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# Relationship between observed liquefaction at Kaiapoi following the 2010 Darfield earthquake and former channels of the Waimakariri River

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ABSTRACT

The Darfield earthquake caused widespread damage in the Canterbury region of New Zealand, with the majority of damage resulting from liquefaction and lateral spreading. One of the worst hit locations was the small town of Kaiapoi north of Christchurch, an area that has experienced liquefaction during past events and has been identified as highly susceptible to liquefaction. The low lying town sits on the banks of the Kaiapoi River, once a branch of the Waimakariri, a large braided river transporting gravelly sediment. The Waimakariri has been extensively modified both by natural and human processes, consequently many areas in and around the town were once former river channels.

Using historical accounts and maps of the region, areas of land reclamation and old channels that had been cut off from the river since the beginning of European settlement in the 1850s were identified. These areas correlated well with many of the areas having significant liquefaction damage following the Darfield event. Substantial lateral spreads and sand boils developed in areas of reclamation along the current river path, causing significant damage to stopbanks and structures along the river, with fissures up to 2 m deep and 1 m wide. Much of the residential housing was damaged by lateral spreading, with cumulative displacement offsets up to 3 m parallel to old channel beds that had aggraded over time due to river shifts. In former channel areas that were free of lateral spreading, large volumes of ejecta were present over wide areas, with depths of up to 400 mm in places. Houses in these regions were damaged as a result of settlement and tilting. In all these areas underground services and roadways were severely impacted as a result of ground deformation. The severity of this damage indicates the importance of knowing the location of old channels when defining liquefaction prone regions.



## 1. Introduction

Kaiapoi is a small town approximately 17 km north of central Christchurch in the South Island of New Zealand. It is situated at the north eastern end of the Canterbury Plains, a region approximately 50 km wide and 160 km long formed by overlapping alluvial fans from rivers flowing east from the Southern Alps. In this area interbedded marine and terrestrial sediments approximately 100 m deep overlie 300–400 m of late Pleistocene sands and gravels (Brown and Weeber, 1992). Surficial deposits in the coastal regions east of Kaiapoi consist of Christchurch formation dune and coastal swamp deposits, with Springston formation silty sand and gravels in the region behind the coast (Brown and Weeber, 1992). The ground water table is shallow and varies between 1 and 2 m below the ground surface.

Present day Kaiapoi, shown in Fig. 1 sits on the banks of the Kaiapoi River, a tributary of the Waimakariri River, a large, steep, braided, gravel bed river that enters the ocean 3 km east of the town. The Waimakariri flows from west to the east curving northwards as it passes beneath the town, but has experienced substantial changes, both natural and man-made, since the times of first European settlement. Historically, flooding of the Waimakariri has caused significant damage to Kaiapoi and the surrounding area, with floods regularly entering the city of Christchurch along old river channels (Logan, 2008). Over time river diversions and a network of stopbanks have been constructed to constrain the river along its current route and provide flood protection.

At 4.35 am on 4th September 2010 (local time and date), a magnitude 7.1 earthquake occurred with an epicentre 42 km south-west of Kaiapoi and a focal depth of 10 km. The Kaiapoi North School strong motion station (KPOC), approximately 900 m north of the Kaiapoi River, recorded a peak ground acceleration of 0.32 g and a bracketed duration of approximately 20 s (GNS, 2010). The town suffered from widespread and severe liquefaction during this event, with large volumes of sand ejected and extensive lateral spreading. In this region the worst damage was to residential structures, underground services and stopbanks. Prior to this event, the only other recorded case of liquefaction in Kaiapoi occurred during the 1901 Cheviot

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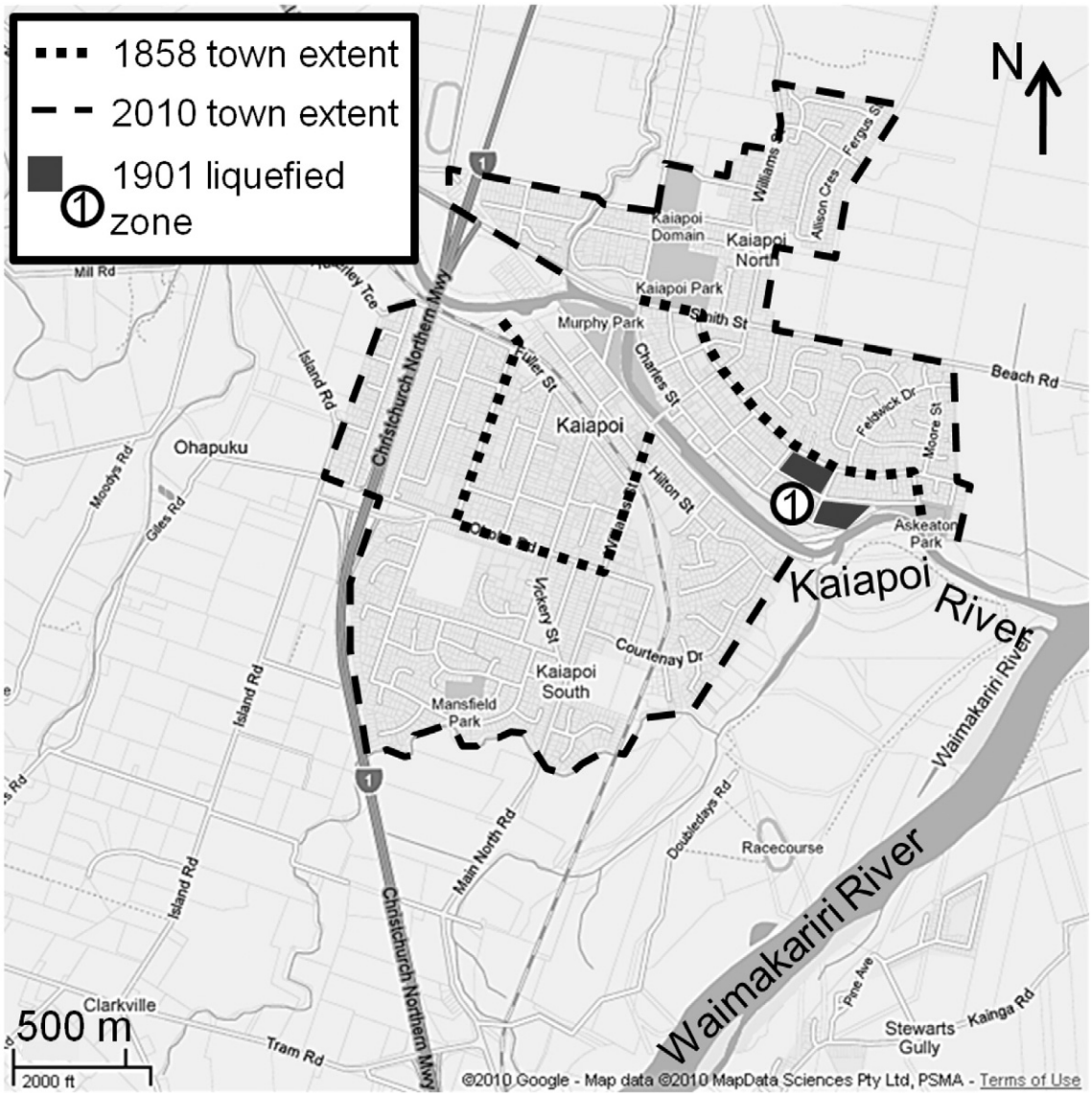


**Fig. 1.** Map of Kaiapoi with town extent in 2010 and town plan extent in 1858 superimposed. Google Inc., 2010.

earthquake (Berrill et al., 1994). Following the 2010 event, the M6.3 aftershock on 22 February 2011 centred 22 km south of Kaiapoi resulted in additional less severe liquefaction damage over a smaller part of the previously impacted region. In this event the KPOC strong motion station recorded a PGA of 0.21 g and a bracketed duration of less than 10 s (GNS, 2011).

Using observations from the 2010 and 2011 events, and records of the 1901 event, the relationship between liquefaction at Kaiapoi and the old channels of the Waimakariri River is presented. An overview of liquefaction damage from the two events is first summarised, followed by details of the changing nature of the Waimakariri River since the first European settlement. A detailed comparison of areas of liquefaction damage and the old river channels is presented and parallels made with observations in previous events worldwide.

## 2. Historic liquefaction in Kaiapoi

Well documented evidence of liquefaction in Kaiapoi during the 1901 Cheviot earthquake can be found in newspaper reports following the event. These detail ejection of sand, lateral spreading and ground settlement features in an area at the eastern edge of Kaiapoi on both sides of the Kaiapoi River (then the North branch of the Waimakariri River). Reports described fissures opening up in a property between 1 and 3 in. (2.5–7.5 cm) wide, and several chains (~40 m) in length in an SW to NE orientation. Water and grey sand deposits were ejected from these fissures, which were probed to a depth of 6 ft (~180 cm). In some areas the water ejected during the liquefaction caused flooding to depths of up to 6 in. (15 cm). Through discussion with local residents, Berrill et al. (1994) showed that these areas were two properties in the block bounded by Cass, Sewell, Beswick and Jollie Streets, and the block between Sewell, Jollie and Charles Streets (shaded area at position 1 in Figure 1). Fissures also opened on the other side of the river up to 2 ft (60 cm) wide, while smaller cracks were filled with ejecta. These cracks emerged from out of the river and continued up the river bed into the farms along the riverbanks. Signs of liquefaction were present in other areas, but their present day locations could not be defined.

Site investigations were carried out in some of these areas between 1986 and 1989 to evaluate their liquefaction potential. Piezocone probing and rotary boring were carried out at four sites, with properties encountered indicating a significant liquefaction risk in Kaiapoi, especially of those areas closer to the river (Berrill et al., 1994). Cone resistances of approximately 2–3 MPa were encountered at these tests