anomaly. The catchment area was further calibrated with downstream flow monitors (downstream of ST52).

3) Case 03: No Flow Rate for a Big Catchment: Short Term Flow Monitor 87 (ST87) and Short Term Flow Monitor 98 (ST98) were installed on two cross connected trunk mains equally splitting the flow. During flow monitoring period, ST87 was found to have very less flow compared to ST98.



		Rainfall			Depth (m)		Flow (l/s)			Velocity (m/s)	
		Depth (mm)	Peak (mm/hr)	Average (mm/hr)	Min	Max	Min	Max	Volume (m3)	Min	Max
Rain		51.000	14.400	0.123							
Observed					0.000	0.265	0.000	149.910	121208.001	0.000	1.220
Model Predicted					0.172	0.386	48.083	186.219	150788.346	0.660	0.886

Fig. 10 ST98 Observed vs. Predicted Flow (Post Calibration)

The asset engineers and construction workers confirmed that due to upstream pipe bung off, ST87 recorded no flow data. As ST87 and ST98 were interconnected, it was decided not to calibrate model with these flow monitors (ST87 and ST98). Flow monitors downstream of ST87 and ST98 were used for calibration.

C. Unauthorized Wastewater Discharge

As part of flow monitoring and calibration works, 9 sites were identified with unauthorized wastewater discharge. A few case studies are outlined below:

1) Case 01: Unauthorized Discharge of 6 l/s: At short term flow monitoring site 58 (ST58), observed flow data was around 6 l/s. According to trade waste database of Christchurch City Council (CCC), upstream industry area was authorized to discharge 1.5 l/s.

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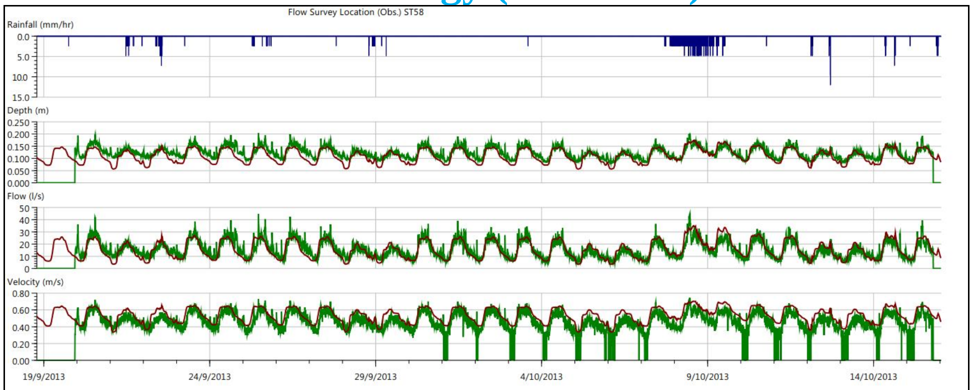
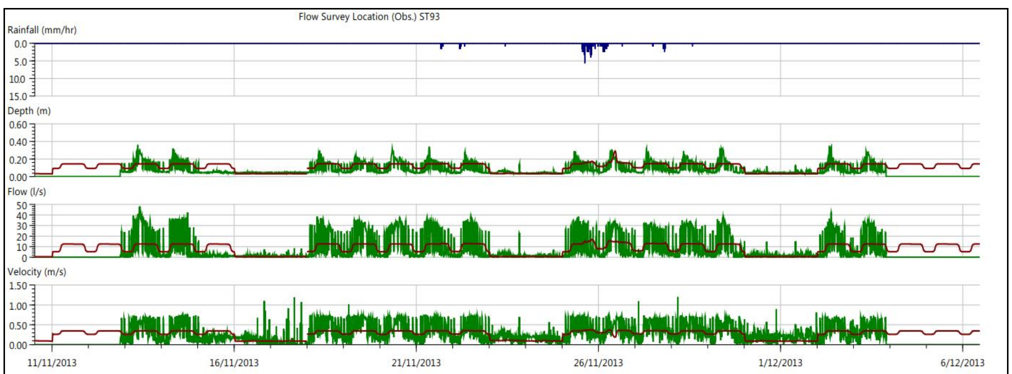


		Rainfall			Depth (m)		Flow (l/s)			Velocity (m/s)	
		Depth (mm)	Peak (mm/hr)	Average (mm/hr)	Min	Max	Min	Max	Volume (m3)	Min	Max
Rain		71.200	12.000	0.109							
Observed					0.000	0.204	0.000	44.710	34843.269	0.000	0.740
Model Predicted					0.057	0.173	3.537	35.047	36398.757	0.337	0.703

Fig. 11 ST58 Observed vs. Predicted Flow (Post Calibration)

The model was calibrated with the observed data at ST58. This ensured a conservative snap shot in the network. A calibration note was added in the model. The information was communicated with the trade waste team of Christchurch City Council (CCC) for enforcement actions.

2) Case 02: Unauthorized Private Pump Station Discharging Unauthorized Wastewater : At short term flow monitoring site 93 (ST93), an unauthorized trade waste discharge using an unauthorized private pump station was observed.



		Rainfall			Depth (m)		Flow (l/s)			Velocity (m/s)	
		Depth (mm)	Peak (mm/hr)	Average (mm/hr)	Min	Max	Min	Max	Volume (m3)	Min	Max
Rain		22.740	5.640	0.037							
Observed					0.000	0.362	0.000	47.590	15548.001	0.000	1.200
Model Predicted					0.031	0.290	0.357	16.850	13042.017	0.087	0.375

Fig. 12 ST93 Observed vs. Predicted Flow (Post Calibration)

Though the model was not updated with an unauthorized pump station site, total flow and volume was matched using a trade waste profile. This ensured a conservative snap shot in the network and a calibration note was added in the model. The information was communicated with the trade waste team of Christchurch City Council for enforcement actions.

VI. CONCLUSIONS

Hydraulic models are used for multimillion dollar decision makings. Any modern water authority's capital works program, operational/maintenance decisions, compliance with environmental consenting, future planning and programming works highly depend on the hydraulic modelling results. There are significant risks with this if the available models are not calibrated properly and if the model is not fit for purpose. The Christchurch wastewater model was successfully calibrated with 102 short term and 13 long term flow monitoring sites. Collaboration among hydraulic modellers, network operation engineers, construction contractors, GIS team, and surveyors made the calibration project successful. Successful calibration ensured high confidence on model predicted results and decision makings.

It was a challenge to keep the models "current and up-to-date" in the face of changes in performance of the wastewater network due to rapidly completed construction projects, changes in design during construction works and also due to rapidly changing design schemes to meet budgetary constraints and other limitations. It was very important to keep the records of these rapid changes in the network and replicate these in the model so that the hydraulics model could be calibrated and used to meet the changing needs of the stakeholders.

he model must be calibrated with great care. A hydraulic modeller must need to understand flow data thoroughly before calibrating the model. It is very important to have network knowledge for calibration.

A hydraulic modeller must avoid "force fitting" of model parameters to match unrealistic data pattern. If anomalies are identified during model calibration, these need to be investigated rather than forcing the model to match observed data.

f any anomaly cannot be resolved then the hydraulic modeller should not use that data for calibration. If required, further flow monitoring needs to be done to properly calibrate the model.

Ongoing rapid construction works and network changes created some unusual model calibration challenges in Christchurch. An effective and efficient collaboration among hydraulic modelers, construction contractors and network operation engineers was important to make the calibration project successful.

VII. ACKNOWLEDGMENT

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