CHRISTCHURCH CITY WASTEWATER INFRASTRUCTURE – RESPONSE ASSESSMENTS AND REPAIR TECHNIQUES

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ABSTRACT

This paper looks at the assessment processes and repair techniques utilised to stabilise the wastewater network and maintain service to the residents of Christchurch. At May 2013 Council had spent a total of $155 million on earthquake wastewater repairs and maintenance. $65 million has been utilised solely on repairs and stabilisation of the wastewater network.

The majority of damaged infrastructure occurred in recent marine sediment deposition areas. Earthquake induced liquefaction resulted in higher than "business as usual" operational costs and increased risk of wastewater overflows to waterways. Once the network was sufficiently cleared of debris, pipe assessments were undertaken covering immediate and longer term requirements.

The assessment processes utilised included pole camera, CCTV and the sewer leak technology of electro scanning. Repair techniques utilised include traditional dig and lay, pipe lining and patching, pipe bursting and pipe insertion, and the injection of compound resins around the pipe exteriors. The compound injection technique was utilised in areas of high ground water infiltration where dig and lay would have required considerable dewatering, resulting in significant costs and longer term disruption. A subset of each repair treatment system was assessed against ground and local environmental conditions, particularly depth to pipe, liquefaction index, pipe material and disruption to communities.

KEYWORDS

Investigation, Electroscan, Repair Techniques, Burst, Injection, Infiltration, Wastewater

NOMENCLATURE

CCTV	Closed Circuit Television
CIPP	Cured in Place Pipe – also referred to as Pipe Lining
EQ	Earthquake
I & I	Inflow and Infiltration
KPI	Key Performance Indicator
LRI	Liquefaction Resistance Index
LoS	Level of Service
Mw	Moment Magnitude Scale
SCIRT	Stronger Christchurch Infrastructure Rebuild Team

1 INTRODUCTION

Christchurch city is situated in the South Island of New Zealand, located on the Canterbury Plains. The Council infrastructure services residential, commercial and industrial customers, and is sited mainly on flat land with a majority of alluvial deposits with ancient volcanic geological formations and approximately 10% marine and river sediments, and wind blown deposits in the hill regions.

The Mw7.1 Greendale (Canterbury) EQ event of September 4 2010, the subsequent three events over Mw6 and interceding 40,000 aftershocks exposed significant weaknesses in the core wastewater infrastructure services of

Christchurch City. It was the marine and river sediments that enabled the most significant EQ driven infrastructure damage to occur, generally through lateral spread and liquefaction.

The Council's infrastructure was developed shortly after settlement began from the 1850's, with swamp land drained and a foul water drainage system progressively installed. Key details of the Council's wastewater assets are:

- Bedding and backfill was not always used or installed to an acceptable standard historically, in some instances native ground was used to backfill trenches
- The majority of pipes are in deep flat areas, resulting in heavy reliance on pump stations. Over 100 pump stations are installed across the city to allow for the gravity collection of waste
- High water tables and liquefiable soils present in those areas close to rivers, wetlands and previously drained swampland
- I&I varied above the design standard peaking factor of four to five due to high seasonal groundwater, as a result overflow to rivers was relatively frequent in winter
- There is a significant proportion of "brittle" pipe material in the network eg. earthenware, asbestos cement

1.1 COUNCIL OBJECTIVES

One of Council's objectives is to deliver efficient wastewater infrastructure services. This is prescribed under the Local Government Act 2002. As part fulfillment of this objective, on 1 July 2010, the Council awarded the water and wastewater maintenance contract to the contractor, City Care Ltd. The partnership contract requires delivery of water and wastewater services including operation and maintenance of the networks, pump stations, reservoirs and treatment plants (Banks Peninsula). The contract provides a set of KPI and performance measures mirroring the Council's 2009-2019 Long Term Plan (Table 1). The contract is based on a shared partnership and risk framework.

Table 1: Selected Wastewater KPI Targets.

CCC Requirement: **Wastewater service is provided in a safe, convenient and efficient manner**	**KPI Target**
Target 11.0.3 – Wet weather sewer overflows each year as reported by Environment Canterbury	No "major and/or persistent non-compliance with resource consent for the Avon and Heathcote Rivers
Target 11.0.1.5 Service interruptions for customers	< 80 properties served affected by service interruptions per year.
Target 11.0.2 Odour Events (includes chemical toilets)	< 4 odour complaints / 10,000 properties served / year Equivalent < 5 / month

In 2012-2013 temporary amendments were applied to the contract targets recognizing the impact EQ damage to the wastewater network had on achieving them. For example target 11.0.1.5 was amended to < 1,000 properties affected, in recognition of the physical assets significantly reduced condition and resulting performance.

Selected wastewater KPI trends are shown in Figure 1. Significant drops in performance against target are generally due to the impact of inflow events. It has been estimated that a series of 20mm rainfall events will currently result in network overflows with multiple jobs logged for loss of service.

Figure 1: Wastewater KPI Trends July 2010 – June 2013

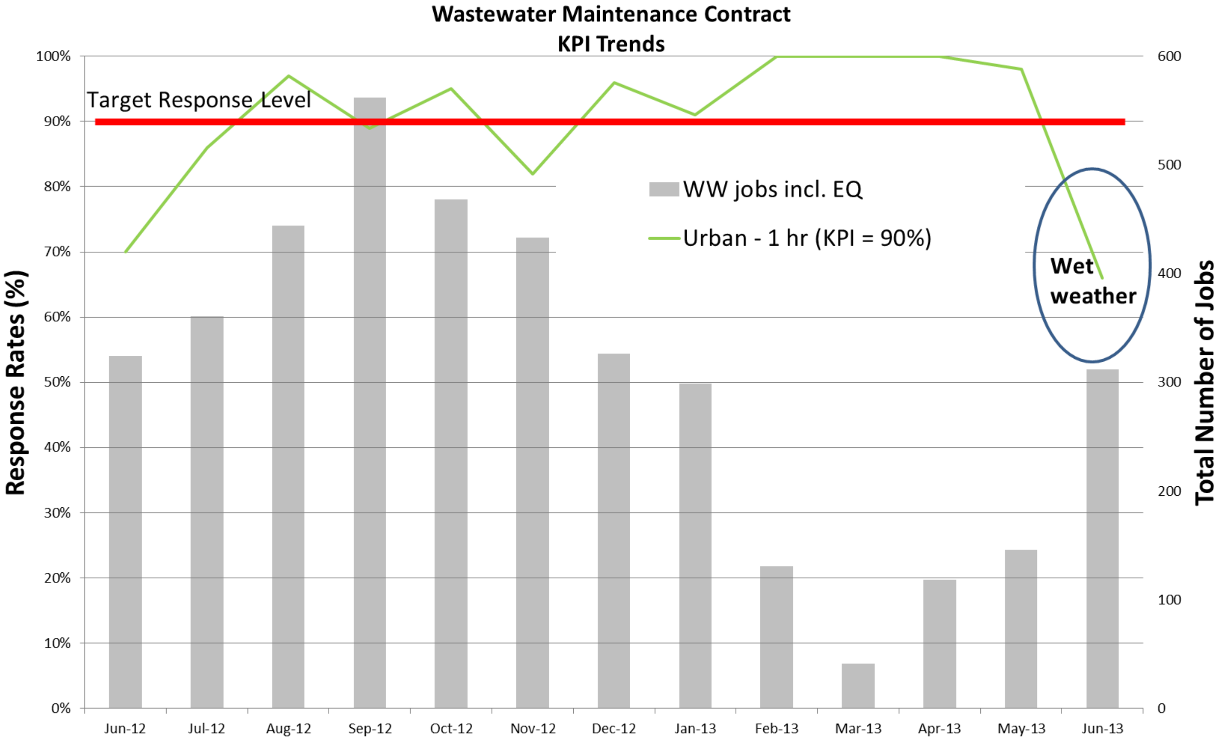


Figure 1 identifies that as wet weather periods occur there is a significant drop in the ability to respond. In this case "Urban – 1hr" requires the contractor to be at the site of the wastewater overflow within 1 hour of notification. Wet weather (several greater than 20mm rainfall events over one week) resulted in network inundation and the LoS not being met.

2 WASTEWATER NETWORK

2.1 GENERAL CHARACTERISTICS

The Christchurch wastewater network consisted of around 1800 kilometres of Council owned gravity pipelines greater than 100mm diameter. The network consists of various different pipe materials and sizes (Table 2). 90.5 % of the network is less than or equal to 399 mm diameter pipe. These pipe suffered the most damage from seismic loadings.

Table 2: Wastewater Network Diameter and Length (source M. Galambos CCC)

Diameter (mm)	<100	100-199	200-399	400-599	600-799	800-999	1000-1099	>1099	Total
Length (km)	13.1	1106.1	504.2	74.8	52.1	18.1	8.1	16.6	1793.1
% (of total	0.70%	61.70%	28.10%	4.20%	2.90%	1.00%	0.50%	0.90%	100%

Of the 1793 km of pipe, 82% or 1356 km are concrete, earthenware and unmodified PVC (Table 3). These materials were the focus of most repairs.

Table 3: Wastewater Network Material and Length (source M. Galambos CCC)

Material	RCRR	EW	uPVC	AC	CONC	PVC	Other	Total
Length (km)	628.6	371.4	356.3	147.9	129.7	62.7	96.5	1793.1

% (of total	35.1%	20.7%	19.9%	8.2%	7.2%	3.5%	5.2%	100%

Based on modelling undertaken by SCRIT, 56% of the network has been installed below the shallow groundwater table, therefore in applicable conditions may be subject to liquefaction induced stress.

These primary asset details will change significantly by December 2016, which coincides with the planned end of horizontal infrastructure rebuild works. This is due to a significant change in system configuration in areas through installation of shallow lift station gravity systems, and low pressure and vacuum system installations as gravity system replacements.

2.2 PIPE FAILURE MATERIALS AND MODES

There were a number of common failure points and modes in the wastewater network – liquefaction being one mechanical vector. In their review of wastewater pipe failure modes Brooks and Craigie (2012) found that small diameter brittle material wastewater pipes at greater than 1.5 metres depth below ground surface failed due to the effect of liquefaction. Modern materials including PE and PVC were reported as performing very well. However, asbestos cement (AC) pipe being 8% of the wastewater network generally performed very poorly.

This paper considers those observations based on a selection of repairs undertaken on the network between 2010 and June 2013.

2.3 NETWORK OPERATION – INITIAL LEVEL OF SERVICE REQUIREMENTS

In the aftermath of the EQ's the immediate requirement from Council was for its contractors to reinstate the wastewater service to the community and provide a functional wastewater network; albeit at a level of service lower than pre- EQ conditions. Appendix A - Figure 2 provides a snapshot of the network status following the third significant EQ in June 2011.

In addition to public health considerations and service reinstatement actions other critical elements which the Council and its contractors sought to minimise or eliminate wherever possible were:

- Wastewater overflows to the Avon and Heathcote Rivers and contributing streams /drains
- I & I of ground and surface water into the piped network
- Liquefaction induced pipeline blockages

While it had been acceptable from a public health perspective to discharge wastewater to the rivers under emergency conditions, this would not be acceptable for the longer term and action was required to minimise the frequency and volume of discharges.

These river discharges were compounded by high I&I which dramatically increased flows arriving at pump stations and the central wastewater treatment plant – Table 4. The associated sediment (sand/silt) deposition not only severely reduced pipelines and pumping and treatment facilities capacity and performance, but often ended up in the rivers through overflows. Where the sediment stayed in the pumped network, it resulted in inefficient pumping and treatment with associated high operational and cleaning costs.

Table 4: Christchurch Wastewater Treatment Plant metrics

Year	Average Daily flow (m3)	Total flow (m3) per year	Total cost incl dep. ($M)	Operational cost ($M)
09/10	173,000	62,986,000	11	6
10/11	180,000	65,536,000	14	8
11/12	223,000	81,240,000	15	9
12/13	205,000	74,748,000	17	8

Source Feary, J. CCC (2013)

In 2011-2012, wastewater flows increased by approximately 16 M cubic metres, with a resulting increase in operational costs. This may in part be attributed to the damaged network inflows. Capital costs are excluded from the figures above.

Following the initial rollout of chemical toilets and waste collections tanks to replace EQ damaged infrastructure and provide for basic wastewater disposal and maintain public health, a variety of immediate inspections and serviceability/damage assessments were undertaken to establish the network status as a precursor to determining follow-up repair /service restoration actions.

Service was progressively restored through a combination of pipeline cleaning, manhole suction, bypass pumping, investigative CCTV, pole camera and Electroscan and interim repairs using a number of repair techniques. Considerable effort was also put into investigating and repairing private lateral damage. These activities collectively enabled the gradual restoration of an operational network and allowed a return to flush toilets usage.

Restoration activities to maintain the still very fragile wastewater service are on-going; particularly pipeline cleaning, manhole suction, waste tank emptying, and localised damage repair.

The Council and SCIRT have continued the pipe network assessment activity with a particular emphasis on network condition and horizontal assets rebuild requirements. Extensive use of CCTV, complimented by pipeline profiling, has been used in the asset assessments and rebuild decision making, leading to a prioritised replacement programme.

3 INVESTIGATION AND REPAIR

3.1 RAPID INVESTIGATION TOOLBOX

A number of assessment tools were used to confirm areas of significant I & I (Table 5).

Table 5: Wastewater Pipe Condition/Performance Initial Assessment Tools

Initial Assessment Type	**Comments – Effectiveness, Use**
Visual inspection	Simple and quick but did not provide reliable data on pipe condition. Provided visual indication at road surface of mains collapse and at manholes of silt –debris volumes
Pole camera	Allowed quick assessment of pipe condition to 20 metres dependent on debris volume. Avoided need for confined space entry and some traffic management dependent on duration.
Closed Circuit Television Camera CCTV and “snake” push camera	Relatively slow rate of data capture, but provided best practice quality, comparison based data. Required pipes to be cleaned and plugged, traffic management in place prior to work commencing
Electroscan	Rapid rate of data capture in non-metallic pipes. Did not require pipe cleaning, but required full wetted perimeter coverage to allow for 100% defect detection to occur. Used selectively from mid 2012.
Pipeline Profiling	Allowed for pipeline grade assessments

Typically site assessments were undertaken either in response to a wastewater blockage – emergency works, or programed and managed by a team of EQ zone catchment managers and Council staff. Their role was to:

- Narrow down the fault location to a lateral or a main
- Consider and select solutions for repair of the fault
- Ensure the fault was fixed

The team’s confirmed whether the wastewater main was surcharged and tracked this to the downstream source. The main sources of surcharge in the wastewater system were:- Pump stations not operating, collapse of sewer mains, blockage of sewer mains and lack of capacity of sewer mains/excessive I & I.

The EQ catchment managers also looked for other factors which identified the root cause of surcharge:

- Impact of groundwater – was the network in an area where groundwater was traditionally high
- Ground deformation – had the ground subsided or dropped in this area
- Carriageway deformation – was the road surface collapsing, particularly in high vehicle volume areas
- Tidal impact – As parts of the network were installed in tidal areas and areas which had fallen below river tidal lines were diurnal tidal (sea) changes resulting in connected pump stations flooding

The teams methodology evolved through experience rather than through documented procedures. There is the risk that EQ catchment manager knowledge will not be captured in detail for the benefit of others prior to their departure, expected to occur as the EQ zone areas are closed and residential property removed. As catchment managers have changed, some knowledge has been documented eg. network condition and catchment issues.

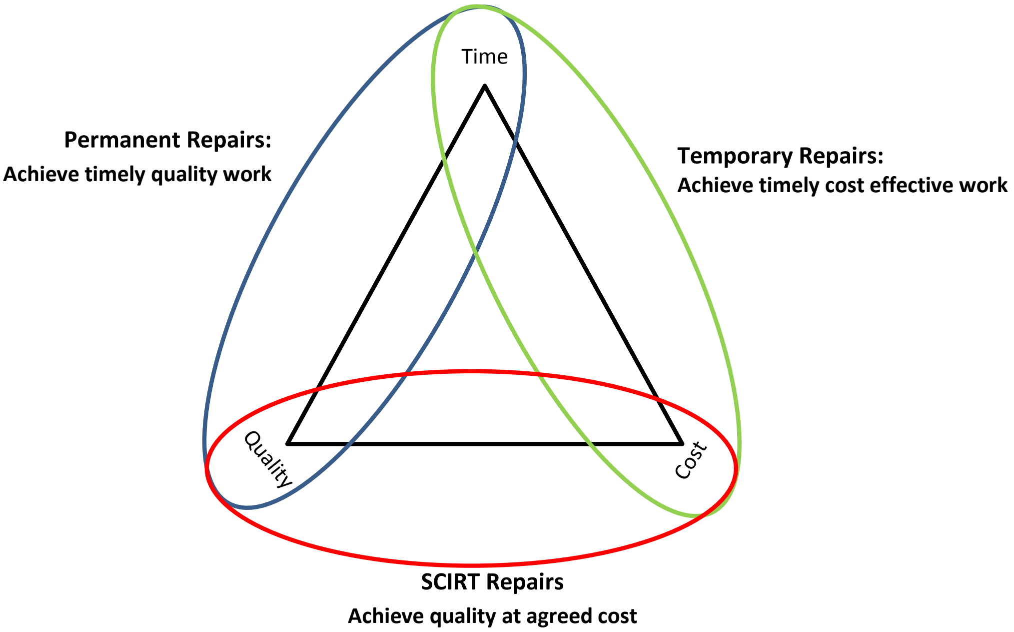
3.2 PIPE TREATMENT TOOLBOX

Four methods of pipe treatment for wastewater mains, manholes and laterals were employed by the team – the asset owner Council, Catchment Managers and City Care Ltd. These were:

Treatment Type	**Description**
• Dig and Lay	– Trench excavation with pipe installation, supported by Councils Infrastructure Design Standards and EQ amendments
• CIPP Lining (patch and section)	– Synthetic sock and resin cured internal pipe lining
• Pipe Bursting and Pipe Insertion	– Breaking of pipe via a plug pulled thorough it, followed immediately with new pipe installation
• Resin Injection “resin”	– Polyurethane / synthetic resin forced into water around defects, reacting with water to cure

Each treatment type is discussed further below. In general each treatment type was selected for the particular situation against two of three primary factors - quality, timeliness and cost. Any two factors eg. time/cost or time /quality were traded off against the remaining – refer Figure 3.

Figure 3: Time, Cost and Quality Trade-off



3.2.1 TREATMENT - DIG AND LAY

This work was carried out where site conditions dictated this methodology, especially where the main/lateral had collapsed causing loss of service and traffic hazards. Typical applications involving dig and lay included situation where shearing of pipes at manholes, shattered and collapsed mains, drop outs and loss of grade had occurred. Dig and lay was chosen as the repair methodology in preference to other techniques in locations where pipe depth was under two metres deep due to economics and ease of repair.

Dig and lay work was generally undertaken on a quality-timeliness basis. This methodology was employed as a "last resort" when the SCIRT rebuild timing was not expected within two years and other repair options such as patches or full pipe lining have not been sufficient to rectify the identified faults.

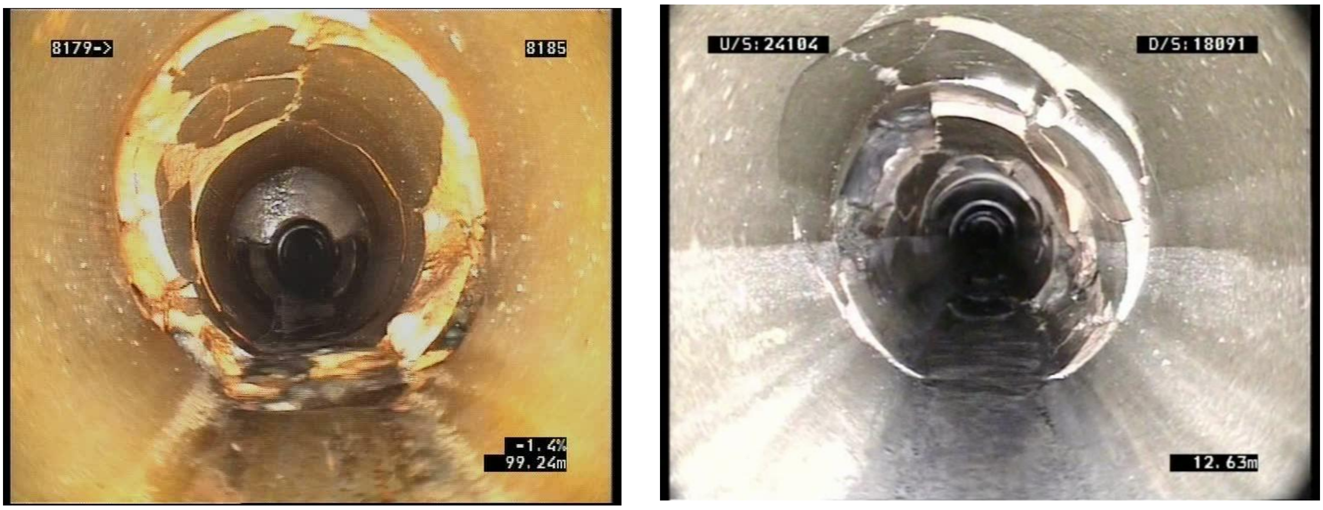
At depths of greater than or equal to two metres, the dig and lay treatment process was weighed against other techniques due to factors including:

- Shields or sheet piling being required (running sand in many areas)
- Groundwater - requiring dewatering/well pointing prior to and during excavation
- Site coverage – extensive in comparison to shallower excavation work, requiring more traffic management
- Suitable specialist contractors

3.2.2 TREATMENT – CIPP LINING

CIPP lining (lengths and patches) was generally undertaken on a timeliness-cost effectiveness basis. Patch lining was utilised in wastewater mains at considerable depth e.g. greater than or equal to two metres where dig and lay would require considerable dewatering, shields/sheet piling, and traffic management. Patches were also utilised in locations where breaks have been located in close proximity to buildings. In these circumstances, dig and lay would prove difficult and could result in building damage. Examples of some locations where patches have been utilised are provided in Photograph 1.

Photograph 1: Locations where CIPP patches would be applied



A. Lyttelton St, 150mm EW, depth 1.7 m

B. Buckleys Rd, 150mm EW, depth 1.8 m

In some cases it proved more economical to undertake manhole to manhole CIPP patch lining where several individual patches would have otherwise been required.

3.2.3 TREATMENT - PIPE BURSTING AND PIPE INSERTION

Pipe bursting and insertion was undertaken on a quality-time basis. In one case the work to prepare and undertake site work and reinstate property damage was very costly. Three sites had pipe bursting employed, particularly as the mains ran immediately adjacent to houses and through back sections. At one site, a 40 metre length of PE was inserted at $335,000, protecting $1.4M of land and structures.

This technique was particularly useful in situations where the wastewater main had been severely fractured and dig and lay repairs were extensive and impracticable. It was also beneficial where deep excavations would have been required or extensive dewatering would have been necessary with a dig and lay approach.

This methodology was based on well proven technology using conventional bursting and polyethylene PE pipe insertion.

3.2.4 TREATMENT - POLYURETHANE RESIN INJECTION

This technique was considered to be more cost effective than pipe replacement or patch lining for some pipe materials, and effective in both tight cracks and wide joints. Polyurethane resin injections have been utilised to eliminate water ingress into sewer pipelines in areas with high groundwater levels. Resin injection requires a running water source e.g. groundwater to react with and form a watertight seal. It also relies on a chemical reaction occurring at a specific rate for curing to occur at the defect point. The resins remain flexible enough to accommodate some thermal expansion and contraction and minor movement of the structure.

It generally achieved the timeliness-cost effectiveness priorities. Repairs using this process were carried out with the intention of holding the wastewater system together until it could be rebuilt, prevent holes forming at the road surface “drop-outs”and reduce/minimise I & I. The supplier stated that the work should “last for decades”, but were unable to provide evidence to support this. Audits of resin injection sites should be undertaken to confirm their long term performance.

The pipe repair methodology utilised CCTV to locate the position of the defect. Once this had been done, spears are drilled through the road surface adjacent to the identified leak location. A dye was injected through the spears while a CCTV camera located in the pipe confirmed if the dye was entering through the pipe wall. If this was the case, then a connection with the leak had been confirmed. Following confirmation the spears were changed and the resin injected until the fluid flow was stopped.

The method was quick enough to allow several leak repairs in a day, it also causes minimal disruption to property owners being a trenchless pipe repair technology. A similar methodology was also utilised to seal infiltration between manhole risers – Photograph 2.

Photograph 2: Polyurethane Resin Injection In Manholes

A: Manhole before leak repair (circle)

B: Manhole after leak repair – small circle (further work required – large circle)

4 ANALYSIS OF PIPE TREATMENT TECHNIQUES

Task details were obtained from various sources including work reports, financial databases and GIS spatial datasets. Key information was assembled for each task, with a focus on wastewater pipe and lateral works. 407 tasks were assessed, with 61% or 249 excluded as the task fell into one of several categories:

- Applied to a treatment on another asset eg. manhole or stormwater asset
- Incomplete dataset eg. no pipe depth information
- The record was not assessed due to time constraints

There were 158 tasks of suitable quality for analysis - refer Table 6. These tasks had details on LRI, depth to pipe, pipe material, pipe diameter, total cost of work and lineal length of repair.

Table 6: Analysed Tasks Types

Repair Method / Subtype	Tasks
Burst	**3**
CIPP Lining	**53**
Length Reline	6
Patch	47
Relay	**51**
Lateral	40
Main	11
Resin	**51**
Pipe	51
Total	**158**

LRI zones as mapped by Cubrinovski et al (2011a; 2013) were conservatively determined against recorded repairs. Reference was made to the Councils version of the LRI, where street level LRI zones were not available. Therefore where doubt existed, a lower LRI zone value was used. Zone numbers indicate the relative liquefaction resistance, with Zone 1 being the reference zone. For example, Zone 3 has three times the liquefaction strength of the lower bound value of Zone 1.

An estimate was made of leakage reduction – litres / second / lineal metre (l/s/m) was made in the absence of field data, being:

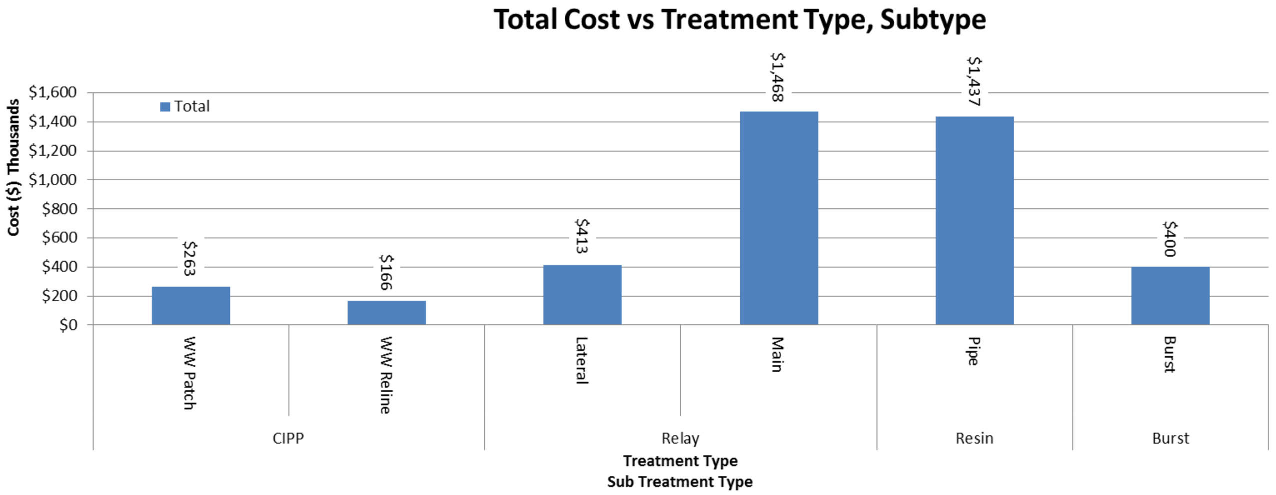
Dig and Repair & Burst	0.04 l/s/m
CIPP Patch/Reline	0.05 l/s/m
Resin Injection	0.12 l/s/m

These were assumed values, based on the authors knowledge of wastewater networks and observations of flows at the time of CCTV.

4.1 COST / BENEFIT

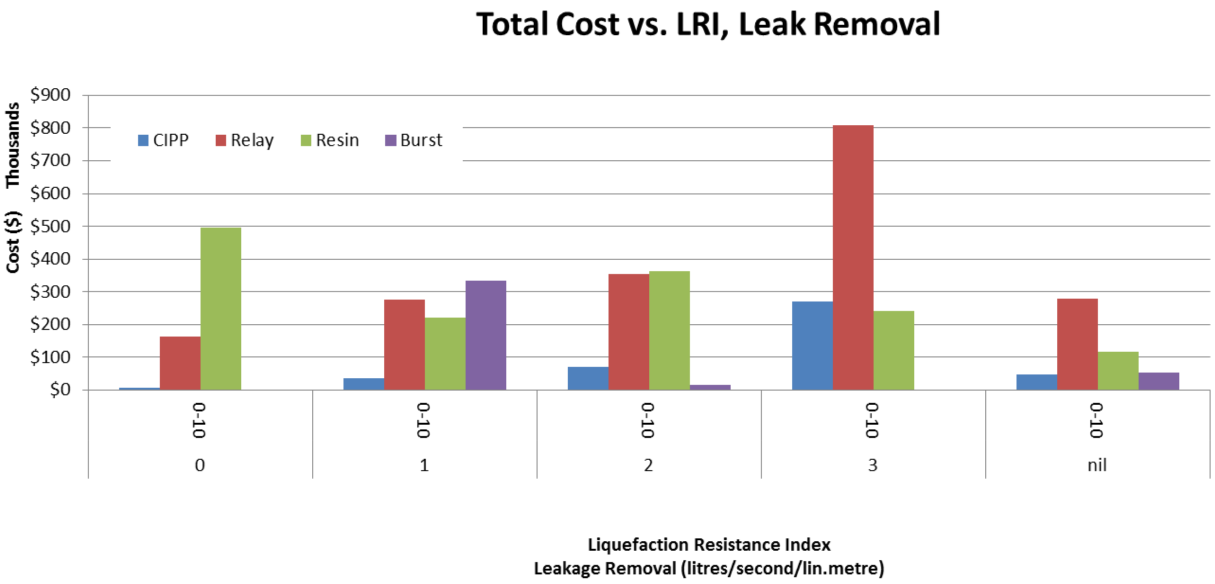
The total costs by treatment and sub treatment type are provided in Figure 4. Of the $4.15 M spent, resin injection accounted for $1.4M (51 tasks) and CIPP $0.5 M (53 tasks).

Figure 4: Total Cost of Selected Tasks (by Treatment Type and Sub Type)



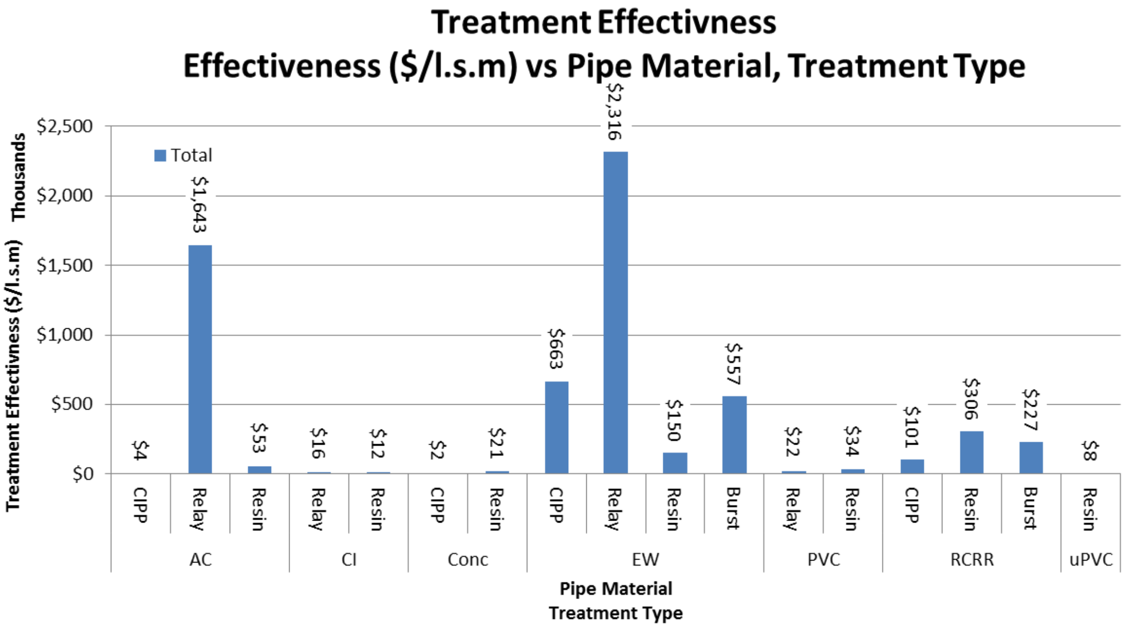
Assessment of treatment application by LRI and leakage removal is provided in Figure 5. The x-axis shows LRI (range 0-nil), leakage (All – range 0-10) against y-axis treatment costs. For LRI between 0-3, $1.1M was spent on resin injection, $0.8M on relay work and $1.1M on lining (patching and lengths). Therefore CIPP lining and resin injection were equivalent over the entire range of pipe depths.

Figure 5: Cost of Leakage Removal in LRI zones



An assessment of each treatments effectiveness was undertaken. High effectiveness is considered to be represented by low cost per lineal metre of I & I removal into the wastewater network. Analysis of this is provided in Figure 6.

Figure 6: - Treatment Effectiveness ($/litres.second.metre)



Resin injection was more effective in earthenware and polyvinyl chloride repairs, but less effective in concrete and asbestos cement repairs that CIPP. Therefore different treatments techniques are required to match the environmental conditions.

The primary assumption made of a treatments ability to reduce leakage has a dominating effect on the effectiveness calculation. Accurate field data would validate the effectiveness of any method.

The length of time to repair a defect was recorded for resin work, but not for the other methods. The total cost of work could be used as a coarse measure of the repair time, however to increase the accuracy of treatment cost/benefit future treatment data should include total task time. This would then allow a measure of response time and savings in reduced network pumping, cleaning and treatment costs to be calculated.

5 SCIRT LEVEL OF SERVICE

Up to March 2013, SCIRT applied an intervention point based (prescriptive) Infrastructure Recovery Technical Standards and Guidelines (IRTSG) base to Christchurch rebuild works. This has changed driven by a clear cap on expenditure and other factors.

From March 2013, SCIRT investigations, assessments and design work shifted focus to areas of lesser infrastructure damage. In these areas key LoS have not been compromised to the same extent as a result of the EQ's, although infrastructure has sustained some EQ damage resulting in reduced asset life and the possibility of increased operational cost.

Instead of repairing all defects that pass damage thresholds, the approach is to restore network LoS by repairing critical damage only (i.e. service below agreed levels, requiring increased maintenance, or significantly reduced asset life). This approach maximises the remaining asset life, thereby achieving the best value outcome. As well as making good sense, the approach is also consistent with Council's 'business as usual' approach applied prior to the EQ's. It is important to note that different rebuild options will still be evaluated using SCIRT's whole of life approach taking account of net present values for both capital works and maintenance.

As existing networks in these less damaged areas have performed relatively well (with moderate to low damage, and short term or no significant loss of service following the EQ) the more expensive resilient options are not considered to be best value for money. For functional but damaged gravity piping networks, repairs are only required to defects that could cause operational issues or reduce the asset life below 15 years. Alternative rebuild options for returning LoS are also being considered in areas where increased flows (inflow and infiltrations) to the wastewater network are the only indicator of EQ damage.

6 CONCLUSIONS

A team formed following the Canterbury EQ's has undertaken wastewater network investigation and repairs, utilising treatment methodologies and techniques relative to site constraints. A significant number of repairs have been undertaken over a 3 year period, primarily to immediately reduce I &I and provide the community with a functional wastewater system. A subset of 157 tasks were analysed against several factors including LRI, depth and cost.

Leakage data was not adequately captured from sites where treatment work was undertaken. If this had been recorded, the quality of cost/benefit results would improve along with confidence in utilisation of the treatment method.

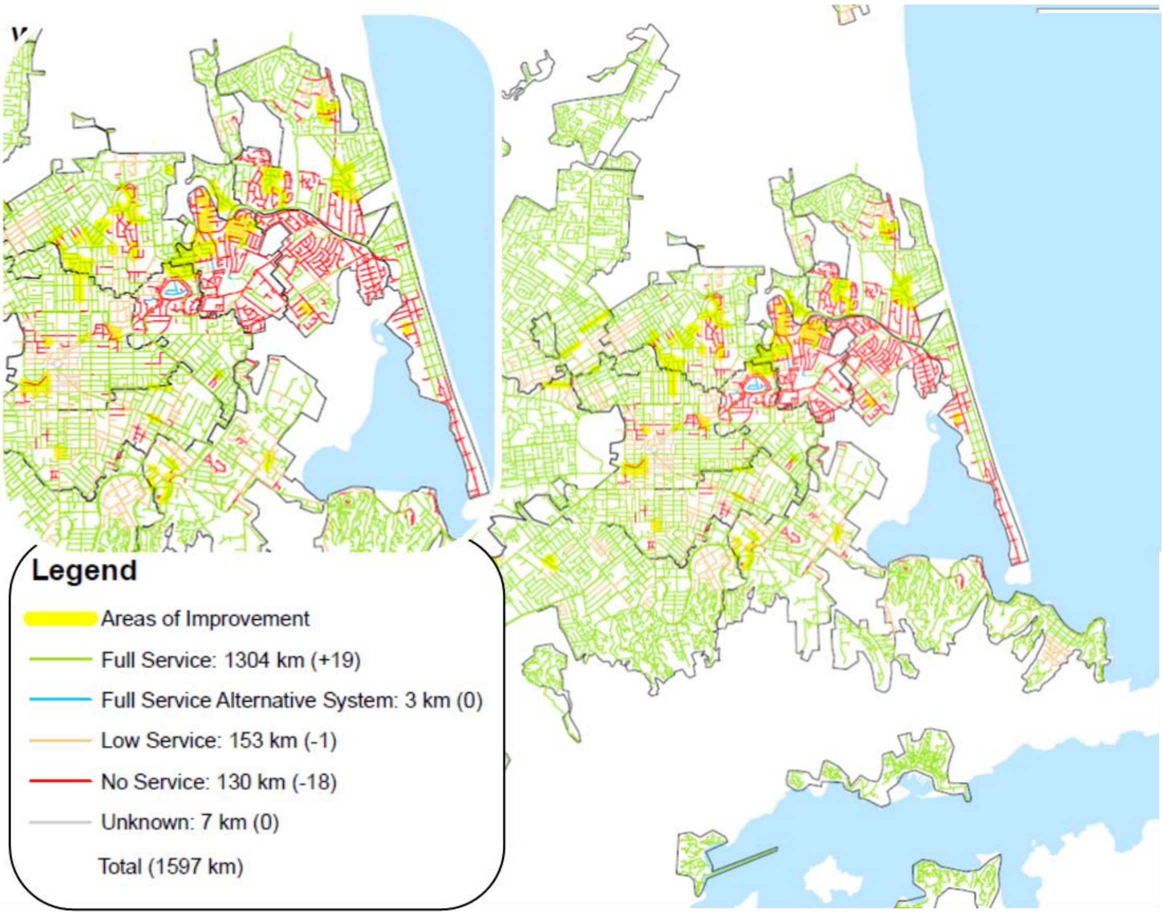
The immediate success of resin injection must be considered against its long term ability to eliminate / minimise I &I and associate downstream treatment costs. In the same manner, pipe patching and lining must also have quality assurance checks undertaken. A review should be undertaken of pipes to confirm the success, especially in areas where SCIRT will not be undertaking asset replacement work.

A return to pre-EQ LoS was not considered at the time of repair, as SCIRT rebuild works were understood to return the horizontal infrastructure to this standard. However, this is no longer the case as a cap on funding and completion date of December 2016 has been prescribed. In this light, immediate repair techniques may become permanent solutions with the benefits of:

- Maximising remaining asset life
- Allowing defect repairs to be deferred, smoothing expenditure and reducing borrowing
- Reducing disruption to community eg. road closures in the short term
- Reducing the risk that new assets will be damaged in further seismic events

7 APPENDIX A

Figure 2: Wastewater Service Status on 28th June 2011



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