Tsunami hazard assessment baseline for the Northland region

NIWA Client Report: CHC2006-069
June 2006

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Prepared for

Northland Regional Council

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Executive Summary

NIWA was commissioned to undertake a comprehensive literature review of the pre- and post-human tsunami record for the Northland Region and a groundtruthing field assessment of representative sections of the coastline of the Northland Region.

The historic record shows that four moderate (1.0-5.0 m) tsunamis have inundated the east coast of the region in the last 150 years. The palaeotsunami record indicates that there has been at least one large event (or a series of large closely spaced events) in the last 600 years. Ongoing research based upon sediment cores taken from Waimamaku River mouth, Hihi Beach, and Mimiwhangata, is aimed at improving our knowledge of the palaeotsunami record.

A comparison between the historic and palaeotsunami records indicates some key points:

- Distant events from South America generate moderately large tsunamis along the east coast. The last moderately large tsunami occurred in 1960 and there has been considerable coastal development since that time.

- Distant/regional events from other sources such as Indonesia and the north (Fiji Basin/Solomon Sea) are poorly represented or not at all. They are unlikely to be large magnitude events – probably moderate, but would be more likely to affect the whole coastline.

- A large regional and/or local tsunami has not occurred in historic time but appears to be recorded in the palaeotsunami record. Some local and/or regional sources are likely to produce large (>5m) tsunamis on all or part of the region’s coastline. The travel times for such events will not exceed 3 hours.

- Four moderate events in 150 years yield a return period of one every 37.5 years for the east coast only. There are insufficient data to calculate a similar return period for the north or west coasts.

- One composite palaeoevent is of limited use for developing return periods for large events. Based on this, one could estimate a return period anywhere from about once every 600-6000 years or so (this approximates the time when sea level reached the present highstand – as sea levels fall the tsunami hazard reduces and vice versa). Data from lakes at Mimiwhangata may help to improve our calculations. Given that a large event is likely to be generated from a local and/or regional source, the extent of coastline affected will vary greatly depending upon these parameters.

A general summary of hazard and risk for the region is proposed. A moderate hazard and risk is suggested for most of the northwest and east coast, a high hazard and moderate risk for the north, and a low hazard and risk for the west.

A series of 23 recommendations have been made which can be summarised as follows:

- A chronology of dune stratigraphy is needed for the west coast.

- A series of eight sites where sediment coring could be undertaken to improve the palaeotsunami record have been identified. This is over and above those cored during the course of this study.

- Reconnaissance surveys for coastlines not accessible during this project are recommended.

- All outer islands off the Northland region coast are a *high priority* for reconnaissance surveys. These sites are likely to be less disturbed than the mainland coastline.

- Three areas were singled out for more detailed, *high priority*, studies: Tauroa Point and the associated archaeological sites; 90 Mile Beach, and Tom Bowling Bay to Waikuku Beach – including the Waikuku Flats wetland.

1. Introduction

The National Institute of Water & Atmospheric Research Ltd (NIWA) has been commissioned by the Northland Regional Council to undertake a comprehensive literature review of the pre- and post-human tsunami record for the Northland Region and a groundtruthing field assessment of representative sections of the coastline of the Northland Region. This also included taking sediment cores for the analysis of palaeotsunami deposit.

2. Literature review of the pre- and post-human tsunami record for the Northland Region

2.1. Post-human (historic) tsunami record

The data presented below (Table 1) are based on the historical database developed by de Lange and Healy (1986), which was updated by Fraser (1998).

Historical data are of variable reliability. 19th century data vary in veracity but, whether or not wave height information is entirely correct, the recording of personal observations is usually indicative of a significant event. 20th century events on the other hand are of increasing reliability up to the present day, as more sophisticated recording technology has become available. This accounts for an increasing number of small tsunamis recorded in the recent historical record. As seen in Table 1, the last moderate event was recorded in 1960, with the exception of a wave runup height of 0.75m in Tutukaka in 1976. All events reported since have had very small wave runup heights, reflecting the level of sophistication of tidal gauges. With this in mind, we have provided only limited data for events from 1976 onwards, including the 2004 Indonesian and 2006 Tonga earthquakes.

There have been only four significant events in the last 150 years or so that have generated moderate (1.0-5.0 m) tsunamis on the coast of the Northland Region: the 1868 earthquake in northern Chile (magnitude 8.5), the 1877 earthquake in southern Peru/northern Chile (magnitude 8.3), the 1883 Krakatau eruption and the 1960 earthquake in southern Chile (magnitude 9.5). Apart from the Krakatau eruption, all major historical tsunamis were generated in South America. Based purely upon the historical record it is evident that the eastern side of the Northland Region's coast is at risk from tsunamis generated from South American sources. It is worthy of note that there has been a marked growth in coastal development along the eastern coast since the last moderate tsunami in 1960.

Table 1: Historic tsunamis in the Northland Region from 1868 to 2006 (after Fraser, 1998)

Date	Runup height (m)	Location (see Fig. 1)	Comments/Damage	Source	Magnitude
1868	1.50	Mangonui (13)	Obs. on 15-17/08. max. rise on 15/08 between 9am-2pm	Quake northern Chile	8.5
	1.50	Russell (9)	Water rushed above normal spring tide		
1877	2.70	Manawaora Bay (10)	Creek bed dry but tide was very high. A house was flooded in 0.3 m water	Quake southern Peru/northern Chile	8.3
	3.00	Waitangi (8)	The boat Iona was swept above high tide mark		
	1.80	Russell (9)	Tide ebbed and flowed seven times		
	2.40	Paihia (7)	At noon, tide dropped 1.2m in 10 min, then rose 1.9 m by 12.25pm		
	2.00	Wairoa Bay (12)	Inundation of 9 m, two boats left high and dry		
	2.50	Bay of Islands (11)	2.5m rise in a few minutes, then ebbing and flowing every 20 min		
1883	1.50	Mangonui (13)	Large waves occurred at 4am on the 29th	Explosive eruption of Krakatau - Rissaga	
	1.50	Russell (9)	Waves continued from the 29th-30th		
1952	0.90	Matapouri (5)	A bore may have formed in the estuary, damage to a boat	Quake Aleutian Islands	8.3
	0.91	Tutukaka (4)	A 0.3m bore travelled up the river, 0.5m tide fluctuations every 30 min		
	1.00	Ngunguru (3)	A launch was washed from its cradle		
1960	1.00	Ahipara (14)	Waves ran up a tidal river	Quake southern Chile	9.5
	1.20	Mangonui (13)	In 10 minutes, a 1.2m rise and fall was observed		
	1.00	Waitangi (8)	Strong ebb and flood tides, whirlpools also formed		
	1.00	Russell (9)	A flashing beacon was washed away		
	3.00	Opua (6)	Boat in 3m water was grounded. Water rose 1 m in minutes		
	3.00	Tutukaka (4)	Max. height of 3m occurred at 3pm on 24th. Damage to bridge abutment		
	1.00	Ngunguru (3)	Severe erosion of sand from beach. Damage to cottage		
	1.00	Whangarei (2)	Series of waves 1 m high		
1976	0.75	Tutukaka (4)	Damage to several yachts	Quake Kermadec Islands	7.8
	0.20	Whangarei (2)			
1977	0.15	Opua (6)		Quake Kermadec Ridge	7.2
	0.13	Whangarei (2)			
1994	0.10	Marsden Point (1)	Oscillations actually less then 0.1m but unknown, so 0.1m used	Quake Kuril Islands	8.3
2004	0.25	Whangarei (2)		Quake west coast of northern Sumatra	9.3
2006	<0.2	Marsden Point (1)		Quake Tonga	7.9

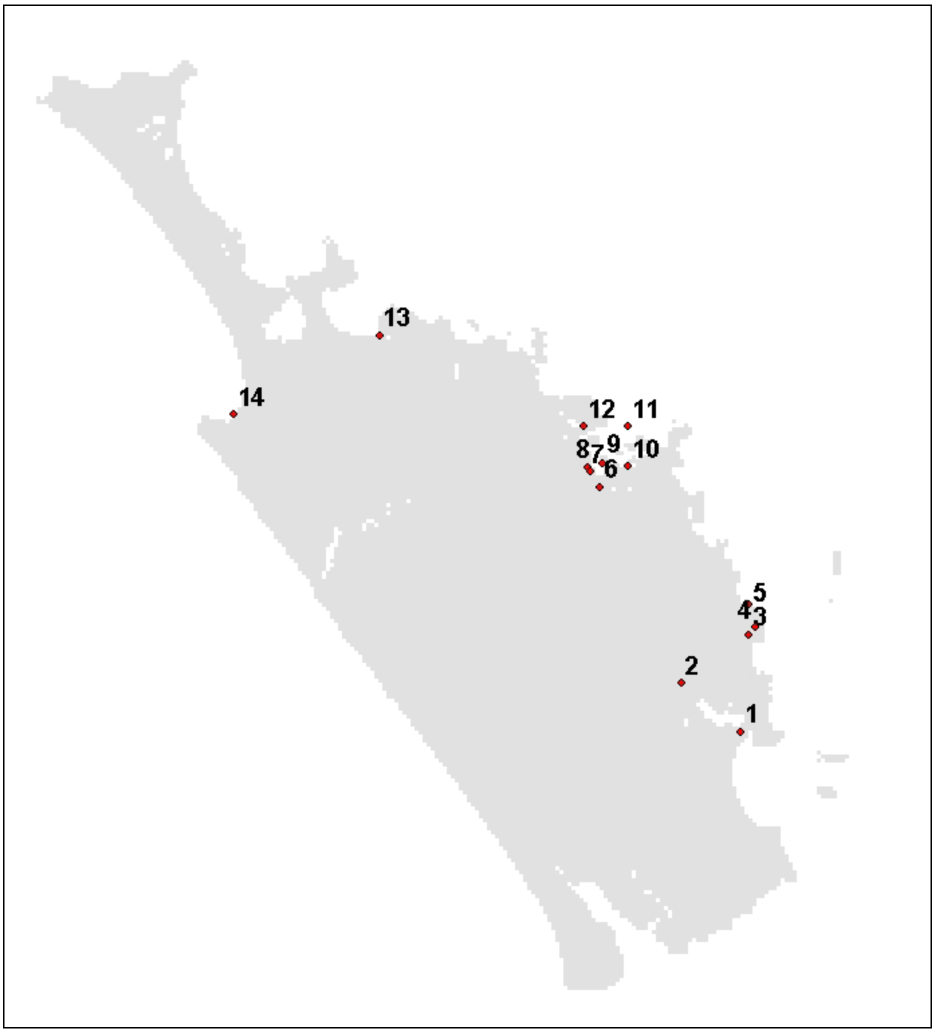

Figure 1: Locations referred to in Table 1.

2.2. Pre-human tsunami record

It should be noted that the record of pre-human tsunamis (palaeotsunamis) is mostly based on archaeological evidence. The veracity of palaeotsunami data must be viewed in a different context to historic events. Some of the sites have been studied by researchers and are verified palaeotsunami deposits (e.g. Henderson Bay; Nichol *et al.*, 2004), whereas others are based upon either the interpretation of past archaeological data, similarities in sedimentary evidence, or as yet unpublished work. Those verified by appropriate geological field research are considered Primary sites (1 in the 'Verification' column of Table 2), others are secondary (2 in the 'Verification' column of Table 2)

Table 2: **Palaeotsunami sites on the Northland coast (Where available a site photo taken during the reconnaissance work is given in Appendix II; all site photographs taken during the reconnaissance work are available on the associated CD, recommendations at base of table relate to superscript numbers in reference column)**

Location (see Fig. 2)	Evidence	Elev. ma MHW*	Date	Reference	Verification**
West Coast					
Glinks Gully south (1)	Dune ridges with pedestals + hummocky topography	~5	late 14th C??	Goff et al., in press; This report[1]	2
Kopuru (2)	Loisels/pebbles in dune – much human disturbance (100m inland)	10	late 14th C??	This report[2,3]	2
Kawerua (3)	Gravels/pebbles on dunes	~10	14-15th C	Hayward, 1974	2
Waimamaku River mouth (4)	Gravels/pebbles in/on dunes (>100m inland)	>10	late 14th C??	This report[4,5]	2
Hokianga (5)	Major dune advance? Tsunami triggered? Archaeological site below WHM	?	14-15th C	Hicks, 1975a; Goff, 2006	2
Tauroa Point, Ahipara (5)	Change in shellfish species from rocky shore to sandy shore	-	14-15th C	Brook, 1999d	2
	Gravels/pebbles in/on dunes (>200m inland)	>30	Post human settlement	This report[6]	2
West Aupouri Peninsula, 90 Mile Beach (7)	Major dune advance-tsunami triggered? Abandonment of coast by Polynesians, and shift of settlement inland Gravels/pebbles on dunes	?	14-16th C 13-15th C	Hicks, 1975a, 1975b; Coster, 1983, 1989; This report[7]	2
Twilight Beach (8)	Gravels/pebbles in/on dunes (>200m inland)	>15	14-15th C	M. Taylor, pers. comm., 2005; This report[8]	2
Te Werahi (9)	Erosion surface Some pebbles mixed with umu/midden material in dunes	>10	14-15th C	Brook, 1999c; This report	2

Location (see Fig. 2)	Evidence	Elev. ma MHW*	Date	Reference	Verification**
North Coast					
Three Kings Group:	Gravels/pebbles on hillside		late 14th C	Hayward, 1991; Brook, 1999a[9]	2
Great		>40			
North East Island		>40			
South West Island		>40			
West Island		>20			
Spirits Bay (11)	Gravels/pebbles on dunes	>10	14-15th C?	Goff, 2006	2
Tom Bowling Bay (12)	Gravels/pebbles in/on dunes	>35 (42?)	14-15th C?	This report	2
East Coast					
Waikuku Beach (13)	Gravels/pebbles in/on dunes	?	?	This report[10]	2
Parengarenga Harbour (14)	Gravels on sand dunes	>10	late 14th C	Hay, 1981; B. McFadgen, pers. obs., 1980s	2
Henderson Bay (15)	Gravels/pebbles in/on dunes	32	late 14th C	Nichol et al., 2004	1
Kowhai Bay (16)	Gravels/pebbles in/on dunes	~20	late 14th C	Goff, 2006	1/2
Houhora, Mt Camel (17)	Erosion of archaeological deposits	~1	late 14th C	Furey, 2002	1/2
Puwheke Beach (18)	Gravels/pebbles in/on dunes	20	late 14th C?	This report	2
Karikari Beach (19)	Gravels/pebbles in/on dunes	~5	late 14th C	Wellman, 1962[11]	2
Tokerau Beach (20)	Shells/Loisels pumice/gravels in sand dunes (>30m inland)	2	late 14th C	Osborne et al., 1991; Brook, 1999b; Brook and Goulstone 1999; Goff, 2006	2
Matai Bay (21)	Gravels/pebbles in/on dunes	-5	late 14th C	Wellman, 1962	2
Hihi Beach (22)	Gravels/pebbles in/on dunes/cliff	9.5	late 14th C?	This report[12]	1/2
Cavalli Islands					

Location (see Fig. 2)	Evidence	Elev. ma MHW*	Date	Reference	Verification**
Motukawanui Island (23) Panaki Island	Gravels on hillside Beach pebbles in soil	~5 <20	late 14th C	Hayward, *et al*. 1979; D. Nevin, pers. com., 2004[13, 14]	2
Wairoa Bay (N. BOI) (24)	Gravels/pebbles in dunes (>10m inland)	12	late 14th C	This report[15]	2
Russell (25)	Gravels on hillside	22	late 14th C	D. Nevin, pers. com., 2004	2
Whangaruru North, Bland Bay (26)	Gravels/pebbles in dunes + hummocky topography	5	late 14th C?	This report, Goff et al., in press[16]	2
Ngahau Bay (27)	Slope failure separating occupation sites – EQ generated same as tsunami?	-	late 14th C?	This report[17]	2
Mimiwhangata (28)	Sand layers (3) in lake sediments. Pebbles in soil	10	?	This report[18]	2
Te Ruatahi (29)	Ohuan sand dune advance over occupation layer – tsunami triggered?	2	15th C	Brooks and Goulstone, 1999	2
N. Whananaki (30)	Ohuan sand dune advance over occupation layer – tsunami triggered?	2	15th C	Brooks and Goulstone, 1999	2
Whananaki South (31)	Hummocky topography landward of dunes	2	?	This report, Goff et al, in press[19]	2
Wooleys Bay (32)	Pebbles/Loisels pumice in sand dunes (>150m inland)	3	late 14th C?	This report[20]	2
Poor Knight Islands (33)	Pebbles in soil on Aorangi Is.	?	late 14C	Hayward, 1991[21]	2
Ngunguru (spit) (34)	Dune remobilisation – tsunami triggered?	2	late 14C	Wellman, 1962[22]	2
Pataua (35)	Gravels/pebbles on dunes	8	late 14C?	Thorne, 1875; Goff, 2006	2
Ocean Beach (36)	Gravels/pebbles on dunes	8	late 14C?	Goff, 2006[23]	2
Mokohinau Islands (37)	Pebbles/cobbles in soil	57	late 14C	Moore, 1985	2

*Elevation in metres above Mean High Water **See text for details; Primary sites = 1, Secondary sites = 2

Recommendations/Comments:

1. The chronology of dune stratigraphy – and therefore potential evidence for tsunami inundation - can be better established by reconstructing early European shorelines along this coastline.
2. Moremonui Gully (2573386E, 6589207N) – potential core site near inland Macrocarpa trees beyond storm surge zone.
3. Little evidence north of here BUT reconnaissance needed for coastline between Maunganui Bluff and Kawerua.
4. Wetland in valley between Waimamaku River and Outer South Head (2545000E, 6628000N) is a potential coring site. Waimamaku River valley cores are currently being studied at The University of Auckland.
5. Reconnaissance needed of coastline between Mitimiti and Whangape Harbour.
6. Tauroa Point and the associated archaeological sites reported at the website http://www.arts.auckland.ac.nz/ant/Tauroa_2003 require geoarchaeological investigation to better determine the timing of tsunami inundation.
7. Pebbles have been reported in the dunes of 90 Mile Beach landward of The Bluff and Matapia Island by NRC, Kaitaia office staff. These were noted during forestry work in the area. It is recommended that the appropriate members of the NZ Forest Service in the area be contacted to produce a sketch map (with comments - elevations? Distance inland? Type? etc..) of these and any other sites where pebbles were found.
8. The coast from Twilight to Te Werahi would benefit from a detailed survey and pebble occurrences coupled with coring of suitable landward wetlands.
9. A site visit to the Three Kings Group is recommended.
10. The section of coastline from Tom Bowling Bay to Waikuku Beach – including the Waikuku Flats wetland - is a high priority for detailed research. Waikuku Beach needs a reconnaissance visit to compare and contrast pebble occurrence with Tom Bowling Bay. Waikuku Flats is a key site for comparing, contrasting and developing a long-term record of past storms and tsunamis.
11. Waipapa Bay and wetland on Kerikeri Peninsula need reconnaissance survey and possible coring.
12. Cores from behind Hihi Beach are currently being studied at The University of Auckland.
13. **All outer islands off the Northland region coast are a high priority for reconnaissance surveys with an aim to more detailed study should evidence be found. These sites are likely to be less disturbed than the mainland coastline.**
14. The coastline between Matauri Bay and Tauranga Bay was heavily grassed and access was difficult – data should be augmented by a reconnaissance survey of Flat Island (see point 13).
15. The coastline to the north around Cape Wiwiki warrants further investigation.
16. Whangaruru North, Bland Bay is a good site for coring and/or trenching at the northern end below the pa.
17. Mokau Bay is a good potential core site – just to the north of Ngahau Bay.
18. Mimiwhangata – both lakes landward of Kaituna Bay have now been cored. Three sand layers have been reported from the cores, although the upper one may represent beach sediments. They are currently being studied at The University of Auckland.
19. There is an excellent coring site here – 26425000E, 6615000N.
20. Trenching and/or coring on farmland landward of the coast road is recommended. The house was empty when visited during this survey.
21. Refer to point 13.
22. There is a good coring site in a wetland at Whangaumu Bay.
23. The coastline from Marsden Point south to Mangawhai Heads requires a reconnaissance survey.

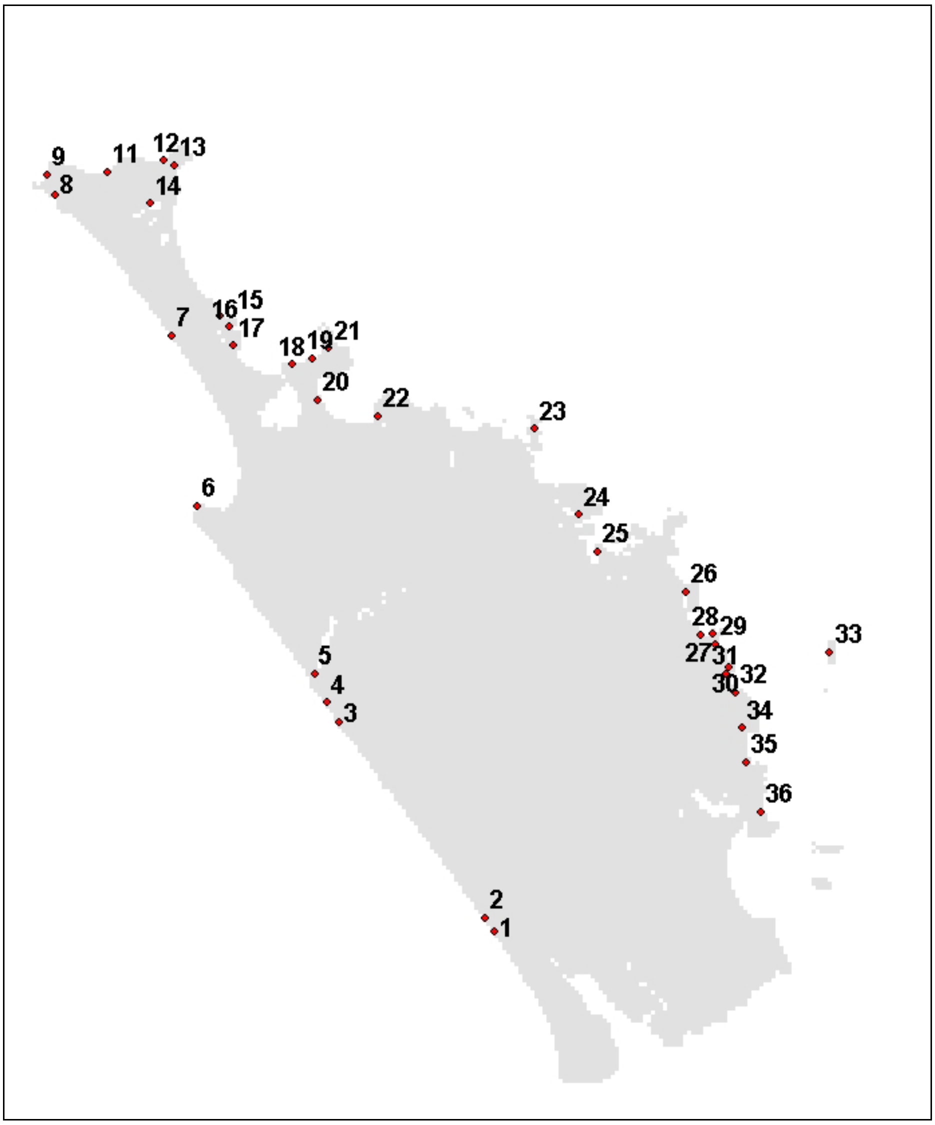

Figure 2: **Locations referred to in Table 2.**

Some of the sites were identified during the groundtruthing field assessment carried out late March 2006 (marked as “This report” in the ‘Reference’ column of Table 2; refer to Field Notes in Appendix I, site photos in Appendix II). The occurrence of the Ohuan Sand phase, sand dune advances, and the presence of Loisels pumice are all useful stratigraphic markers when considered in association with archaeological data (e.g. McFadgen, 1985; Goff and McFadgen, 2002).

Archaeological data also give some indication of runup height (the vertical distance from the pre-event tide level to the maximum elevation that the tsunami attains, regardless of how far inland). Maximum elevations of deposits are indicated in the ‘Elev. ma MHW’ column in Table 2 (MHW = mean high water).

These data provide some context for the present historical database and, in particular, show evidence for lower frequency, higher magnitude events not recorded in the historic record over the last 180 years or so.

2.2.1. Summary of pre-human tsunami record

In summary, there appears to be evidence for at least one large tsunami around the late 14th century. It is possible that the evidence is showing:

- One event that affected the whole coast around the late 14th/early 15th century.
- More than one contemporaneous event from different sources.
- Several events, closely spaced in time, but spanning a period of 100 years or more.

Based upon work from other parts of New Zealand (e.g. Goff *et al*., 2001; Bell *et al.*, 2004; Goff *et al.*, 2005) and ongoing research into tsunami sources, it seems most likely that the evidence relates to more than one contemporaneous event from different sources. It is difficult to be sure however because there are no sites where more than one event has been unequivocally recorded. In other words, either separate events inundated separate sections of coastline with no overlap, or one event affected the whole coastline. Based upon our current understanding of tsunami sources for Northland, the latter seems highly unlikely and the former more probable. The high elevations noted at several sites on the west, north and east coasts point to local source tsunamis. It is possible, but unlikely, that such extreme runups could be generated by a larger than currently predicted earthquake from a regional source, but not from a distant location. It is more likely that either a large regional earthquake, or preferably a moderately large local earthquake, generated sufficient instabilities on the edge of the continental shelf to cause one or more large submarine landslides. These can cause extreme local runup elevations but have little or no significant effect 10's of kms along the coast.

A lack of further evidence for palaeotsunami inundations does not mean that they did not happen, but rather that the data have not been collected. As a result of the work undertaken for the report, a Masters student in the School of Geography and Environmental Science at The University of Auckland is currently examining sediment cores taken from sites at Waimamaku River mouth, Hihi, and Mimiwhangata. Initial observations of the cores taken from Mimiwhangata indicate that there are at least three sand layers. Whether these relate to one event, three events, storms, tsunamis, or other coastal processes is currently not known.

3. Summary

A comparison between the historic and palaeotsunami records indicates some key points.

- Distant events from South America generate moderately large tsunamis along the east coast. The last moderately large tsunami occurred in 1960. It is worthy of note that there has been considerable coastal development since that time.

- Distant/regional events from other sources such as Indonesia and the north (Fiji Basin/Solomon Sea) are poorly represented or not at all. They are unlikely to be large magnitude events – probably moderate, but would be more likely to affect the whole coastline.

- A large regional and/or local tsunami has not occurred in historic time but appears to be recorded in the palaeotsunami record. Some local and/or regional sources are likely to produce large (>5m) tsunamis on all or part of the region's coastline. The travel times for such events will not exceed 3 hours.

Examining the evidence collated from historic and palaeotsunami sources, it is prudent to use the former data as an indication of the magnitude and frequency of a moderate (1.0-5.0 m) tsunami, and the latter for a worse-case event (>5.0 m), albeit that there is only one known event (or one series of events as discussed above) at this time.

- Four moderate events in 150 years yield a return period of one every 37.5 years for the east coast only. There are insufficient data to calculate a similar return period for the north or west coasts.

- One composite palaeoevent is of limited use for developing return periods for large events. Based on this, one could estimate a return period anywhere from about once every 600-6000 years or so (this approximates the time when sea level reached the present highstand – as sea levels fall the tsunami hazard reduces and vice versa). Data from lakes at Mimiwhangata may help to improve our calculations. Given that a large event is likely to be generated from a local and/or regional source, the extent of coastline affected will vary greatly depending upon these parameters.

In summary a moderate hazard and risk is suggested for most of the northwest and east coast, a high hazard and moderate risk for the north, and a low hazard and risk for the west (Figure 3).

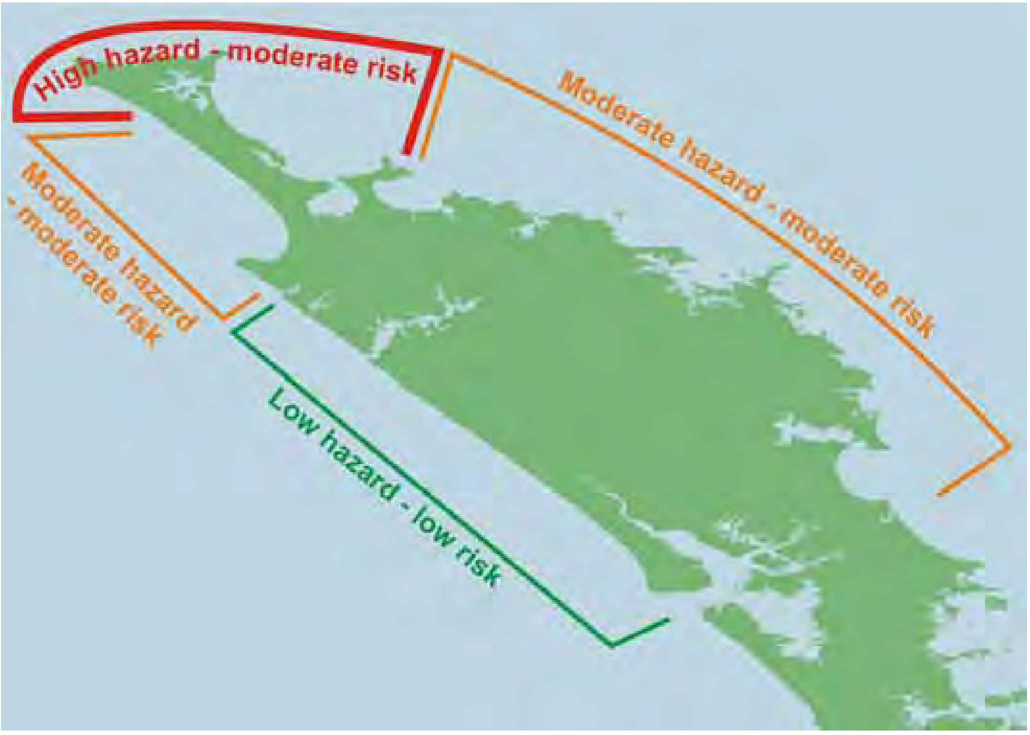

Figure 3: Summary of estimated hazard and risk based upon the above information.

Based upon the outcomes of the field reconnaissance a series of 23 recommendations have been made. These are listed beneath Table 2 but can be summarised as follows:

- A chronology of dune stratigraphy is needed for the west coast.
- A series of eight sites where sediment coring could be undertaken to improve the palaeotsunami record have been identified. This is over and above those cored during the course of this study.
- Reconnaissance surveys for coastlines not accessible during this project are recommended.

- All outer islands off the Northland region coast are a high priority for reconnaissance surveys. These sites are likely to be less disturbed than the mainland coastline.

- Three areas were singled out for more detailed studies: Tauroa Point and the associated archaeological sites; 90 Mile Beach, and Tom Bowling Bay to Waikuku Beach – including the Waikuku Flats wetland.

4. Acknowledgements

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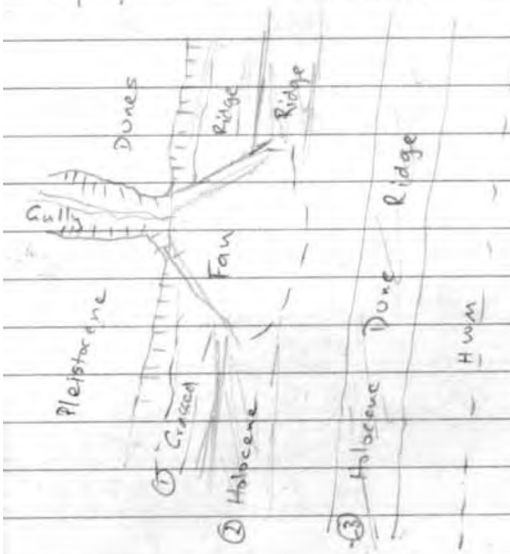
Appendix I: Field notes, B. McFadgen

27/03/06. NORTHLAND. Kaipara Coast North.

BGNOF, Claire N, Bruce H, James Goff, Catherine C-G. (Fine & sunny, mod N wind) (11.20am)



See Photos 884, 885, 886.

Holocene Dune ridges, in front of old Pleistocene ridges
Old PD eroded bringing sand down as fan, this moved along coast forming Ridge ①. Has weathered sand but not apparently "in situ". Holocene ridges ② & ③ seem very young.

No sign of pebbles. Don't know if there are any offshore, and also don't know how old dunes are.

Bruce Hayward says the coast is prograding rapidly.

Need to know precisely where HWM was at and since first surveys.

✓ WP ③ Pumice in road cutting beneath soil
Check pumice id.
Est hgt 12m asl. Photo 887.JPG

✓ WP④ Shell midden on bank of stream. Eroding dune sand. Taheroa prominent. Basalt o/s (ore). Loisels pumice sparse. No good strat.

Herekino 28/03/06.
BGMcF
JRG
BH.

Scattered Shells
✓ ~~Midden~~ WP6 Scattered shells
Mussel*, spisula subtriangulatum, tuatua. Few pebbles, Loisels pumice. Deflated in dune hollow, bird bone (widely) Rusty metal, green glass. gastropod (White rock shell?)
Covers 20m x 20m.
(* Perna canaliculus). Photo 888.JPG.

2nd scatter 10m away in hollow. With taheroa, cockle, perna, round & angular stone. Deflated in hollow.
Note possibly storm surge. V. close to beach.

✓ WP7. Scattered burnt stone, rusty iron (corrugated) Blue & white dinner plate fragments (late 19th early 20thC) Deflated hollow 20x20m, mammal bone (inc teeth) poss sea mammal).
Loisels on top – covers dune hollow.

✓ WP8. Most seaward deposit of LP [illegible].

✓ WP9. Midden in road cutting – forestry road
Band 20m long up to 10 cm thick,
Pipi, cockle, ~~Photo~~

✓ WP10. Burnt stone, charcoal, pipi, cockle.
On opp side of forestry road about
30m further along.
Exposure about 20m long, up to 20cm
thick. (Photo 889.JPG)

✓ WP11. Midden in road cutting. Cockles (~5%) and
Pipis (small) eroding layer, about 20 cm
thick 5m long. Burnt stone present. Photo 890.

Tauroa

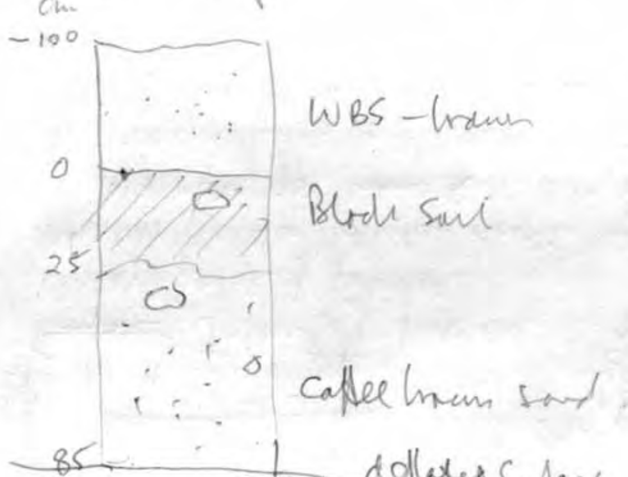
✓ WP12 Pebble scatter, up to 200m from beach
(See GPS to check (WP13 = furthest inland extent))
Same width at least.
Pebbles well rounded up to   cm.
Compared to present beach, they differ –

Also shell middens in deflated deposit
mostly well smashed up., & oven stones
(burnt & fractured & diff from pebbles)
Plus 1 burial – well-deflated (WP 14)

Hgt est 20-25m above hwm
(See BH GPS Hgt)

(See BH GPS Hrt)

Pebbles derived from sand wedge/layer under soil on top



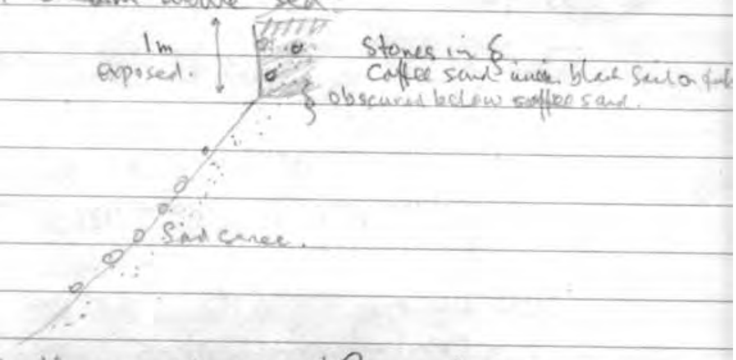
See Photos 891–908.JPG.

✓ WP 15 & 16 Deflated oven area with pavement of burnt fractured stones, very different from pebble scatter where stones mostly unburnt & round & complete. Shell inc. Paua, White Rock Shell (small), melagraphia, Lunatica. mussel. See Photos 909–912.JPG.

[Note Pebble scatter inland of reef. OK at end of reef.]

[Note Sites at stream mouths — where there are gaps in shoreline rock platform.]

✓ WP 17. Pebbles eroding from stream section
8–10m ~~6–8~~m above sea



Mostly round pebbles. V. Rare o/s some very frag shell.

Nearby stream: photo'ed for stones – more angular & sub angular than eroding from §

nb Coffee sand prob dark ∴ reworked Pleistocene sand.

Tom Bowling Bay 29-03-06

BG BH
JG CN
CCG
Nick DOC

✓ WP 18 Photo of horizon.
✓ WP 19 ~~Furthest~~ Inland edge of pebbles.
✓ WP 20 Inland edge of pebbles.
Midden scatter tuatua, cockle, catseye, limpet, o/s, ~~white~~ Rock shell, seamammal? moa?
✓ WP 21 Pleistocene pedestal with pebbles on it
Ca 40m above HWM. Photo 941.JPG
// Pebble scatter on dune sand, distinct patches of midden o/s.

Nick = Conrad Nconrad@Doc.govt.nz

Note

① Tsu mobilising dunes – see Fred Brooke's papers.

② Age of Tsu – tauroa – post-dates midden – big patch frag shell must have been under the sand ∴ not dispersed by wind – wash top black soil.

Te Werahi Bch

✓ WP 22 Loisels Pumice in dune swale. 20x20m scatter.

✓ WP 23 Loisels + pebbles & occ shells (worn haled = natural)

✓ WP 24 Sparse LP.

✓ WP 25 4x4m Scatter of stones in swale. Round, sub round, sub angular. V. rare shell frags. (no evidence of cultural origin)

✓ WP 26 Lp in blowout. Sparse. Occ shell frags. Pebbles as for WP25, 20m seawards.

✓ WP 27 Lp, pebbles & cobbles up to 15cm, and shell frags inc (Spirula spirula) cockle, mussel, limpet. on sand flat (wet) 30 x 30m.

✓ WP 28* Shell midden – pedomtt O/S over surface, (photo ops.jpg) burnt stone, mostly fractured. 30 x 30m Some rocky shore limpet, gastropod.

✓ WP 29 Pebbles + Cobbles on dune slope, few
Shell frags. Rare ~~Ab~~ o/s*. ~~[Natural]~~
(Fractured + burnt).
Stones -> 20 cm long axis. Subround.
Further up slope have midden on the
soil. 30m away round stones in soil.
Could be cultural.

✓ WP 30 Pebbles/cobbles natural.
✓ WP 31 Round marine pebbles on pass summit
between Te Werahi & Twilight
✓ WP 32, 33, 34 Pebbles at Twilight
✓ 35 Pebbles + oven of Diorite pebbles.
✓ 36 Pebbles + dell oven. Est 30m + high
Est 200m inland

Sweetwater Stn. 90 mile beach
Kauri lying same way.

* nb WP28 is probably Site M02/186
Middens & ovens [GR on SRF is 2481500E
6750200N
Which is closest site to WP28]

Photos

✓1	884.JPG	Coast North of Kaipara Harbour Looking South
✓2	5	Coast North of Kaipara Hbr. Looking South
✓3	6	Coast North of Kaipara Hbr looking North
✓4	7	Road cutting with LPumice WP3
✓5	8	Herekino. Deflated shell, stones, Loisels pumice, WP6.
✓6	9	Shell midden in road cutting to Herekino WP 10.
✓7	90	Shell midden in road cutting to Herekino. WP11.
✓8	91	Tauroa Pebble scatter WP 12. (Pano)
✓9	2	Tauroa Pebble Scatter (Panorama)
✓10	3	" " " "
✓11	4	" " " "
✓12	5	" " " "
✓13	6	Tauroa closeup of pebbles.
✓14	7	Tauroa section, sand with pebbles
✓15	8	Tauroa Pebble scatter.
✓16	9	Tauroa Section
✓17	900.JPG	Tauroa looking back to beach.
✓18	901	Tauroa " " " " .
✓19	2	" " " " " .
✓20	3	" " " " " .
✓21	4	Panorama " " " " " .
✓22	5	" " " " "
✓23	6	Tauroa ~~Skeleton~~ o/s
✓24	7	Tauroa Shell scatter.
✓25	8	Tauroa Skeleton.

✓26	909.JPG	WP15 & 16	Deflated over area.
✓27	910.JPG	"	" " "
✓28	911.JPG	"	" " "
✓29	912.JPG	"	" " "
✓30	913.JPG.	WP17.	Pebbles eroding from
✓31	914.JPG	"	stream bank.
✓32	915.JPG	"	Pebbles in stream for comparison
✓33	916.JPG	"	Rock platform ".
✓34.	917.JPG.	"	" " "
✓35.	918.JPG.	"	Looking back to stm.
✓36	919.JPG.		Tom Bowling Bay.
✓37	920.JPG		" " " From west
			Showing pebbles on dunes.
✓38	921.JPG (WP18)		Tom Bowling Bay from dune
✓39	922.JPG (WP18)		" " " "
✓40	923.		" " " Pebbles ~~Panorama~~
✓41	924.		TB Bay looking to Waikuku.
✓42	925.		TB Bay " " "
✓43	926.JPG		TB Bay pebbles
✓44			
✓45			
✓46			
✓47			Panorama.
✓48			
✓49			
✓50			
✓51			
✓52	935.JPG		TB Bay Panorama
✓53	936.JPG		" "
✓54	937.JPG		" "
✓55	938.JPG		[illegible]

✓ 54	937. JPG	" "
✓ 55	938. JPG	TBB Pebbles, Cathunie C-G
✓ 56	939. JPG	" " Nicle, Claire, Bruce
✓ 57	940. JPG	" "
✓ 58	941. JPG (WP021)	" " . Nicle Conrad
✓ 59	942. JPG	" Conglomerate West End
✓ 60	943. JPG	" " " "
✓ 61	944. JPG	Te Werehi from Cape Reinga
✓ 62	945. JPG	Midden Nth end Te Werehi Bay
✓ 63	946. JPG	Te Werehi from Sth end.
✓ 64	947. JPG	" " " " "
✓ 65	948. JPG	" " " Point at Sth End
✓ 66	949. JPG	Twilight Beach from Point.
✓ 67	950. JPG	" " Panorama
✓ 68	951. JPG	" " "
✓ 69	952. JPG	" " "
✓ 70	953. JPG	" " "
✓ 71	954. JPG	" " "
✓ 72	955. JPG	Twilight Beach pebbles
✓ 73	956. JPG	" " "
✓ 74	957. JPG	" " "
✓ 75	958. JPG	" " . ~~Ovens/pebbles~~
✓ 76	959. JPG	" " .
✓ 77	960. JPG	" " .
✓ 78	961. JPG	" " ovens/pebbles
✓ 79	962. JPG	" " ovens/pebbles
✓ 80	963. JPG	Karikari view nth
✓ 81	964. JPG	Karikari view sth
✓ 82	965. JPG	Karikari. Pleist. sand cliff.
✓ 83	966. JPG	Tauranga Bay. Bch &

~~83~~	~~966 JPG~~	~~Tauranga Bay Beach~~
✓84	967.JPG	Tauranga Bay Beach
✓85	968. JPG	Tauranga Bay ~~over mahinapua~~
✓86	969. JPG	Gen'l view over mahinapua
✓87	970 JPG	Gen'l view ~~Wairoa Beach. Pebbles i sand~~
✓88	971 JPG	~~beach?~~ Wairoa Bch Pebbles i sand
✓89	972. JPG	Pa Site #1 at Bland Bay west end ~~of 37~~
✓90	973. JPG	Pa Site #1 at Bland Bay "
✓91	974. JPG	Pa Site #1 at Bland Bay "
✓92	975. JPG	Pa Site #2 at Bland Bay East end
✓93	976. JPG	Pa Site #2 at Bland Bay "
✓94	977. JPG	Midden at Bland Bay, foot of Pa #1 (Whalealuria Pa)
✓95	978. JPG	Wharanahi ~~Whangaruru~~ Sth } Panorama
✓96	979. JPG	Wharanahi ~~Whangaruru~~ Sth } Panorama
✓97	980. JPG	Wharanahi ~~Whangaruru~~ Sth } Panorama
✓98	981. JPG	Ngunguru Spit from road
✓99	982. JPG	" " " "
✓100	983. JPG	" " " "
✓101	984. JPG	" " " "
✓102	985. JPG	" " " "

(Midden & Pa near

31-03-06 Pa & midden pictures. (Midden & Pa near WP 37)
9-56am. (see 972 – 977.JPG)
Bland Bay. Whakaturia Pa = Q05/428
[N16/71 NZMS1]

Whananaki Sth – Pan of bay.

Ngunguru Spit – Panorama & midden closeups.

Appendix II: Site photographs.

Figure AII.1 Glinks Gully south (1). Dunes in middle distance have a geomorphology comprising possible hummocky topography and pedestals. The area has either been recently (last 200 years) reworked completely to the cliffs or these dunes have been affected by tsunami inundation (refer Goff *et al.*, in press).

Figure AII.2 Kopuru (2) Loisels pumice in upper part of track cutting. Site much disturbed by humans, but ~500 BP pumice layer is high in dune.

Figure AII.3 Waimamaku River mouth (4) Pebbles in dunes at least 10 metres above sea level, possibly much higher.

Figure AII.4 Tauroa Point, Ahipara (5) Pebbles in dunes at least 30 metres above sea level overlying occupation site.

Figure AII.5 **Twilight Beach (8) Gravels/pebbles up to at least 15 metres above sea level, in similar geomorphological and chronological position to others.**

Figure AII.6 **Te Werahi (9). Some marine pebbles mixed with midden material. These reach an elevation of at least 10 metres above sea level, although middens continue much higher.**

Figure AII.7 Tom Bowling Bay (12) Pebbles overlying sand dunes up to an elevation greater than 35 metres and estimated at 42 metres above sea level.

Figure AII.8 Henderson Bay (15) Pebbles found up to 32 metres above sea level. Photo: Scott Nichol, Auckland.

Figure AII.9 Puwheke Beach (18) Rare pebbles found at 20 metre contour on the dunes in the middle distance.

Figure AII.10 Hihi Beach (22) Pebble layer found immediately beneath grass and 'A" horizon along the shoreline. This rises to a maximum estimated elevation of about 9.5 metres above sea level. Photo: Catherine Chagué-Goff

Figure AII.11 Wairoa Bay (N. BOI) (24) Pebbles found in path cutting up to 12 metres above sea level.

Figure AII.12 Whangaruru North, Bland Bay (26) Hummocky topography in middle distance linked with rare pebbles found in dunes.

Figure AII.13 Ngahau Bay (27) Slope failure from hills behind separating two occupation layers. Possibly earthquake-generated and linked with tsunami inundation?

Figure AII.14 Mimiwhangata (28) Core taken from wetland (and subsequently from adjacent wetland) has revealed at least three sand layers. There were also rare pebbles in the soil on the surrounding hills. Photo: Catherine Chagué-Goff

Figure AII.15 Whananaki South (31) An inland hummocky topography was complemented by pebbles and gravel in sand dunes up to ~2 metres above sea level, but over 200 metres inland.

Figure AII.16 Ngunguru (spit) (34) Dunes remobilised over the top of middens. Chronologically this fits with pebble layers and other geomorphological change elsewhere in the region.