Liquefaction Records For Buller District

Liquefaction Hazard Information

West Coast

Assorted papers held at WCRC as of August 2008

1. Liquefaction During Historic Earthquakes in New Zealand, GJ Fairles and JB Berrill, Bulletin of the NZ National Society for Earthquake Engineering, Vol 17 No 4, December 1984

2. Seismic Liquefaction in the Buller: Preliminary Results, JB Berrill, RJ Adlam, ECT Ooi and P Foray, not dated (but post 1985)

3. Seismic Liquefaction in the Inangahua New Zealand Earthquake, JB Berrill and, University of Canterbury, NZ, not dated (but post 1985)

4. Liquefaction in the Buller Region in the 1929 and 1968 Earthquakes, JB Berrill, VC Bienvenu and MW Callaghan, Bulletin of the NZ Society for Earthquake Engineering, vol 21 No 3 , September 1988

5. Chapter 3, Seismic Liquefaction and Lifelines, from "Risks and Realities", CAE, Uni. Of Canterbury, Edited J Lamb, 1997

6. West Coast Regional Council Natural Hazards Review, 5.0 Earthquake Hazards: Derek Todd Environmental & Coastal Consulting, 2002. *(good summary/overview statement)*

***7. Liquefaction Case Histories from the West Coast of the South Island, New Zealand**, Kirsti Carr, Dept Civil Engineering, University of Canterbury, March 2004. Part Masters Thesis in Civil Engineering supervised by Dr JB Berrill and sponsored by BDC, GDC & WCRC, 2000 – 04.

8. Preston Road Sub-Division Geotechnical Investigation Report for Grey District Council: W Blair, Consulting Engineer, Paroa, Jan 2005

Compiled:
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Natural Hazards Analyst

*** large document held separately at WCRC, BDC & GDC**

1988

LIQUEFACATION IN THE BULLER REGION IN THE 1929 AND 1968 EARTHQUAKES

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SUMMARY

This article describes the results of a search for sites of liquefaction in the 1929 M=7.6 Murchison and the 1968, M=7.1 Inangahua earthquakes in the Buller region of New Zealand. Evidence of liquefaction was found for nine sites in each earthquake; two sites were common to both events. Widespread ejection of sand occurred in the epicentral regions of both earthquakes. Liquefaction was more sporadic at larger epicentral distances, except in the North Beach area of Westport, the most distant 1968 site, where sand boils occurred over several hectares, together with the toppling of utility poles and some lateral mass movement. This area corresponded to the very young beach sands deposited since extension of the Westport harbour breakwaters towards the end of last century. Liquefaction was much less common in the river-lain sands in the same vicinity.

INTRODUCTION

A general study of historical cases of seismic liquefaction in New Zealand (Fairless, 1984; Fairless and Berrill, 1984) suggests that liquefaction has been common in large New Zealand earthquakes, and that it occurred quite widely in the 1968, M = 7.1 Inangahua earthquake. Prompted by the number of cases found in the literature by Fairless, a more intensive search was mounted for occurrences of liquefaction in the Buller region, the scene of the 1968 earthquake. Several new cases were found, together with additional information about previously known ones. As well, a number of cases from the 1929, M = 7.6 Murchison earthquake were discovered, some sites having liquefied in both earthquakes. Further, two sites near Westport possibly liquefied during the 1962 Westport earthquake sequence (Adams and Le Fort, 1963) but we wish to obtain corroboration of this before publishing details.

The aim of this article is to report the evidence of past liquefaction found in the Buller region and to pin-point sites for further investigation, and for inspection following future earthquakes.

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Sources of information include reports in the literature and press interviews with eyewitnesses and aerial photographs taken a few days after the Inangahua earthquake. Even in 1968, sand liquefaction did not attract the interest that it does today and most references to liquefaction in the literature are cursory, with few details or specific locations given. For 1929 no mention of liquefaction effects such as sand ejection or movement of near-flat slopes could be found in the technical literature.

Figure 1 shows isoseismal patterns for the earthquakes. Both were shallow focus events with surface faulting, predominantly in a thrust mode. Brief seismological descriptions of the earthquakes are given in the appendix and further geological and seismological references may be found from the bibliography. It is of interest to note that most of the Inangahua aftershocks lie within the MM IX isoseismal, indicating this was the region of rupture, with rupture propagating southwestwards from a northern hypocentre.

SITES OF LIQUEFACTION

General Remarks

Figure 2 shows the sites of liquefaction that have been positively identified. These sites are listed in Table 1 together with epicentral distances and notes giving the type of evidence found. All sites shown are on level or near level ground.

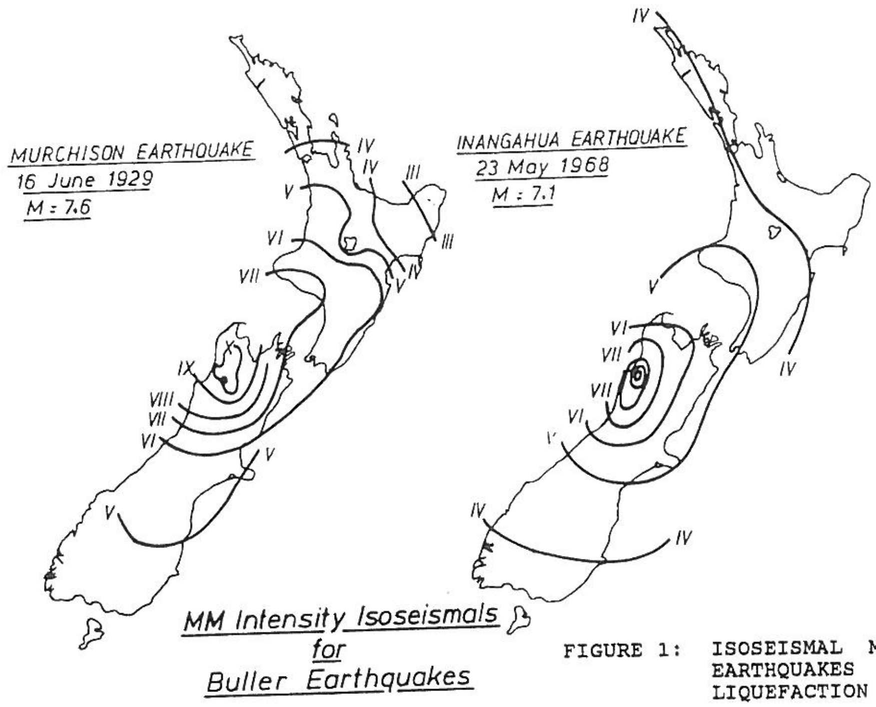

FIGURE 1: ISOSEISMAL MAPS FOR THE TWO EARTHQUAKES IN WHICH LIQUEFACTION WAS IDENTIFIED.

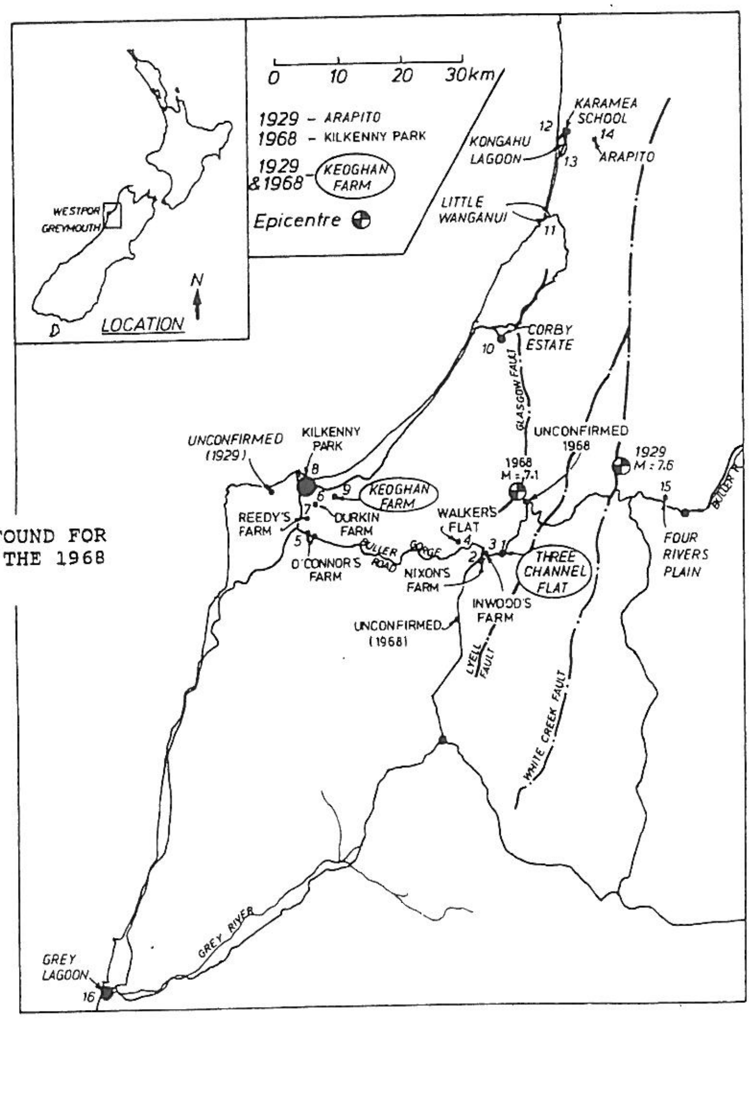

FIGURE 2: SITES OF LIQUEFACTION FOUND FOR THE 1929 MURCHISON AND THE 1968 INANGAHUA EARTHQUAKES.

"Liquefaction in the Buller Region"
Berrill Bienvenu & Callaghan 1988

TABLE 1: SITES OF LIQUEFACTION FOUND FOR THE 1929 AND 1968 BULLER EARTHQUAKES

SITE	EARTH-QUAKE	EPICENTRAL DISTANCE	EVIDENCE
1. Three Channel Flat, Inangahua	1929 1968	23 km 10	Newspaper report Eyewitnesses, aerial photos
2. Nixon's Farm, Inangahua	1968	12	Eyewitnesses, aerial photos
3. Inwood's Farm, Inangahua	1968	11	Eyewitnesses, aerial photos
4. Walkers Flat, Buller Gorge	1968	12-15	Eyewitnesses, aerial photos
5. O'Connor's Farm, Westport	1968	30	Eyewitness report; MM Intensity report.
6. Durkin's Farm, Westport	1968	32	Eyewitness
7. Reedy's Farm, Westport	1968	33	Eyewitness
8. Kilkenny Park, North Beach Area, Westport	1968	34	Several eyewitnesses, Newspaper reports & photos
9. Keoghan's Farm, Sergeants Hill, Westport	1929 1968	45 29	Eyewitnesses
10. Corby Estate, Seddonville	1929	27	Eyewitness
11. Little Wanganui	1929	41	Eyewitnesses
12. Karamea School	1929	54	Several eyewitnesses
13. Kongahu Estuary, Karamea	1929	51	Indirect eyewitness report
14. Arapito, Karamea	1929	52	Eyewitness
15. Four Rivers Plain, Murchison	1929	8	Eyewitness
16. Grey Lagoon, Greymouth	1929	114	Newspaper report

The main evidence for liquefaction in all cases was the ejection of sand. At one site, Kilkenny Park, Westport, this was accompanied by large-scale mass movement and by the toppling of electric power poles.

By far the most extensive occurrences of liquefaction were found in the flood plains of the Buller River at Three Channel Flat, about 3km northeast of Inangahua Junction, and at Walker's Flat, about 5km west of Inangahua Junction. Several hundreds of sand boils show up on aerial photographs taken on May 29 and 30 and in terrestrial photographs taken by various observers. In both places, the ejection of sand was quite pervasive. Figure 3 gives the flight plan of the post-earthquake aerial photography flown by New Zealand Aerial Mapping Ltd. The pilot was Mr Cyril Whittaker who confirms that runs A and B shown in the plan were not flown, due to poor weather.

Note that at least two sites, Three Channel Flat and Keoghan's Farm liquefied in more than one earthquake. Furthermore, one site near Meddows' Farm, Walkers Flat, liquefied in an aftershock of the 1968 earthquake as well as in the main shock.

Three unconfirmed sites are also marked in Figure 2. For these there is some indefinite evidence for liquefaction in 1968 in the form of vague word-of-mouth reports or apparently ejected sand in aerial photographs that could not be confirmed on the ground.

In the following paragraphs each site will be discussed in more detail.

Three Channel Flat

Extensive ejection of sand was observed at Three Channel Flat following the 1968 earthquake. The flat comprises a system of low terraces of Recent alluvium. The photograph shown in Figure 4 was taken on the day after the earthquake. The present owner of the land, Mr Warren Inwood, also remembers seeing the ejected sand, although he did not own the land himself at the time. The extent of sand ejection is clear from Figure 5, a vertical aerial photograph taken 5 days after the earthquake.

The flat comprises a system of low terraces of Recent alluvium. Extensive hand auger boring at the south end of the flat shows a layer of silt 3 to 4m thick overlying fine sands of variable thickness over gravels (Ooi, 1987; Adlam, 1988). Thickness of the sand layer increases towards the outside of the abandoned south channel evident in Figure 5, and decreases towards the inside of the channel, marked by the absence of sand boils. It appears that where there is sand, it was ejected in 1968.

The paddocks to the north of the central vehicle track have been extensively regraded since 1968 and their contours changed markedly. But to the south of the track the terrain is essentially the same, although some fences have been moved. The two paddocks at the south end of the flat (in the foreground of Figure 4) have been ploughed two or three times since 1968 yet in them it is still possible to pick up lenses of fine grey sand, presumably the ejecta, starting at depths of up to 200mm below the ground surface. After ploughing, while the soil is still moist, Mr Inwood reports that the patches of grey sand stand out markedly from the darker silts. The sand possibly owes its being buried to the ploughing, but possibly also to a build up of silt since 1968, as the paddocks are flooded about once a year.

Of the various sites of liquefaction in 1968, Three Channel Flat was the most extensively studied at the time.

Sutherland (1970) notes that patches of ejected sand occurred either in a linear arrangement with a fissure linking the flows or in a random pattern with no linking fissures. Presumably the formation of the linear fissure with sand ejection indicated some lateral mass movement, while the unconnected random pattern of boils, which he notes were found at Three Channel Flat and Walkers Flat, mark areas of complete liquefaction on virtually level ground.

Dodd and Dunlop (Dodd, 1970; Dunlop, 1968) investigated sand boils at the south west of the flats with auger borings and sieve analysis. The log of their boring, starting from the bottom of a recently excavated trench, is shown in Figure 6; grain size distributions of the ejected and subsurface sand strata are shown in Figure 7. Note the similarity of the sand gradings. Presumably the ejected sand came from the lower layer, below the water table.

Liquefaction also occurred at Three Channel Flat in the 1929 Murchison earthquake according to an article in the June 19, 1929 issue of the Wellington "Evening Post", which reports "Paddocks at Three Channel Flat are covered with white sand".

Sand Ejection near Inangahua Township

The confluence of the Buller and Inangahua rivers near the Inangahua township is marked by large areas of young alluvial river terraces. There are several contemporary reports (Lensen and Suggate, 1968; Adams et al., 1968, Sutherland, 1970; Dodd, 1970) of sand boils on these terraces in 1968; and patches of sand show up well on the aerial photographs. Figure 8, drawn up from the photographs, shows the areas in which ejected sand is apparent.

Sutherland (1970) reports a witness's account of water gushing to a height of 3m in the fields immediately to the north of Inangahua and that the "gusher" was active for at least an hour and a half after the earthquake.

Walkers Flat

Aerial photographs from runs C and D of the 1968 post earthquake photography show ejected sand over a large part of Walkers Flat. Figure 8 shows the extent of the 1968 sand boils.

"Dtec Report" 2002

5.3 Effects Of Earthquakes

The regional effects of earthquakes are numerous and have been described in detail in Benn (1992) and more recently in Yetton *et al.* (1998). Earthquake effects and their general time scales in relation to the earthquake shock include:

- Ground shaking: Immediate.
- Surface rupture: Immediate.
- Liquefaction: Immediate.
- Landslides: Immediate - Moderate/Long Term
  Note: An earthquake can initially weaken slopes, and then subsequent trigger mechanisms may actually cause the slope to fail and slide. (See Chapter 3 & Appendix 3).
- Landslide dammed lakes: Immediate - Long Term.
  Note: Dams and lakes can form almost instantly, and fail in a few hours, or last thousands of years. (See Chapter 3 & Appendix 3).
- Tsunamis: Immediate - Short Term.
  Note: Near field tsunamis generated by local earthquakes will be felt within a matter of minutes (See Chapter 4).
- Seiches: Immediate.
- River avulsion and sedimentation, by landslides: Immediate - Long Term (See Chapter 1 and Appendices 1 & 3).
- Severing of engineering lifelines (roads, rail, water supplies, sewage pipes, telecommunication lines, powerlines): Immediate - Moderate Term.

The time scales mentioned above give an indication of the duration of the effects actually occurring, but the physical clean-up, repair work, and economic effects may last for many months, or years. The effects mentioned between numbers 4-8 above were discussed in detail in previous chapters, and hence only passing references are made to them in this chapter.

5.3.1 Surface Rupture

Berryman (1984a) noted that a good correlation existed in New Zealand between surface rupture (faulting) and shallow earthquakes equalling M7 or greater. It was also observed by Berryman that a good correlation existed between surface rupture and felt intensities of greater than MM9. However, examples of surface rupture have occurred with earthquakes of less than M7. These include the 1929 Arthur's Pass earthquake (M6.9, Rynn 1975, M7.1, Dowrick 1991, Yang 1992), the 1983 localised earthquake swarm of M3-M4 on the Kaiapo Fault (north Taupo Fault Zone, Berryman 1983), and the Edgecumbe earthquake in 1987 (M6.3, DSIR 1987).

Notable West Coast examples of surface rupture include the 1929 Murchison Earthquake (M7.8) and the 1968 Inangahua Earthquake (M7.1). Respective felt intensities of these earthquakes in the epicentre regions were MM9 and MM10. Surface rupture on the White Creek Fault during the Murchison Earthquake was 4.5m vertical where the fault crosses the Buller Gorge Road (now SH6) (Ferrar & Grange 1929, Fyfe 1929, Hendersen 1932, Bastings 1933). Maximum uplift of 4.9m occurred about 503m east of the fault, and was recorded by Fyfe (1929). The uplifted block tilted gradually to the east, with the tilt becoming non–existent at about 19.5km from the fault. Hendersen (1937) detected the fault trace displacement for 8km, and Berryman (1980) recorded 2.1m of sinistral horizontal movement and 3.1m vertical movement at a fence crossing the fault scarp.

During the Inangahua Earthquake, surface rupture was recorded on the Glasgow-Inangahua Fault, and the Rotokohu Fault traces. Maximum displacement on the Glasgow-Inangahua Fault was near the railway lines at Inangahua. Lensen & Otway (1971) recorded 190mm of sinistral displacement, 400mm of vertical displacement, and a shortening component of 270mm (i.e. high angle reverse faulting as in the Murchison Earthquake). Maximum uplift occurred 4km east of Inangahua, and an area of at least 1 000km^2 was uplifted by an average of 1m. The Rotokohu Fault traces were formed during the Inangahua Earthquake, and were formed by slippage of bedding planes (bedding plane faults) in underlying Tertiary sediments. All were up-thrown to the south- east, with maximum vertical and dextral displacements reaching 1m on some traces: 400mm of thrusting was indicated by compressional rolls on the ground surface (Lensen & Otway 1971).

Although no movement of the Alpine Fault has been recorded historically, geological evidence suggests that individual dextral movements associated with large-scale earthquakes are in the order of about 8m horizontal (Hull & Berryman 1986, Yetton *et al.* 1998). The most recent earthquake on the Alpine fault occurred in 1717AD, with an associated minimum rupture length of 375km, from Milford Sound to the Haupiri River (Yetton *et al.* 1998). This rupture may actually be up to 450km in length (see Section 5.5).

5.3.2 Liquefaction

Liquefaction occurs as a result of ground shaking, when pore fluids in fine grained sediments are prohibited from escaping, hence the sediments become saturated, lose their strength and behave like a fluid – that is, the sediments flow. Liquefaction is commonly associated with geologically young sediments, especially those less than 10 000 years old, deposited in low energy environments such as lagoons, estuaries and artificially reclaimed ground. Bell (1994) also noted a high ground water table was necessary for liquefaction to occur. Fairless and Berrill (1984) noted that with the exception of the 1895 Taupo Earthquake (greater than M6, in pumice soils which have unique properties), all cases of liquefaction in New Zealand have occurred in earthquakes of at least greater than M6.9. However, liquefaction occurred in the 1913 Westport (Fairless & Berrill 1984), which was assigned a magnitude of greater than M5 by Eiby (1968), although the exact magnitude is not known. Liquefaction was also recorded in the January 1991, M6 Westport earthquake (Benn 1992). Keefer (1984) suggested that M5 might be the minimum magnitude required for liquefaction to occur. For New Zealand, Hancox *et al.* (1998) claimed that MM7 was the minimum shaking intensity threshold for sand boils, and MM8 was for lateral spreads. They also noted that both might occur at one intensity level less, in highly susceptible materials.

With the region's main settlements being established on river mouth/estuarine deposits, and reclaimed lagoons, there is a considerable risk of damage by liquefaction during earthquakes. Fairless & Berrill (1984) commented that *"...it is now recognised that liquefaction is a fairly common seismic effect and one with great potential for destruction"*.

Liquefaction causes damage by water ejection (like a high pressure fountain), sand boils, settlement of sediments, landslides on moderate slopes, foundation failures, and floatation of light structures. Numerous examples of liquefaction have been reported on the West Coast (Fairless & Berrill 1984, Berrill *et al.* 1987a, 1987b, Adlam 1988, Berrill *et al.* 1988, Benn

1992). The most damaging case, described by Berrill *et al.* (1988), occurred during the Inangahua Earthquake: At 10A Romilly St, Westport, a sand boil under the house had sufficient force to lift the house, rotate it, and leave it skewered on it's foundations. The house had to be demolished. Appendix 4 summarises liquefaction cases recorded in Benn (1992).

As can be seen from Appendix 4, most cases of liquefaction have been recorded in the Buller District, being coincidental with earthquake epicentres in the district. However, if earthquakes are generated elsewhere in the region, it can be expected that reported liquefaction cases would also increase from those areas. Berrill *et al.* (1988) noted that liquefaction becomes more sporadic with increased epicentral distances, and all West Coast examples have been recorded from level or near level ground.

Benn (1992) noted that:

"Widespread liquefaction is possible on the West Coast, given the geologically young, near level flood plains of many river valleys. The most extensive flood plains (potentially the highest liquefaction risk) occur in the Grey and Inangahua river valleys, the Buller and Karamea river flood plains, and in the valleys of the Arahura, Hokitika, Wanganui and Poerua Rivers.

All of these floodplains have been intensively settled and developed. Hence, because all the major West Coast settlements are located on river flats (e.g. Inangahua, Murchison, Reefton) or at river mouths in a lagoonal environment (e.g. Greymouth, Westport, Karamea, Hokitika, Okarito), the potential for liquefaction damage is high"

Potential liquefaction sites can be determined to a certain degree by basic soil identification, and scientific soil and pore pressure tests, although Fairless & Berrill (1984) noted that predictions of liquefaction potential are far from reliable due to the mechanics of liquefaction not being fully understood. However they did state that *"If we ask whether liquefaction would have been predicted at Three Channel Flat* (Inangahua area, Buller Gorge) *given the soil properties found, the answer is definitely yes".*

Benn (1992) suggested that locating potential liquefiable sites should be considered important, especially in areas of intense development or proposed development. Fairless & Berrill (1984) concluded that Three Channel Flat and Kilkenny park in Westport would be interesting to investigate further because of their recorded liquefaction, as would the Grey River site if it could be located more precisely. This was suggested: *"...to establish soil properties there and to check the results of various predictive liquefaction models against the known occurrence of liquefaction".*

Identifying potential liquefaction sites and creating hazard maps was one of the main hazard priorities expressed by the three District Councils, when interviewed for this project (See Chapter 7).

5.3.3 Seiches in Lakes

Landslides falling into lakes, or disturbances of the lake floor by submarine slides or fault ruptures, can cause waves in the order of tens of metres high (Hawley 1984). Two such reported cases occurred during the 1929 Murchison earthquake, when it was reported from Lake Rotoroa (now in the Tasman District):

"Lake Rotoroa rocked from side to sided like a huge basin of water being tipped out. Half an hour after the main shake, the water receded from the hotel shore and exposed the lake bed for 50 yards. It then came back in a series of large waves. The bridge over the Gowan River at the lake was torn from its piles and banks of the river and was hurled upstream by the Gowan waters, which were temporarily flowing back into the lake. The water then returned back to its normal course" (Greymouth Evening Star 20/06/29, *in* Benn 1992).

The same edition of the paper also reported: *"Lake Moana (Brunner) sank down in the middle then came up like a typhoon"*. Lake margins were flooded. It is assumed that these two seiches were generated from submarine disturbances, as no contemporary reports or observations of landslides falling directly into either lake have been found.

Benn (1992) noted that since there are numerous deep lakes in the region, located in steep sided glacial trench valleys, landslides into lakes and seiches are a potential threat throughout the region. At Lake Brunner and Lake Kaniere there is a threat to the substantial settlement and development around their shores, However, development is not intense around many of the other smaller lakes in the region. Yetton *et al.* (1998) stated that: *"In general lake seiches are more likely to cause damage during an Alpine Fault earthquake than are tsunami"*. This was based on the proximity of the lakes to the Alpine Fault trace, and it was noted that Lake Brunner and Lake Kaniere were 7km and 500m from the fault respectively, and both have steep peaks on their shorelines, elevated at more than 1000m above the lake levels. Yetton *et al.* also noted the potential effects of seiches on individual lakes throughout the region.

K. Cull, Research Report 2004

4.4.3 Westport

The areas of the town built on the old sand dunes and near the Orowaiti Lagoon seemed to be affected considerably more by the earthquake than other areas, effects similar to those observed following the 1929 Murchison earthquake. The known sites of liquefaction in the Westport area are detailed on the map in Figure 4-4 below.

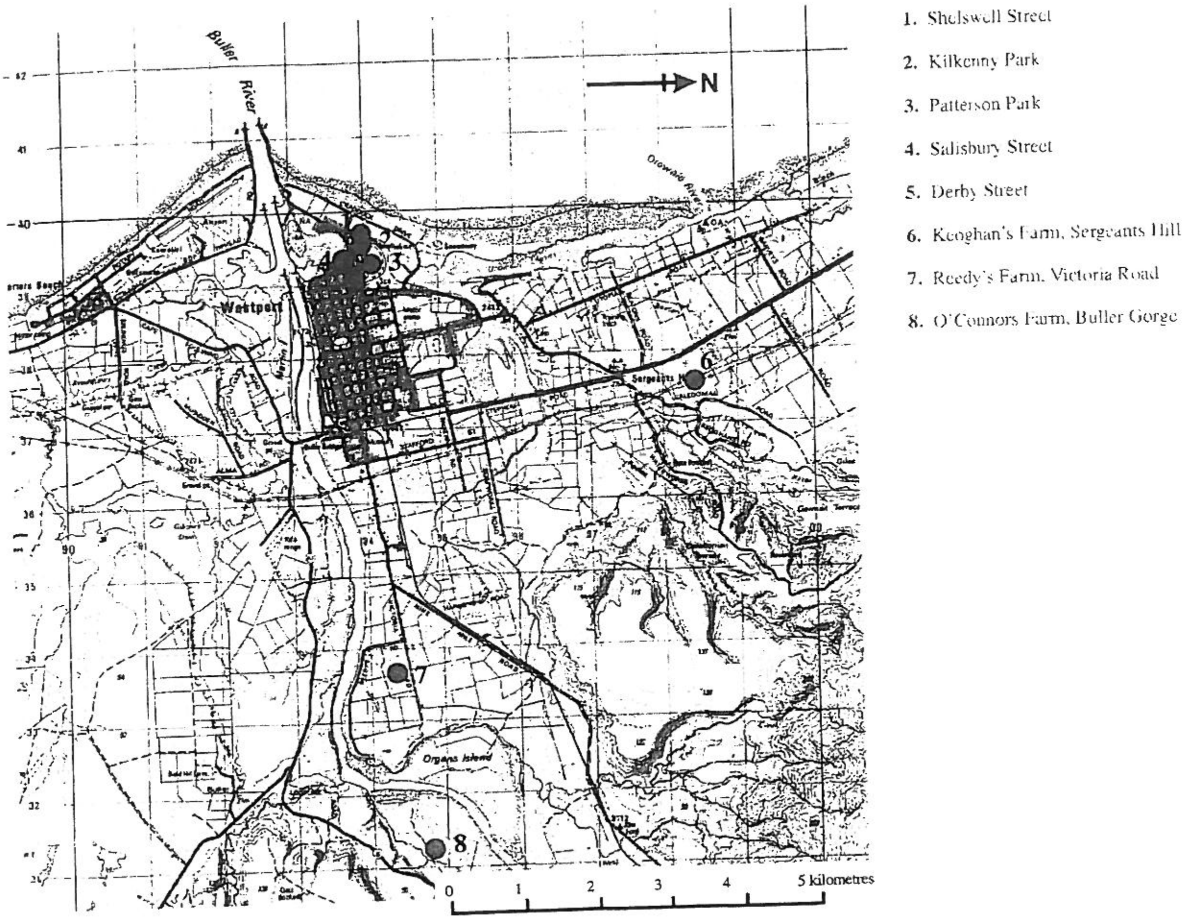

Figure 4-4. Sites of Liquefaction in Westport following the 1968 Inangahua earthquake (Base Map from Topomap, 2001)

It was stated in *The Press* ("Buildings in Westport Damaged, Roads Cut", Saturday May 25,1968, pg 1) that, "*Three houses in the North Beach area were disjointed and the occupants were surprised to see sea-water bubbling up on lawns a mile from the waterfront, leaving thick layers of sand...... Approaches to the Orowaiti Bridge, the main outlet to the north, and the Waimangaroa overhead bridge were lowered 6in to a foot..*".

It was also written in the same article that, "*At least one residence in the badly-hit North Beach area is beyond repair and sand and seawater continue to seep through some gardens and lawns*" but no specific locations are given.

Following the 1968 Inangahua earthquake the underground services, including both the drainage and water supply, were affected in the coastal areas. This is similar to the damage that occurred following the 1929 Murchison earthquake as noted in Chapter 3. Fairless (1984) cites Andrews (1969) who also noted that buildings were distorted and pavements were also broken in this area. Andrews (1969) also wrote that none of the buildings were damaged to a point of collapse.

Berrill *et al.* (1988), reported in order to reconnect the broken water main, which was located approximately north-south along Derby Street, near Kilkenny Park, 1.2 m of pipe had to be added. Mr Gaynor, who was employed by the Westport Borough Council at the time, supplied the information. Berrill *et al.* (1988) surmised that "*together with the cracking, the broken water main suggests that a large mass of surficial soil had moved towards the coast on a layer of liquefied sand*".

Shelswell Street

Cracks opened in the ground on both the south side of Shelswell Street and at 14 Shelswell Street, where they were found to be passing though the Gaynor's house. Berrill *et al.* (1988) noted that these "*cracks were roughly parallel to Shelswell St, (and to the nearby beach) and were of the order of a few hundred millimetres wide*".

Kilkenny Park

Berrill *et al.* (1988) noted that extensive water and sand ejection occurred in the area surrounding both Kilkenny and Patterson Parks. It was written that, "*Mr M. Dyer remembers seeing numerous sand boils in the paddocks immediately north of Shelswell St and over the land to the west of Patterson Park south of Orowaiti Road... He also remembers boils along the east side of Derby St at Kilkenny Park. Several other eyewitnesses reported sand and water boiling from the ground in Kilkenny Park; these include Mrs MacDonald of Morgan's Lane, and Mr and Mrs Bill Gaynor and Mrs Naylor of Shelswell Street, whose properties back onto Kilkenny Park...*".

Ooi (1987), Bienvenu (1988) and Dou and Berrill (1992) all undertook testing at Kilkenny Park. As part of her research Bienvenu also undertook a number of SPT tests in the park. Ooi undertook a number of cone penetrometer tests and bore holes. From these, it was found that beneath the silty topsoil there were four to five metres of medium dense sand containing lenses of silty sand and dense sand. This was underlain by a one metre thick silty sand layer which in turn was underlain by gravely sand. Ooi found that each of the different methods used to predict the liquefaction potential suggested different layers would liquefy. All the liquefaction potential prediction methods used by Ooi suggested that the top silty sand layer had the greatest potential to liquefy. Dou used this site to check the reliability of the Scala Penetrometer tests he undertook, as well carrying out some CPTU testing.

Patterson Park Racecourse

In *The Nelson Evening Mail* ('Quake damage at Patterson Park ', May 1968) it was written that the ground fissured on the inside training track, and at the entrance to the main straight (which covers an area of approximately 18ft x 24 ft) there was sand and water extruded from the ground. There were also numerous cracks and subsidence of the ground.

Berrill *et al.* (1988) recorded another article from *The Nelson Evening Mail* (31 May 1968) where the occurrence of "*several fissures on the race track and a large 6m by 8m 'boil up' of sand and water at the entrance to the front straight of the inside training track*" were reported. The newspaper also presented photographs of both the sand boils and fissures.

Salisbury Street

Nearby, at 2 Salisbury Street, Mr James Fischer saw a sand boil erupt in the grass verge in front of the house (Berrill *et al.*, 1988).

Derby Street

Berrill *et al.* (1988) gives one of the most extraordinary reports stating "*To the west of Patterson Park at 10a Derby St, sand erupted under a house with sufficient force to lift it, rotate it and leave it skewed on its foundations…*". Ooi (1987) wrote that this occurrence was confirmed by Mr. Wally Forsyth, and the house was subsequently abandoned and demolished.

Berrill *et al.* (1988) also wrote that a, "*less definite report also had water coming out of the ground somewhere near 23 Romily Street, in the same general area*".

Keoghan Farm, Sergeants Hill

Following both the 1929 Murchison and 1968 Inangahua earthquakes, Mr Keoghan noticed sand boils in the paddocks of his farm which is situated on the banks of the Orowaiti River, south east of Sergeants Hill. According to *Berrill et al.* (1988), "*From 1929, when he was a boy of 11, Mr Keoghan remembers geysers of sand and water 5 to 6 feet high, leaving sand cones 2 to 3 feet high. In 1968, smaller cones were formed, about 6 inches high, in the same general area. Small sand boils were also observed by Mr Keoghan in the bed of the Orowaiti River immediately to the south of his house.*"