CHLORINATION OF CHRISTCHURCH WATER SUPPLY AFTER THE EARTHQUAKE; THE PLANNING AND THE REALITY

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ABSTRACT

Following the magnitude 6.3 earthquake in Christchurch on Tuesday the 22nd of February City Council requested that GHD review the reticulated water network in Christchurch.

GHD staff were in Christchurch on the 2nd and 3rd of March 2011 to review the situation and gather the information to prepare a report in regards to disinfection requirements.

The main objectives of the report were to:

- Confirm the requirement for disinfection,
- Review the implications of introduction of chlorination, and
- Provide a process, and guidelines for, the eventual lifting of the boiled water notice.

Franz Resl, working for City Care Ltd, led the team that managed the chlorination regime.

Commissioning, optimization and maintenance happened in parallel while the stations had to operate at the required dosing rate. A smart control strategy was developed to allow for a fast (less than 1 hour) response for required repairs. Well understood routines about plant start-up and operation had to be left behind. Success under the amazing time pressure was relying on engineering intuition and novel strategies for maintaining dosing equipment.

This paper compares and contrasts the theory behind the chlorination exercise with the practicalities of implementing a chlorination strategy.

KEYWORDS

Chlorination, disaster response, Christchurch, Operations and Maintenance

1 INTRODUCTION

Christchurch's reticulated water supply is made up of approximately 200 bore wells that extract water from aquifers below the city to approximately 75 pumpstations. Due to the nature of the water, and the closed network, there is no history of disinfection in the system excepting spot dosing in cases of repairs and where isolated incidents of contamination have been observed.

Christchurch experienced two major earthquake events in a relatively short period of time. The first was in Sept 2010, with the second larger earthquake taking place on the 22nd of February 2011.

While both quakes resulted in damage to the reticulated water supply system, the second quake caused damage that was much more widespread. Estimates given on the number of leaks in the water supply network ranged from 2000-3000 leaks. The wastewater system and the stormwater drainage were also severely compromised during the quake. The potable water system was being constantly pressurised and depressurised to allow for leak repairs. These conditions gave rise to concern as to the integrity of the reticulated water supply, and hence a decision was made by the Ministry of Health to issue a boiled water requirement for all water taken from the reticulated water supply system.

On Wednesday the 2nd of March Christchurch City Council started a pilot study of chlorination at the Main Pump station (Christchurch's largest pumpstation) on Colombo Street. This pilot study was based on the premise of dosing 1mg/l sodium hypochlorite on the downstream side of the discharge pump. GHD were requested to assess the suitability of this approach, and to advise of any adverse effects that could be caused by the dosing.

In order to assess the potential impacts GHD undertook the following

- A review of available water quality data
- Site inspections and interviews of staff in the field
- Discussions with key staff from Christchurch City Council

The report produced was used as the basis of design for a chlorination regime. This regime was based on proven experience elsewhere, and was largely theoretical. After the release of the report, Citycare were tasked with implementing the chlorination scheme.

The implementation of the scheme bought forward a number of issues that were not foreseen at the report stage. This paper looks at both the theory of the chlorination regime, and how this worked in practice.

2 POST EARTHQUAKE WATER QUALITY ISSUES

GHD visited the Christchurch City Council laboratory at the Bromley wastewater treatment plant. This plant undertakes all testing of the reticulated water supply system for the compliance tests for the New Zealand Drinking water Standards. Samples are taken both at well locations and at random points throughout the reticulation system, normally at household taps.

2.1 MICROBIAL WATER QUALITY

Following the earthquake a much greater number (approximately 8 times as much as normal) of samples were being taken and analysed. GHD sourced a list of the results of this analysis. Table 1 below shows the percentages of samples that tested positive for Ecoli and Coliforms, both before the earthquake and after the earthquake.

Table 1 Microbial Water Quality Comparison

WQ parameter	Before (Sept10/Feb11)	After (to 28th Feb)
% results Ecoli detected.	0.5	1.8
% results Coliforms detected	6.2	9.9
Number of tests	5318	556

2.2 CHEMICAL WATER QUALITY

Table 2 below shows the results of the chemistry of the aquifer water before and after the September 2010 quake.

Table 2 Water Chemical Analysis

WQ parameter	18/20 May 2010	5/7 Oct 2010
Turbidity >1 to 34 NTU	Auburn PS , well3, Mairehau PS , well 1 Averill PS, well2 Aldwins	Mairehau PS , well 1 Averill PS, well2, 3
Manganese >0.02 to 0.03mg/L	Auburn PS , well5, Mairehau PS , well 1 Bexley	Mairehau PS , well 1 Averill PS, well2, 3 Aldwins
Iron >0.3 to 2.3mg/L	Mairehau PS , well 1	Mairehau PS , well 1 Averill PS, well2

2.3 WATER QUALITY OBSERVATIONS

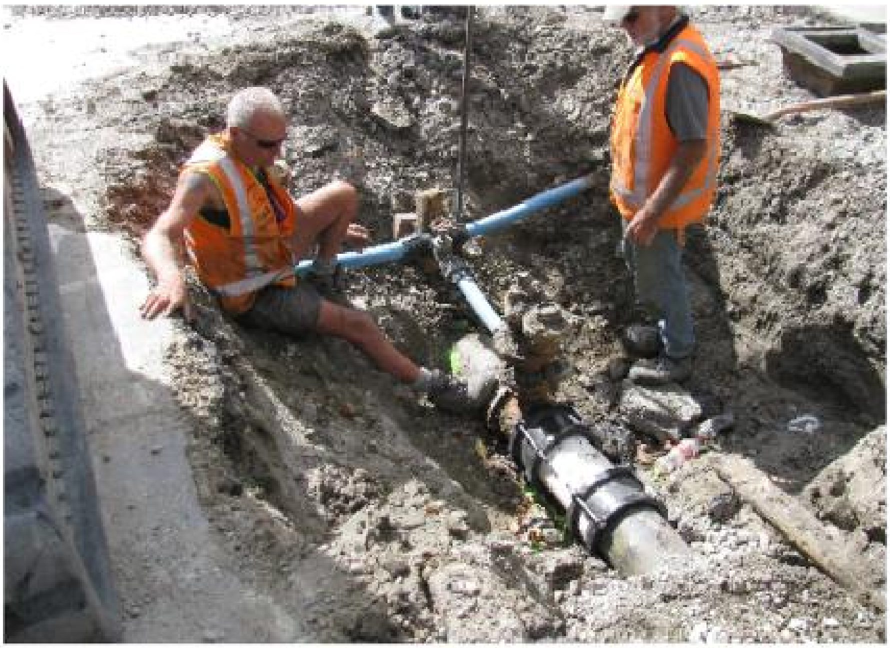
GHD made the following observations related to water quality:

- Sampling from customer taps is not considered best practice and bad sampling technique can result in unreliable results.
- These results suggest a large increase in the positive detection of microbes after the quakes, as would be expected.
- Generally manganese levels are low enough so as to not be affected by the addition of chlorine.
- Iron levels are high in cases; however this appears to be related to turbidity rather than iron that will react with chlorine.
- Turbidity in some bores can get very high. Turbidity levels of <1NTU are normally required for effective disinfection from chlorine.

3 SITE OBSERVATIONS AND INTERVIEWS

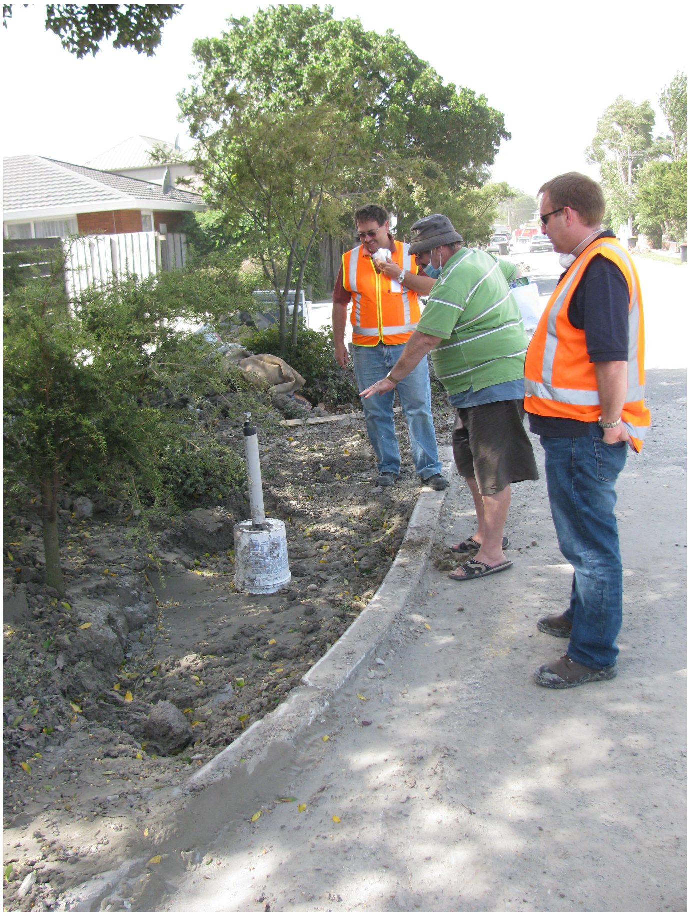
3.1 PIPE REPAIRS

GHD observed three repairs of watermains on Wednesday the 2nd of March 2011. One of the repairs observed had a wastewater lateral above the watermain, and the watermain being repaired was in a pool of wastewater. The photographs attached below illustrate both this repair, and another repair which was being undertaken in a dry excavation.



3.2 UNUSUAL COMMUNITY RISKS

While water was off to some areas, the use of local private bores and “innovative” use of water leaking from pipes were used. This is illustrated by the photo below showing a plastic bucket and riser pipe that had been placed over a watermain leak and used to obtain water by residents. Private bores were also used as a primary water source, and were made available to other users.



4 SPECIFIC RISK AREAS FOR CHRISTCHURCH

Significant potential points of risk for entry of microbiological contamination that arose from the local site inspections are listed in order of priority below.

- Bores; compromised surface caps and bore hole concrete linings down to the screens- those with high turbidity indicate near surface water (sewage effected), need to test for turbidity, ammonia, microbes as markers and define the source of turbidity, especially for bores in south and east areas where lots of sewer blocks and overflows.

- Bore water balance tanks; especially those located underground and that can be drawn down by pumping into pipe network. They may have cracked walls/floors allowing in infiltration. Focus on those near to sewer overflow/blockage areas and those in areas with high water tables.

- Entry pump station; especially those sustaining direct pressure into the pipe network. No substantial delay time to house hold taps and big pressure fluctuations and negative pressure (sucking in groundwater) and focus on those in high water table/sewage contaminated areas, e.g. south and east of city.

- Large mains; especially those with lots of leakage that can experience pump stops causing no pressure and negative pressure from pressure surge, focus on south and east of city where sewers not in good state and cross the large water mains. Particularly where sewers are above water mains.

- Small pipe network; as for large mains.

- Flushing and cleaning of sewer pipes; there is the possibility of backflow from water supply hoses used to jet flush and for cleaning of silt from sewerage system, especially if negative pressure events occur due to nearby pump power failures or large water main breaks when hoses are submerged in sewage.

4.1 MANGANESE AND IRON BIOFILMS

Manganese and iron levels in the Christchurch water supplies were not at levels that would interfere with chlorination disinfection. Biofilms are usually a problem if the soluble manganese level exceeds about 0.03 mg/L and/or the iron level exceeds 0.3 to 0.5 mg/L. Usually, if biofilms are a problem there are customer complaints of “dirty water”, a poor “bitter” taste in hot drinks and/or brown/black staining of household plumbing.

The iron and manganese levels for this water supply are also generally too low to cause a significant reduction in chlorine residual. It appeared that 3 -4 bores out of approximately 200 were unsafe to use due to significant iron/manganese levels.

4.2 SUGGESTIONS FOR MAINTAINING CHLORINE RESIDUAL CONCENTRATION WITHIN THE PIPE NETWORK

Some techniques suggested to maintain the chlorine residual within the desirable range of 0.3 to 1mg/l across each water supply zone are listed below:

- Open scours at the ends of pressure zones to direct water flow into local water courses or stormwater. This will keep water moving thru the network and dilute out any problems. In this process it is important to control the flow rate so that it does not significantly reduce local pipe network pressure.

- Locate booster chlorinators within the pipe network at the inlets to service reservoirs to maintain minimum chlorine residual in the water leaving the reservoir.

- Ensure that flushing after each pipe repair occurs until the local system chlorine residual is re-established in the water leaving the flushing point.

5 THEORETICAL IMPLEMENTATION OF A CHLORINATION STRATEGY FOR CHRISTCHURCH

5.1 SYSTEM CHARACTERISTICS

The Christchurch water supply system is characterised by a large number of bores supplying water into balance tanks. Water is then pumped from these balance tanks into the pipe network. Pumps start and stop either:

- at pressure set points at the pump discharge point or
- at level in a balancing tank located at a high elevation (with gravity flow back into the pipe network). These systems are mainly along the southern border of Christchurch.

5.2 THEORETICAL RULES FOR SELECTING DOSING POINTS, CHLORINE DOSE AND CHEMICAL TO BE DOSED

The GHD report suggested the following “rules” for designing the chlorine dosing regime:

- Locate chlorine dose points at the pump station entry points to the pipe network. Where possible dose chlorine into a common point on the discharge side of the pumps. If the suction side is the only available location, install a load valve on the chlorine dosing line to prevent syphoning of chlorine due to low pressure in the water pump suction pipe.
- Prioritise the sequence of installing dosing systems to match the downstream risk of contamination of the water supply pipe network. This means that the first dosing systems needed to be installed at pump stations supplying water into areas where water pressure is low, there are lots of water pipe breaks, there is a high water table and the most sewer blockages/overflows are present.
- Prioritise sites with a high current water demand. The focus for the chlorination strategy is to provide maximum chlorinated water to the most people as soon as possible.
- Set chlorine dose rate so that free chlorine residual in the water entering the pipe network is around 1-1.5 mg/L. This level may then need to be adjusted based on follow up monitoring of each pipe network as the main objective is to achieve a free chlorine residual >0.3mg/L in each pipe network, especially at extremities.
- Chlorine dose rate ideally needs to be flow paced to pump flow rate with automatic trim to a continuously measured free chlorine residual. the delay time between the chlorine dose and aim for measurement of chlorine residual should be <5 minutes and not more than 10 minutes
- Either sodium hypochlorite or gaseous chlorine can be used without causing excessively low ph in the chlorinated water. However, sodium hypochlorite would be preferred in populated areas as there is no chlorine gas release risk and installation costs are usually lower and quicker.
- Identify key “end of pressure zone sites” where valves/hydrants can be opened to permit turnover of water through the pipe network aimed at maintaining a minimum chlorine residual by reducing very long detention times. Water would be released ideally to water courses or stormwater pits. It is essential that flow rates be controlled to avoid causing low pressure in the local area of the pipe network.

5.3 RULES FOR EQUIPMENT SELECTION AND INSTALLATION

- Where sodium hypochlorite is used, dosing pumps need to have vapour lock prevention as this form of chlorine releases gas bubbles that can build up in the dosing pump head resulting in stopping the flow of sodium hypochlorite.

- The best continuous chlorine analysers are usually amperometric or three electrode potentiostatic type units.

- Out in the pipe network use handheld DPD based kits to measure free and total chlorine residual. Often this work is done by both chlorinator operators and staff collecting water quality samples for lab analysis.

- Use 4% or 10% available chlorine type sodium hypochlorite, selection is based on dose rates to suit the chlorine dose pumps.

5.4 CUSTOMER COMMUNICATIONS PLAN FOR CHLORINATION AND GENERAL WATER QUALITY MATTERS

Customers are an asset. A well organised communication plan with customers can really assist in the management of water quality.

The following series of communications are required prior to the introduction of chlorination;

- Customers to see their aquarium provider about the correct chemical to add to avoid the problem of chlorine killing your tropical fish

- Hospitals to follow up dialysis patients to ensure they have correct activated carbon filters if using the chlorinated water supply.

- Food and beverage industries that may need to review their operations to allow for the chlorine concentration if connected to the reticulated water supply system.

After chlorination has commenced (and generally) the various customer groups are the most rapid form of detection of water quality problems that a water manager has. The following is suggested;

- Provide training of call center staff to “unpack’ drinking water quality complaints into at least the following categories;

    - Low pressure or no water- this is the high risk situation as it may result in contaminated water back into pipes. The response is flushing the pipe network area when pressure is restored and maybe increase chlorine dose

    - Taste/odour that is not chlorine related. This can mean contaminated water.

    - Dirty water means biofilms or scour of sediments. This is not that important at the start-up of chlorination , but is important to know if it happens later in the chlorination period as it may be a dirty bore in use or cross connected pipes and as such be a health risk

    - Blue water or blue stains which are copper corrosion because the pH is less than 7 and there is chlorine present resulting in copper plumbing corrosion.

    - Alleged illness caused by drinking water.

    - Taste and odour of chlorine.

- Set up a customer complaint recording system that records complaints by type and street address in a manner that enables you to import the data into the GIS framework so that complaints can be plotted by type and locations. This will enable rapid detection of areas where contamination or overdosing of chlorine have occurred, and will allow a rapid operation response.

- Get a rapid response contact route directly to local Doctors and particularly children health center nurses (schools and independent ones) and ask them to report any unusual increase in background levels of children or elderly coming in ill with stomach upsets

6 KEY THEORETICAL RECOMMENDATIONS

A "multiple barrier" approach was recommended for the Christchurch water supply to minimise health risks to the reticulated water supply during the recovery from the recent earthquake. This approach needs to include the following:

1. Inspection and if needed repair of the bore supply and balance tanks prior to the water supply pumps to prevent ingress of local near surface groundwater.

2. Chlorination at main entry point pump stations and, if needed, at downstream tanks or key points to maintain Free Chlorine Residual (FCR) across the entire pipe network. This may mean FCR levels are significantly higher (e.g. 1-1.5 mg/L) at some locations near chlorinators.

3. Boil water notices, noting that these may not always be effective because:

   (a) Young children/elderly may not understand;

   (b) Boiling time is too short; and

   (c) Advice is ignored.

   (d) Burst main repairs that include always adding small amount of calcium hypochloride powder and effective flushing of the dewatered section of pipeline.

4. Developing a customer complaint recording and interpreting process aimed at detecting unusual changes in water conditions that may indicate a contamination risk is present or may develop (e.g. low pressure, poor odour/taste that is not chlorine related).

5. Ongoing intensive water quality monitoring of E. coli, Coliforms, turbidity, and chlorine residual and possibly ammonia to check the performance of the Preventative Measures and provide a basis for reactive investigation of areas where poor quality water is detected.

6. Rapid reporting system from child welfare nurses and local doctors if unusual increases in reported stomach upset type illnesses may occur. The key is where do the affected people live and is the illness the type that could be related to drinking water.

6.1.1 CHLORINATION

The highest priority for a staged implementation of chlorination is to commence in zones where the pipe network has:

- the largest number of bursts/km

- the lowest pressures

- the most pressure surge potential (biggest variations in pressure)

- the most broken up sewer system, and

- the highest water table.

It was recommended that Christchurch City Council measure both total and free chlorine residual, because if sewage contamination occurs it will cause chlorine residual loss and increase the level of ammonia causing free chlorine residual loss, but not necessarily total chlorine residual loss.

Also, it is a good idea to complete a chlorine decay trial in the labs to assess possible decay rate of free chlorine residual. It also helps detect where contamination is happening in the pipe network. That is, a sudden loss the chlorine residual where it previously was normally present suggests infiltration to the pipe network of contaminated water.

6.1.2 WATER QUALITY MONITORING

Proper sampling points should be established to ensure repeatability and consistency of sampling.

6.1.3 CUSTOMER / HEALTH REPORTING

Customers are a good surveillance mechanism for detecting contamination that could make people sick. This includes complaints related to turbidity, foul smell, and taste & odour. The call centre staff should be trained to ask the right questions.

Get a rapid response contact route directly to local Doctors and particularly children's health centre nurses and ask them to report any unusual increase in background levels of children or elderly coming in ill with stomach upsets.

6.1.4 BIOFILMS

Manganese and iron are not a problem as the concentrations are too low to cause substantial biofilms or cause a significant reduction in chlorine residual.

6.1.5 BOIL WATER NOTICE LIFTING

Delay lifting the boiled water notices until the following criteria have been checked, assessed and are deemed to be acceptable:

- **Measurement of Minimum Night Flow for the water entering the zone.** The MNF can be expressed as litres/connection/hr and should return to what was present before the quake. For example in Sydney , which has an annual real leakage loss of about 8 to 10% , it was not uncommon to see a MNF of around 4 to 12L/connection/hr , the higher values occurring at 90m water pressure and the lower values occurring at 50 to 60m water pressure.
- **Evidence of ground-water that is always below the water main level and/or is not sewage contaminated**. This can be checked by including in reports of mains repairs whether there was ground water coming into the repair pit during the repair, with labs taking samples of the water coming in near the end of the repair period for Ecoli and Coliforms, and possibly phosphorus, Total Nitrogen and ammonia measurement. These are markers of sewage contamination. Note that viruses and protozoans will continue to be present well after coliforms, and especially Ecoli, have died and hence the need to consider other markers of possible sewage contamination.
- **Water main burst numbers and rates are back to what was present before the earthquake and pressure is stable in an acceptable range**. Based on various other water utilities the nominal number of mains breaks per year has been expressed as 2 – 7 breaks/100km/yr, but is influenced by soil conditions. It is a factor in understanding the risks of recontamination as the higher the number of especially breaks in water mains requiring repair after dewatering the pipe rather than repair under pressure, the higher the recontamination risk. It was also found in Sydney that lowering the pressure from a 90m value to around 40 to 50m did decrease the leakage rates and number of pipe bursts. However, it is important to consider the local min pressure needs for fire-fighting and to avoid negative pressures during pump start/stops and local elevation variations. The objective is to avoid negative pressure risk.
- **The ongoing frequency of detection of sewer pipe/MH breaks resulting in significant release of sewage into the near surface water table.** Reporting of the sewer repairs that had sewage release to the environment is important to gauge the areas where there is a of high risk ground-water. These areas will require special attention to water main repairs in relation to maintaining stable water pressure, and CCC should focus on, where possible, completing water main repair under pressure.

- **Mapping of the area of extensive liquefaction.** The areas where extensive liquefaction occurred would tend to produce high uplift forces on sewer manholes and PS resulting in sewer pipe breakage. These areas are also a location where a special focus on careful water main repairs is needed.
- **Detection of no Ecoli and Coliforms in the reticulated water entering and being distributed within each pressure zone**; The presence of no Ecoli and Coliforms is only one test and will not indicate the risk from protozoans such as Cryptosporidium is now low. This is one of the main reasons why the other tests described above need to be also "passed". The Ecoli/coliform results will also not tell one what happened between the samples when most of the water is passing through the system. Recontamination events that are a severe health risk may well be due to occasional relatively small volume infiltration events at the few km lengths of dewatered main during pipe repairs or during negative pressure events associated with pressure surges from power failure or normal pump stops especially while zone water pressures are low or when big flows occur due to very large pipe breaks. These events may be worse than contamination of bore water entry points because the entry locations may be further away from most of the sewer break areas and have more dilution from higher bore water flows.

It is suggested that a set of "pass" / "fail" tests that relate to at least the above list need to be developed during the detailed Planning stage as the basis for Lifting Boil water notices. It is also emphasised that lifting Boil water Notices does not mean that chlorination should cease in that zone. That is, as noted in this report contaminated ground-water containing harmful viruses and protozoans can last around 3 to 9 months after most of the sewer breaks are fixed, especially as water temperatures drop over the coming winter.

6.1.6 PIPE NETWORK

Consider opening scours at ends of pressure zones dumping into river, stormwater to keep water moving through the network and dilute out problems and help achieve a measured chlorine residual throughout the pipe network.

6.1.7 WHERE TO FROM HERE?

Finally, there was a need for a detailed “Plan of Action” that defined the key implementation actions now required and the tests to validate performance of the Plan for this “multiple barrier” approach. This Plan would be submitted to the Public Health Medical Officer for review and approval. The Plan would set a ‘baseline’ of activities which will, during implementation, need to be adjusted to achieve the objectives. For example the existing ‘temporary’ chlorination facility at the Main Pump Station at Colombo Street has not produced as yet a detectable chlorine residual in water within the nearby local pipe network, even though the chlorine dose is around 1 mg/L. A higher set point than initially thought necessary will be required.

7 PRACTICAL IMPLEMENTATION OF A CHLORINATION STRATEGY FOR CHRISTCHURCH

The CCC decided to use high strength Sodium Hypochlorite for disinfection.

7.1 THE DOSING SYSTEM

A rig was assembled with a small 200 litre storage container and a panel to mount the dosing pump and associated pipe work. Local MAG flow-meters were calibrated to achieve chemical flows proportional to pumping action. The system had a built-in measuring cylinder to adjust dose rate exactly to the pumped water volume matching the concentration required by DHB and CCC (manual operation by service personnel). The chemical was pumped directly into the pressure pipe as no mixing device could be installed.

7.2 THE CHALLENGE

Christchurch drinking water reticulation had never had a full area Chlorine treatment before. Uncertainty about its effectiveness within the reticulation was high as the piping was expected to be covered internally by organic growth which would cause a high natural Chlorine demand. A separate flushing programme addressed this issue to reduce high losses of Free Available Chlorine (FAC) in the pipe work

Watercare from Auckland demonstrated their professional calibre. Their approach to design, procure, build and commission the 26 stations for dosing Sodium Hypochlorite reflected top level professional standards. The set up was clear and straight forward- tailor-cut for the task. The team was absolutely committed, working round the clock for about 3 weeks, offering their overtime for free to help Christchurch people in troubled times.

Dosing station installed in concrete container

All the plants were built in Christchurch, tested and pre-commissioned in the workshop, installed on-site, tested and commissioned to check settings were okay and plants were working according to process design requirements. The time pressure got critical around process commissioning and start-up. There were just a few days left for the team on site. The stations were switched on without the opportunities to test run them for a given timeframe.

7.3 THE TIME FACTOR

In a standard project we would have monitored the stations for about 3 months. In this case we were lucky to have 3 days, often just hours, or – in some cases even just finished testing when the team had to leave. There was no time for a classic handover.

During subsequent site visits it became obvious that some of the stations had issues with pumping the correct amount of Sodium Hypochlorite. At first there did not seem to be a pattern to explain why some pumps performed well and others failed within minutes of being in service. It was now City Care Ltd's duty to operate and maintain these stations. The clock was ticking and CCC expectations to see drinking water contamination mitigated quickly and reliably were high.

7.4 QUALITY ASSURANCE IN AN EMERGENCY OR HOW TO DO THE SPLITS

Strict adherence to procedures is important, especially in emergencies. Commonly organisations rely on procedures and most follow standards like ISO 9001, 14001, 31000. Emergencies are test scenarios for procedures. Emergency response work can only be successful within a strong, conclusive framework of robust quality control and procedures. There is no doubt about that. On the other hand it is clear that some procedures which are valid and useful for ordinary day to day business prove to be of little or no use in emergencies.

The main contributors to the successful operation were collaboration and creativity, and of course – Kiwi ingenuity. The team spirit could be described as 'accelerated agility'. Day to day pre-requisites like complying with contractual framework documents could not be strictly followed. NZS 3910 had less priority; safeguarding the drinking water was paramount.

7.5 ENGINEERING INGENUITY BEYOND COMPLIANCE

In our engineering practice we all understand the term "defects liability period (DLP)". This means that the contractor has to remedy defects arising from unsuitable workmanship or material within a certain period of time after the date of completion. A certificate is issued in relation to certain criteria when the period has expired successfully.

The organisational mix of design, supply, build and operate did not allow for a clean DLP. In fact having no DLP proved to be a success factor for saving the water supply of Christchurch so quickly.

In real world terms a consultant would never accept a plant that has not been positively commissioned, a contractor would never operate a plant that has not been handed over, and a client would never accept a plant that has not achieved a defects liability certificate. A process that would take 6 to 12 months or longer outside an emergency was cut down to three weeks – a net 90 % reduction of start up time.

8 OPERATIONS PLANNING AND THE INFLUENCE OF ROUTE CAUSE ANALYSIS

8.1 THE BOTTLENECK OR IS LESS MORE?

Staff availability was critical. Most people were already over committed in other projects around the City. Prices for contractors went through the roof. Recruiting untrained Council staff for the operation was considered, but dismissed. The people we needed would need to know their way around the City, report problems reliably, order chemicals and negotiate maintenance issues with technicians. Desktop planning indicated the need for nine monitoring staff for two rounds a day and three teams on a revolving roster, plus three maintenance personnel and a supervisor; a total of 13. Every team needed a vehicle, a cell phone and a Chlorine tester. It all seemed too hard.

8.2 ROUTE CAUSE ANALYSIS – A SAVING GRACE

The stations operated at a low reliability level with high staff demand. We realized very early that the issues we were facing with dosing stations not pumping to specified levels would trigger a personnel hungry set-up – a no goer for an emergency. Moreover it was unclear at that stage how long the stations would need to remain in service, so a sustainable, long-term solution needed to be found.

That is where the ground breaking new monitoring strategy using route cause analysis was a saving grace. The key was to make the stations self–sustainable. A thorough assessment of the installation revealed that the main issue was the presence of gas in piping systems and dosing pumps. Nine remediation options were evaluated and tested on all underperforming stations in service. Four staff were constantly investigating, testing, evaluating and making changes according to a set schedule. After only two weeks the solution was identified; all stations were re-designed, and back in service, working reliably dosing a set rate of chemical.

8.3 KEY MODIFICATIONS TO THE SET UP AND STAFFING

The day tank for the chemical was lifted to stretch the suction pipe work so that all local high-points of the piping were flattened. An actuated valve with timer, which depressurised the system on a set time interval to release gas trapped in the dosing head, was installed.

The final team structure was very slim with two monitoring and two maintenance staff and one supervisor (part time). In total five people for 26 stations, 24 hours daily. This was a reduction by more than 60 % and it was proven again that creativity is a key skill to overcome problems and shortages in emergency response work.

8.4 MONITORING, MAINTAINING AND OPERATING UNDER PHYSICAL STRESS

Main Pumps	30/04/2011 12:23	29/04/2011 12:50	28/04/2011 11:13
Elasped time (hrs)	24	26	22
Tank Diameter (m)	0.817	0.817	0.817
Recorded hypo level (mm)	779	772	768
Level before fill (mm)	700	640	710
Level after fill (mm)	790	790	770
Level increase (mm)	90	150	60
Actual drop / increase in Hypo level (mm)	83	146	45
Recorded flow meter total (m3)	917922	905011	891796
Total water volume pumped (m3)	12911	13215	11004
Actual Hypo used (Litres)	43.5	76.5	23.6
Cumulative Hypo Used / site (litres)	2700.9	2657.4	2580.9
Actual average chlorine dose rate	**0.40**	**0.70**	**0.26**
FAC required	0.6	1.0	1.0
Notes		Changed dose rate to 0.6ppm today at 7.29am, level was 644mm. Check correct dose rate tomorrow.	Airlocked. Pump not running on arrival. Released large amount of air then pump started running per normal.
Filled	Y	Y	Y
Pumping Y/N	Y	Y	Y
Air locked Y/N	N	N	Y

Though highly critical, testing for FAC was impossible to achieve. Control and condition of the reticulation system were unknown factors. Chemical testing of effectiveness of the dosing station would have required detailed knowledge about location and status of each valve in the reticulation system – was it open or shut, in a leg out of service or which fire-hydrant was supplied by which station? It is important to note that the set up of the pressure zones was completely disrupted. A test on a fire hydrant resulted in street flooding when flushing the line. Repeated testing if the first one gave false readings would cause more flooding. Trial and error was unacceptable particularly with looming staff shortages.

8.5 REINVENTING THE MONITORING STRATEGY

Redesigning the monitoring strategy was warranted. The primary monitoring strategy took concentrations in the reticulation system as feedback control parameter for the pump operation. For the reviewed strategy only the dosed amount of Sodium Hypochlorite relative to the amount of pumped water determined adequacy of working levels.

We could calculate exactly how much chemical we had to dose (measured as litres taken out of the storage tank between two visits) to achieve a set concentration of FAC in the reticulation. The simple multiplication of litres used per day times the grams per litre concentration equates the load of FAC per interval dosed (% strength of Sodium Hypochlorite means % of FAC, hence 12 % strength equal 120 mg/l FAC). As every pumping station was fitted with a modern MAG flow meter we could easily read out the flow between visits.

The simple calculation to monitor pump performance was FAC load divided by water pumped which gives ppm FAC. The dose concentration at the station outlet was determined by the local authority, usually 0.6 ppm FAC. A traffic light system was developed to allow for better control of operation and maintenance, indicating good – green, > 0.5 ppm - and no – red, < 0.3 ppm - operation, and a trouble indicating range – amber, 0.3 … 0.5 ppm – in between.

8.6 WORKING REMOTELY

The monitoring site engineer could initiate repairs or notifications to CCC simply by taking the readings of the two media streams, Hypo and water pumped. Response to maintenance was immediate, with the monitoring engineer still on site, corresponding to the maintenance engineer via phone. Several issues were resolved remotely without a separate visit from the maintenance team. Testing on site, verifying the results and possible re-testing would have required about 60 min per station; valuable time not to be lost – while wasting great amounts of water when highest water restrictions were in place. The modified monitoring structure reduced time spent per station by 80 % with zero loss of water.

8.7 VALIDATING INFORMATION ON FAULTY STATIONS

The onsite testing at the reticulation was executed by CCC and the DHB. The information derived was implemented in a GIS data model. This model helped to validate the information City Care Ltd collated, with a delay of one day. For example on site evaluation ("pump is ok – green") and mapping based on actual sampling (red dot on the GIS, no Chlorine in the system) might differ substantially. This would trigger a detailed site inspection which might reveal bad surprises like broken underground piping or leaking dosing lines spilling into shafts instead of pumping into the reticulation.

9 CONTRASTING THE THEORY AND THE PRACTICE

As can be seen from above the theoretical study was undertaken as a partially desktop and partially site based study. It was also undertaken a mere matter of days after the earthquake. The practicalities of actually implementing a strategy in an emergency situation were not 100% realised. This resulted in the theoretical report providing recommendations of what to do under ideal working conditions. As this was implemented it was apparent that this was unfortunately not the case in Christchurch after the earthquake.

The main differences between the theory and the practice are summarised and contrasted in the table below:

Factor	*Theory*	*Practice*
Sampling	Sampling should be from dedicated sampling points.	No time to establish monitoring points. Samples taken where possible. Correlated with GIS system data for pumps.
System Repairs	It should be noted when repairs are being made, when the system is being turned off, when valves are being closed etc.	Things were happening at a fast rate. Valves were operated in the field as required, but not always with notice. This could not be tracked.
FAC Monitoring	Monitoring should be system wide and should include decay modelling.	Monitoring not available. FAC estimated from dose rates only.
No of Dosing Stations	Dosing stations should be installed on all bores.	Only 26 dosing stations were available for use, rationalisation required.
Acceptance of Dosing Equipment System	The dosing equipment should have a prolonged acceptance period to ensure compliance, normally for about a 3 month period.	There was no time for this. The handover/acceptance period was only around 3 days.
Contractual Conditions	NZS 3910 should be used and followed stringently, especially in respect to recording and sign offs.	The need to complete the work quickly outweighed the need for documentation. Documentation was completed afterwards.
Inspection of System	The engineer should inspect the system daily to ensure it is working.	Daily checks were mainly undertaken by technicians with telephone discussions with the engineer.
System Compliance	FAC monitoring plan based on feedback monitoring in each catchment should be used to assess	GIS utilised to try and correlate sample test results with chlorine dosing points to assess system

	system compliance.	compliance.

10 PRACTICAL CONCLUSION

Implementation of a chlorination strategy based on 'ideal conditions' in an emergency situation to supply a City the size of Christchurch with safe drinking water was not as clear cut as it seemed.

Several new avenues have been explored to achieve reliable chlorination within the constraints of an emergency. Stripping standard project cycles to a bare minimum by reducing start up by 90%, staff numbers for operation and maintenance by 60% and testing and reporting time for "dosing stations fit for work" by 80% was a genuinely creative effort to safeguard public health. The key to success was engineering passion to help, using well founded principles in a new, constrained context and total commitment to teamwork.

Within only three weeks 26 chlorine pumping stations operated faultlessly supplying the City of Christchurch with safe drinking water. While it was impossible to follow all the recommendations made in the report, the key point was that safe drinking water was made available for Christchurch as quickly as possible.

ACKNOWLEDGEMENTS

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REFERENCES

NZS 3910 (2003), Conditions of contract for building and civil engineering construction, New Zealand Standard

ISO 9001 (2008), Quality management systems, International Standards Organisation

Micklewright, M (2008), Why Root-Cause Analysis Sucks in the United States, Quality Digest