# Head of Lake Wakatipu Natural Hazards Adaption

## Engineering Approaches for Managing Liquefaction-Related Risk

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Tonkin+Taylor

# Outline

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## Background

- What is liquefaction
- Regulatory context & increasing awareness of natural hazard risk

## May 2022 report: Liquefaction Vulnerability Assessment

- Ground investigations and analysis
- Predicted damage

## February 2023 report: Engineering Approaches for Managing Liquefaction-Related Risk

- Engineering mitigation options
- Effectiveness
- Relative cost comparison

## Examples from elsewhere around NZ

# Why me?

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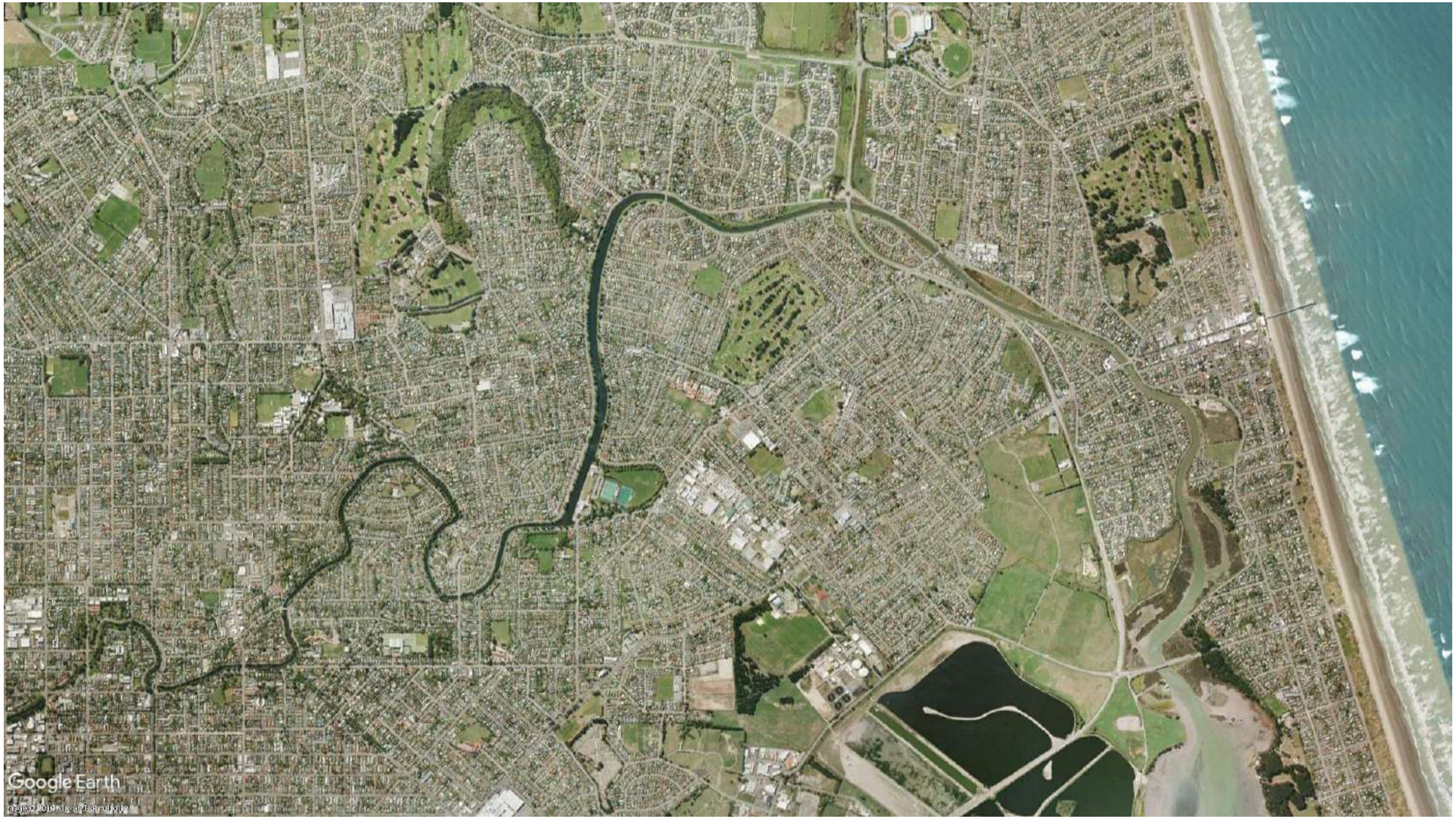
Then....                                                  ...Now



# Why me?

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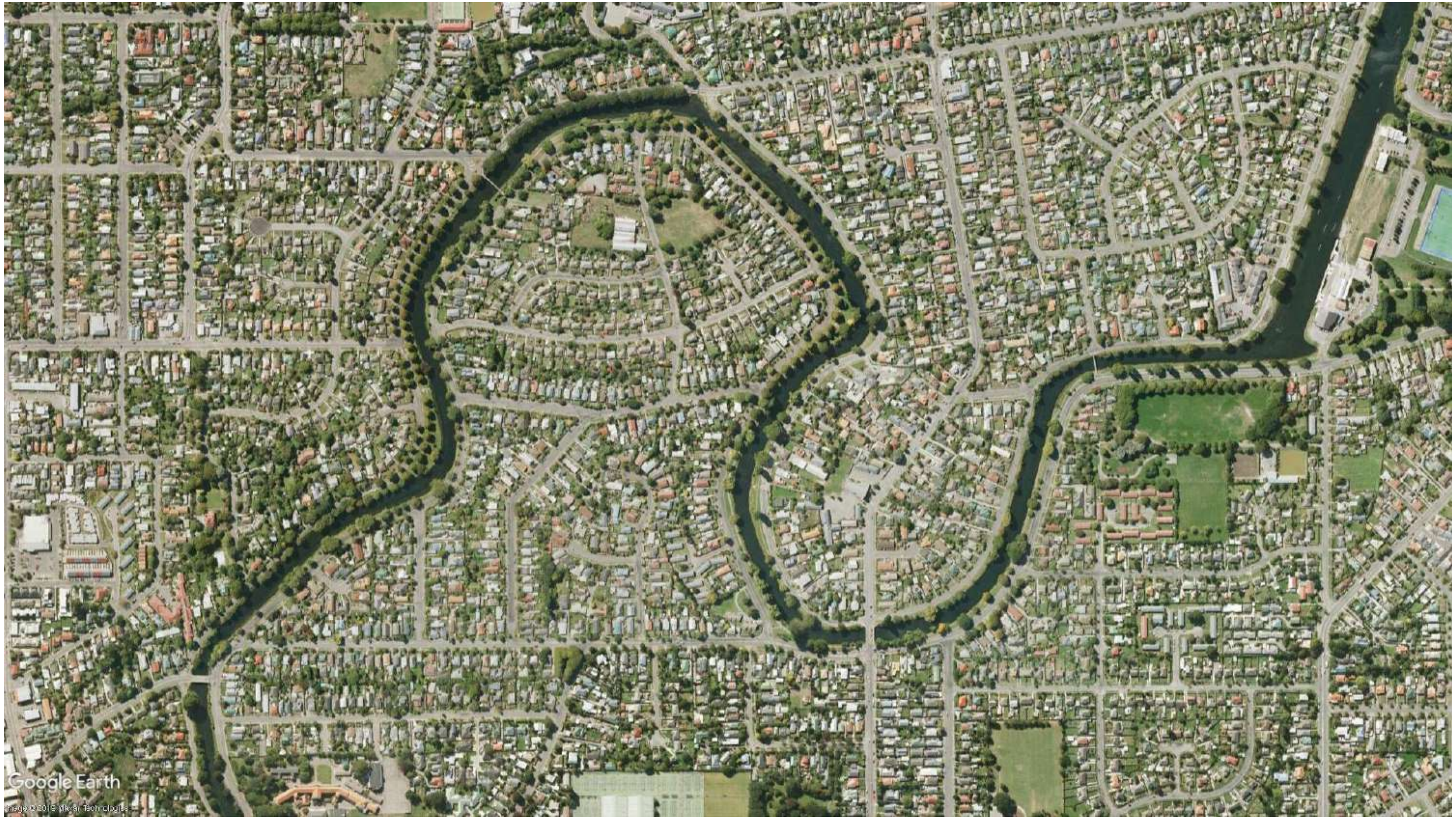
## Then.... ...Now

# Then…. …Now

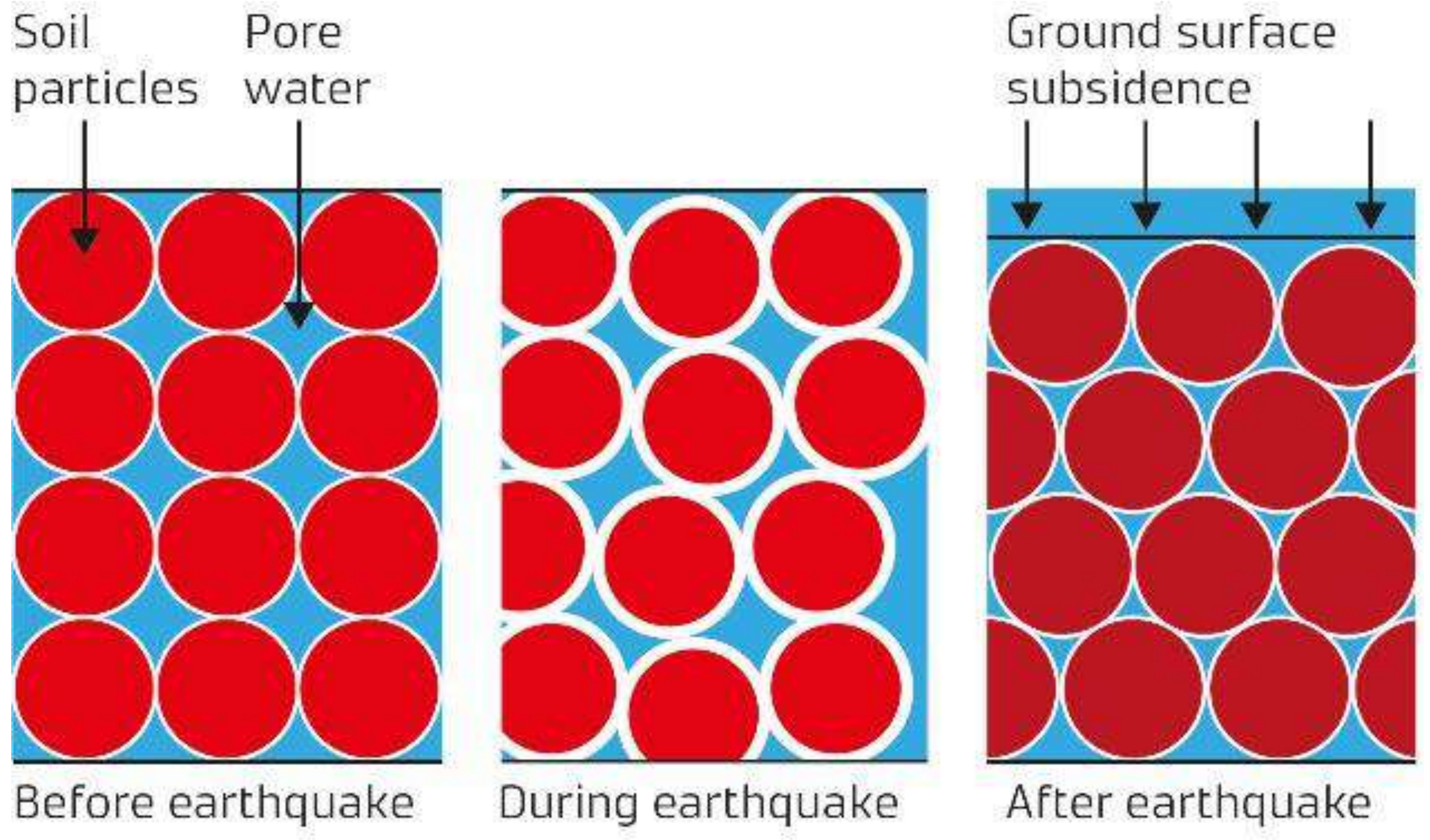


# Then....                                        ...Now

Then.... ...Now

# Then.... ...Now

## What is liquefaction



# What is liquefaction

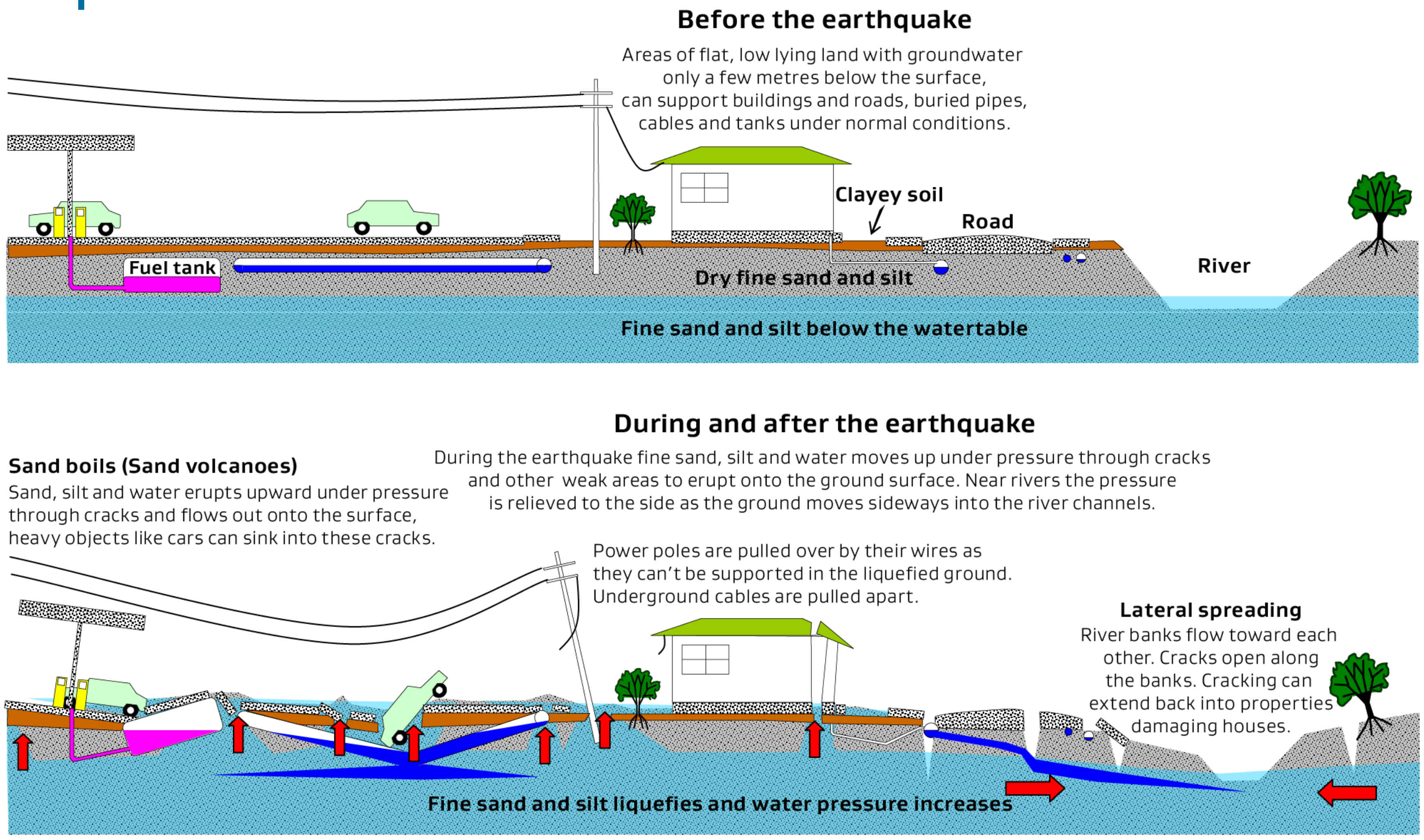
Three key elements are all required for liquefaction to occur:

1 Loose non-plastic soil (typically sands and silts, or in rare cases gravel)

2 Saturated soil (ie below the groundwater table)

3 Sufficient ground shaking (a combination of the duration and intensity of shaking).

# What is liquefaction




Tanks and pipes float up in the liquefied ground and break through the surface, pipes break, water and sewerage leaks into the ground.

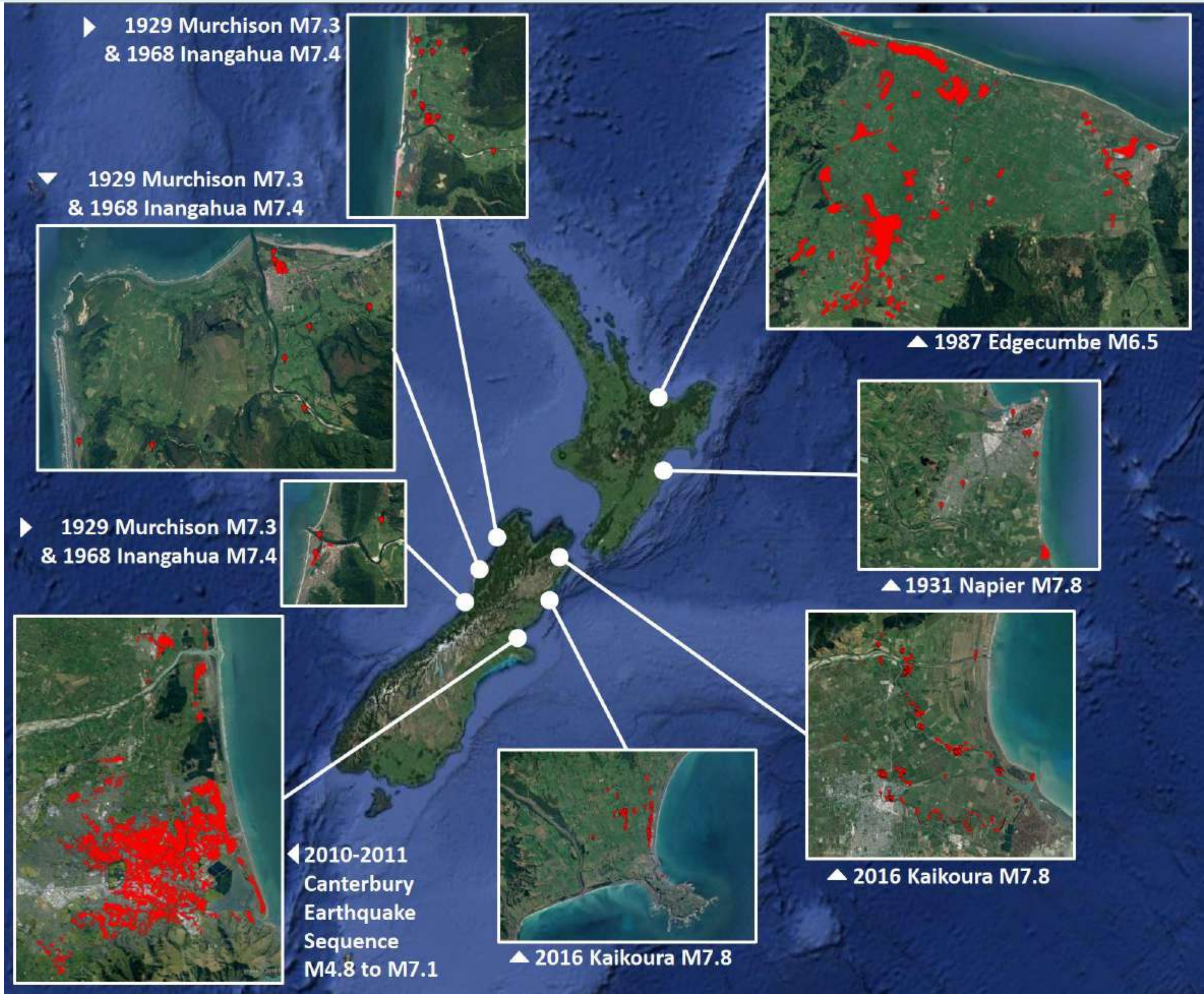
# Regulatory context & increasing awareness of risk

**Canterbury Earthquakes Royal Commission findings:**

- Inadequate geotechnical investigations and understanding of the geology.
- Limited appreciation of the impacts of widespread liquefaction.
- Land-use planning decisions have not always considered liquefaction hazards.
- Foundations not designed for liquefaction = poor foundation performance and damage to the building.
- Building settlement and structural damage occurred at serviceability limit state (SLS) earthquake loading.

Similar observations following 2013 Lake Grassmere and 2016 Kaikoura earthquakes.

## Observed liquefaction from the last 100 years of earthquakes in NZ



# Regulatory context & increasing awareness of risk

## Guidance on current good practice:

- **MBIE (2012)** – Repairing and rebuilding houses affected by the Canterbury earthquakes
  *Site investigations, liquefaction assessment, ground improvement, foundation options*

- **MBIE & MfE (2017)** – Planning and engineering guidance for potentially liquefaction-prone land
  *Risk-based process to manage liquefaction related risk in land use planning & development decision-making*

- **MBIE & NZGS (2016 / 2022)** – Earthquake geotechnical engineering practice series
  *Aims to lift the level and improve consistency of earthquake geotechnical engineering practice in NZ*

# Regulatory context & increasing awareness of risk

**Recent regulatory changes:**

- **RMA S6 (2017)** – Natural hazard risk added to matters of national importance that must considered at all levels of planning and decision-making.
- **RMA S106 & 220 (2017)** – Definition of natural hazards broadened to ensure all natural hazards considered.
- **RMA S106 & 220 (2017)** – Risk based approach to considering subdivision consent applications, including natural hazards with low probability but high impact.
- **NZ Building Code B1/AS1 (2019)** – Definition of 'Good Ground' amended to exclude land with potential for liquefaction and/or lateral spreading.

# Liquefaction Vulnerability Assessment

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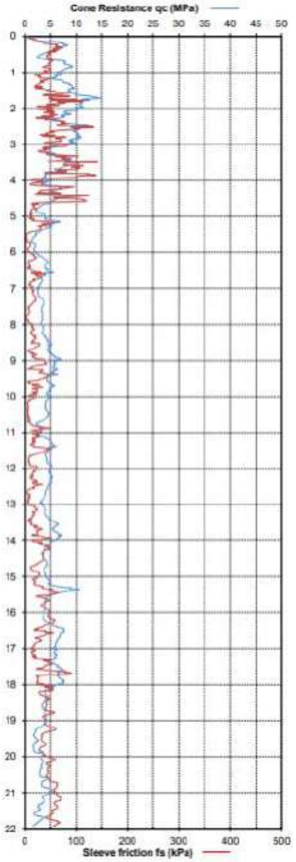
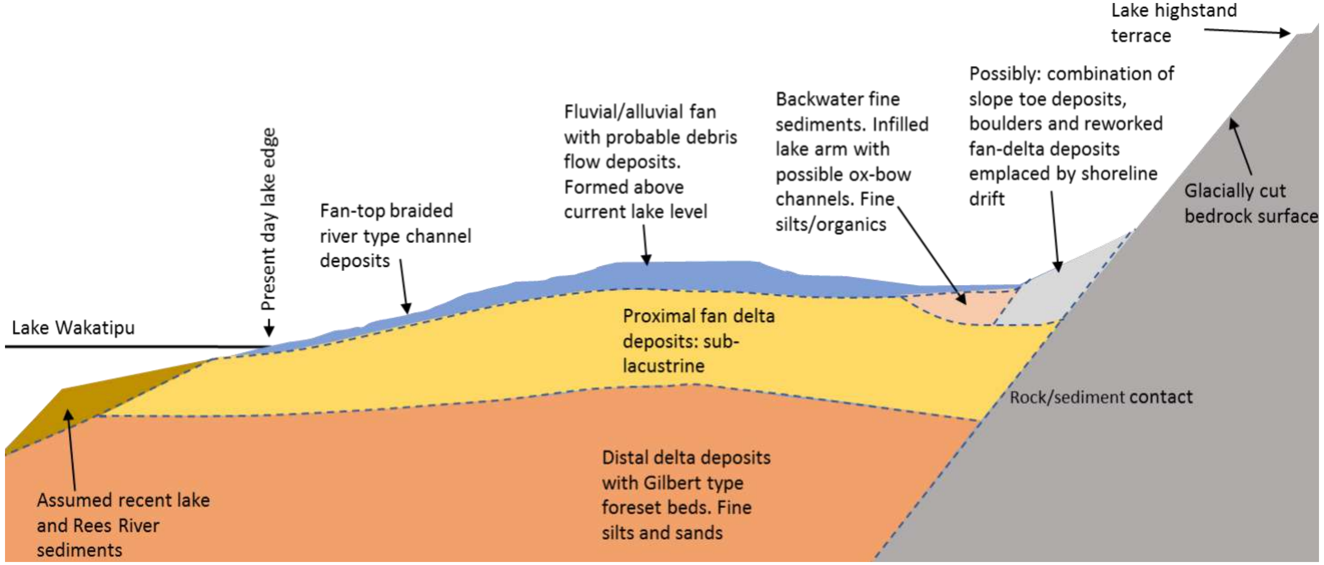
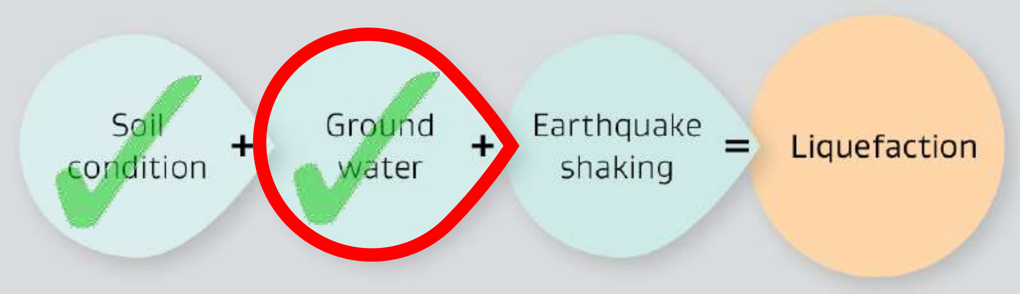
***Loose to medium-dense sands.***



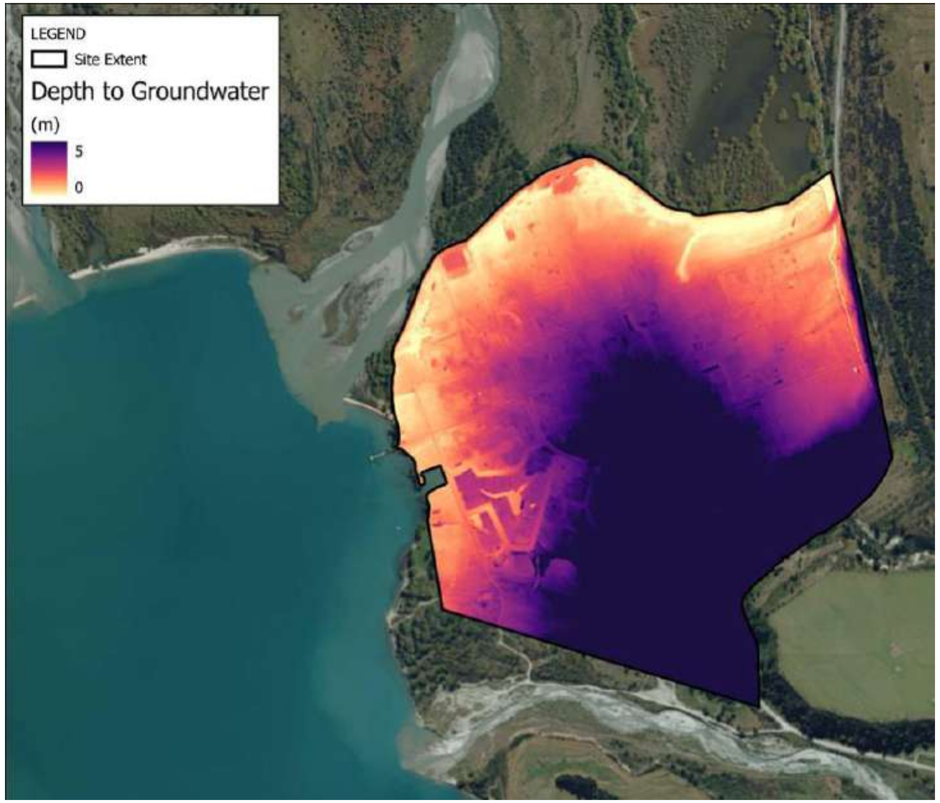





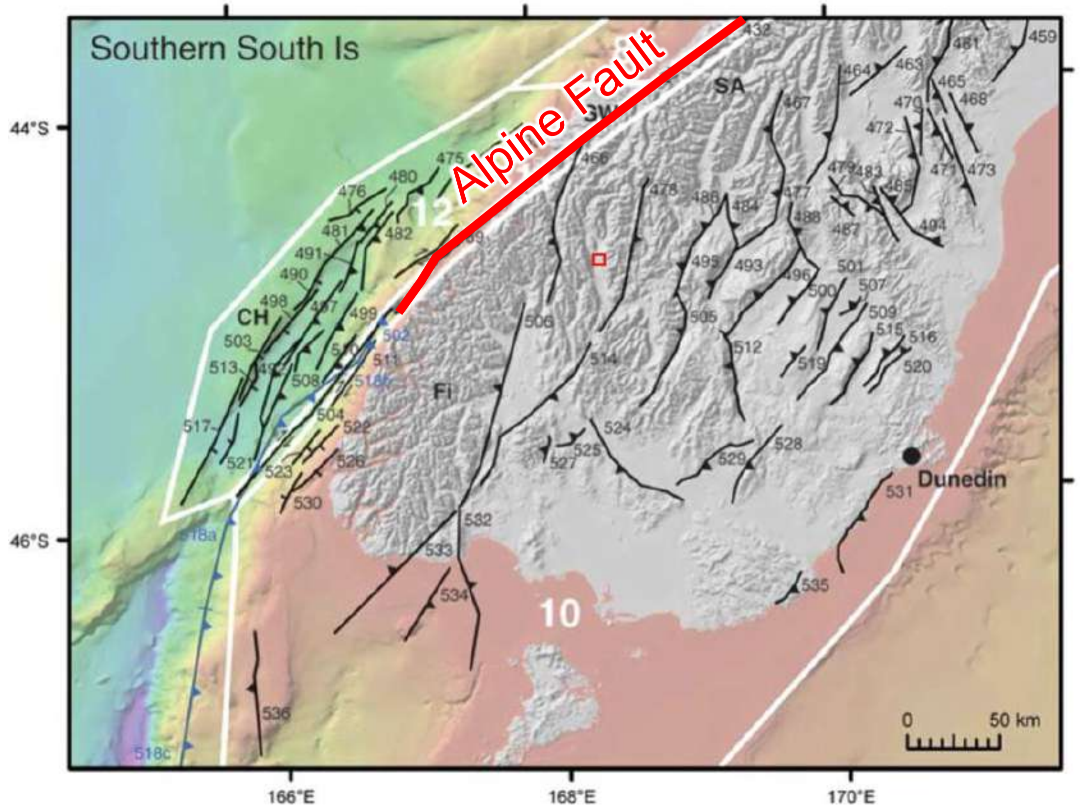

***Groundwater is shallow.***

## Groundwater Level


## Groundwater Depth




*Strong earthquake shaking is likely.*

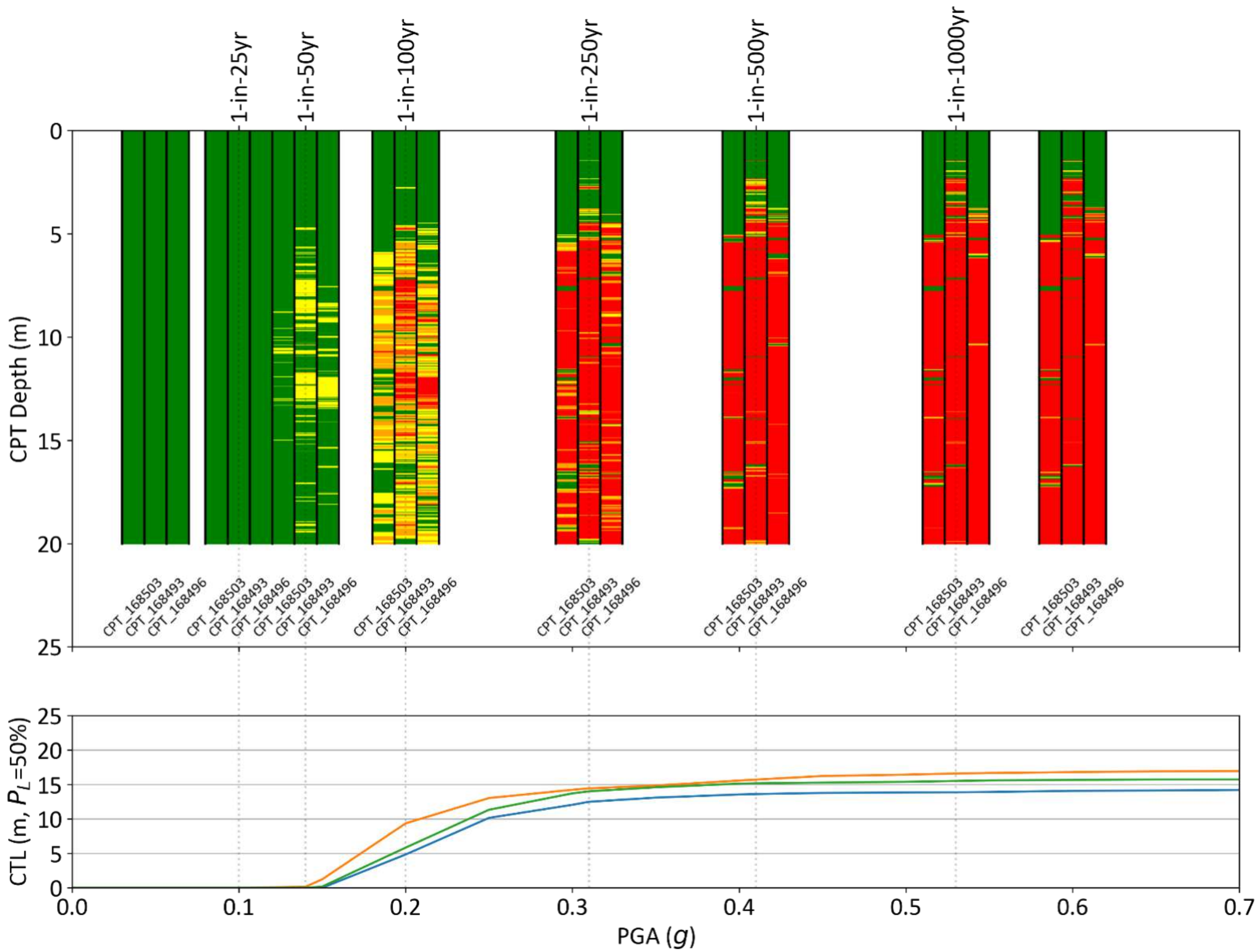



| Return Period | 25-yr | Alpine Fault Rupture Scenario (approx. 30-yr, conditional) | 50-yr | 100-yr | 250-yr | 500-yr | 1000-yr | 2500-yr |
|---|---|---|---|---|---|---|---|---|
| **Annual Exceedance Probability** | **4%** | **3%** | **2%** | **1%** | **0.4%** | **0.2%** | **0.1%** | **0.04%** |
| PGA (*g*) | 0.1 to 0.16 | 0.11 (16th percentile) 0.19 (50th percentile) 0.32 (84th percentile) | 0.14 to 0.22 | 0.20 to 0.32 | 0.31 to 0.48 | 0.41 to 0.63 | 0.53 to 0.82 | 0.74 to 1.14 |
| $M_w$ | 6.1 to 6.5 | 8.1 | 6.1 to 6.5 | 6.1 to 6.5 | 6.1 to 6.5 | 6.5 to 7.1 | 6.5 to 7.1 | 6.5 to 7.1 |
| Seismic Source (km) | 62 to 17 | 55 | 60 to 17 | 57 to 17 | 54 to 17 | 50 to 17 | 46 to 17 | 41 to 17 |


- ***Liquefaction triggering predicted above 50 to 100 year earthquake shaking.***

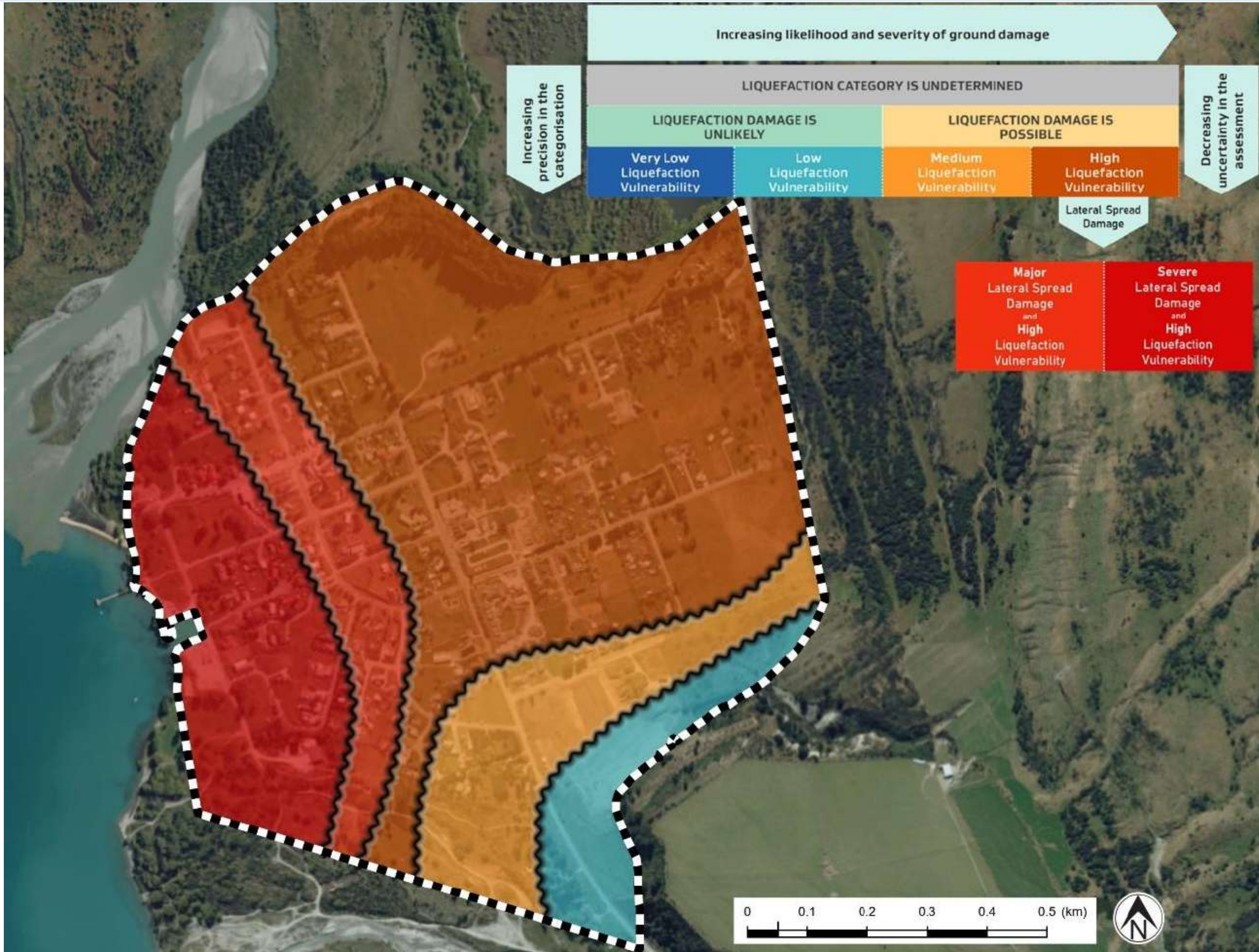
- ***Liquefaction to more than 20m depth expected for most of Glenorchy.***

- ***Alpine Fault earthquake is likely to trigger widespread liquefaction. This has a 75% probability in the next 50 years.***



# Liquefaction vulnerability map

- Areas where both liquefaction and lateral spreading damage could occur. Subdivided into Major and Severe lateral spreading.
- Areas where only liquefaction damage is expected. Subdivided into Medium and High liquefaction vulnerability.



# Liquefaction consequences

## Major and Severe lateral spreading

# Liquefaction consequences

## Medium and High Liquefaction Vulnerability






# Engineering Approaches for Managing Risk

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**Reduce Impact:**

- Improve land
- Improve buildings
- Improve infrastructure

**Accept:**

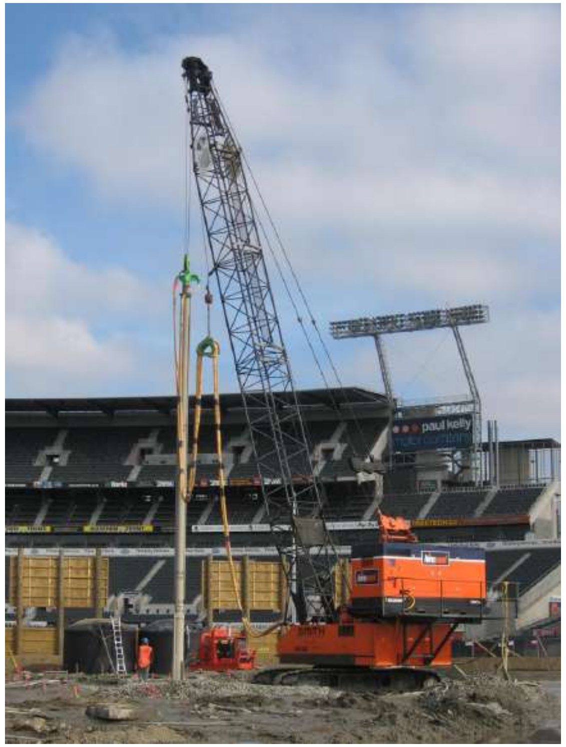
- Analysis to understand risk
- Make informed decision to accept risk (or residual risk after mitigation)

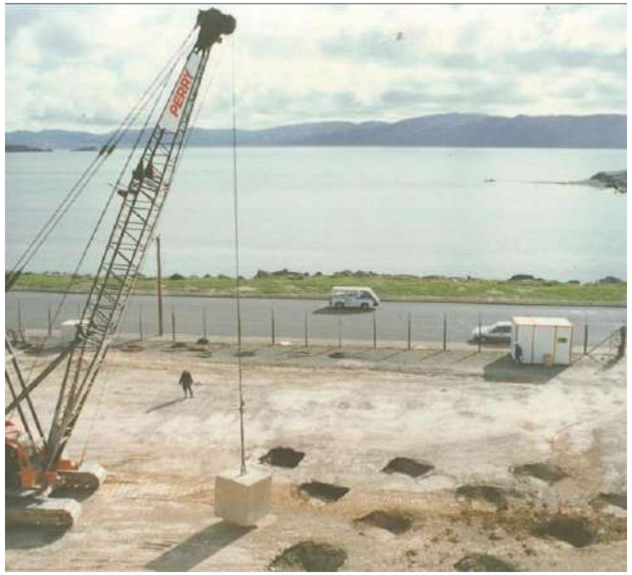
## Techniques to improve land:

- Stone columns (4 – 20m deep)
- Dynamic compaction (4 – 20m deep)
- Impact roller (up to 4m deep)
- Geogrid-reinforced crushed gravel raft (1.2m deep)
- No improvement

## Layout options:

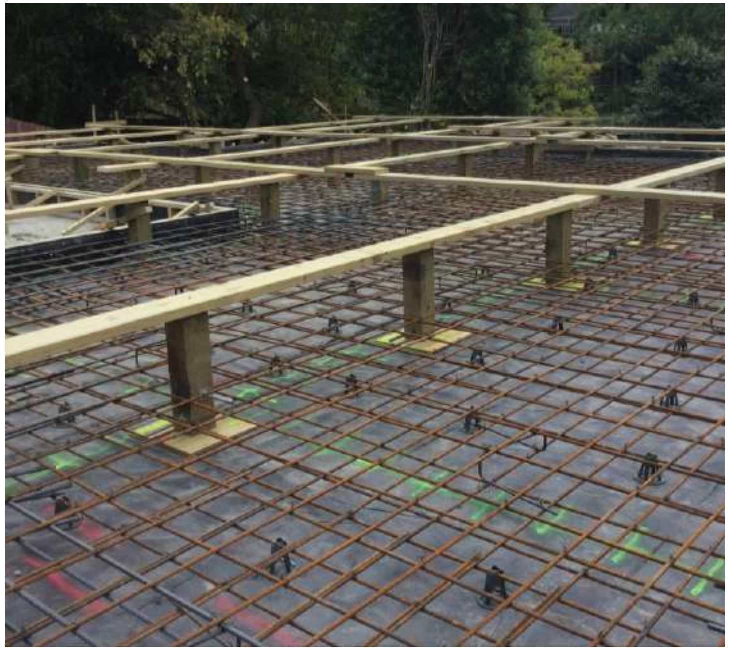
- 30 – 40m wide strip alongside lake
- Under new buildings & infrastructure only
- Under existing buildings & infrastructure
- All land across the town





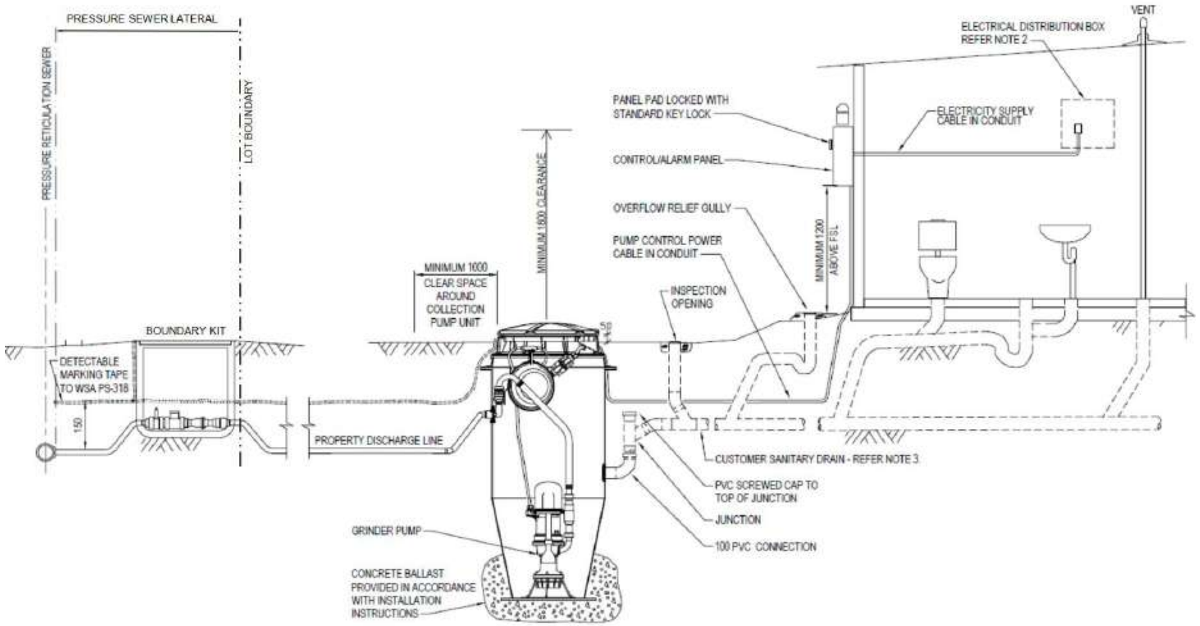
## Techniques to reduce damage to buildings:

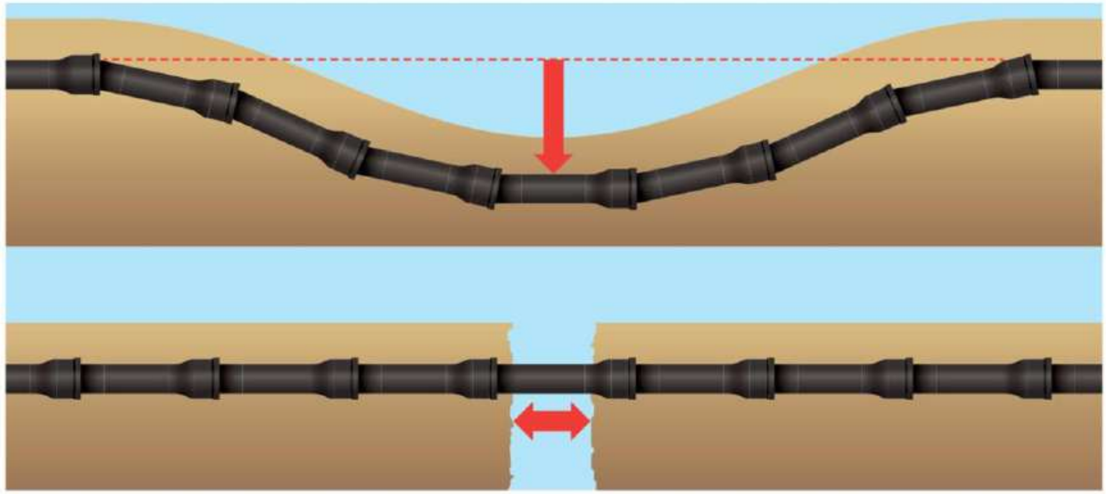
- New TC3 surface structure foundations
- New TC2 waffle slab foundation or enhanced lightweight platform on timber piles
- Retrofit to strengthen existing foundations and buildings
- No improvement



## Techniques to reduce damage to infrastructure:

- New infrastructure with resilient detailing
- Retrofit to strengthen existing infrastructure
- No improvement



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## Layout options:

- Varies depending on current vulnerability to liquefaction and lateral spreading
- Existing vs new development
- Options towards top might prove to be impractical or unaffordable
- Options towards bottom might not meet building consent requirements or be difficult to obtain insurance for

Current

Option A1

Option B1

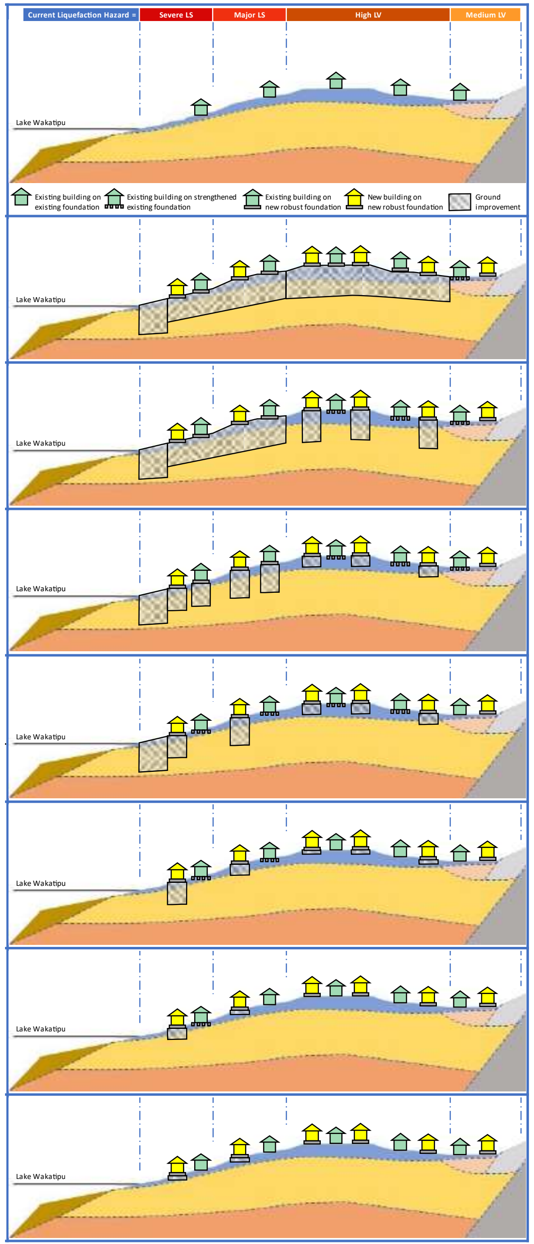
Option C1

Option D1

Option E

Option F

Option G



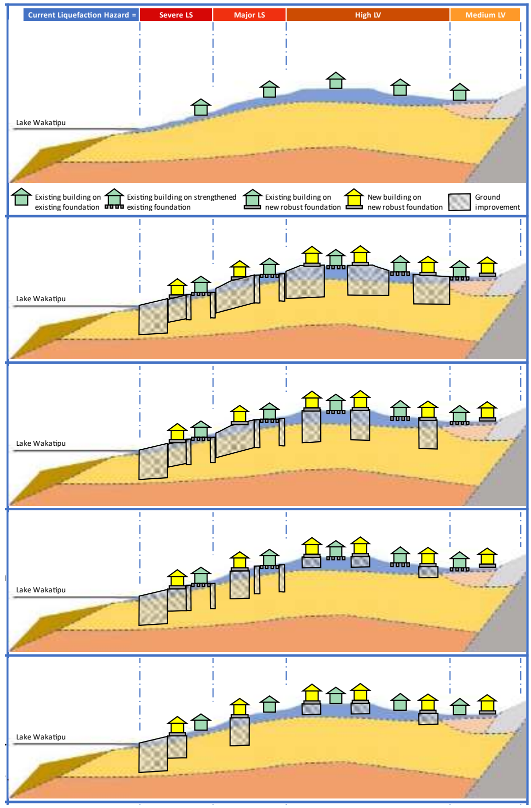

Current

Option A2

Option B2

Option C2

Option D2



# Effectiveness:

Indicative liquefaction hazard, after mitigation

| | EXISTING DEVELOPMENT | | | | NEW DEVELOPMENT | | | |
|---|---|---|---|---|---|---|---|---|
| **Current liquefaction hazard:** | Severe LS | Major LS | High LV | Medium LV | Severe LS | Major LS | High LV | Medium LV |
| **Option A1** | High LV | High LV | Medium LV | Medium LV | High LV | High LV | Medium LV | Medium LV |
| **Option B1** | High LV | High LV | High LV | Medium LV | High LV | High LV | Medium LV | Medium LV |
| **Option C1** | High LV | High LV | High LV | Medium LV | High LV | High LV | Medium LV | Medium LV |
| **Option D1** | Severe LS | Major LS | High LV | Medium LV | High LV | High LV | Medium LV | Medium LV |
| **Option E** | Severe LS | Major LS | High LV | Medium LV | Major LS | Major LS | High LV | Medium LV |
| **Option F** | Severe LS | Major LS | High LV | Medium LV | Severe LS | Major LS | High LV | Medium LV |
| **Option G** | Severe LS | Major LS | High LV | Medium LV | Severe LS | Major LS | High LV | Medium LV |
| **Option A2** | Major LS | High LV | High LV | Medium LV | High LV | High LV | Medium LV | Medium LV |
| **Option B2** | Major LS | High LV | High LV | Medium LV | High LV | High LV | Medium LV | Medium LV |
| **Option C2** | Major LS | High LV | High LV | Medium LV | High LV | High LV | Medium LV | Medium LV |
| **Option D2** | Severe LS | Major LS | High LV | Medium LV | High LV | High LV | Medium LV | Medium LV |

Indicative proportion of buildings & infrastructure with severe liquefaction damage in large EQ, after mitigation

| | EXISTING DEVELOPMENT | | | | NEW DEVELOPMENT | | | |
|---|---|---|---|---|---|---|---|---|
| **Current liquefaction hazard:** | Severe LS | Major LS | High LV | Medium LV | Severe LS | Major LS | High LV | Medium LV |
| **Expected damage for current ground conditions:** | 90% | 75% | 50% | 25% | - | - | - | - |
| **Option A1** | 30% | 25% | 15% | 15% | 25% | 20% | 10% | 10% |
| **Option B1** | 30% | 25% | 40% | 15% | 25% | 20% | 15% | 10% |
| **Option C1** | 35% | 30% | 40% | 15% | 30% | 25% | 20% | 10% |
| **Option D1** | 55% | 50% | 40% | 25% | 35% | 30% | 20% | 10% |
| **Option E** | 75% | 65% | 50% | 25% | 40% | 40% | 25% | 10% |
| **Option F** | 80% | 75% | 50% | 25% | 50% | 50% | 30% | 10% |
| **Option G** | 90% | 75% | 50% | 25% | 60% | 50% | 30% | 10% |
| **Option A2** | 45% | 40% | 40% | 15% | 30% | 25% | 10% | 10% |
| **Option B2** | 45% | 40% | 40% | 15% | 30% | 25% | 15% | 10% |
| **Option C2** | 45% | 40% | 40% | 15% | 30% | 25% | 20% | 10% |
| **Option D2** | 65% | 60% | 50% | 25% | 35% | 30% | 20% | 10% |

# Indicative relative cost comparison:

| | | EXISTING DEVELOPMENT | | | | NEW DEVELOPMENT | | | |
|---|---|---|---|---|---|---|---|---|---|
| Current liquefaction hazard: | | Severe LS | Major LS | High LV | Medium LV | Severe LS | Major LS | High LV | Medium LV |
| MITIGATION WORKS | | | | | | | | | |
| LAND | 15 – 20m deep by 30 – 40m wide perimeter treatment ground improvement alongside lake | $$$$ | $$$$ | N/A | N/A | $$$$ | $$$$ | N/A | N/A |
| LAND | 12m deep ground improvement, all land | $$$$$ | $$$$$ | $$$$$ | N/A | $$$$$ | $$$$$ | $$$$$ | N/A |
| LAND | 12m deep ground improvement, land under buildings & infrastructure only | $$$$ | $$$$ | $$$$ | N/A | $$$$ | $$$$ | $$$$ | N/A |
| LAND | 12m deep ground improvement, land around buildings & infrastructure where accessible | $$$$ | $$$$ | N/A | N/A | N/A | N/A | N/A | N/A |
| LAND | 4m deep ground improvement, land under buildings & infrastructure only | $$$ | $$$ | $$$ | N/A | $$$ | $$$ | $$$ | N/A |
| LAND | 1.2m deep geogrid-reinforced crushed gravel raft, under buildings & infrastructure only | $$$ | $$$ | $$$ | N/A | $$$ | $$$ | $$$ | N/A |
| LAND | No land improvement | - | - | - | - | - | - | - | - |
| BUILDINGS | New TC3 surface structure foundations | $$$$ | $$$$ | $$$$ | N/A | $$$ | $$$ | $$$ | N/A |
| BUILDINGS | New TC2 waffle slab foundation or enhanced lightweight platform on timber piles | N/A | N/A | N/A | $$$ | N/A | N/A | N/A | $ |
| BUILDINGS | Retrofit to strengthen existing foundations and buildings | $$ | $$ | $ | $ | N/A | N/A | N/A | N/A |
| BUILDINGS | No foundation or building improvement | - | - | - | - | - | - | - | - |
| INFRASTRUCTURE | New infrastructure with resilient detailing | $ | $ | $ | $ | $ | $ | $ | $ |
| INFRASTRUCTURE | Retrofit to strengthen existing infrastructure | $ | $ | $ | $ | N/A | N/A | N/A | N/A |
| INFRASTRUCTURE | No infrastructure improvement | - | - | - | - | - | - | - | - |

**INDICATIVE RELATIVE COST SCALE**

| | |
|---|---|
| - | No mitigation works, so no construction cost |
| $ | Estimate in the order of $25,000 |
| $$ | Estimate in the order of $50,000 |
| $$$ | Estimate in the order of $100,000 |
| $$$$ | Estimate in the order of $200,000 |
| $$$$$ | Estimate more than $300,000 |
| N/A | Mitigation option is not applicable for this scenario |

Notes:
1) These indicative estimates are based on the results of the EQC residential ground improvement trials and ground improvement pilot projects undertaken in 2015, uplifted by 50% for construction cost inflation between 2015 and 2022.
2) All estimates are per property, assuming an average building footprint of $150m^2$ on a lot size of $800m^2$.
3) For perimeter treatment & infrastructure, the total estimate for mitigation is divided between the properties which benefit.
4) For existing development, TC2 and TC3 foundation estimates include the foundation construction as well as the enabling and reinstatement works required (e.g. lifting the existing building, repairing damage and reinstating services). These estimates relate to the direct construction work only, and do not include indirect costs such as overall community-wide programme management or temporary accommodation.
5) For new development, TC2 and TC3 foundation estimates are calculated as the additional over and above a NZS3604 foundation (the standard foundation typically used for ground that is not liquefaction-prone).
6) Infrastructure mitigation works relate to underground services only. Estimates are calculated as the additional over and above standard infrastructure construction on ground that is not liquefaction-prone.
7) The estimates presented in this report are indicative only, to illustrate the potential order of magnitude and relativity between options. These estimates are based on assumed concepts – no analysis or design has been undertaken. Consequently, a significant margin of uncertainty exists on the estimates. If decision-making is found to be sensitive to these estimates, then we recommend further, more location-specific engineering design and construction cost advice is sought.

Overall cost for could be many tens to hundreds of millions of dollars

# Examples from elsewhere around NZ

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**New subdivisions:**

- Pegasus Town (2007) – Vibrocompaction around lake edge and commercial centre, 8 hectares to 4 – 13m depth (8m avg).
- Prestons Park (2010's) – Impact roller compaction to 3m depth, over ~100 hectares.
- Beach Grove (2020's) – Stone columns along stream, 4500m$^2$ to 4m deep. Plus 1.5m thick gravel fill over ~40 hectares

## Major projects:

- Christchurch Metro Sports Facility
- Canterbury Multi-use Arena
- Tauranga Bay Link Expressway

# Questions?

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