The Effects of the Earthquake on Urban Freshwater Resources in Christchurch

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Introduction

On February 22 2011, at 12:51pm, a deadly earthquake measuring 6.3 on the Richter scale at a depth of only 5km struck Christchurch killing 185 people and injuring thousands more. Christchurch's service infrastructure was badly damaged in the earthquake with many suburbs lacking power and water. Roads and bridges were also badly damaged, impairing the ability of rescue workers to reach those trapped and injured. The majority of homes in the eastern suburbs were flooded by a combination of broken sewage/water pipes and liquefaction. With drinking water supplies contaminated, the city was forced to boil their drinking water due to the threat of disease. This study assesses the impact of the earthquake on Christchurch's water supply and sewage infrastructure. The study also assesses the earthquake's impact on Christchurch's freshwater ecology.

Background of Christchurch's waterways

There are more than 400km named waterways in Christchurch, 356km of which are open waterways (less than 1km of waterway). The Avon River is one of two major rivers that flow into the Avon-Heathcote Estuary. It flows 26km from its source in Avonhead through the suburbs of Ilam, Riccarton, Fendalton, Hagley Park and Central City. It then continues east through Avonside, Dallington and Aranui out into the Estuary near South Brighton. The entire catchment area of the Avon River is around 84km² with nearly half of it in urban areas. The major tributaries of the Avon River include Wairarapa Stream, Waimari Stream and Dudely Creek, all of which are spring-fed. The water quality in the Upper Avon and its tributaries are pristine, reflecting the quality of the water in the aquifers that feed the springs, however, as the river flows through the city its quality deteriorates due to activities of people. Christchurch's second major river, the Heathcote River, is made up of water from springs and creeks that run off the Port Hills. The river begins in the area of Templeton Road where there are some large springs. The river flows through Hoon Hay and Spreydon before meeting the Cashmere Stream before flowing through Cashmere, Beckenham, St Martins, Opawa and Woolston. It then drains out in the Avon-Heathcote Estuary at Ferrymead.

Impacts of urbanisation

In 1849, Captain Joseph Thomas chose the vicinity of the Avon River as the best location for Christchurch City. The development of approximately 400 hectares was built over Raupo swamp, marsh, peaty gullies and sandy soils. However, the water quality of the Avon River had deteriorated significantly and by 1866 drinking water had to be boiled. Due to an epidemic of Typhoid fever in 1875, the Christchurch Drainage Board (CDB) was established to manage waterways, construct sewers and drains and eliminate sewage and storm water (CCC, 2003). Over the next 114 years, the CDB had established an extensive network of separate underground sewage pipes, storm water drains and gutters for drainage. Christchurch's slow-flowing streams that criss-crossed land were straightened and cleared of vegetation or piped to increase drainage. However, this had adverse impacts on the waterways ecology with native fish numbers declining and loss of native vegetation removing breeding habitats for birds and fish (Suren, 2000). Historically, many parts of Christchurch were covered by wetlands. These wetlands provided a buffer against floods and droughts by acting like a sponge – in times of high rainfall these wetlands soaked up water while in dry times the water was released slowly. However, many wetlands were drained and cleared resulting in further loss of habitat (CCC and ECan, 2010).

Regular monitoring of Christchurch's surface water quality indicates that many contaminants in the waterways in and around the city exceed recommended guidelines. The contamination of the waterways is made worse by the city's many hard impervious surfaces, which flush during rain events contaminants such as lead, copper and zinc from roofing material straight into the waterways. The increased use of impervious materials / structures for buildings, paths and roads has led to less infiltration of rainwater into the soil and groundwater. The result has been lower groundwater of groundwater recharge resulting in most of the five springs of the Avon River drying up (ECan, 2011).

Christchurch's water supply and the effect of the earthquake

Most cities in New Zealand get their water from rivers; however, Christchurch is different because it draws its water supply from the artesian basin under the city. The city's water is naturally filtered through layers of gravel beds and sand laid down by glaciers and rivers during the formation of the Canterbury Plains. This naturally filtered water does not require treatment to remove bacteria making Christchurch's water one of the purest in the world (CCC, 2005). Christchurch's aquifers are recharged from precipitation falling on the Southern Alps flowing into the Waimakariri River and from precipitation filtering through the pervious layers. The filtering through from aquifer to impervious layer to aquifer repeats to about five layers. Water in Christchurch is taken from 50 different locations with water wells sunk down into the natural reservoirs and pumped into the pipe network. At each location there is one and sometimes up to five wells. Christchurch is serviced by a vast network of underground water pipes totalling about 1,500 kilometres (CCC, 2005).

Water supplies to Christchurch was disrupted following the earthquake due to severe damage to the reticulation network (breaks to pipes required repairing followed by the replacement of approximately 150km of water main and sub-mains to restore the infrastructure to its pre-quake condition), storage facilities (four reservoirs were badly damaged) and wells/bores (20 wells need to be re-drilled, 55 have been repaired, 27 need repairs while 72 have no issues). It is estimated that the total cost of repairing this damage will be $17 million (CCC, 2011).
Following the earthquake groundwater quality in wells were tested. Regularly monitoring of the wells has shown no evidence of ground water contamination from nitrate leaching from surface sources or bacterial contamination after the earthquake event. Faecal contamination of water could occur following earthquakes due to damage of sewage infrastructure. However, Christchurch's sewage pipelines are close to the surface while the wells are 16 – 177m deep, therefore there is low risk of bacterial contamination of the city's aquifers (ECan, 2011). Until the earthquakes, the water was drawn from the first aquifer (18 – 25m deep). As a precaution and now for quality reasons (no sand or silt present), water is drawn from the 4th to 5th aquifer (approximately 180m deep). Nearer to the surface however there was contamination of drinking water supplies with both private and street laterals and water pipes cracking causing mixing of sewage and drinking water. As a result, twenty-five chlorination units at pump stations servicing the east side of the city were installed as a precaution due to the damage to the sewage network and residents warned to boil all drinking water (Canterbury earthquake, 2011).

To ease the pressure on the city's earthquake-damaged water infrastructure over the summer period, the Christchurch City Council introduced water restrictions commencing October 8 2011 for the first time in thirteen years. Setting the restrictions at level three, the aim of these restrictions is to protect and maintain artesian resources and minimise the threat of insufficient water and water pressure particularly for fire-fighting. With typical summer use reaching 12,000 cubic metres per hour over a 24-hour period and temperatures predicted to be warmer than average, the Council has warned resident's that if they don't stay below the target of 8,200 the city will be forced to ban all outdoor watering. In order to enforce the water restrictions, the city's by-laws permit the council to fine offenders up to $20,000 and even restrict the offender's water supply (The Press, 2011).

Table 1: Christchurch City Council water restriction levels

Restriction Level	*Water Conservation Method*	*Notes*
Level 1 Alternative day watering	Use of hoses, sprinklers and garden irrigation systems is permitted on alternative days. - Even numbered properties on even days. - Odd numbered properties on odd days.	-The water supply is expected to start to come under pressure.
Level 2 Hand held hosing only	Hand-held hoses may be used at any time. Unattended hoses, sprinklers, and garden irrigation systems are not permitted at any time.	-The water supply is under considerable pressure. -Imposed when there is a water shortage and considerable water savings are required. -Often imposed during peak demand periods
Level 3 Alternate day hand-held hosing only	Hand-held hoses may be used on alternative days. - Even numbered properties - hand-held watering only on Tuesdays, Thursdays and Saturdays. - Odd numbered properties - hand-held watering only on Wednesdays, Fridays and Sundays. Unattended hoses, sprinklers, and garden irrigation systems are not permitted at any time.	-The water supply is under extreme pressure. -Imposed when previous restrictions have not resulted in sufficient reduction in water use, and/or when a significant increase in demand is predicted. -Often passed-by, with restrictions moving directly from Level 2 to Level 4.
Level 4 Total hosing ban	All use of water outside the house must cease. Hand held hoses, unattended hoses, sprinklers, and garden irrigation systems are not permitted at any time.	-The water supply level is critical.

(CCC, 2011)

Christchurch's sewer infrastructure and the effect of the earthquake

Christchurch's wastewater system comprises of a vast network of over 1,800km of gravity sewage pipes and 91 pumping stations continuously conveying wastewater to the Christchurch Wastewater Treatment Plant for processing. Compared to other New Zealand cities, Christchurch is very flat and because of this more pumping is required on the plains as the ground is often too uniform for gravity alone to move wastewater along naturally (CCC, 2011). It is important that sewage reaches the treatment plant as soon as possible to avoid odour. Christchurch has a problem with ensuring waste reaches that plant in a timely manner as it has one of the flattest sewage systems in the world. When the volume of wastewater is not sufficient for rapid flow, it is necessary to flush extra water through the pipes to move waste along (CCC, 2011).

The sewer system for households and street sewer pipes were significantly damaged in the earthquake with 300km out of 1,858km street sewer pipes requiring repair and 13 out of the 97 sewage pumping stations needing total replacement (ECan, 2011). Ten of the city's pumping stations, which transport wastewater through the system to the treatment plant, suffered extensive damage while pressure pipes from 13 out of the 97 pumping stations needed total replacement. Christchurch's sewer mains also suffered extensive damage following the earthquake. Three months after the earthquake, 6% or 96km of the city's sewage mains were not working and a further 27% or 474km were working only slowly (Rebuild Christchurch, 2011). The Christchurch Wastewater Treatment Plant also suffered significant damage and was processing sewage at only 30% of its normal level due to the plant sucking in around 1,000 tonnes of sand and silt out of the sewage network. With the plant overload, the city council was forced to release untreated wastewater into the plant's 230 hectare oxidation ponds. This has led to a 50% chance that dissolved oxygen levels will drop below functioning level essentially turning the city's oxidation ponds at the treatment plant into giant cesspits causing odour problems for Christchurch (Christchurch Earthquake, 2011). To reduce the amount of sand and silt entering the plant, 92 trucks were dispatched to clear sediment out of the city's sewage pipes in an attempt to reduce clogging of the treatment plant's primary tanks (Rebuild Christchurch, 2011). However, it will take an estimated 12 to 18 months to complete the repairs to the treatment plant.

The result from the damage to the sewage system has been the leaking of millions of litres of raw untreated sewage into backyards, rivers and the sea. Immediately after the earthquake, a quarter of Christchurch's sewage, approximately 40 million litres, had leaked out of broken pipes. On July 15th 2011, the Christchurch City Council announced the level of sewer discharge into the waterways had dropped to 18,778 cubic metres per day from 31,360 cubic metres per day at the beginning of May (CCC, 2011).

Table 2.Wastewater discharges into Christchurch's rivers, estuary and sea since February 22nd 2011

Date	*Cumulative total (litres)*
Feb 23rd 2011	40 million
March 15th 2011	1.8 billion
Mar 20th 2011	2.1 billion
Apr 8th 2011	2.8 billion
Apr 20th 2011	3.2 billion
May 6th 2011	3.7 billion
May 20th 2011	4.2 billion
Jun 8th 2011	4.9 billion
Jun 22nd 2011	5.7 billion
Jul 8th 2011	6.5 billion
Jul 21th 2011	6.7 billion
Aug 10th 2011	7.1 billion
Aug 23rd 2011	7.3 billion
Sep 8th 2011	7.4 billion
Sep 22nd 2011	7.6 billion

(CCC, 2011)

Christchurch's freshwater ecology and the effect of the earthquake

Christchurch's waterways contain 13 of the 35 indigenous fish species in New Zealand, of which five are considered well-distributed and common. The Short fin eel is the most common fish species found in the city's waterways because it has low requirements for instream cover and is extremely tolerant of varying water quality. In comparison, numbers of Long fin eel are lower because it prefers logs and vegetation for shelter and poor water quality affects their numbers. Meanwhile, common bullies can be found in rivers, streams and drains throughout the city while the bluegill bully has been recorded in the central city area of the Avon River but it now appears to be rare in the Christchurch area (CCC, 2003). Inanga (adult whitebait) is commonly found in diverse freshwater habitats including lowland and coastal rivers, streams and lakes. In Christchurch, Inanga can be usually found in the slow-moving regions of the city's downstream rivers. The urban waterways of Christchurch are also typically dominated by the snail *Potamopyrgus* while the most diverse invertebrate community found is the aquatic fly larvae in particular midges. Caddisflies are common but numbers are declining due to their sensitivity to pollution of the waterways. Other common invertebrates include snails (*Physa*) and crustaceans such as the amphipod *Paracalliope*.

The earthquake caused severe liquefaction in Christchurch resulting in an estimated 21,500 tonnes of sediment entering river ways either from bubbling up from within the rivers or draining into them. A study conducted by Professor Jon Harding of University of Canterbury found 25km of the Avon river's 99km long course had either medium (2 cubic metres of silt and sand in a 10m stretch of river) (17km) or heavy (4 cubic metres per 10m) (8km) silt concentrations while 34km of the 62km-long Heathcote was found to have medium (28km) or heavy (6km) silt concentrations. The majority of the liquefaction in the Avon River was in its upper reaches while the Heathcote was found to be worst in the lower reaches closer to the Avon-Heathcote estuary (The Press, 2011).
A number of fish in Christchurch's waterways use the beds of rivers to lay eggs on with many preferring finer-grained gravel in well-oxygenated areas, however, the liquefaction has smothered river beds with sand and silt removing spawning habitats and places to lay eggs while lowering oxygen levels. Liquefaction has also surged down rivers and streams leaving grey tidal marks across banks and riparian vegetation resulting in Inanga losing their spawning grounds (The Press, 2011). Oxygen levels have also severely decreased following the earthquake due to broken sewage pipes discharging untreated sewage into the city's waterways.

A study on survival rates of *Paracalliope* in the lower Avon River following the earthquake found numbers had decreased over time, most likely due to elevated ammonia levels and lower dissolved oxygen levels. The long-term effects of discharged sewage in Christchurch's waterways on fish and invertebrate species are likely to be increased disease susceptibility and impaired reproduction (ECan, 2011).

Discussion and conclusion

The physical damage to Christchurch's drinking and sewage infrastructure has been immense with pump stations, wastewater trunk mains, water trunk mains and storm water drains requiring repairing or replacement. These repairs are likely to take months or even years if aftershocks continue. As a result, it is now necessary to conserve water in preparation for the forecasted high demand for water over summer. It is likely that because the population is aware of the damage to the system it is most likely the city will reduce water consumption and meet the targeted level. Nonetheless, it is possible that water restrictions will be in place the following year. To prevent contamination of drinking water supplies from broken sewage pipes in future earthquakes, the drinking water pipes and sewage pipes should be installed at considerable depth from one another. The city could also investigate the feasibility of laying drinking water pipes above the surface. The benefit of this would be immediate repair of broken drinking water supplies following another earthquake. Sewage discharges are likely to decrease over the following months, however, there needs to be continual monitoring of the waterway's aquatic life as the effects of the contamination is likely to be long-term. Potentially, species may have to be reintroduced in the most severely impacted areas. Christchurch's waterways have been severely affected by liquefaction resulting in raised river beds, smothered aquatic plants, covered riparian vegetation and increased turbidity. If the city's upper catchments are not dredged in the near future the city's waterways are likely to decline in health. Furthermore, due to the many demolition sites throughout the city, particular in the CBD, there is the potential for construction site sediments entering the Avon River further harming the waterway's ecosystem.

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