KAIKOURA EMERGENCY RESPONSE AND RECOVERY – HOW RESILIENT IS YOUR WASTEWATER SYSTEM

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ABSTRACT

The November 2016 earthquakes rocked the upper South Island and cut-off Kaikoura from the outside world. Wastewater infrastructure was unusable in parts of the town and parts of the treatment plant destroyed. This paper outlines the steps the Emergency Response teams took to get the town back flushing within 10 days and outlines the Long-term recovery investigations. It also demonstrates the benefits of resilient design, small pressure sewers and decentralised treatment options and that land application systems don't need much to keep functioning.

EARTHQUAKE DAMAGE

General

Contrary to the perception the world has of the damage to Kaikoura, the township itself was let off rather lightly in the November 2016 earthquake. The major impacts were felt in the surrounding rural communities, while the township was mainly impacted on by lack of access due to rail and road links being severed.

Damage within the township was generally limited to houses adjacent to Lyell Creek to the north of the CBD and Totara/Mount Fyffe area, both associated with soils that are either water logged or near streams.

Wastewater Treatment Plant (WWTP)

The assets at the WWTP include the following:

i. Inlet Screen;
ii. Aerated lagoon and Associated Infrastructure;
iii. Oxidation Pond and Associated Infrastructure;
iv. Effluent Pump Station;
v. Infiltration Basins;
vi. Septage Pond; and
vii. Pipework between the facilities.

Post-earthquake investigations were undertaken by LEI and Fluent Infrastructure Solutions Ltd, with assistance from Tonkin & Taylor (Geotech), GHD (structural and electrical), Harrison Grierson (manhole inspections) and Bowden Environmental (pond drop test). The investigations found the following:

1. The concrete foundation slab for the inlet screen of the WWTP moved and settled during the earthquake. The screen shifted and the pipe connections broke, thereby disabling the inlet screen operation;
2. The aerated lagoon suffered the following damage as a result of an earthquake induced landslip:
    - A landslip extends the full length of the pond resulting in tearing to the liner and the draining of the pond (see Figure 1);
    - A graben approximately 8 – 10 m in width has formed extending through the pond with approximately 500 mm of vertical deformation;
    - A toe bulge was identified at stream level to the south of the lagoon approximately 8 m below the crest of the pond;

- Multiple tension cracks were observed on the eastern, western and southern embankments;
- Movement from the landslip is predominantly in a southerly direction but some movement occurred towards the south west;
- Fencing around the pond has been deformed;
- The damage to the lagoon has made it inoperable. All wastewater sitting in the aerated lagoon prior to the earthquake has drained into the sea and the lagoon is now empty. The aerated lagoon is temporarily being bypassed, with the screened influent and the septage going directly into the oxidation pond;

3. The oxidation pond initially appeared undamaged following the quakes, apart from the waveband in the southwest quadrant. Which had broken away and slipped 200 mm into the pond. It was clear that the earthquakes caused this as it has exposed fresh areas of soil that have not yet vegetated;
4. To assess the damage to the oxidation pond a Pond Seepage Test was carried out on 21/22 December 2016 showing significant leakage of the oxidation pond of approximately 15 mm/day or 250 m^3/d;
5. No damage occurred to the effluent pump station, the pipework between facilities, the septage pond or the infiltration basin.

Figure 1: Damaged Aerated Lagoon

Reticulation Infrastructure

The reticulation infrastructure assets (see Figure 2) include the following:

i. 10 Branch Line Stations;
ii. 4 Trunk Main Pumps Stations;
iii. 49.5 km of gravity sewers including 5 km of AC pipe, 2 km of PE, 24.5 km of PVC and 4 km of concrete pipe;
iv. 11.5 km of pressure mains including 2 km of AC, 4.5 km of PE and 5 km of PVC pipe; and
v. 558 Manholes.

Findings from the post-earthquake investigations found the following:

- Six of the 14 pumping stations received damage during the earthquake ranging from ground subsidence around the wet well to pipe failure and chamber concrete riser displacements (see colour coding in Figure 2 and Table 1, based on SCIRT).

Table 1: SCIRT Defects Category for Damage

Defects Category	Description
R1 (red)	Critical defects that require repair (all materials). Where these defects are present, the pumping station is considered to be at risk of collapse and/or compromised service within 15 years. Designers need to specifically review with Asset Owner Representatives any defects in this category that they believe do not warrant repair.
R2 (orange)	Review the defects identified by R2 (all materials) to determine if repair is required. These are defects that could have a high or low significance depending on the location of the pumping stations and the nature/size of the defect. To review these defects the Designer will need to view snap shots of the defect or view the video footage to determine whether the defect requires repair.
R3 (yellow)	Defect is non-critical and does not require repair – Maintenance required.
Blank (green)	No damage observed.

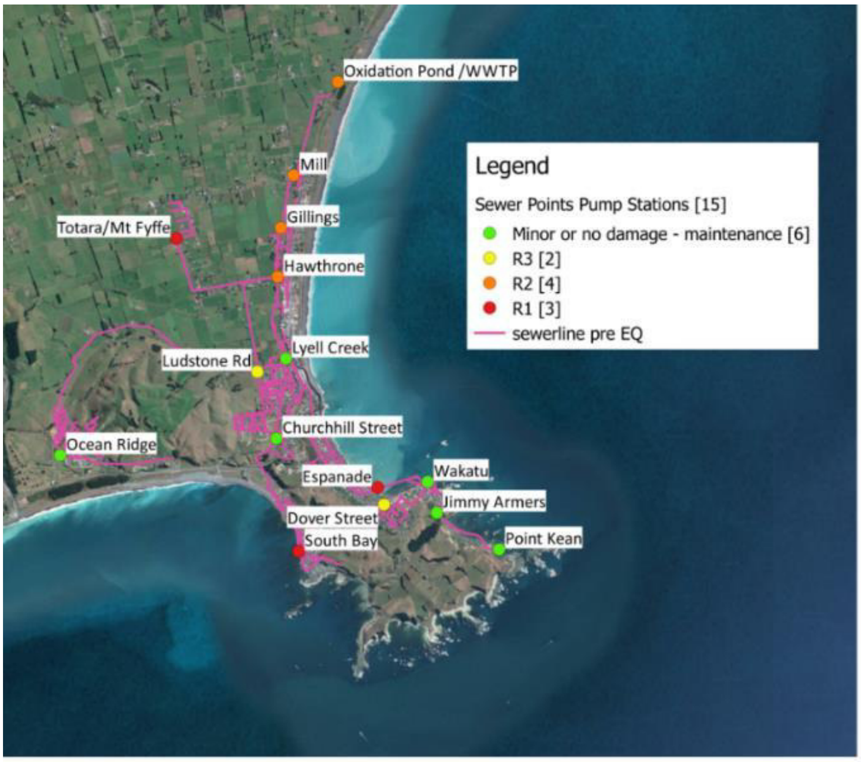

Figure 2: Wastewater Infrastructure showing Pumps Stations

- The manholes inspection results have been split in structure issues, joints issues, water infiltration, no damage with and without maintenance needed, missing and general further assessment needed. In total, 109 (64 missing, 10 with joints issues, 29 with structural issues and 6 that require general further assessment) of the wastewater manholes require repair or replacement work, or further investigation - that is 20% of the manholes. See Figures' 3 and 4.

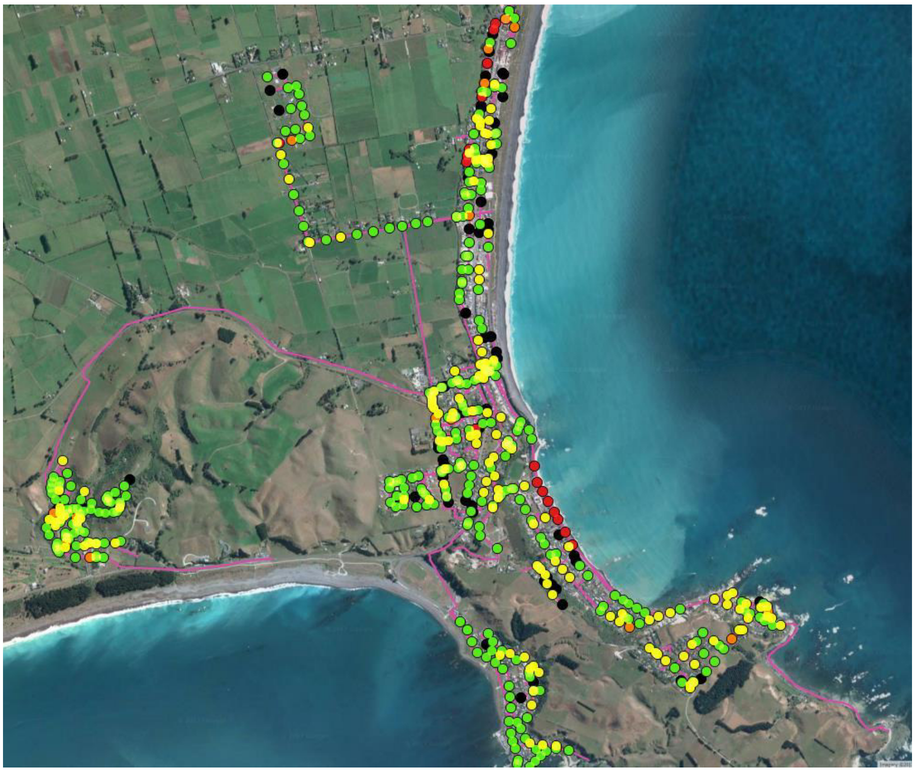

Figure 3: Wastewater Manhole Damage

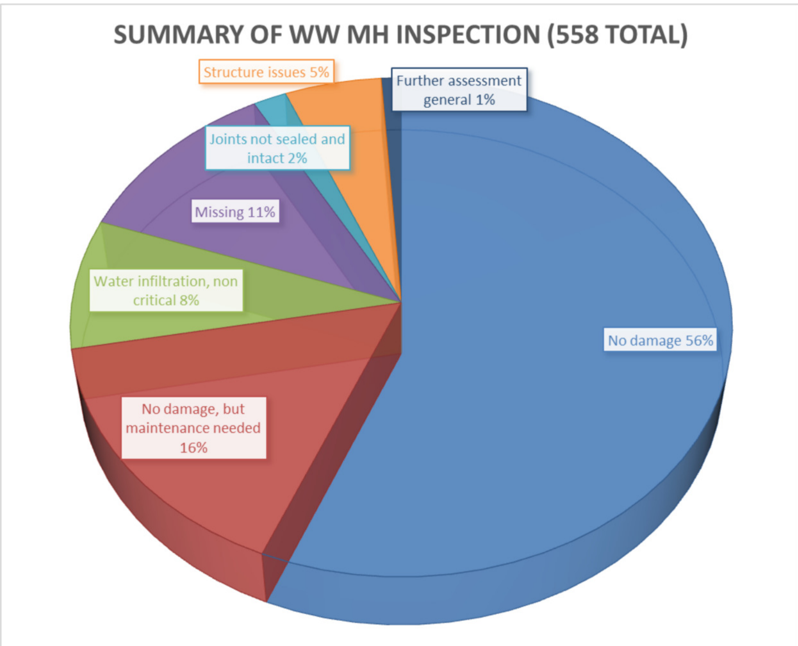

Figure 4: Wastewater MH Summary

- CCTV survey assessments show 22 sections of 450 mm AC main damaged and requiring replacement (about 102 m). In addition, preliminary ground damage assessment hazard maps show wastewater pipelines in areas of high and medium geotechnical hazard around: Mill Road and Mt Fyffe Road intersection and along Mill Road and Mt Fyffe Road; Mill Road pumping station and upstream along Lyell Creek, to Gillings Lane pumping station and Hawthorne Road pumping station, and further down along Lyell Creek to 47 Beach Road; and Esplanade along coastline (medium geotechnical hazard). The assessment is shown in Figures 5.

- 250 m of the 300 mm diameter main immediately upstream of the WWTP that runs through a boggy area was damaged and needs replacing.
- The Mt Fyffe / Totara Lane gravity main needs repairing in a number of places.

Figure 5: Reticulation Pipe Damage

EMERGENCY RESPONSE

Emergency response, or patching the wastewater treatment system to get it temporarily operating again in some form, was mainly undertaken by Innovative Waste Kaikoura (IWK), the Council's operation's group, City Care from Christchurch and local contractors.

The Emergency Response Team were fantastic. They worked around the clock and managed to have about 80% of the sewerage system functioning in 9 days, although at decreased flows. Some of the actions are shown in Figures' 6 and 7.

The following emergency works were undertaken:

- The Aerated Lagoon was bypassed by attaching lay flat hose to the rising main, taking it over the now disused railway line, and direct to the oxidation pond. Later on, the step screen was reinstalled;
- Following the oxidation pond drop test, inlet and outlet pipework were inspected and disused pipes sealed or removed – this stopped the leakage from the pond;
- Installing portable diesel pumps at the main trunk main pump stations that were damaged;
- Fixing the pump stations that were not too badly damaged;
- Installing variable speed drives on the main pump stations to manage flows; and
- Running lay flat hoses to bypass damaged trunk main areas.

Figure 6: Temporary Trunk Pump Station

Figure 7: Temporary Rising Main

WWTP REPAIR / REPLACE OPTIONS ASSESSMENTS

Repair options were considered and costs estimated to rectify the defects found in the WWTP inlet screen, aerated lagoon, oxidation pond, effluent pumping station and WW pumping stations.

Further to these works alternative options were also considered for the replacement or otherwise of the aerated lagoon which suffered significant damage. Options considered for these works included:

- Repair the existing aerated lagoon in the current location but with embankment toe support to stop it collapsing into the creek in another quake;
- Replace the aerated lagoon with a new lagoon north of the existing oxidation pond; and
- Replace the entire WWTP with a membrane bioreactor (MBR).

Aerated Lagoon

The lagoon and the aeration system were installed in 2011. The aerated lagoon receives influent wastewater from the town via the inlet screen and anaerobic effluent from the septage pond. The basin was 4.1 m deep with a volume of 6,560 m^3 and surface area of 2,830 m^2. The lagoon was lined with fusion welded HDPE membrane.

The aerated lagoon was designed for a flow of 2,000 m^3/d at a BOD load of 400 kg BOD/d with solids loading of 300 kg TSS/d and nutrient loading of 60 kg TKN/d and 8 kg TP/d. The design was based on a BOD removal rate of 90%, resulting in an estimated BOD concentration of 20 mg/L that is loaded to the oxidation pond.

From aerial photos (Figure 8), the pond and equipment appeared to be undamaged and working as intended. The aerial photos also show the extent of aeration in the pond. Large areas of the inner berm of the pond are not aerated or mixed and the lagoon wastewater showed a red-brown colour, possibly indicating insufficient aeration. The aerated lagoon was built as a not-fully mixed reactor.

The test results for the raw wastewater entering the aerated lagoon indicate that concentration of organics, nutrients and solids are higher than it was estimated in the design. The BOD_5 and TKN removal rates vary for the two sampled days but show that >50% of organics are removed. Test results for 16th April 2014 show good nitrogen and solids removal (79% and 67% respectively) while on 15th October 2014, BOD_5 removal was 76%. Nitrification shows reasonable results for both sampled days.

Figure 8: WWTP pre-Earthquake

An evaluation of the options including preliminary cost estimates determined that the most cost effective recovery is to build a new lagoon to the north of the existing oxidation pond and alter the pipework to allow flow to be transferred appropriately.

Oxidation Pond

Although the oxidation pond did not appear damaged, its health did not look good soon after the earthquake. As can be seen in Figure 9 (8 days after the earthquake), there does not appear to be any algae in the pond. The reason for this was never known, as it was not possible to get pond samples away for analysis. Possible reasons are:

a. the system was so overloaded due to the aerated lagoon being bypassed (unlikely as DO levels were taken and these were about 3 mg/L); and
b. The system was underloaded. Due to there being no inputs for about 1 week, along with high I/I when the system was restarted (most likely).

Figure 9: Oxidation Pond Caged Rotor – no Algae

Figure 10 shows the pond colour in early February 2017. Apart from slowly increasing the loading to the oxidation pond with people returning to Kaikoura, the only other change made was to increase the pH on the pond by lime addition.

Figure 10: Oxidation Pond Caged Rotor – Algae Levels back to normal

Land Application System

The land application system comprises of 4 rapid infiltration basins. These were constructed in the sand dunes to the north of the WWTP. Flow tests were conducted to each of the basins by measuring the height of discharge above the outlet and compared to the pump operating curve. The measurement showed that all the basins were receiving the design 35 L/s, with no pipe or fitting leakage. Figure 11 shows the discharge into one of the basins.

The infiltration rate through the basins has not been impacted on.

Figure 11: Infiltration Basin Inlet

RETICULATION SYSTEM REPAIR / REPLACE OPTIONS

Manholes

It is recommended to repair 20 manholes and replace 19 manholes of the Kaikoura sewer network.

Main Pump Stations

The options for repair are summarised in Table 2.

Table 2: Pumping Stations Repair Summary

PS	Investigation Results & Comments	Defect Category (DG043)
Hawthorne Road	Significant settlement has occurred around the PS and valve chamber with differential settlement between the structures, resulting in both of the outlet pipes breaking.	R2

Gillings Lane	No visible damage to pipes, but the extent of adjacent land settlement indicates potential for damage, or loss of resilience. Significant settlement has occurred and the concrete slab joining the PS and valve chamber has suffered some movement. Control cabinet replacement required.	R2
Mill Road	Lateral movement between top slab and surrounding soil and chipped riser connection indicate damage, or loss of resilience is possible. Significant movement between the two lower rings. Displacement by up to 75 mm, even though the rings are bolted together. This indicates that there is a risk of leakage/groundwater ingress from this location. This damage corresponds with that observed in the old PS across the SH, where similar displacement of the lower rings has also occurred.	R1
Esplanade	Ground subsided and needs to be built up again to prevent surface water ingress beside the structure and to make it safe to access. The backflow preventer has been knocked over as a result of the movement, but appears undamaged, needs to be re-positioned and secured. Control cabinet replacement.	R2
Ocean Ridge	Some subsidence of the ground. Some reinstatement needed. The wet well is approximately 9 m deep and so it is very difficult to see misalignment of rings deeper down in the structure.	R3
Totara Lane	PS is significantly damaged and has floated out of the ground. The current structure is unsuitable for the location, where groundwater is as high as the surface level. PS is approximately 4 m deep and mostly submerged. Wet well and upstream manhole require significant repair or replacement. No visible damage to pipes, but differential settlement has damaged in the pipework in and around the PS and MH's.	R1
WWTP Effluent PS	Settlement and ground movement indicate the potential for damage and an internal inspection indicates that movement between the PS risers has occurred with loss in loss of integrity. Excavation to fix pond leaks next to the PS confirmed this cracking by exposing the outside of the PS.	R2

Reticulation System

There are a number of different options for re-instating the main sewer line between Lyell Creek PS and Mill Road PS:

1. Repair each damaged section and replace the broken pipe sections in-place without any additional measures put in place for future earthquake resilience ($1,030,000);
2. Repair each damaged section and replace the broken pipe sections in-place with the addition of 4.8 m posts at 0.8 m centres to stop the pipe moving towards Lyell Creek from Lyell Creek to Mill Road to provide additional future earthquake resilience ($7,510,000);
3. Relay the main sewer line on SH 1, leave the pump stations (PSs) where they are. Replace the damaged sewer along Lyell Creek with a smaller PE line to each PS ($5,322,000); and
4. Relay the main sewer along SH 1, replacing the PSs and connect low lying properties to the main via a pressure sewer network or minor PSs ($5,814,000).

In addition, 300 m of the main sewer upstream of the WWTP is to be replaced with a 300 mm diameter PE pipe ($189,000). The Mt Fyffe to Totara Lane gravity main is to be repaired in a number of places ($250,000), sections of the Ocean Ridge main ($109,000) and sections of Esplanade main ($315,000).

ESTIMATED COSTS OF RECOMMENDED REPAIRS

The following estimated costs have been determined for the recommended repair works:

- **WWTP TOTAL $805,000**
- WW Pumping Stations:
  - Effluent PS at WWTP $35,000.
  - Hawthorne $20,000.
  - Gillings Lane $65,000.
  - Mill Road $150,000.
  - Esplanade $55,000.
  - Ocean Ridge $5,000.
  - Totara Lane $250,000.
  - **TOTAL Pumps stations of $576,000**
- **Manholes TOTAL $433,000.**
- Reticulation:
  - Trunk Main Option 3 $5,322,000

- Main upstream of WWTP $189,000
- Mt Fyffe main $250,000
- Esplanade and Ocean Ridge $424,000
- **TOTAL Reticulation $6,185,000**

In total, the recommended options **repair/replace capital costs are $8,000,000.**

DISCUSSION

The Kaikoura earthquakes did not do major damage to the wastewater system. The main reason for this was the system was simple and mostly relying on natural systems to keep operating – algae photosynthesis, and infiltration through sand beds.

The main damage that occurred was due to poor siting (not understanding earth movement in earthquakes but lack of ground condition analysis was reasonably normal at that time prior to the Christchurch earthquake sequence), or lack of resilience (elasticity or ability to spring back to shape). If the aerated lagoon had been located away from the stream or it had a rubber liner (300% elongation) instead of a HDPE liner (12% elongation), then it probably would have survived in a functional form.

Likewise, if the main reticulation system had been located away from Lyell Creek, then damage would have been limited to brittle AC pipes only.

There was no damage to the land application system.

The take home messages here are:

- Accurate GIS is critical to a speedy response and recovery operation. Where knowledge of an asset is owned in an operator's head, it means that planning and strategic response cannot be initiated or coordinated effectively. If there is a representative GIS, then teams can be sent to multiple areas with reliable system information. Similarly, having the GIS set up so that repair information can be fed back into the system on a daily basis means that work needs and achievements can be tracked. Good information management systems are the key to ensuring a coordinated, strategic and therefore cost effective response.

- Planning the system's location is paramount. Don't take the easy option of laying mains in the lowest areas to enable gravity feed of all pipework. This not only results in the pipelines being in boggy areas (more prone to liquefaction) but are usually near waterways which can have lateral spread and pipeline movement issues and are more prone to groundwater infiltration. The use of pressure sewers for dwellings below major pipelines is a credible solution to assist in locating mains on higher ground;
- Build in resilience where possible. For example; the use of GRP pump stations instead of concrete, using more flexible pipes such as PE, using short sections of pipe with flexible couplings at structures, the use of rubber pond liners; using earthen embankments rather than concrete structures;
- KISS. Keeping it simple and using natural systems as much as possible. Although there is a trend to higher tech biological nutrient removal plants, systems that can survive without power and use soils, plants and microbiota for treatment will keep going while their high-tech mates that rely on blown in air will not.

CONCLUSIONS

I have had enough of earthquakes. They are not enjoyable, they cause stress, they cause too much work to be done in too short a time and cause you to drink too much single malt.

If designing a wastewater system in an earthquake prone area, which is pretty much all of New Zealand apart from Northland, then sort out the master planning first. Use flexible materials. Locate critical mains away from boggy low lying areas and away from creeks/rivers that may have lateral spread issues. If houses are already located in these low areas, use pressure sewers with PE pipe to connect them to the mains. Use natural treatment systems where possible. Land treatment systems are generally resilient and the simpler they are, the less damage there will be.

REFERENCES

Lowe Environmental Impact Ltd and Fluent Infrastructure Solutions Ltd. January 2017. Kaikoura Township Wastewater Recovery; Options Assessment for Wastewater Treatment Plant and Pump Stations. Prepared for Kaikoura District Council.

Lowe Environmental Impact Ltd and Fluent Infrastructure Solutions Ltd. March 2017. Kaikoura Township Wastewater Recovery; Options Assessment for Wastewater Reticulation and Stormwater Assets. Prepared for Kaikoura District Council.