8. EFFECTS ON LIFELINES

Over the past decade, the people of Canterbury have undertaken a deliberate and dedicated effort to increase the resiliency of the entire lifeline system within the region. And, with the exception of water and waste water distribution lines in the areas affected by liquefaction, lifelines performed quite well. The case for hardening of the lifelines was made in the report "Risks and Realities: A Multi-Disciplinary Approach to the Vulnerability of Lifelines to Natural Hazards" (CAENZ 1997). Following preparation of the report, a plan to enhance the resiliency of lifelines in Canterbury was developed and implemented across all sectors, including transportation, water, waste water, electric power, and communications. In addition, the interdependence of lifelines was recognized and addressed through detailed planning and coordination efforts.

This chapter includes the GEER-NZ Team's observations for the transportation system (highways and rail and bridges are covered in separate chapters), water and wastewater systems, electric power, and waste management, as well as other lifelines.

Highways

Most highways and major surface transportation routes remained open following the M_w6.2 earthquake, or were only closed temporarily for inspection or minor repairs. State Highway 1 North was found to be good shape with some damage to the approaches of Chaney's overpass (Chapter 7). The State Highway 74 tunnel from Christchurch to Lyttelton was briefly closed due to a rock fall. Dyers Pass and Evans Pass roads were also closed due to rock fall (Chapter 9) limiting the supply of fuel from the Lyttelton Tank farm to the city, which resulted in long waits at the gas stations several days after the event. Summit Road between Evans Pass and Dyers Pass Road remained closed 5 weeks after the event.

Many surface streets were closed and severely damaged in Christchurch as a result of liquefaction and lateral spreading (Chapter 4). A floated manhole is seen in Figure 8-1 on Orrick Crescent. Figure 8-2 shows a large lateral spread on the north bound lanes of Fitzgerald Avenue and Cambridge Tce.

Figure 8-1. Floated manhole on Orrick Crescent (-43.50174°, 172.696487°).

Figure 8-2. Lateral spreading at Fitzgerald Avenue along the Avon River (-43.524048°, 172.650851°).

The Moorhouse Avenue Overbridge was out of service to all traffic for an extended period following the 22 February earthquake due to damage sustained to a single column where a deck expansion joint is located. The Overbridge is an eleven span T-girder supported by dual reinforced concrete column bents constructed in 1960. Damage was caused by ground shaking, with a conditional PGA of 0.42 g and a vertical velocity pulse that may have combined to cause the flexural-bucking failure mechanism in the columns.

The expansion joint detail was extended into the column, increasing the slenderness of the piers (i.e., these column were of a size comparable to the other columns along the span, except that they were split in the middle by the expansion joint). The columns also had widely spaced transverse reinforcement. Upon first inspection the bridge had only suffered shear cracking in both columns, but several hours later the bridge was inspected again and it was observed that the damaged columns had started to buckle putting the central span at risk of collapse. Temporary props were then put in place to provide gravity support for the span until a rehabilitation plan could be implemented.

Rail System

KiwiRail operations in and out of the Port of Lyttelton were halted for 11 days as a result of the 22 February earthquake. KiwiRail sustained damage to two bridges in Christchurch which are described in more detail in the Chapter 7. These bridges are located between the Annex Road rail yard and Heathcote Valley, which resulted in no rail access to the port. Bridge No. 7 sustained minor damage to its abutments and remained operational and did not require repair. Bridge No. 3 at Martindales Road in the Heathcote Valley sustained moderate damage to the abutments and resulted in a six car derailment (Figure 8-3). KiwiRail was able to repair the bridge within two days after the event.

Figure 8-3. Bridge No. 3 at Martindales Road in the Heathcote Valley (-43.576013°, 172.706567°).

The impact of the port closure had an effect on rail operations and coal mining operations. Coal trains coming from the West Coast to the Lyttelton Port were loaded and staged in Springfield and on the West Coast. On Saturday, 5 March coal trains were able to enter the port and unload. Had the trains not been able to enter the port starting on the 6 March coal mining operations on the West Coast would have had to been suspended due to the lack of stockpile space at the mines.

The GEER team visited the section of rail south of Kaiapoi at Woodford Glen that suffered damage during the September 2010 event (Figure 8-4a). Liquefaction was found in the fields adjacent to the damaged area but no damage to the track was reported. KiwiRail was in the processes of widening the ballast over the soft soils as a precautionary measure (Figure 8-4b). The team also found that a separation geotextile and reinforcing geogrid were being installed. Aside from the two damaged bridges no other damage was caused to rail lines.

(a) (b)

Figure 8-4. (a) Damage to rail line at Woodford Glen after 4 Sept. event, (b) Rail line at Woodford Glen after 22 Feb. event with additional ballast being added (-43.406114°, 72.649319°)

KiwiRail continued to haul supplies into the city after the earthquake. This included 50,000 liter tanks of potable water for distribution in the residential areas. The Transalpine service had been suspended due to lack of tourism as a result of the earthquake.

Water and Wastewater Systems

The large ground movements and deformations (in extension, compression, shear, and combined modes) including ground distortion, cracks, fissures and venting sink-holes, resulting from the severe liquefaction and lateral spreading caused severe damage to underground pipe networks such as the potable water, wastewater and stormwater systems. These systems have different characteristics and they were affected and performed quite differently in the 22 February earthquake.

The potable water system is a system of relatively shallow pipe network (mostly in the top 60 cm of the ground). It is a pressurized system composed of mains and sub-mains. Figure 8-5 shows a summary of the water mains network in Christchurch indicating pipe materials (solid lines) and the location of breaks (red solid symbols) caused by the 22 February earthquake. Superimposed in this figure is the liquefaction map (Chapter 4) indicating the areas affected with different severity of liquefaction. It is apparent from this figure that most of the breaks were located in the area affected by liquefaction. A more rigorous preliminary analysis indicates that about 4.6 % of the pipes (pipe segments) were damaged, or about 78 km out of 1676 km total pipe length. About 80% of the damaged pipes were in areas that manifested either moderate-to-severe or low-to-moderate liquefaction. Similar observations and preliminary findings were obtained for the sub-mains system which is dominated by polyethylene (PE) pipes. Despite the relatively large number of breaks, the potable water supply was quickly restored within several days of the earthquake.

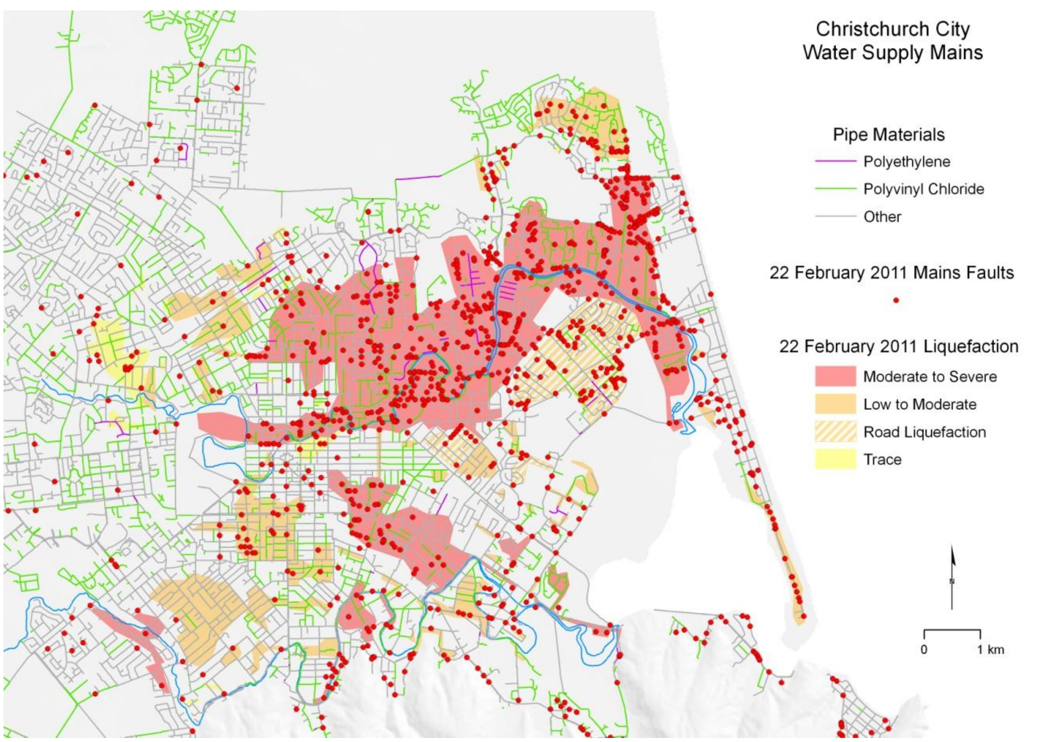


Figure 8-5. Water mains pipe network and location of breaks (faults) caused by the 22 February 2011 earthquake; colored lines indicate pipe materials; colored areas indicate liquefaction severity.

The wastewater system was hit particularly hard in the areas severely affected by liquefaction and lateral spreading. Out of the 1766 km long wastewater network, 142 km (8%) were out of service; and 542 km (31%) with limited service on 16 March 2011 (i.e. three weeks after the February earthquake), as shown in Figure 8-6. A significant part of the network was still out of service even three months after the quake, and it is estimated that it will take two to three years to fully recover the system.

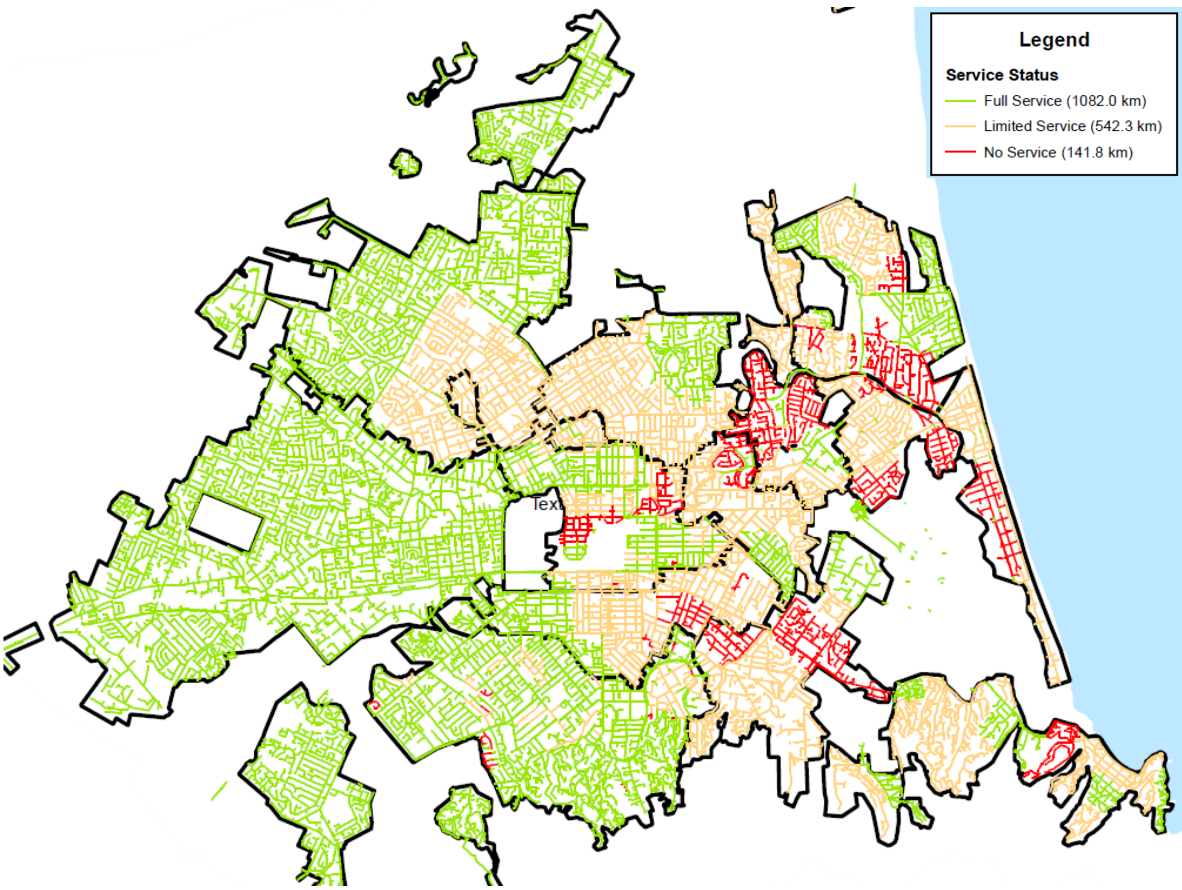


Figure 8-6. Waste water service status on 16 March 2011 (M. Christinson, pers. comm.)

Loss of grade, joint failures, cracks in pipes and failure of laterals were the most commonly observed types of failures. Loss of critical facilities such as pump stations also contributed to the overall poor performance of the system. Buoyancy of concrete vaults at potable water and wastewater pump stations, compounded by liquefaction-induced settlement, caused pipeline breaks at their connections with the vaults. Approximately 1 m of settlement at the Bexley Pump Station ruptured the well, flooding the surrounding neighborhood at 140 m^3/hr.

Note that the wastewater system includes both pressurised and gravity components, and the network consists of pipes of different sizes and materials including concrete, ceramic, cast iron and plastic (PVC and PE) pipes. This system is much deeper, at typically at 3-4 m depth from the ground surface, making it more vulnerable to liquefaction effects. For both potable water and waste water systems, the most severe damage was inflicted by lateral spreading.

Nearly all components of the Bromley sewage treatment plant were affected by liquefaction, which caused differential settlement of the clarifiers, thereby seriously impairing secondary treatment capabilities. Silt and sand from liquefaction washed into the plant from broken wastewater pipelines, causing damage in the primary settling tanks. Also, the scraper chains in the settling basins (Figure 8-7) had jumped there cogs.

Figure 8-7. Waste Water Treatment Plant Settling Basins (-43.526016°, 172.700922°)

The trickling filters at Bromley sewage treatment plant appeared to perform well (Figure 8-8a). The team was told that the filters were placed on stone columns. The team also documented 25-50 mm of lateral movement (Figure 8-8b). The filters did suffer some damage in that the distributor was not operating properly.

The team completed their reconnaissance of the Bromley sewage station by walking the levees (stopbanks) at the oxidation pond. The team noted several separated concrete pipes that were used to move water from one pond to another during the treatment process (Figure 8-9). Lateral spreading in the stopbank separated pipes.

(a)

(b)

Figure 8-8. Bromley Waste Water Treatment Plant trickling filters placed on stone columns performed well (-43.52118°, 172.701752°)

Figure 8-9. Pipe damage at the oxidation ponds (-43.3145211°, 172.430083°)

Gas Distribution System

The natural gas pipeline system in Christchurch is owned by Contact Energy, and is operated under the name of Rockgas. The network is shown in Figure 8-10, in which the red and blue lines indicate streets with existing and planned future pipelines, respectively. A large portion of the gas pipeline network was located in areas that experienced large ground deformation and liquefaction.

The gas reticulation network in Christchurch outside of the Central Business District (CBD) performed well. At the time of the investigation it was unclear how the pipe network inside the CBD had performed.

Within the first hour after the earthquake on 22 February, a Rockgas technician was enroute to Woolston Terminal and noticed that there was a higher than normal flow on the Brisbane Street feeder to the CBD which the technician stopped and shutoff. At the same time Rockgas was receiving notice from Civil Defense to close all feeders to the CBD. This was accomplished within 5 hours after the earthquake and resulted in a pressure drop in the system from 90 to 25 kPa.

Although two to three inline valves for the CBD feeder lines had been closed within hours of the event, Contact Energy employees also cut and capped the feeder lines at Petersbourgh/Victoria, Columbo/Petersbrough, Brisbane, and Fitzgerald streets to physically isolate the CBD within two to three days after the event. The isolated area can be seen as the dark red square in the center of Figure 8-10 around the CBD.

Rockgas crews also worked to restore service and continued to provide services immediately following the earthquake. This was done by doubling Rockgas' field staff to 22 people. Figure 8-10 depicts the dates and areas that services were restored to after the 22 February event. Rockgas provided hospitals and other critical infrastructure that were connected to the gas network with fuel via drop off cylinders until the network had been pressure tested and service restored.

A 2 ton above ground gas storage cylinder at 417 Brighton Road suffered damage. The team also learned of a Rockgas underground tank that had been floated due to liquefaction at the intersection of New Brighton Road and Bower Ave. At the time of GEER visit we were not able to examine either tank.

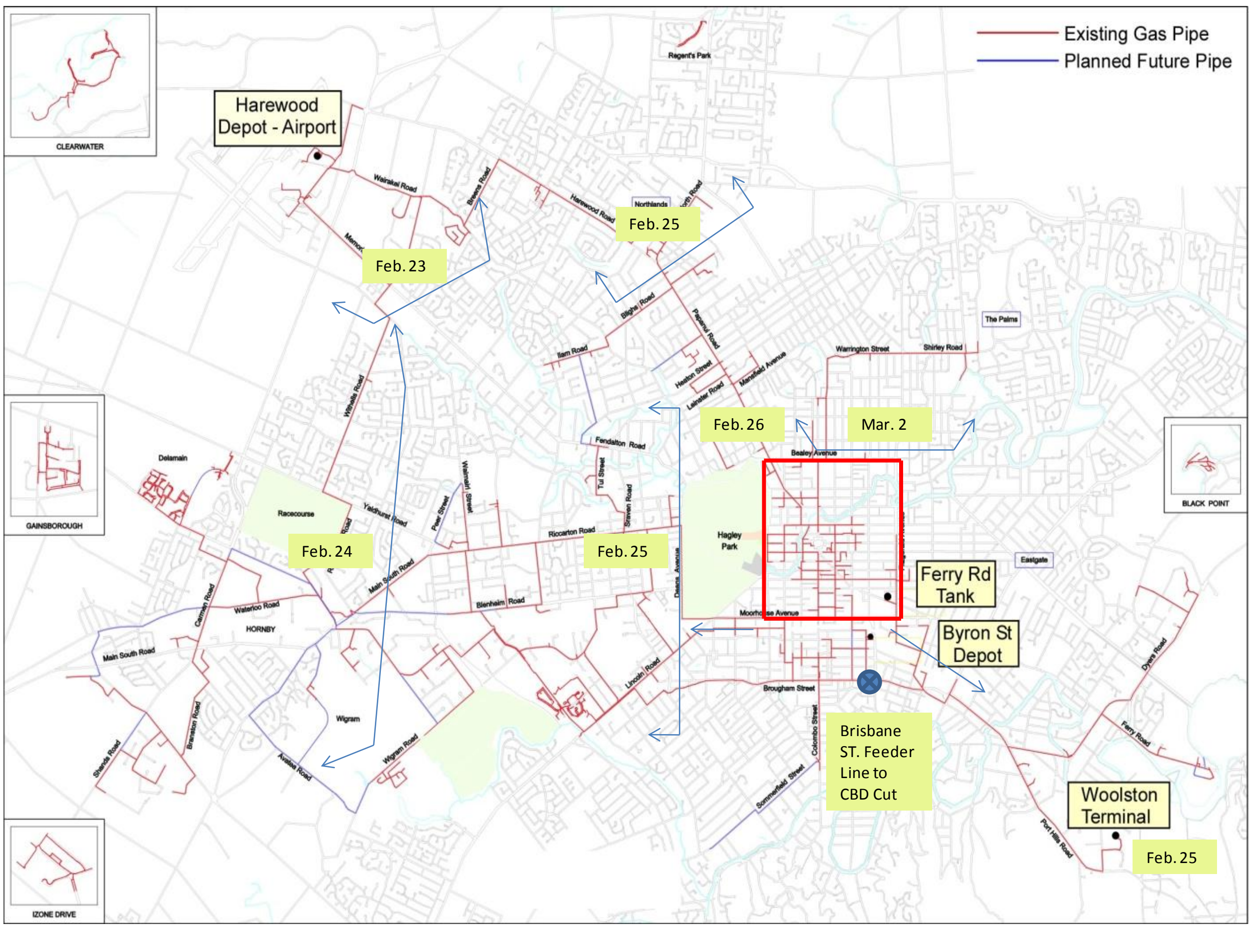


Figure 8-10. Map of Christchurch gas distribution system.

The Burwood Landfill gas system was not connected to the gas network at the time of the GEER teams visit and was flaring its gas. No damage to the overland Liquagas pipeline that connects the Lyttelton tank farm and Woolston terminal was reported.

Electric Power

The Bromley substation is divided by Ruru Road and located in eastern Christchurch near the Waste Water Treatment Oxidation Ponds. Liquefaction was noted within the fence line at the

Bromley substation.

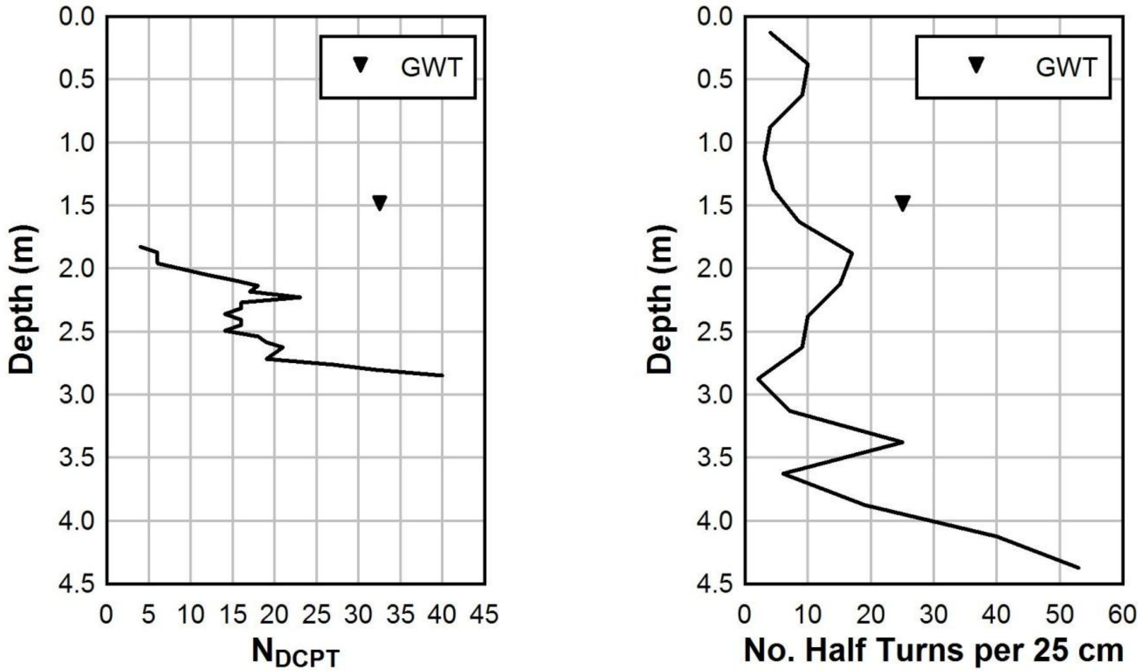
Liquefaction ejecta was found at the substation on both sides of the road. The soils under both power line supports outside of the fence line liquefied (Figure 8-11). Liquefaction ejecta was found around concrete pile groups supporting circuit switchers (Figure 8-12) and earthquake retrofitted transformers. No visible damage or settlement to substation was found by the GEER and it appeared that it performed well.

DCP and SWS tests were performed by the GEER team (Figure 8-13) and the data are presented in Figure 8-14. SASW data could not be collected due to the high voltage power line interference. As shown in Figure 8-14, the groundwater table was at depth of ~1.5 m and the top of the liquefied layer was at a depth of ~1.75 m. (Note that a hole was hand augered to the top of the liquefied layer, with the DCP being performed in the hole from then down to refusal).

Figure 8-11. Liquefaction ejecta at the base of an electrical tower (-43.531764°, 172.697467°)

Figure 8-12. Liquefaction ejecta around concrete (-43.532629°, 172.698029°)

Figure 8-13. Swedish Weight Sounding (SWS) Testing at Bromley Substation (-43.531534°, 172.697942°)



(a) (b)

Figure 8-14. In-situ data from Bromley Substation: (a) DCP test; and SWS test.

Waste Management

The GEER team visited the previously closed Burwood Landfill in the Bottle Lake Forest Park which had been re-opened for emergency waste handling by Christchurch City Council. The Burwood Landfill was opened after the Darfield Earthquake for a short period of time to assist with waste disposal until the Kate Valley Landfill was able to take over for waste disposal operations. An aerial photo of Burwood Landfill can be seen in Figure 8-15. Four distinct areas were reopened at the landfill for processing waste.

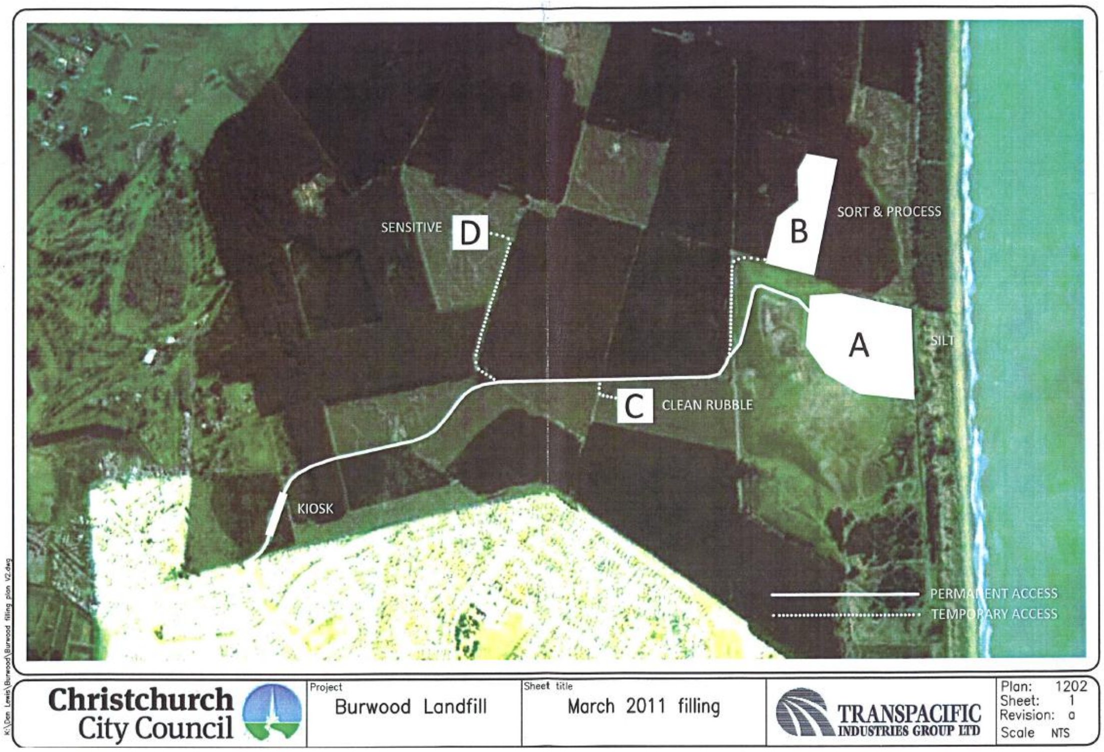


Figure 8-15. Aerial photo of Burwood Landfill depicting land use.

Area A was being used to dispose of ejected sand that was being cleaned up in city. CCC was expecting to accept 300-400,000 tonnes of ejected sand (Harris, 2011). The sand was being removed from residential, commercial, and public properties. The team witnessed the Student Volunteer Army collecting and moving the ejected sand into the streets by hand (Figure 8-16). Once the sand was placed in the streets it was collected with heavy equipment and transported to the Burwood Landfill, Pad A for disposal (Figure 8-17a). The team also found a large stockpile of ejected sand at the Bromley Waste Water Oxidation Ponds (Figure 8-17b).

The University of Canterbury Student Association, Student Volunteer Army was organized through Facebook and Twitter by students (McInnes, 2011). A Facebook page was created after the September event that allowed for the dissemination of information and allowed people to sign up for help. Assignments were also provided by New Zealand Civil Defence. Every morning up to 3000 students would meet at the university and head out into city to assist Christchurch citizens. Students were organized in Autobots or a bus full of students, Squadrons or a car full individuals, and street teams. Most of the work that was performed involved the removal of ejected sand from individual homes, streets, and buildings. The Student Army played a critical role in allowing people to get to their homes and in cleaning up the city after the September and February earthquakes. This may be the first case where a social media network provided assistance as a lifeline in a geotechnical capacity. The Facebook page can be found at http://www.facebook.com/StudentVolunteerArmy.

Figure 8-16. University of Canterbury Student Army at work (courtesy of Dan Neville).

(a) (b)

Figure 8-17. (a) Ejected Sand Stockpile at Burwood Landfill, and (b) Ejected Sand Stockpile at Bromley Oxidation Ponds at Dyers Road.

Area B in Figure 8-15 was being developed as a working pad for the recycling of demolition debris taken from the Central Business District in Christchurch and surrounding areas. The pad was under construction at the time that the team visited the landfill. CCC was expecting to receive in excess of 1.5 million tonnes of demolition debris. The area B pad was being developed as a recycling and processing centre where CCC would attempt to recycle as much waste as possible. Timber debris would be turned into hogfuel and a concrete crushing plant was also going to be installed at Pad B to assist with the recycling of the debris. It was estimated that it would take 5-10 years to recycle all of the waste but that the majority of the tonnage could be recycled (Pinkham, 2011).

Areas C and D were not visited by the team. However the team did visit a liquid solid waste disposal area not marked in aerial photo. The site had temporarily been allowed spread liquid solid waste collected by vacuum trucks from the sewer system in Christchurch until the waste water treatment plant could be brought back online.

Canterbury Waste Services (CWS) who operates the collection centres in and around Canterbury and the Kate Valley Landfill was visited again after the 22 February earthquake. CWS learned from the September event that the mixing of liquid wastes with MSW at the collection centres was an excellent way to reduce the liquid content prior to hauling the material to the Kate Valley Landfill, where high liquid content waste could possibly result in an unstable waste body. After the September event, CWS also worked with New Zealand Civil Defence to not allow large liquid retailers such as breweries and soda pop manufacturers to dump their liquids immediately, but to dispose of them in a controlled manner. Lastly, after the 4 September event the Christchurch City Council had suspended the clean fill disposal law, which removed restrictions on the dumping of waste at the collection centres. This abandonment of the clean disposal law meant demolition debris that contained hazardous materials, could to be disposed of at the landfill. CWS has been working closely with the insurance companies and CCC to separate hazardous materials from the debris prior to accepting the material at the transfer station or the Kate Valley Landfill.

After the 4 September earthquake CWS saw tonnages being delivered to the Kate Valley Landfill rise from the typical 800 tonnes per day to approximately 1800 tonnes for about a two week period after the event. After the 22 February earthquake it took until 28 February before daily tonnages begin rising. Daily tonnages after the 28th ranged between 1100 and 1500 tonnes per day. CWS transfer stations and the Kate Valley Landfill all performed well following the 22 February earthquake.

Other Lifelines

Access to other lifeline at the time of the 03 to 08 March 2011 reconnaissance was unavailable due to earthquake recovery.

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McInnes, Alan (2011) “Personal Communication with GEER Team Members Allen, Bradshaw, and Dr. Mark Milke of University of Canterbury”

New Zealand Centre for Advanced Engineering (CAENZ), (1997) “Risks and Realities: A Multi-Disciplinary Approach to the Vulnerability of Lifelines to Natural Hazards”, http://www.caenz.com/index.php?option=com_content&view=article&id=100%3Arisks-and-realities-a-multidisciplinary-approach-to-the-vulnerability-of-lifelines-to-natural-hazards&catid=8&Itemid=54.

Pinkham, Martin (2010) “Personal Communication with GEER Team Members Allen, Bradshaw, and Dr. Mark Milke of University of Canterbury”