8.0 RESULTS

8.1 Tsunami modelling for Distant Sources

8.1.1 100 year event – M_W 9.1 earthquake in Peru

For this scenario, two sea levels related to tidal conditions are considered in the model simulation. First, the model runs using Mean Sea Level (MSL) and second, the model runs during the High Tide condition (HT). The high tide condition implemented in this study is only an approximation to that in reality, achieved by simply raising the sea level 0.75 meters above the Mean Sea Level. This increment does not vary in time and space. Tsunami propagation and its interaction with coastal areas are modelled at this increased water level.

8.1.1.1 100 year event – M_W 9.1 earthquake in Peru at Mean Sea Level

Numerical simulation shows that, fourteen hours after the earthquake, the positive leading waves reach most of the eastern coast of New Zealand and start to enter Poverty Bay. The model results of maximum distribution of tsunami inundation around Poverty Bay show that tsunami mostly inundates the Muriwai area, and penetrates up the Waipaoa and Turanganui Rivers (Figure 8.1.1.1-1). The tsunami hits the coastal areas around Wainui and is refracted and diffracted by Tuahine Point and Young Nick Head (Tekuri) at the southwest end of the bay, while the main leading waves continue to propagate inside Poverty Bay. The time histories (Figures 8.1.1.1-2 and 8.1.1.1-3) show that the first waves arrive along the coast about 10 minutes after the wave enters the bay, and the sea level starts to rise inside the Bay within a range of 0.5 – 1.0 m. The following wave arrives about an hour later with higher elevation that reaches up to 2.0 m, and hits the Muriwai area and the rest of Poverty Bay.

Figure 8.1.1.1-1 Distribution of maximum tsunami inundation around Poverty Bay.

The time histories show that more than 5 waves with considerable height, up to 2.0 m, occur inside Poverty Bay with a wave period of about 1 hour (60 – 70 minutes). The sea level inside the Bay oscillates for several hours as occurred during the 1960 event. With these tsunami elevations, most of the low-lying areas at the southwest-end of the Bay (Muriwai – section D) are inundated, while the rest of the Bay suffers minor impacts. Further analyses are made for Gisborne City, Wainui and Muriwai.

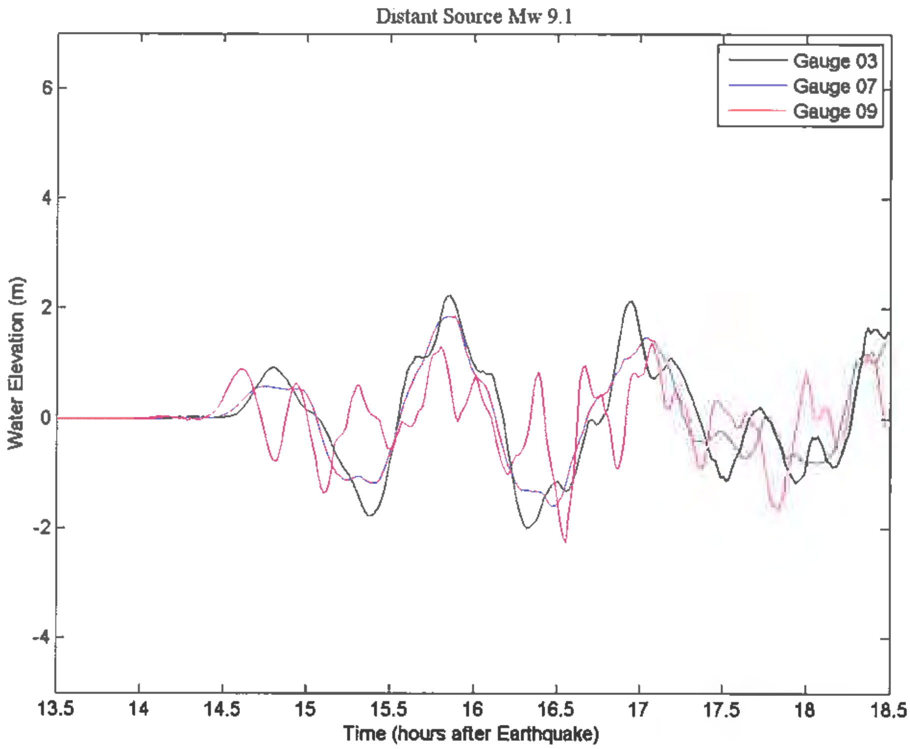

Figure 8.1.1.1-2 Time histories plot (cross shore) in the middle of Poverty Bay.

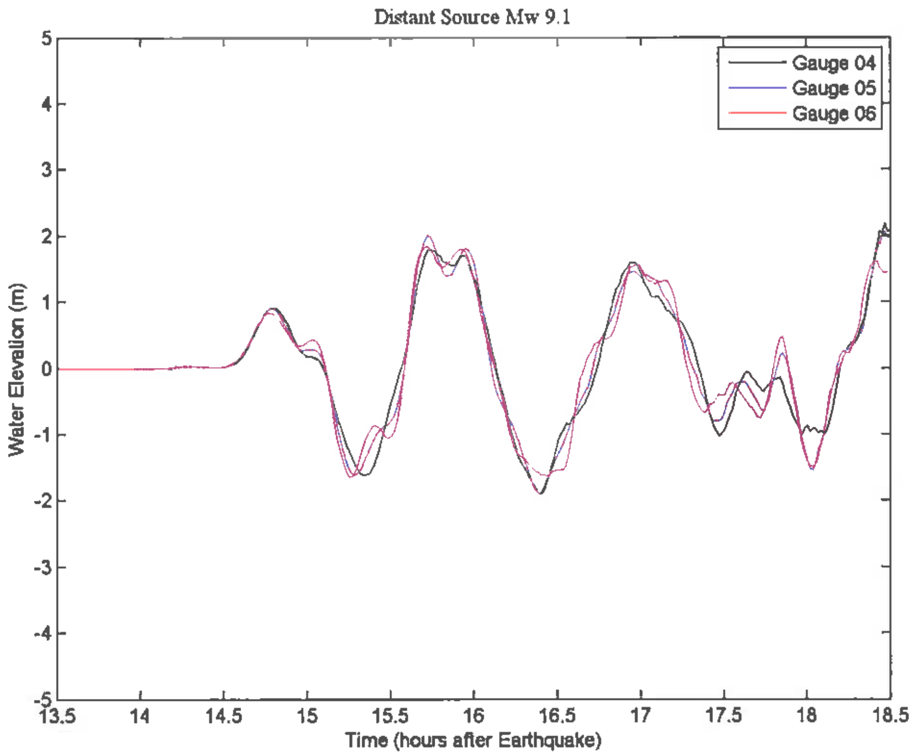

Figure 8.1.1.1-3 Time histories plot along the coast of Poverty Bay.

Gisborne City

With this scenario, Gisborne City experiences a rising of sea and water level along the coast in front of the city as well as inside the Port, and along the Turanganui River. The maximum inundations reach up to the maximum tide level along the beach face. The increasing water level inside the Port and Turanganui River that splits into the Taruheru and Waimata Rivers did not flood the areas along the Riverbank or the Waikanae Creek (Figure 8.1.1.1-4).

Figure 8.1.1.1-4 Distribution of maximum tsunami inundation at Gisborne City.

Wainui

Minor impact also occurs along the Wainui coast for this scenario event as seen in Figure 8.1.1.1-5. The tsunami only affects the beachfront, with the maximum inundation reaching up to maximum tide level along the beach face, and does not penetrate further inland.

Figure 8.1.1.1-5 Distribution of maximum tsunami inundation at Wainui

Muriwai

The Muriwai area at the southwestern end of Poverty Bay up to the Waipaoa River is the most vulnerable area since the topographic conditions along the coast are very flat with the maximum beach face height of 1.0 m above the Mean Sea Level. The model shows that most of the Muriwai beach area was inundated ~700 m inland. The incoming tsunami with elevation as high as 2.0 m overtops the sand spit and surges into Wherowhero Lagoon behind it. The inundation stops at the edge of Muriwai Beach Road as illustrated in Figure 8.1.1.1-6. The flow that rushes up to the Waipaoa River increases the water level of the river but does not cause any inundation on either side of the river.

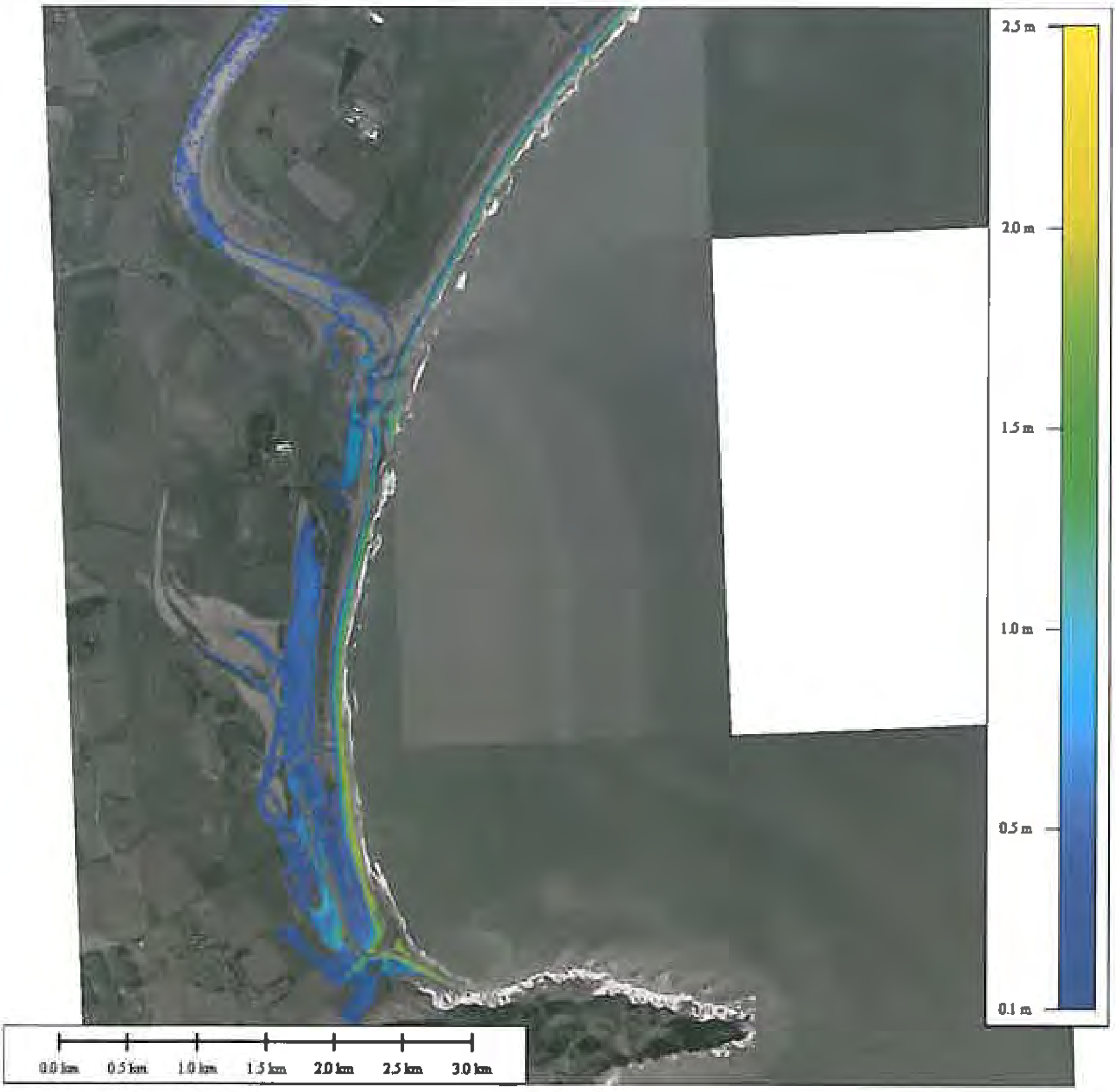

Figure 8.1.1.1-6 Distribution of maximum tsunami inundation at Muriwai.

8.1.1.2 100 year event – M_W 9.1 earthquake in Peru at High Tide Level

For this M_W 9.1 event, the coincidence of tsunami strike and high tide level was also considered. This was approximated by modelling tsunami propagation and inundation at an increased water level, +0.75 meters above the Mean Sea Level.

Numerical modelling shows that the oscillation patterns of water level inside the bay are very similar to those results at Mean Sea Level but occur at an increased water level, 0.75 meters above the Mean Sea Level (Figure 8.1.1.2-1 and 8.1.1.2-2). The water oscillations inside Poverty Bay will last several hours with amplitudes still above 2.0 meters. With these increased amplitudes, strong surges of water up to 2.5 meters are found in front of the sand dunes and along Waikanae Creek and Turanganui River. In Figure 8.1.1.2-3, no obvious increase of inundation range can be observed in the coastal areas of Gisborne City and Wainui. However, a much larger area is inundated at the southwest side of Poverty Bay.

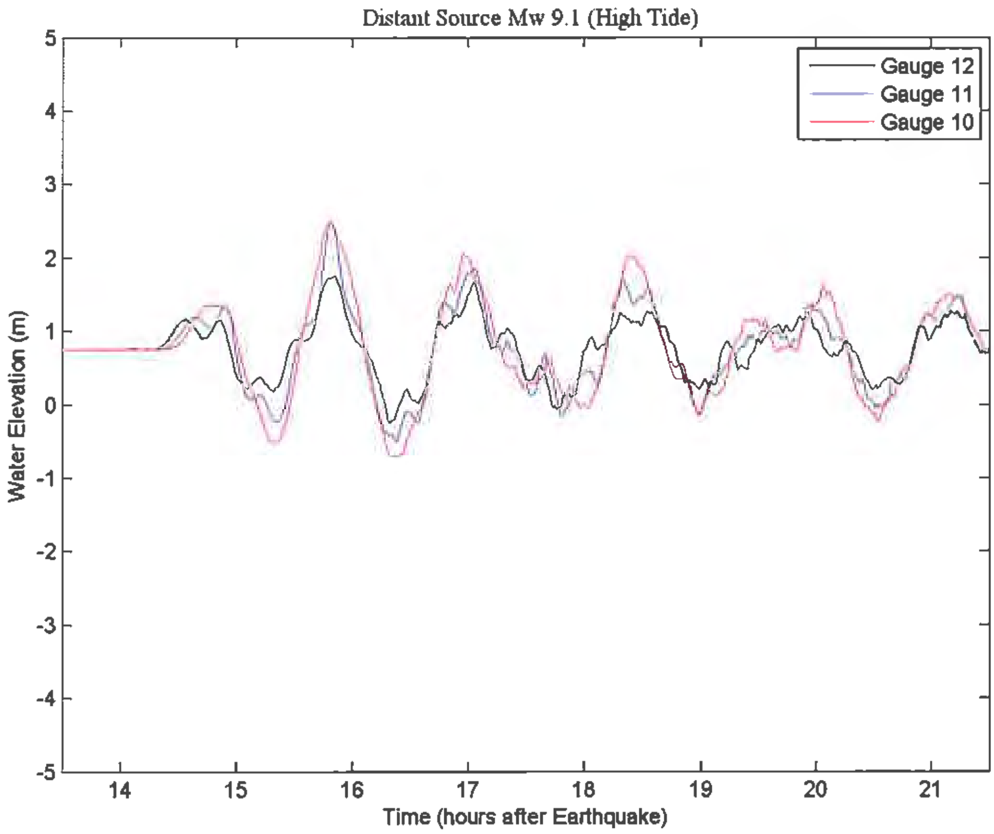

Figure 8.1.1.2-1 Water level fluctuations in the middle of Poverty Bay in this M_W 9.1 event at high tide level.

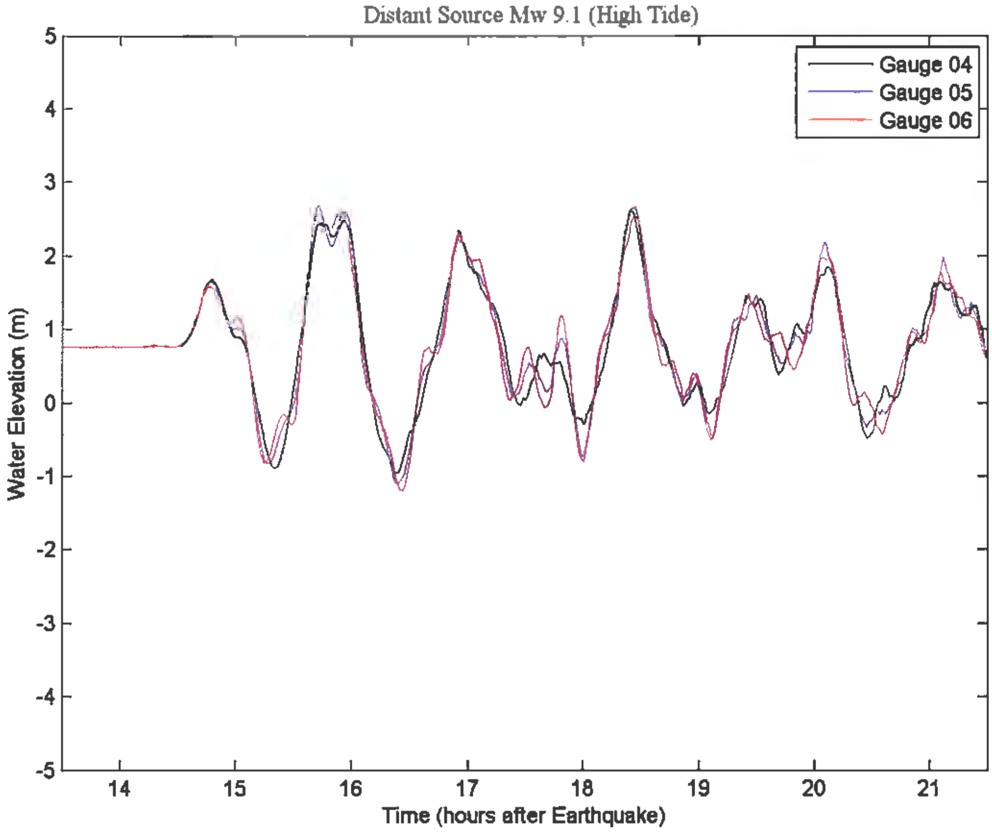

Figure 8.1.1.2-2 Water level fluctuations in coastal areas of Poverty Bay in this M_W 9.1 event at high tide level.

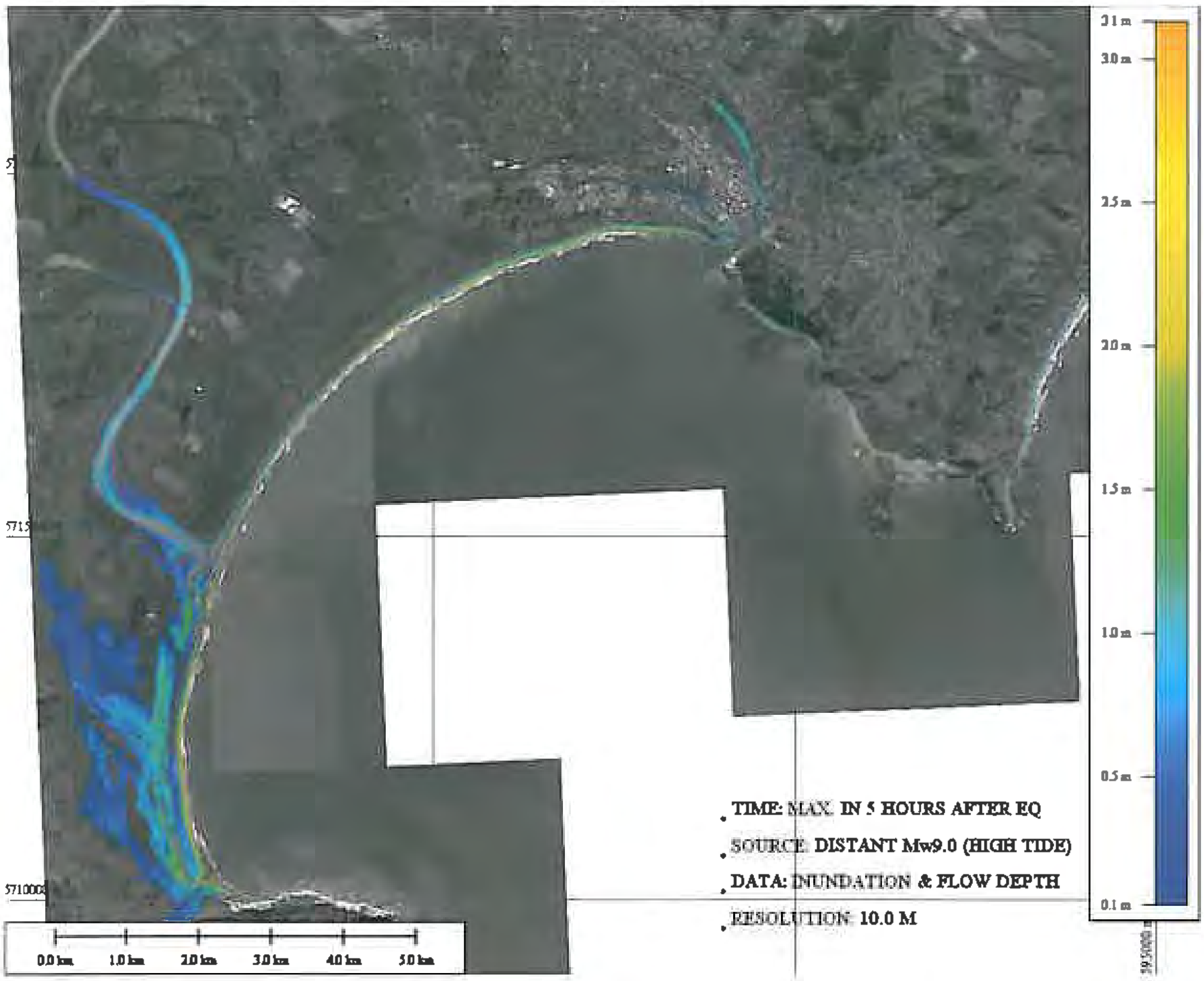

Figure 8.1.1.2-3 Maximum inundation and flow depth in the coastal area of Poverty Bay (M_W 9.1 event in Peru at high tidal level).

Gisborne City

In this tsunami event at high tide level, the beach front in front of the sand dunes experiences stronger runup and rundown in comparison with the scenario at Mean Sea Level. The tsunami almost reaches the top of the sand dunes near the city area, but it does not overtop the sand dunes to flood inland (Figure 8.1.1.2-4). The first wave starts to attack the coastal area about 14.5 hours after the earthquake with an amplitude of 1.5 meters above Mean Sea Level. The second wave, about one hour after the leading wave, is much more violent, capable of raising water to a level about 1.0 meter higher than the leading wave. The increasing water level causes strong upstream surges into the port and Turanganui River at over 1.5 m/s (Figure 8.1.1.2-5). The water level in the river and the port will be elevated by up to 3.0 meters. Both sides of the river will be affected and boats inside the port may be damaged.

Figure 8.1.1.2-4 Maximum inundation and flow depth in the city area of Gisborne (M_W 9.1 event in Peru at high tide).

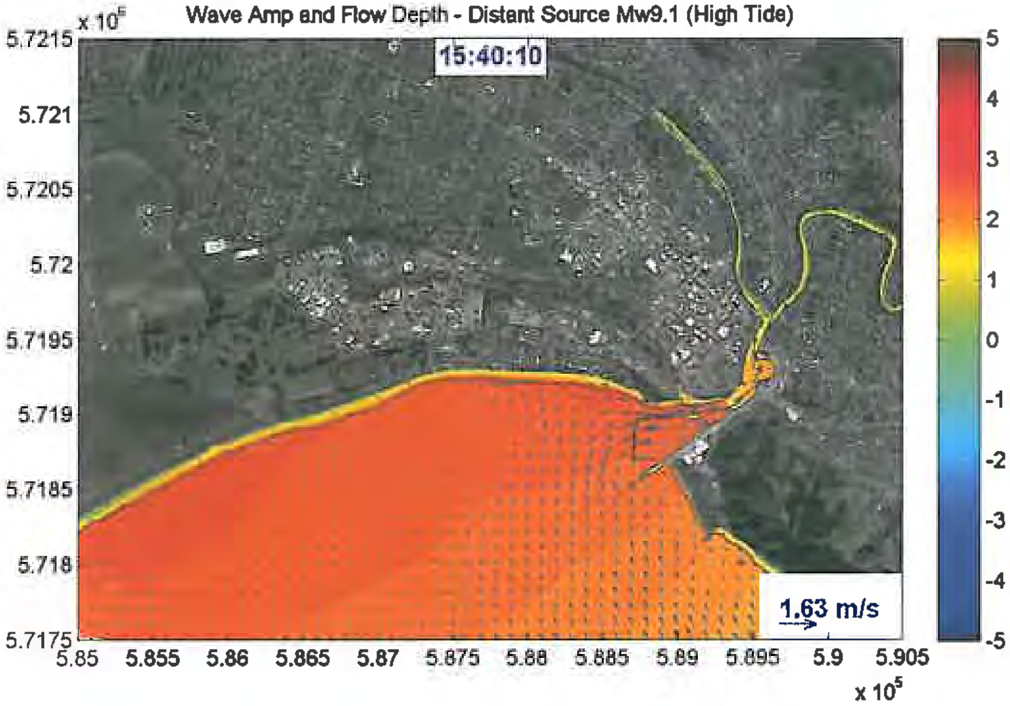

Figure 8.1.1.2-5 Snapshot shows that the water level in front of the sand dunes is raised to over 2.5 meters above Mean Sea Level and water surges into Turanganui River at over 1.6 m/s. The arrow in the lower right corner shows the scale for the velocity vectors.

Wainui

Minor impact will be observed along Wainui beach for this scenario event as seen in Figure 8.1.1.1-5. Tsunami waves up to 2.5 meters in amplitude can be expected at the beachfront, not sufficient to overtop the beach face except where creeks come down to the beach. The waves are not high enough to penetrate further inland and flood residential areas.

Figure 8.1.1.2-6 Maximum inundation and flow depth in the coastal area of Wainui (M_W 9.1 event in Peru at high tide).

Muriwai

Compared to the scenario event at Mean Sea Level in which only the lagoon area is inundated, in this high tide scenario, a much larger area is flooded at the southwest side of Poverty Bay. Sequential snapshots show that during the leading wave, sea water rushes through the opening of Wherowhero Lagoon and floods only the low-lying lagoon area (Figure 8.1.1.2-7). However, the following waves are much higher than the first one and are able to overtop the sand dunes along Muriwai Beach (i.e., Sand dune section D in Figure 7.1-2) where the sand dunes are only about 1.0 – 2.0 meters high (Figure 8.1.1.2-8). With the water periodically being fed into the lagoon area by the following waves after the first one, the flood continuously surges up to 2.5 km inland along Wherowhero Stream and submerges all the low-lying areas on both of its sides as indicated in Figure 8.1.1.2-9. The model results show that in most of the inundated areas, the flow depth ranges from 0.5 to 1.0 meters. In the lagoon area, it may reach up to 2.0 meters.

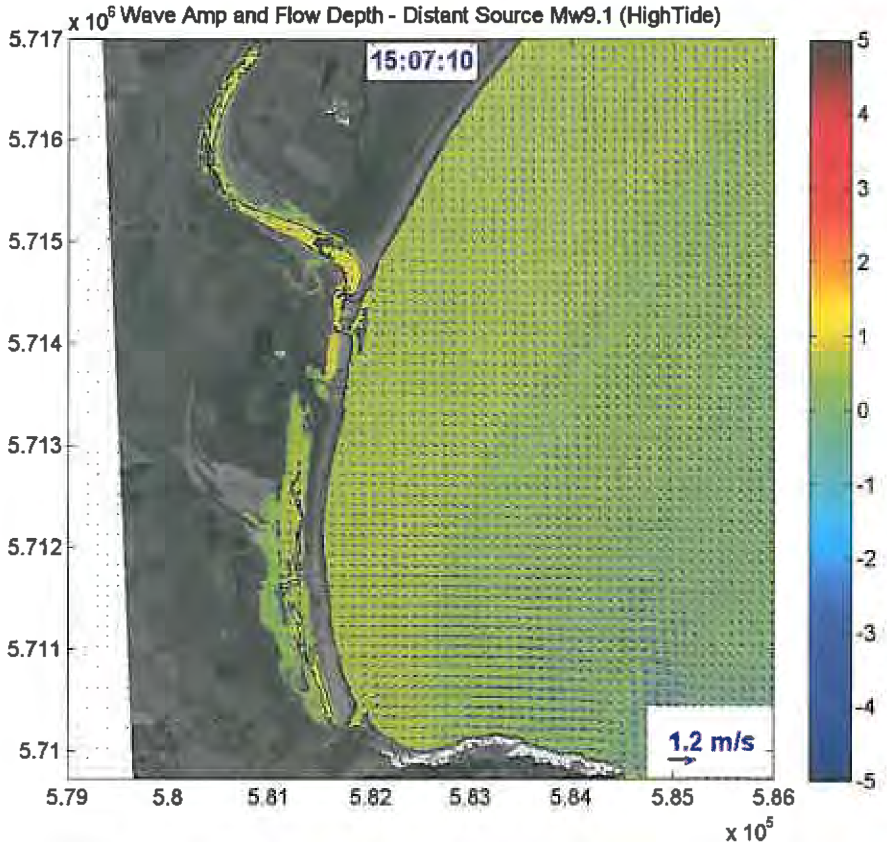

Figure 8.1.1.2-7 Snapshot showing the point when the first wave starts to retreat and only the lagoon area behind the sand dunes is flooded. The arrow in the lower right corner shows the scale for the velocity vectors. The scale bar is in metres.

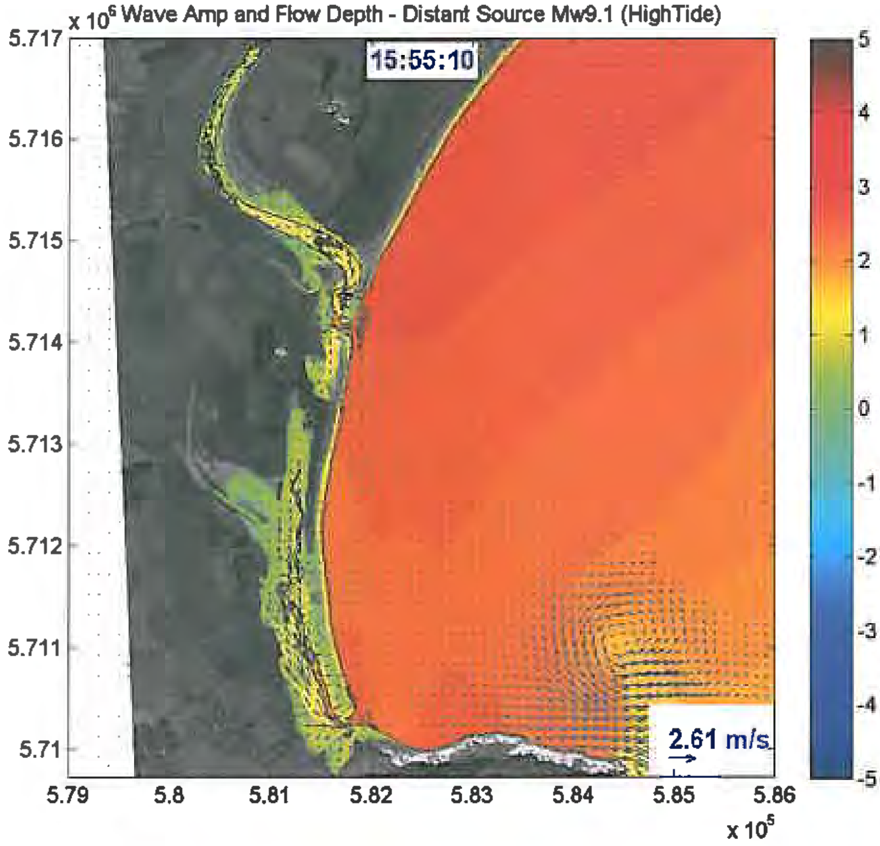

Figure 8.1.1.2-8 Snapshot at the time when the second wave is overtopping the sand dunes in front of Wherowhero Lagoon (Sand dune section D) whose height is below 2.0 meters. The arrow in the lower right corner shows the scale for the velocity vectors. The scale bar is in metres.

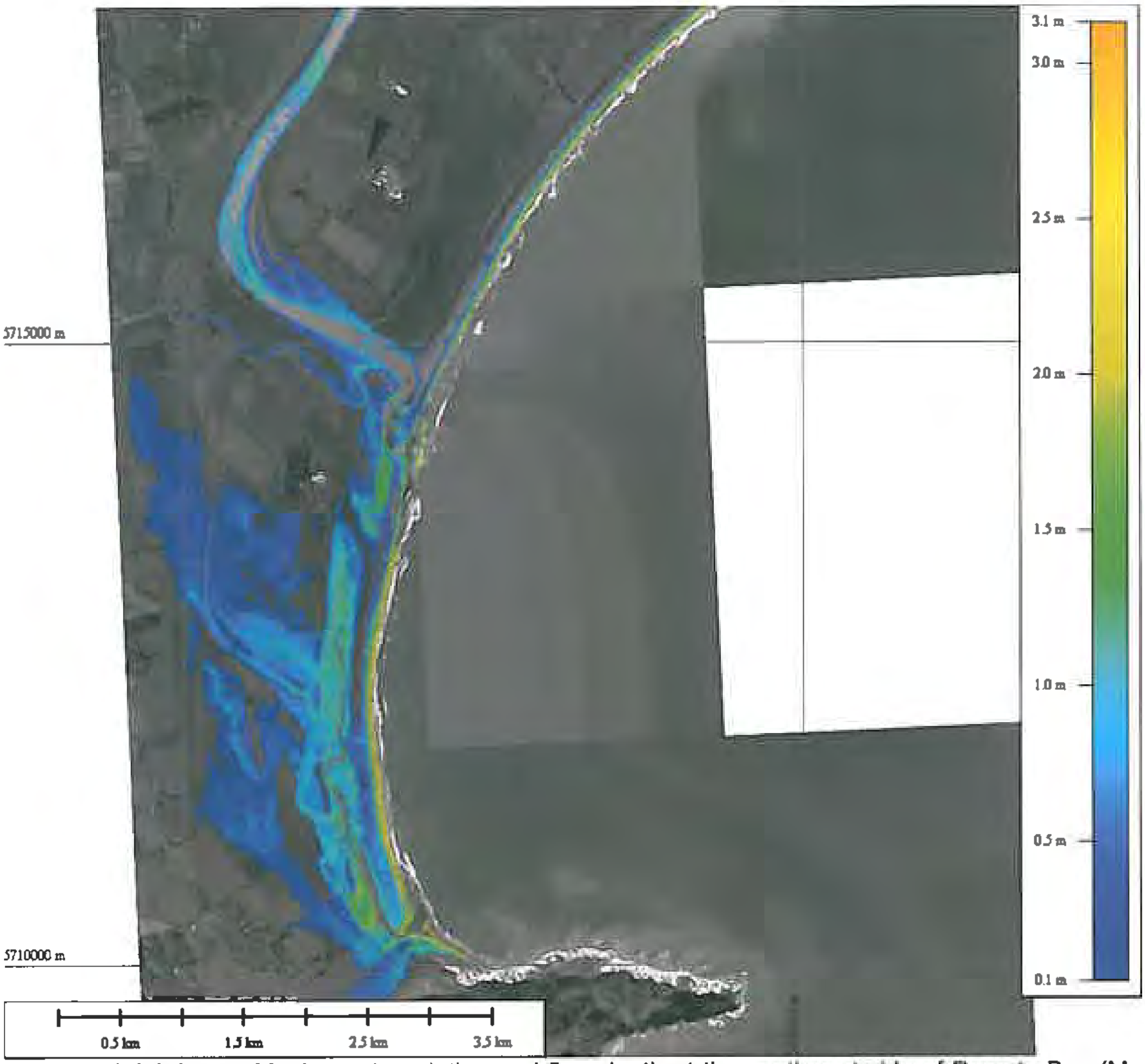

Figure 8.1.1.2-9 Maximum inundation and flow depth at the southwest side of Poverty Bay (M_W 9.1 event in Peru at high tide).

8.1.2 500 year event – M_W 9.4 earthquake in Peru

For this scenario, two sea levels related to tidal conditions are considered in the model simulation. First, the model runs using Mean Sea Level (MSL) and second, the model runs during the High Tide condition (HT).

8.1.2.1 500 year event – M_W 9.4 earthquake in Peru at Mean Sea Level

Similar to the 100 year scenario event, about fourteen hours after the earthquake, a positive leading wave strikes coastal areas east of Poverty Bay and the first wave starts to enter Poverty Bay at about fourteen hours and thirty minutes. Near the coast of Wainui, north of the entrance of Poverty Bay, the sea surface is elevated by nearly 3.0 meters above Mean Sea Level (Figure 8.1.2.1-1). At the entrance of Poverty Bay, despite being refracted and diffracted by Tuahine Point and Young Nick Head, the leading wave is still about 1.5 meters high (Figure 8.1.2.1-2). And about 10 minutes after entering Poverty Bay, this leading wave strikes all the coastal areas surrounding the bay, from Muriwai beach to the mouth of Turanganui River, at almost the same time by raising the water level to about 2.5 meters above Mean Sea Level (Figure 8.1.2.1-3). A second wave, lagging about one hour behind the first, enters the bay with relatively lower amplitude; however it coincides with the oscillation induced by the first wave, raising the water to a much higher level, up to 4.0 meters in front of the sand dunes. The time histories from virtual tidal gauges also show that the sea level in the bay remains oscillating for several hours with a period of 60 – 70 minutes (Figure 8.1.2.1-2). Although the amplitudes start to decay after the second wave, the wave amplitudes are still over 1.5 meters near the coastal areas (Figure 8.1.2.1-3). These large amplitude oscillations, combining with tides, may still cause severe damage in the port and coastal areas even hours after the first strike. The long duration of large-amplitude bay oscillations was also observed during the 1960 Chilean Tsunami event.

With these tsunami elevations, a significant area southwest of Poverty Bay (sections C and D) are inundated. Sea water overtops the sand spit and surges into Wherowhero lagoon behind it and continuously floods up to 2.0 km inland. In the city area of Gisborne, both sides of Turanganui River mouth are flooded including the Victoria area, railyards area and the wharf of Gisborne Port (8.1.2.1-4). Further analyses have been completed for Gisborne City, Wainui and Muriwai.

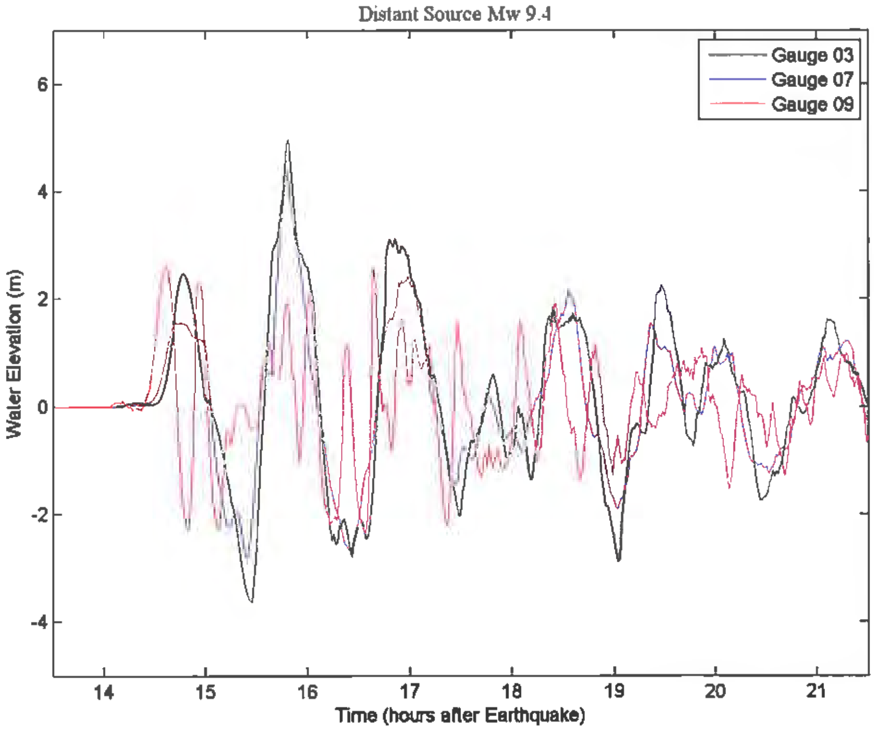

Figure 8.1.2.1-1 Water level fluctuations at virtual tidal gauges 03, 07 and 09 (M_W 9.4 Earthquake Event in Peru). The results indicate that the water level is about 3.0 meters high near the Wainui coast (Gauge 09).

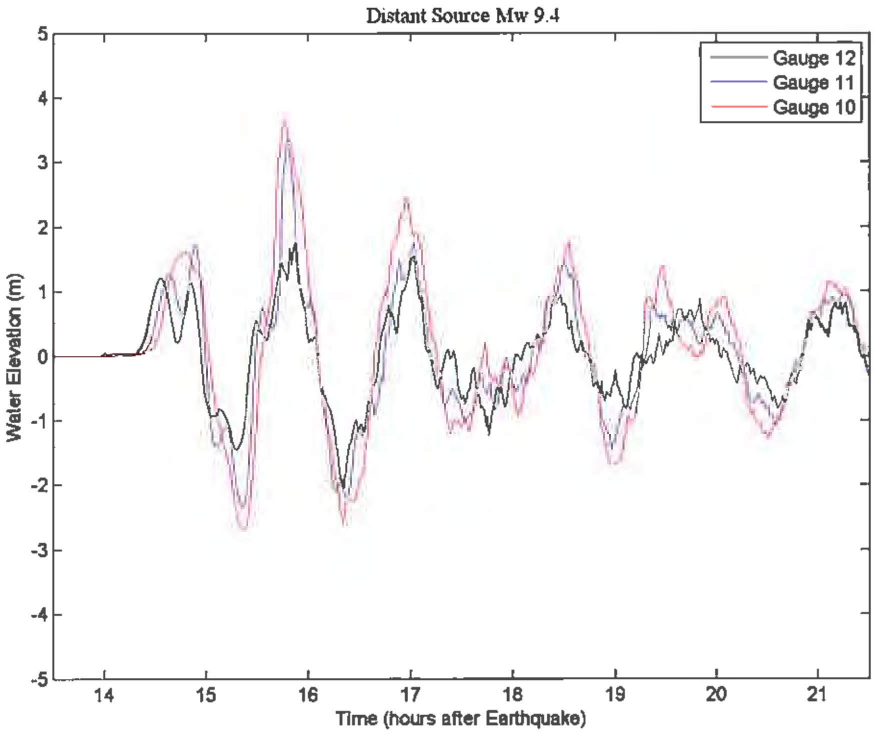

Figure 8.1.2.1-2 Water level fluctuations in the middle of Poverty Bay at virtual tidal gauges 10, 11 and 12.

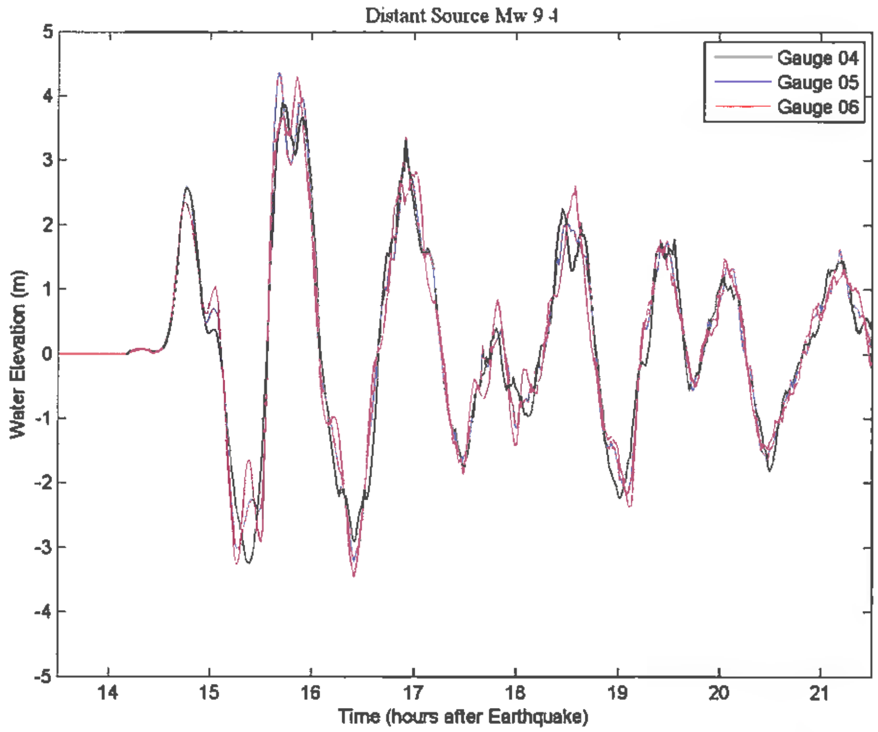

Figure 8.1.2.1-3 Water level fluctuations along the coast of Poverty Bay at virtual tidal gauges 04, 05 and 06.

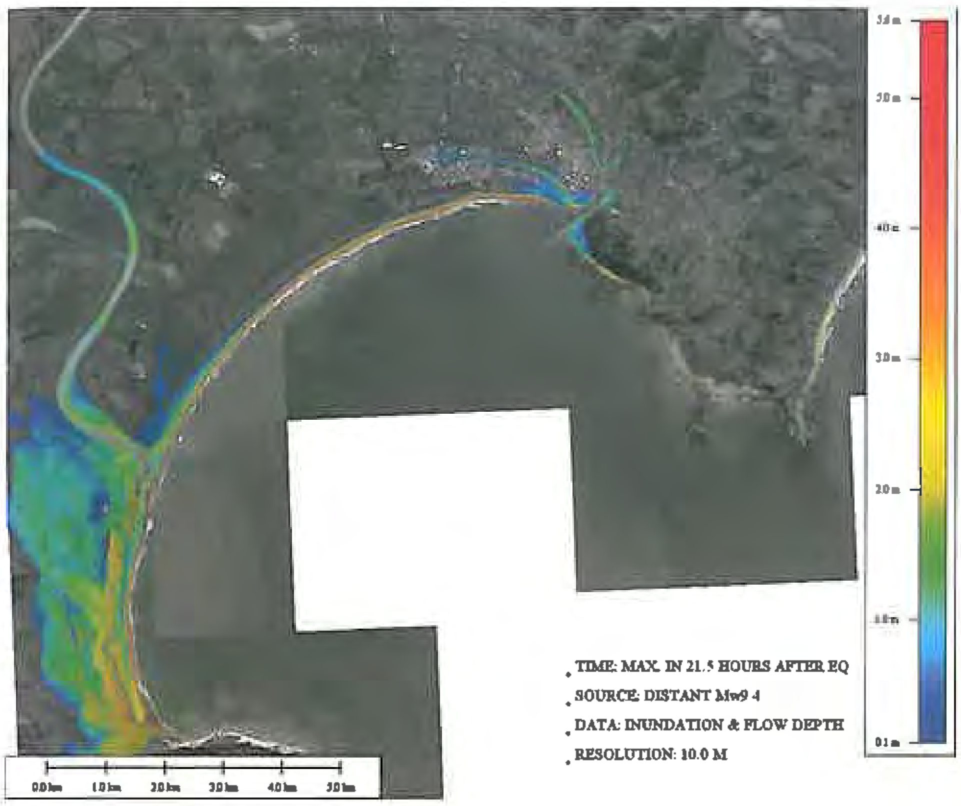

Figure 8.1.2.1-4 Maximum tsunami inundation and flow depth around Poverty Bay (M_W 9.4 earthquake in Peru)

Gisborne City

With this scenario, the leading wave does not overtop the sand dunes and cause obvious inundation in Gisborne City. However, the water level reaches the top of the sand dunes and the coast in front of the city, Turanganui River and Waikanae Creek experience strong surges with water level rising by about 2.5 meters (Figure 8.1.2.1-5). About an hour later, the coincidence of the second wave incoming from the sea and the bay oscillation raises the water level in the bay up to 4.0 - 5.0 meters above Mean Sea Level, which results in overtopping of the sand dune section from the river mouth to the Victoria area. The tsunami waves first penetrate the sand dune gap at the road end of Grey Street, overflow into the street and then (Figure 8.1.2.1-6) within ten minutes overtop the sand dunes on both sides. The flow overtopping the sand dunes merges with floods from Waikanae Creek, creating strong surges to the northwest at around 1.5 m/s upstream along Waikanae Creek (Figure 8.1.2.1-7 and 8.1.2.1-8). The railyards area, a significant part of the Victoria area, and the south tip of Gisborne City centre are submerged by the flooding (Figure 8.1.2.1-9). Numerical simulations also indicate that the two breakwaters of the port reduce the momentum of the tsunami waves approaching the inner harbour, at least at the initial stage and especially those from the south. During the second wave, both breakwaters are overtopped and the high water level produces strong upstream surges along Waikanae Creek and Turanganui River at 1.0 – 2.0 m/s. The water level in the river increases by over 3.0 meters and both sides of the creek and the river are seriously affected (Figure 8.1.2.1-7 and 8.1.2.1-8). The wharf, at the south side of the Turanganui River mouth, is also flooded by the second tsunami wave. Although the wall on the west side of the wharf seems to effectively protect the wharf behind it, the surrounding flooding finally makes its way to the wharf, first from the north end and then from the south side where the land elevations are about 3.0 meters (Figure 8.1.2.1-7). The two floods merge together and sweep the entire wharf in less than 15 minutes (Figure 8.1.2.1-8). As illustrated in Figure 8.1.2.1-9, the flow depth may reach 1.0 meters in most of the flooded areas.

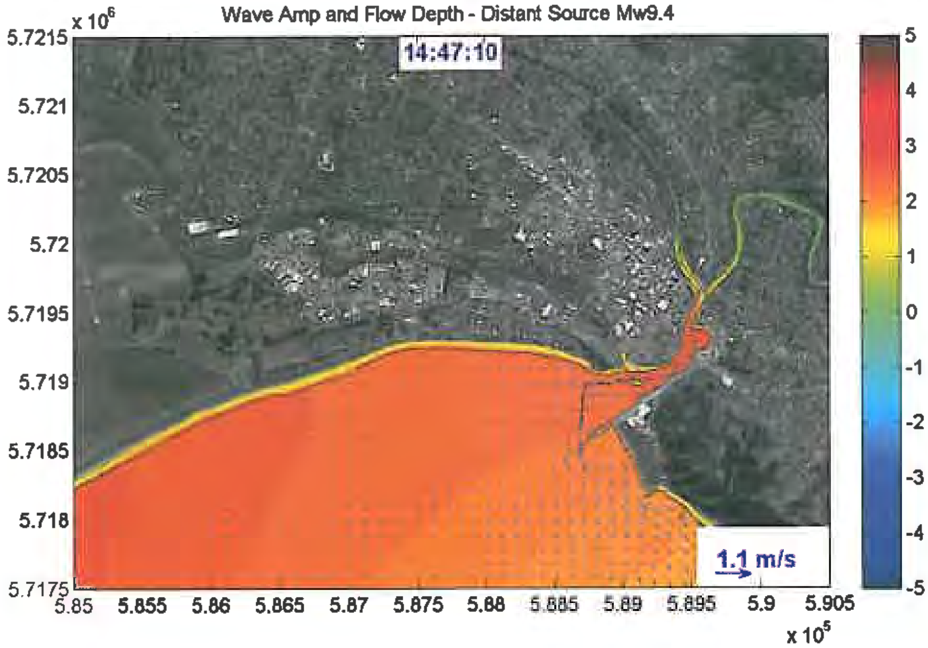

Figure 8.1.2.1-5 Snapshot of tsunami amplitude (in water) and flow depth (on land) at the moment when the first wave starts to recede. The arrow in the lower right corner shows the scale for the velocity vectors. The scale bar is in metres.

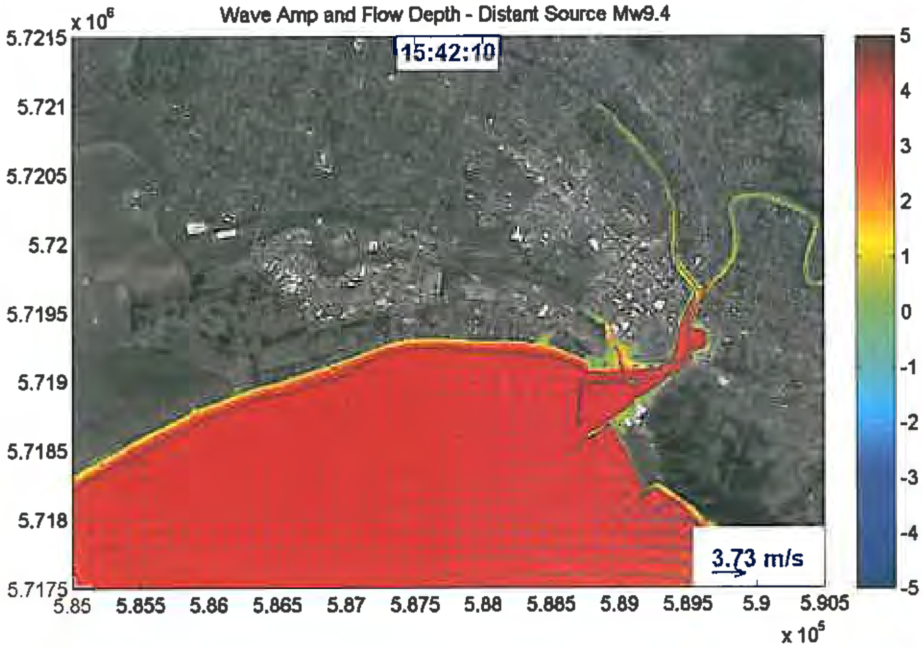

Figure 8.1.2.1-6 Snapshot showing the point when the second wave initially penetrates the sand dune gap into Grey Street and also surges upstream into Waikanae Creek and the Turanganui River. The arrow in the lower right corner shows the scale for the velocity vectors. The scale bar is in metres.

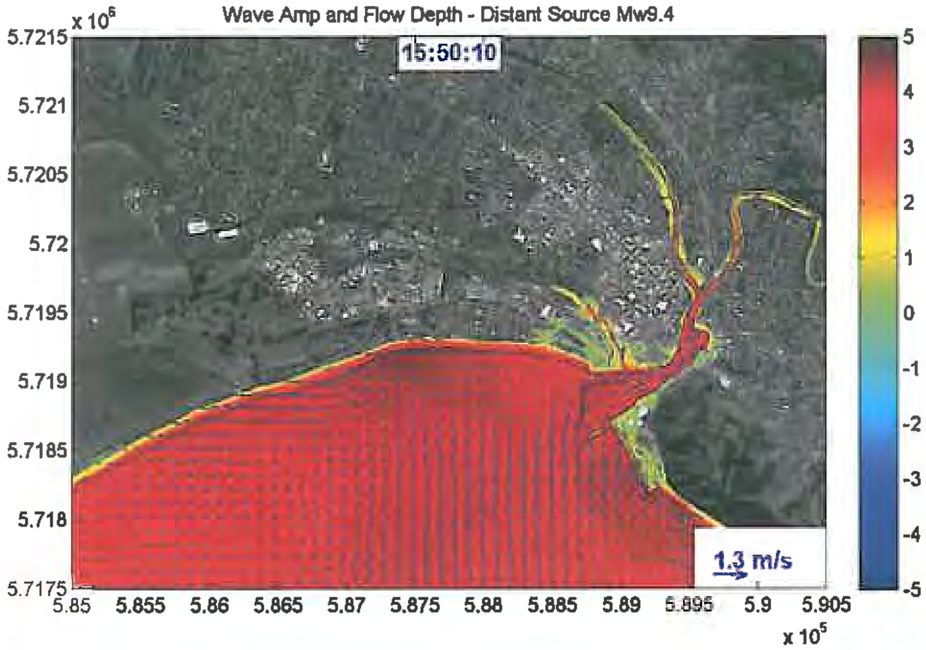

Figure 8.1.2.1-7 Snapshot of tsunami amplitude (in water) and flow depth (on land) shows that during the second wave the flood overtopping the sand dunes merges with the surge of water upstream into Waikanae Creek. The wharf is also flooded by the flows from its south and north sides. The arrow in the lower right corner shows the scale for the velocity vectors. The scale bar is in metres.

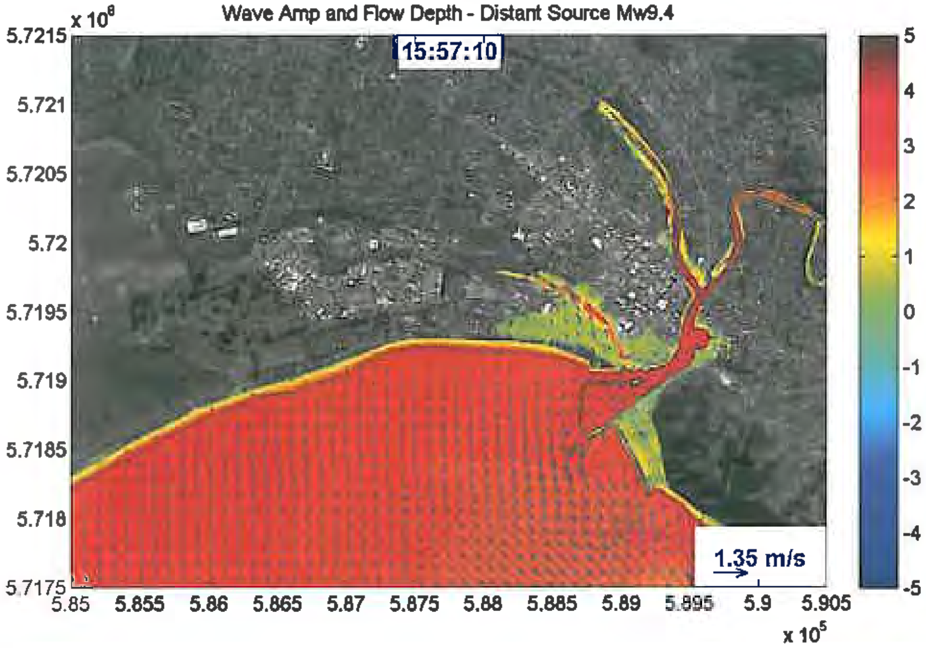

Figure 8.1.2.1-8 Snapshot of tsunami amplitude (in water) and flow depth (on land) shows that the second waves starts to recede from the river and throughout the bay. However the flood still moves upstream into Waikanae Creek. The entire wharf is also completely flooded by the flows from its south and north sides. The arrow in the lower right corner shows the scale for the velocity vectors. The scale bar is in metres.

Figure 8.1.2.1-9 Maximum tsunami inundation and flow depth in the Gisborne City area (M_W 9.4 earthquake in Peru).

Wainui

Numerical modelling also shows significant increase of water levels along the Wainui coast for this scenario event as seen in Figure 8.1.2.1-10. The water on the beach front may reach as deep as 4.0 meters. The maximum inundation reaches up to the top of the beach face and the residential areas closest to the beach will be affected. Strong surges into the creek can also be observed and both banks are exposed to the threat of flooding.

Figure 8.1.2.1-10 Maximum tsunami inundation and flow depth at Wainui (M_W 9.4 earthquake in Peru)

Muriwai

Due to low land elevation and low sand dune height, most of southwest areas of Poverty Bay from Muriwai up to the Waipaoa River (Sections C and D) are severely flooded during this scenario event as shown by the computed maximum inundation range in Figure 8.1.2.1-11. The sequential snapshots of model results illustrate that the first wave starts to strike the coastal front of Poverty Bay at about fourteen hours forty-five minutes after the earthquake (Figure 8.1.2.1-12). And it is able to overtop the sand dune section D. However the small volume of water being poured behind is only enough to inundate the Wherowhero Lagoon area. A small area near the Waipaoa River mouth is also flooded. About one hour later, the second and biggest wave arrives, raising the water level to 0.5 to 4.0 meters higher than the sand dunes between the Waipaoa River and Young Nicks Head (section C and D) and therefore causes extensive flooding once water overtops the sand dunes (Figure 8.1.2.1-13). The tsunami waves from Wherowhero Lagoon and Waipaoa River finally merge together and surge about 2.0 to 2.5 km further inland at a speed of up to 3.0 m/s (Figure 8.1.2.1-14). In most of the flooded areas, a flow depth of 1.0 to 2.0 meters can be observed (Figure 8.1.2.1-10).

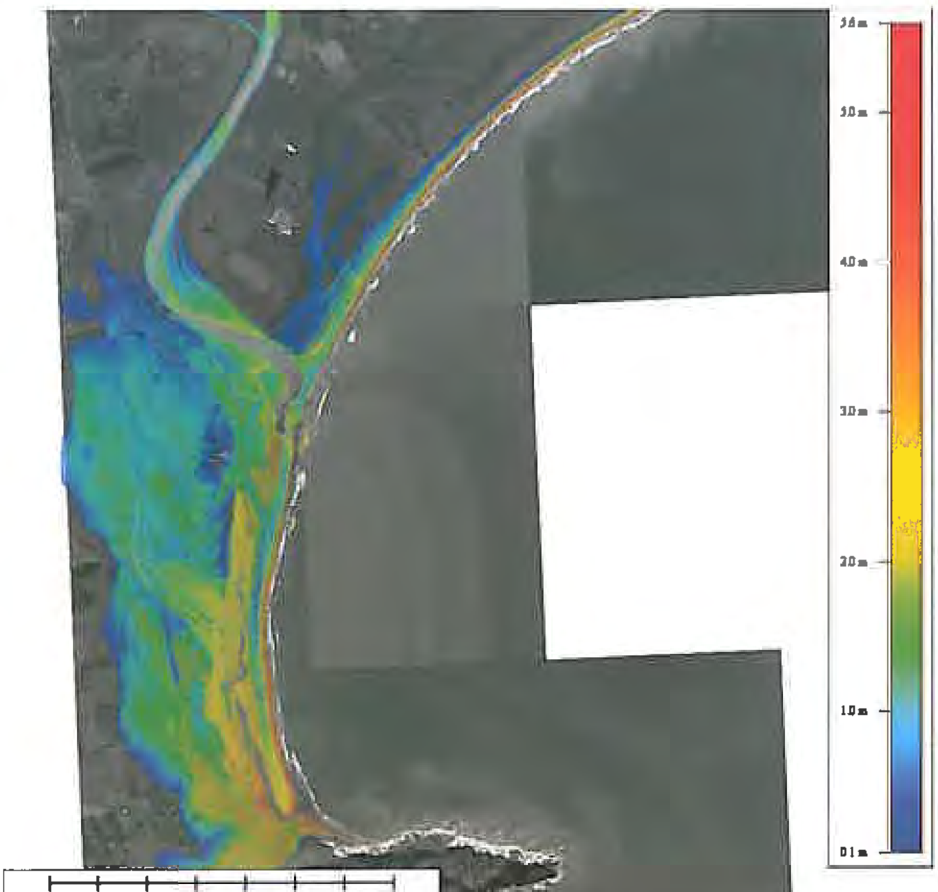

Figure 8.1.2.1-11 Maximum tsunami inundation and flow depth at Muriwai (M_W 9.4 earthquake in Peru).

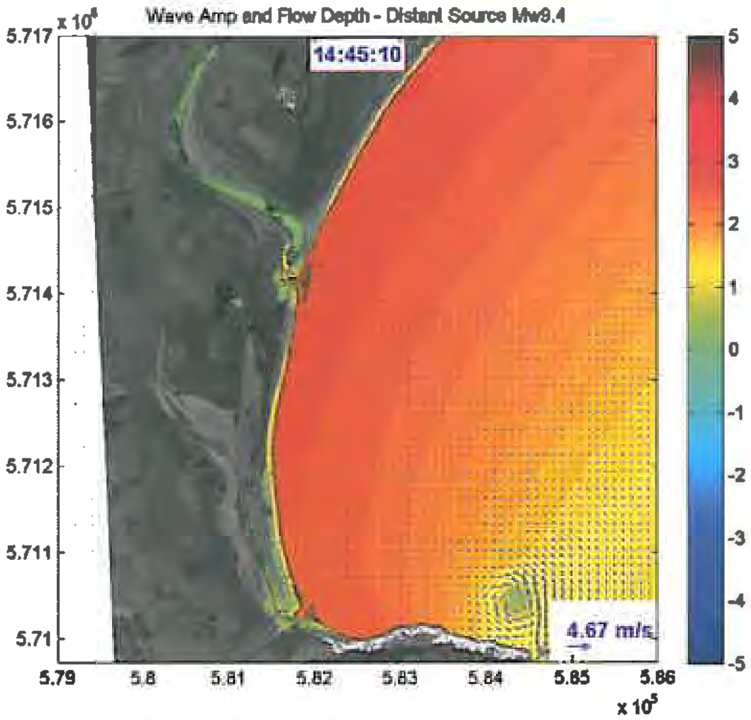

Figure 8.1.2.1-12 Snapshot shows that the first wave is positive and starts to rush into Wherowhero Lagoon and Waipaoa River (M_W 9.4 earthquake in Peru). The arrow in the lower right corner shows the scale for the velocity vectors. The scale bar is in metres.

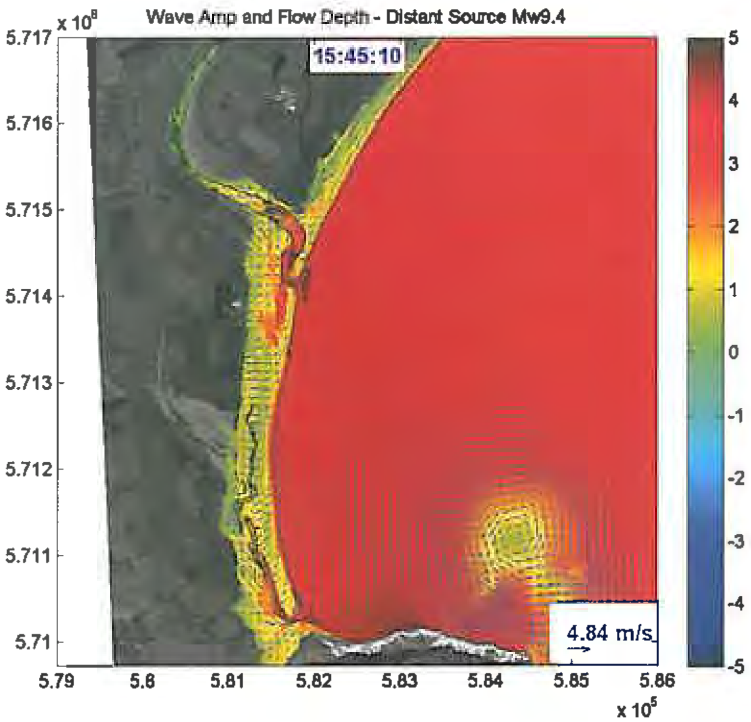

Figure 8.1.2.1-13 Snapshot shows that the second wave is much bigger and is overtopping the entire sand dune sections C and D and flooding further inland at 2.- 3.0 m/s (M_W 9.4 earthquake in Peru). The arrow in the lower right corner shows the scale for the velocity vectors. The scale bar is in metres.

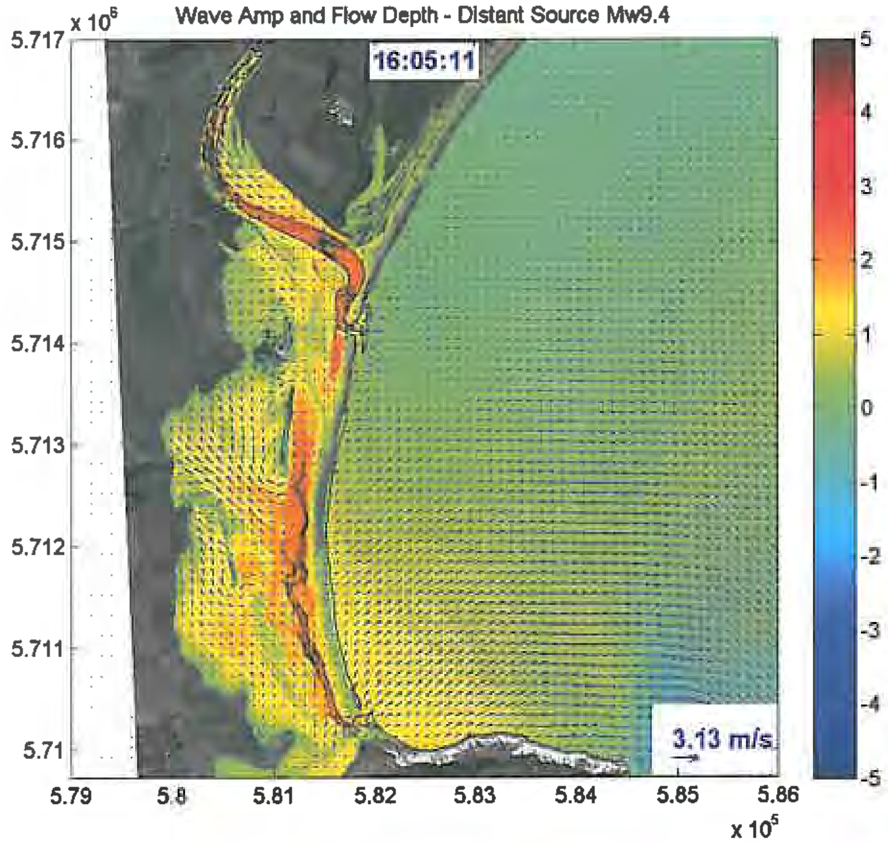

Figure 8.1.2.1-14 Snapshot of flow depth and velocity field shows that after the low-lying area west of Wherowhero Lagoon becomes flooded, the flow goes upstream of Wherowhero Stream, finally picking up the flow from the mouth of Waipaoa River and inundates further inland. The arrow in the lower right corner shows the scale for the velocity vectors. The scale bar is in metres.

8.1.2.2 500 year event at high tide– M_W 9.4 earthquake in Peru

For this 500 year event, a severe condition is also modelled – tsunami at high tide by increasing the water level by 0.75 m above Mean Sea Level. The modelling results show that, in this scenario, both the profiles of incoming tsunami waves and the pattern of water oscillations in the bay are very similar to those of the previous scenario, but the maximum water levels are being consistently increased by almost the same amount, 0.75 meters, in the bay in comparison with the event at Mean Sea Level (Figure 8.1.2.2-1). This 0.75-meter increment causes much more severe impacts in both the coastal areas of Gisborne City and the southwest side of Poverty Bay. Except for part of section B, overtopping of most sand dunes can be observed. The maximum inundation range and flow depths are shown in Figure 8.1.2.2-2.

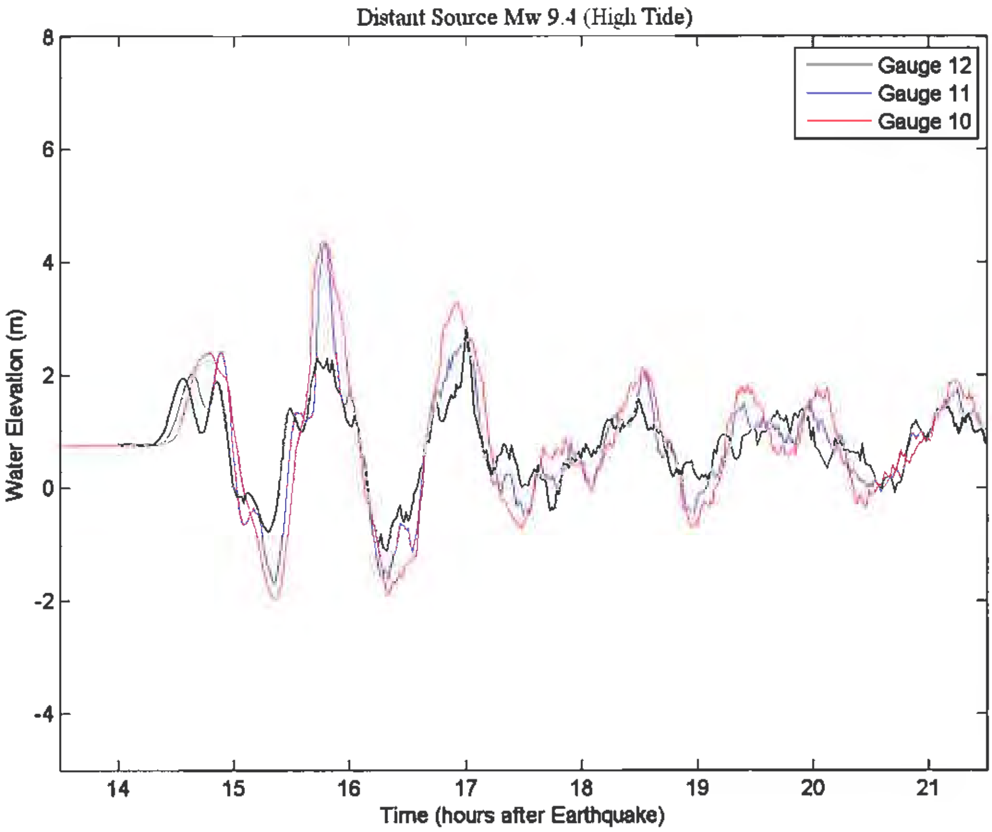

Figure 8.1.2.2-1 Water level fluctuations in the middle of Poverty Bay at virtual tidal gauges 10, 11 and 12. The wave profiles and oscillation patterns are very similar to the event at mean tidal level, however the water levels are increased by almost 0.75 meters.

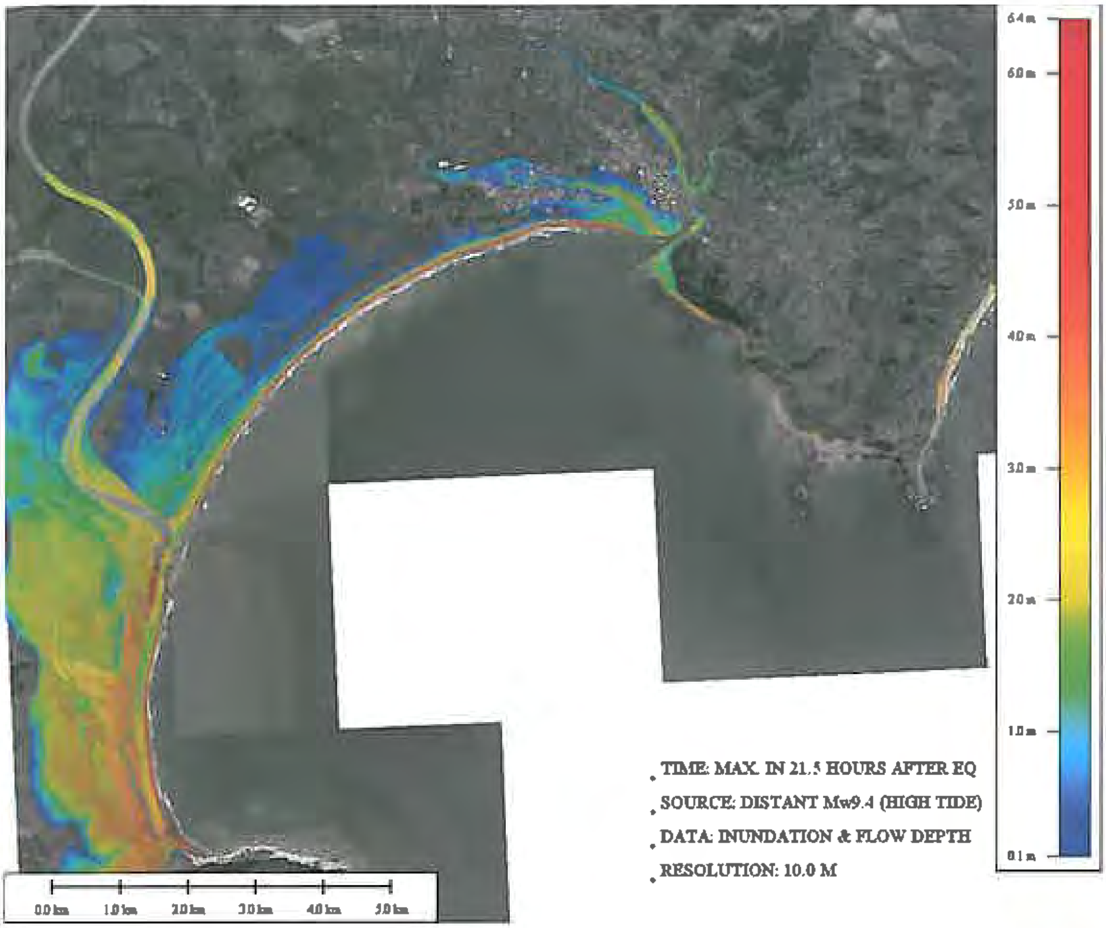

Figure 8.1.2.2-2 Maximum tsunami inundation and flow depth around Poverty Bay (high tide, M_W 9.4 earthquake in Peru)

Gisborne City

In this scenario, tsunami wave amplitudes in the bay reach up to 5.0 metres high and overtop the sand dunes in front of Watson Park, Churchill Park and the Victoria area (section A in figure 7.1-2). The flooding is much more severe than the event at mean tidal level. From the sequential snapshots of tsunami waves, it is also identified that for this earthquake event, tsunami at high tidal level will overtop the coastal sand dunes of Poverty Bay about 10 minutes earlier than the tsunami at mean tidal level. The tsunami first starts to flood inland through the gap at the end of Grey Street and in less than two minutes it overtops the sand dunes on each side of Grey Street, and floods half of the Victoria area (Figure 8.1.2.2-3). The flood finally merges with the strong upstream surge of water along Waikanae Creek at the Railyards area (Figure 8.1.2.2-4). Within 20 to 30 minutes, almost the entire Victoria area and both sides of the Waikanae Creek are flooded with a flow speed of 1.0 ~ 2.0 m/s (Figure 8.1.2.2-5a). Part of the Awapuni area is also submerged by an upstream surge from Waikanae Creek. During the second wave, lagging about one hour behind the first, although some water is capable of overtopping the sand dunes, a significant water volume accumulates in front of the sand dunes and the incoming flow finally bends its way toward the mouth of Turanganui River, overtops the breakwater and rushes into the river at a speed of nearly 4.0 m/s. Turanganui River experiences strong surges, with the water level rising by over 3.0 meters which penetrates over 3.5 km upstream. Both sides of the river are flooded. As illustrated in Figure 8.1.2.2-5b, the wharf of Gisborne Port is also flooded in a pattern similar to the event at mean tidal level with a flow depth of up to 2.0 meters.

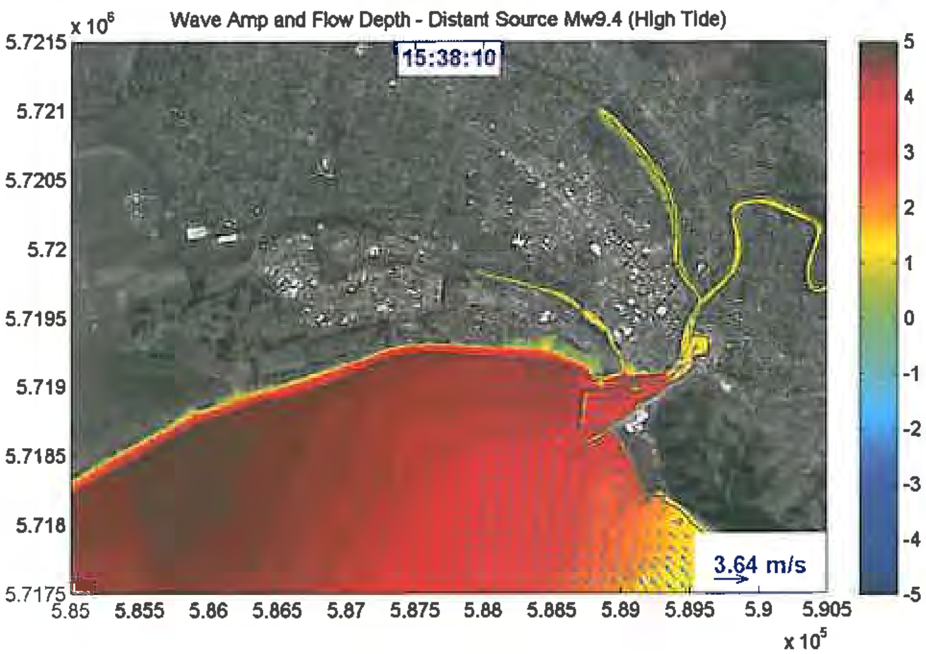

Figure 8.1.2.2-3 Snapshot of tsunami amplitude (in water) and flow depth (on land) shows the second wave starting to overtop the sand dunes and surge into Turanganui River. The arrow in the lower right corner shows the scale for the velocity vectors. The scale bar is in metres.

Figure 8.1.2.2-4 Snapshot of tsunami amplitude (in water) and flow depth (on land) shows that the flood overtopping the sand dunes merges with the surge of water upstream into Waikanae Creek. The wharf starts to be flooded by the flows from its south and north sides. The arrow in the lower right corner shows the scale for the velocity vectors. The scale bar is in metres.

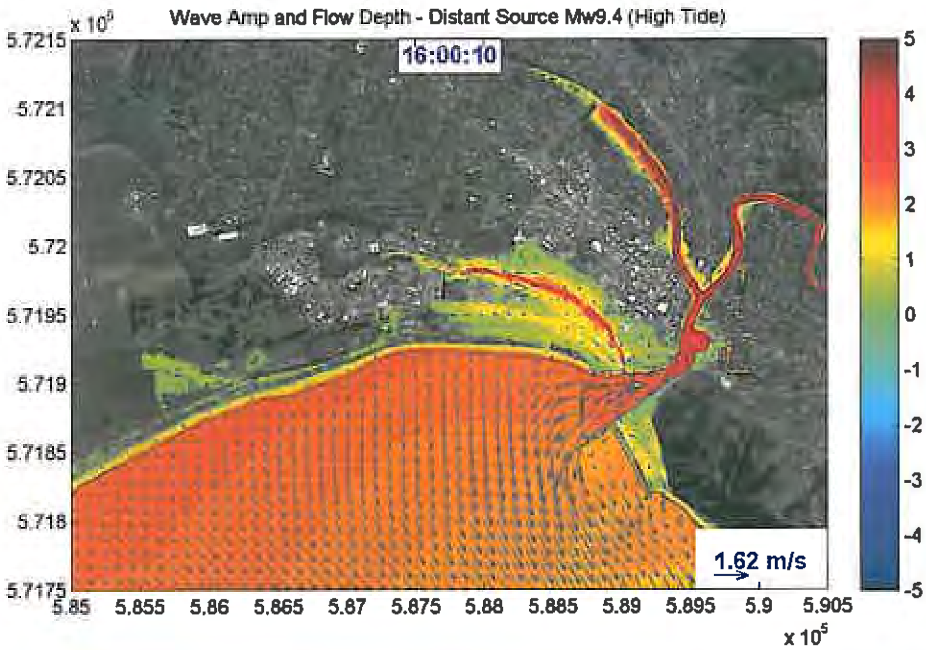

Figure 8.1.2.2-5a Snapshot of tsunami amplitude (in water) and flow depth (on land) shows that the second waves already starts to recede from the river and throughout the bay. However the flood still moves upstream of Waikanae Creek. The entire wharf is also completely flooded by the flows from its south and north sides. The arrow in the lower right corner shows the scale for the velocity vectors. The scale bar is in metres.

Figure 8.1.2.2-5b Maximum tsunami inundation and flow depth in the Gisborne City area (high tide, M_W 9.4 earthquake in Peru)

Wainui

A significant impact also occurs along the Wainui coast for this scenario event as seen in Figure 8.1.2.2-6. The maximum inundation reaches the residential areas closest to the beach front. Strong upstream surges into the creek can also be observed which affects both sides of the creek.

Figure 8.1.2.2-6 Maximum tsunami inundation and flow depth at Wainui (high tide, M_W 9.4 earthquake in Peru)

Muriwai

Compared to the modelling at mean sea level, in this scenario event much of the low-lying area behind Muriwai beach is flooded by the first wave, creating an easy path for the much bigger second wave. The inundation range in the southwest area of Poverty Bay is increased from the Waipaoa River mouth by about 3.0 km further to the north (see Figure 8.1.2.2-7). The inundation stops right in front of the south side of Tuaraki Road. In contrast to the scenario at mean sea level, the sand dunes between the landfill and the Waipaoa River mouth (Section C) are no longer able to effectively suppress the overtopping of tsunami waves. A significant volume of water is poured behind the sand dunes (Figure 8.1.2.2-8). Consequently, most areas enclosed by the river, the sand dune, the Palmerston North - Gisborne railway line and the landfill are flooded. The flood can also pass around the landfill, especially through the passage between the rail track and the landfill, to affect a significant part of the low-lying area behind the sand dune of section B which is not overtopped. At the west side of Poverty Bay, just north of Muriwai, after the flooding reaches its limit about 2.0 km inland, the flow starts to bend its way upward and pick up the incoming flows from the river mouth and then moves together further to the northwest (Figure 8.1.2.2-9). For most of the flooded area, the flow depth is between 2.0 and 3.0 meters. In some areas with particularly low elevation, the flow depth may reach up to 4.0 meters.

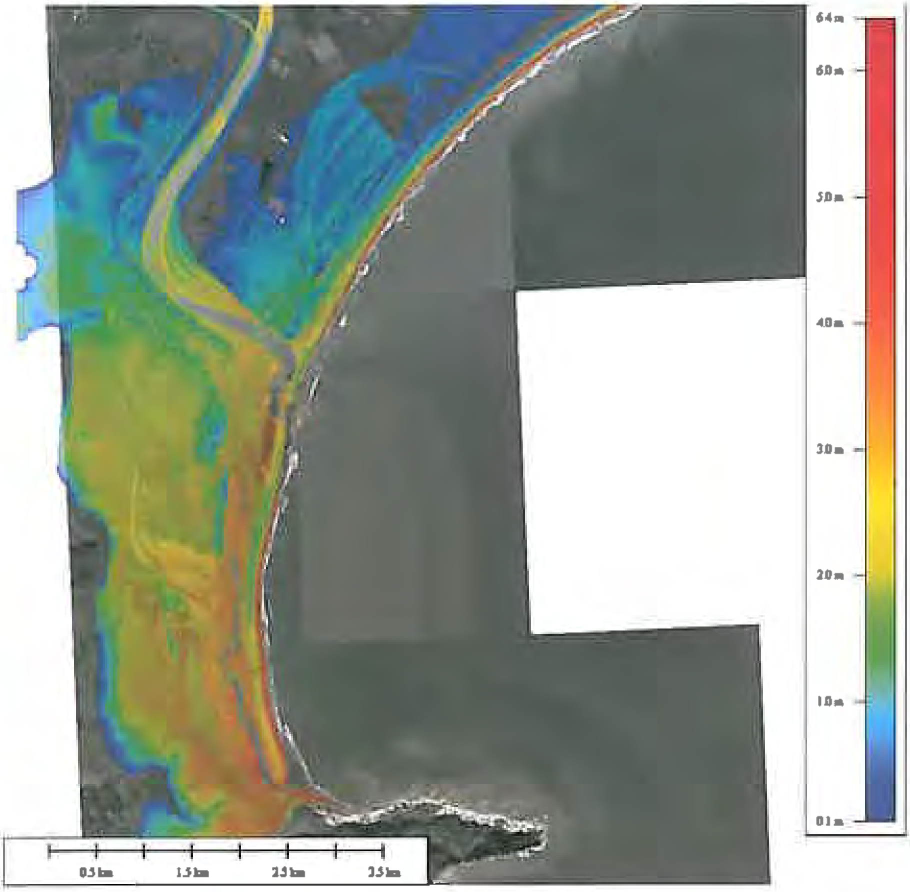

Figure 8.1.2.2-7 Maximum tsunami inundation and flow depth in the southwest area of Poverty Bay (high tide, M_W 9.4 earthquake in Peru)

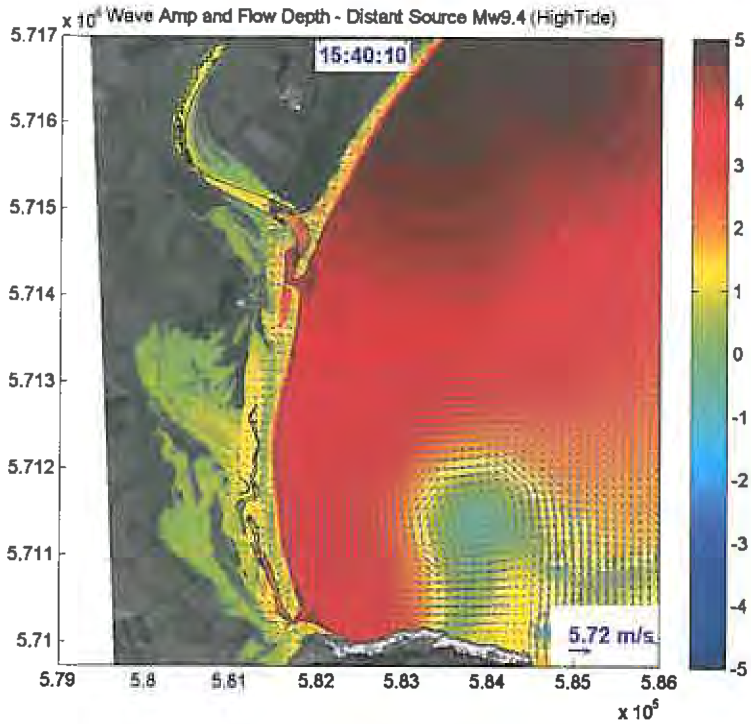

Figure 8.1.2.2-8 Snapshot of tsunami amplitude (in water) and flow depth (on land) shows that the second wave overtops the sand dunes sections C and D. The arrow in the lower right corner shows the scale for the velocity vectors. The scale bar is in metres.

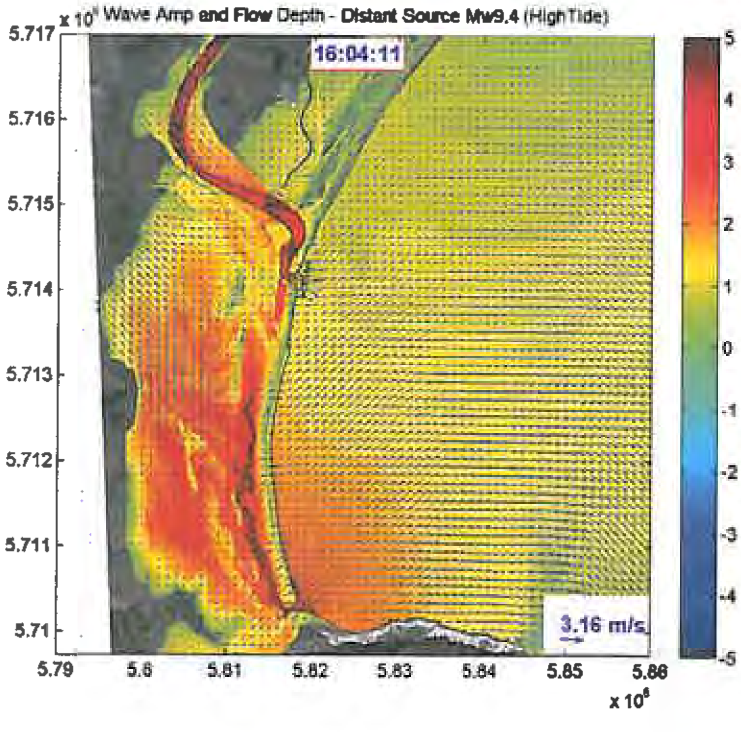

Figure 8.1.2.2-9 Snapshot of tsunami amplitude (in water) and flow depth (on land) shows that the flood from Muriwai beach merges with the flow from the river mouth and creates severe flooding further to the northwest at over 2.0 m/s. The arrow in the lower right corner shows the scale for the velocity vectors. The scale bar is in metres.

8.2 Tsunami Modelling for Local Sources

8.2.1 Lachlan Fault

The modelling results show that the M_W 7.6 earthquake on the Lachlan Fault is not able to generate tsunami that significantly threatens the coastal areas encompassing Poverty Bay. The amplitude of water fluctuations inside the bay is below 1.5 meters with a wave period around 45 minutes (Figure 8.2.1-1). This magnitude of tsunami wave is not capable of inundating the Gisborne City area and Wainui; however from the simulation minor inundations can be identified near Wherowhero Lagoon where land elevation is only around 1.0 metre above Mean Sea Level (Figure 8.2.1-2).

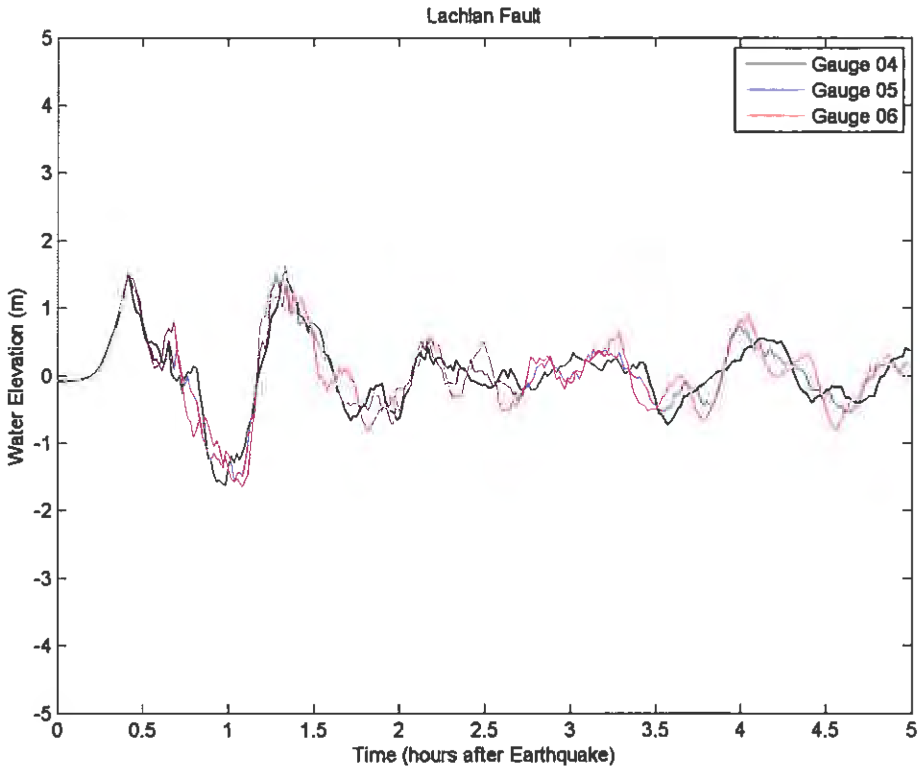

Figure 8.2.1-1 Water fluctuations along the coast of the bay for the M_W 7.6 earthquake at Lachlan Fault. The amplitude of fluctuations is below 1.5 meters in front of the sand dunes and is not able to cause significant inundation in most of the coastal areas encompassing Poverty Bay.

Figure 8.2.1-2 The maximum inundation range and flow depth show that only the lagoon area near Muriwai is affected by this M_W 7.6 earthquake event on the Lachlan Fault.

8.2.2 Ariel Bank Fault

The modelling results show that the M_W 7.5 earthquake on the Ariel Bank Fault is not able to generate tsunami that significantly threatens the coastal areas encompassing Poverty Bay. The water fluctuations in the bay are below 1.0 metre. This magnitude of tsunami wave is not capable of flooding the Gisborne City area or Wainui, and only very minor inundation can be found around Wherowhero Lagoon where land elevation is only around 1.0 meter above Mean Sea Level (Figure 8.2.2-1).

Figure 8.2.2-1 The maximum inundation range and flow depth show that only the lagoon area near Muriwai is affected by this M_W 7.5 earthquake event on the Ariel Bank Fault.

8.2.3 Gable End Fault

The modelling results show that the M_W 7.4 earthquake event at Gable End Fault is not able to generate tsunami that significantly threatens the coastal areas encompassing Poverty Bay. The water fluctuations in the bay are below 0.5 meters in magnitude and do not result in notable inundation in the Gisborne City area, Wainui, or the southwest side of Poverty Bay (Figure 8.2.3-1).

Figure 8.2.3-1 The maximum inundation range and flow depth show that only a very minor part of the Muriwai beach area is affected by the tsunami generated by this M_W 7.4 earthquake event on the Gable End Fault.

8.2.4 Lachlan fault + deeper plate interface

By incorporating part of the deeper plate interface into the rupturing process, this earthquake scenario generates tsunami with much higher amplitude and longer wave period than the event without the deeper plate interface rupture in Section 8.2.1. The time history records from the virtual tidal gauge 03, 04 and 05 indicate that the earthquake initially uplifts the entire Poverty Bay area by 20 to 50 cm and the amplitude of water waves in the bay may reach as high as 3.5 meters (Figure 8.2.4-1 and 8.2.4-2). The wave period is about 65 - 70 minutes. The leading wave with an amplitude of nearly 2.5 meters enters the bay almost immediately after the earthquake and starts to strike the coastal areas surrounding the bay in less than 10 minutes; but does not cause significant inundations in the Gisborne City area and Wainui, although 2.0 - 3.0 meter surges are expected in the Port. The second wave, arriving one hour after the first one, is over 1.0 metre higher than the first one and raises the water level in front of the sand dunes to 3.5 meters high (Figure 8.2.4-1). At this level, the modelling results show that water is not likely to overtop the sand dunes between the mouths of the Waipaoa and the Turanganui Rivers. However, part of the Gisborne City area and the southwest side of Poverty Bay are inundated, as shown in Figure 8.2.4-3.

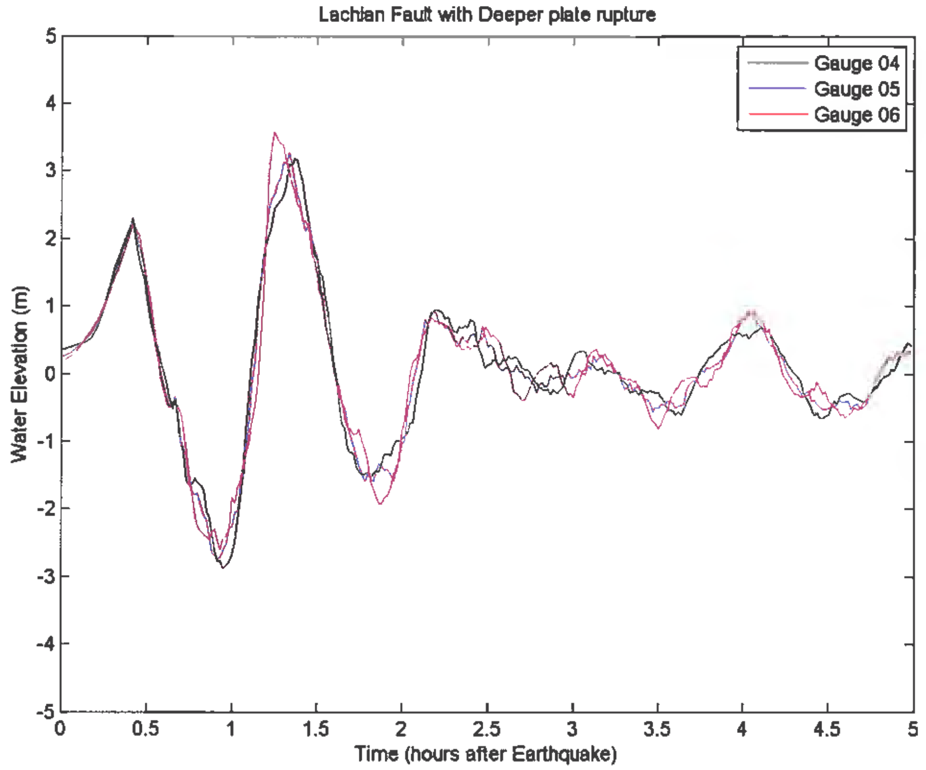

Figure 8.2.4-1 Water fluctuations along the coast of Poverty Bay for the M_W 7.9 earthquake on the Lachlan Fault with deeper plate interface rupture. Numerical modelling shows that the water fluctuations may reach as much as 3.5 meters high in front of the sand dunes and are able to cause significant inundation especially in the southwest side of Poverty Bay.

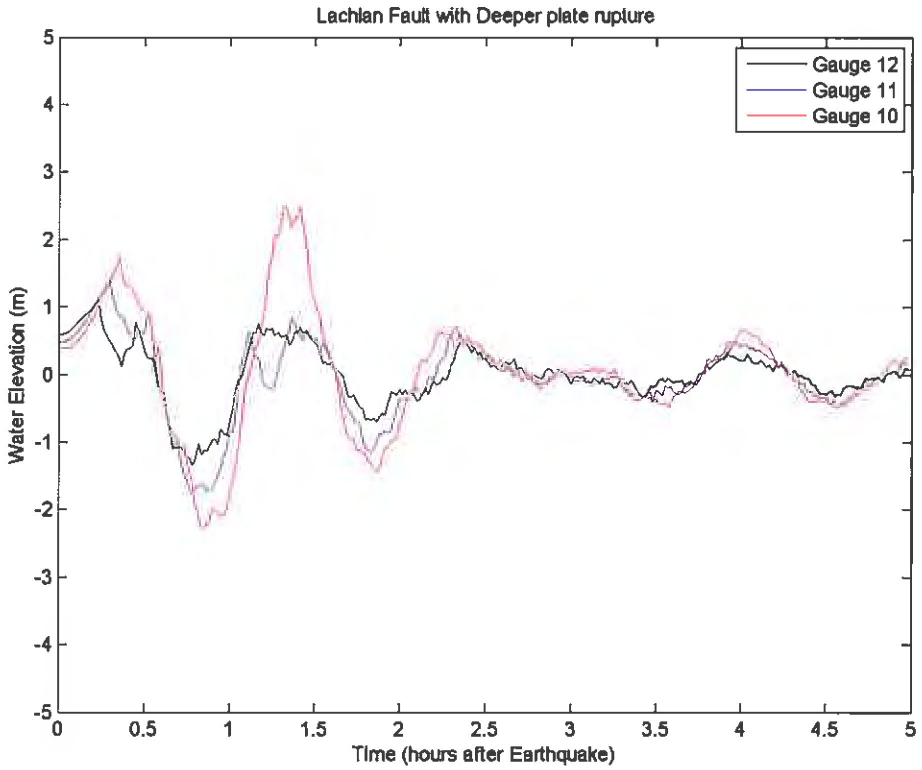

Figure 8.2.4-2 Time history records in the middle of Poverty Bay at virtual tidal gauges 10, 11 and 12. It is observed that the seafloor of Poverty Bay is initially uplifted by about 0.5 meters.

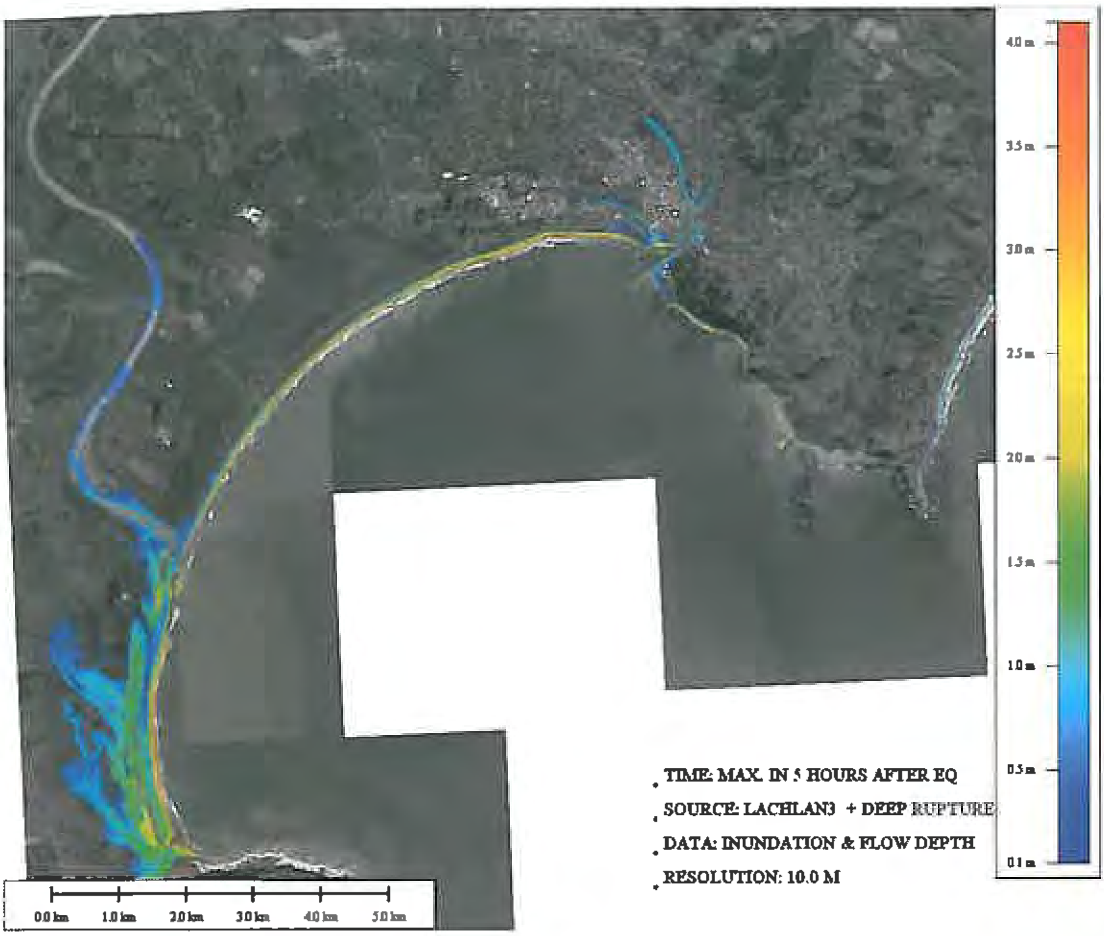

Figure 8.2.4-3 Maximum inundation and flow depth of the tsunami generated by this M_W 7.9 earthquake event on the Lachlan Fault with deeper plate interface rupture. The model results show that most of the low-lying areas near the Wherowhero Lagoon behind Muriwai Beach are flooded. In the city area of Gisborne, the area near the river mouth is also inundated by strong upstream surges of water.

Detailed analyses show that the gap at the end of Grey Street in the Victoria area, the Waikanae Creek and Turanganui River provide easy access for tsunami waves. The waves are able to pass through the gap at the end of Grey Street with a flow depth of about 0.5 meters, penetrate further inland along the street and finally in the middle of Awapuni Road merge together with the flood coming from Waikanae Creek. Both sides of Grey Street and Awapuni Road are submerged about 0.5 meters under water. Strong surges of water, above 1.5 m/s, are also observed to flood into the Waikanae Creek and especially Turanganui River through the river mouth after overtopping the breakwaters, and travel upstream at least 1.5 km inland (Figure 8.2.4-4). Both sides near the mouth of the Waikanae Creek, including the Railyards area, are severely flooded. The northwest part of the wharf and the Port area embraced by Esplanade Road are also inundated (Figure 8.2.4-4). The maximum inundation range and flow depth in the city area of Gisborne is shown in Figure 8.2.4-5.

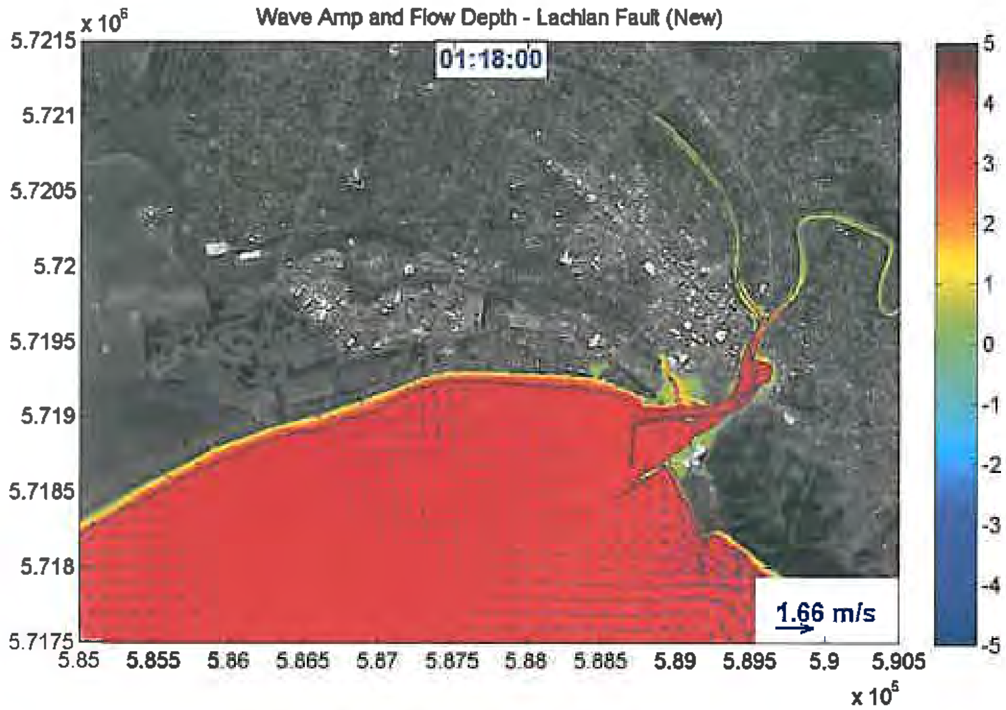

Figure 8.2.4-4 Snapshot of tsunami waves shows that strong currents of water surge into Turanganui River and penetrate upstream inland at over 1.5 m/s. Water is also able to pass through the sand dune gap at the end of Grey Street and flood the Victoria area along the street. The arrow in the lower right corner shows the scale for the velocity vectors. The scale bar is in metres.

Figure 8.2.4-5 Maximum inundation and flow depth in Gisborne City area by the tsunami generated by the M_W 7.9 earthquake event at Lachlan Fault with deeper plate interface rupture.

At the southwest side of Poverty Bay, the second wave of the tsunami starts to overtop the sand dunes 1 hour 15 minutes after the earthquake (Figure 8.2.4-6). The overtopping starts from the opening of Wherowhero Lagoon and then gradually extends further to the north up to the mouth of Waipaoa River (Figure 8.2.4-7). About 1 hour 25 minutes after the earthquake, the waves begin to retreat back to the bay, leaving a large volume of water behind the sand dunes (Figure 8.2.4-8). The sequential snapshots from the numerical modelling indicate that after Wherowhero Lagoon and nearby areas are flooded, the water can still flow upstream along Wherowhero Stream at 1.0 ~ 2.0 m/s, and gradually submerge all the low-lying areas on both sides of the stream with a maximum extension of 1.5 km inland. The maximum inundation range and flow depth is illustrated in Figure 8.2.4-9.

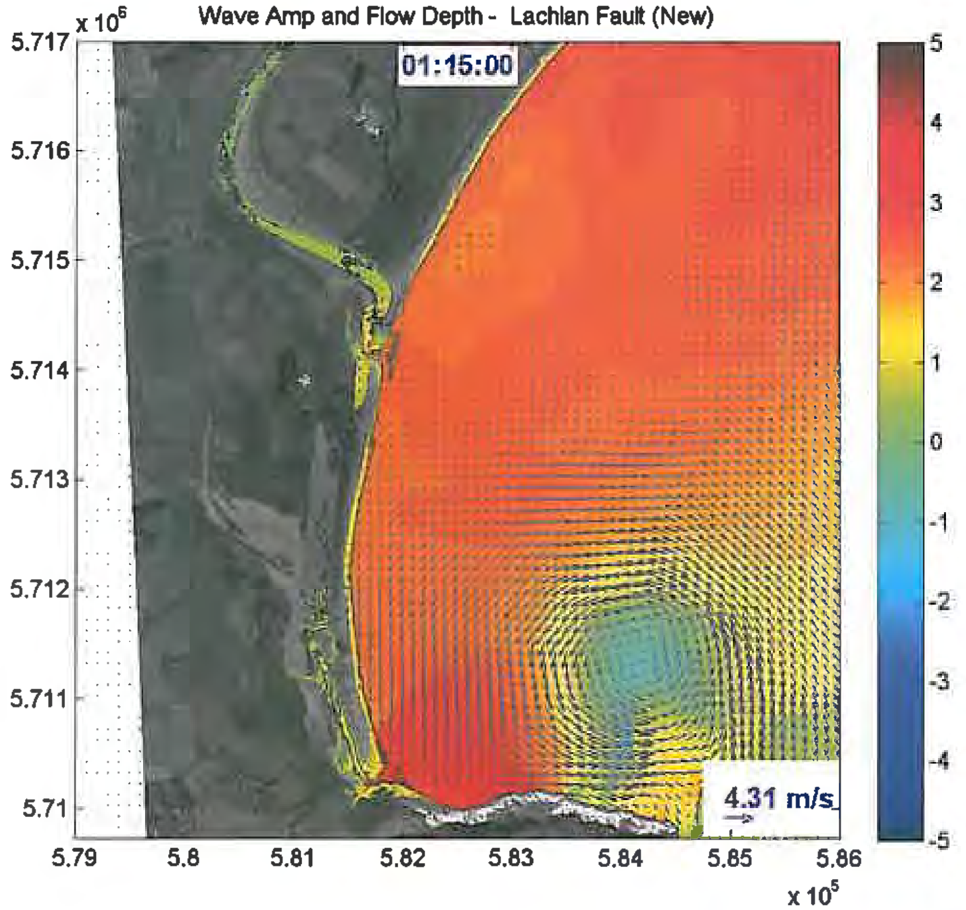

Figure 8.2.4-6 Snapshot of tsunami waves at 1 hour 15 minutes after the earthquake shows that strong currents of water start to overtop the sand dunes near the opening of Wherowhero Lagoon at up to 2.0 m/s. The arrow in the lower right corner shows the scale for the velocity vectors. The scale bar is in metres.

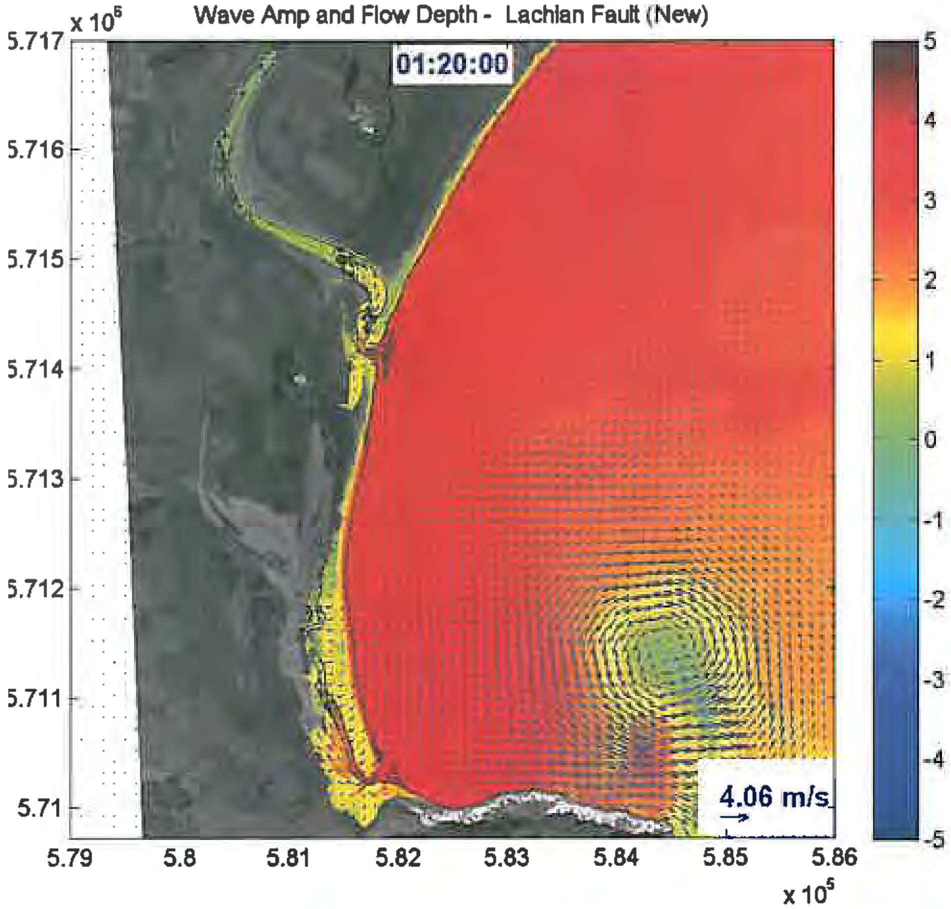

Figure 8.2.4-7 Snapshot of tsunami waves at 1 hour 20 minutes after the earthquake shows that the waves gradually overtop all the sand dunes from the opening of the lagoon north to the mouth of Waipaoa River. The arrow in the lower right corner shows the scale for the velocity vectors. The scale bar is in metres.

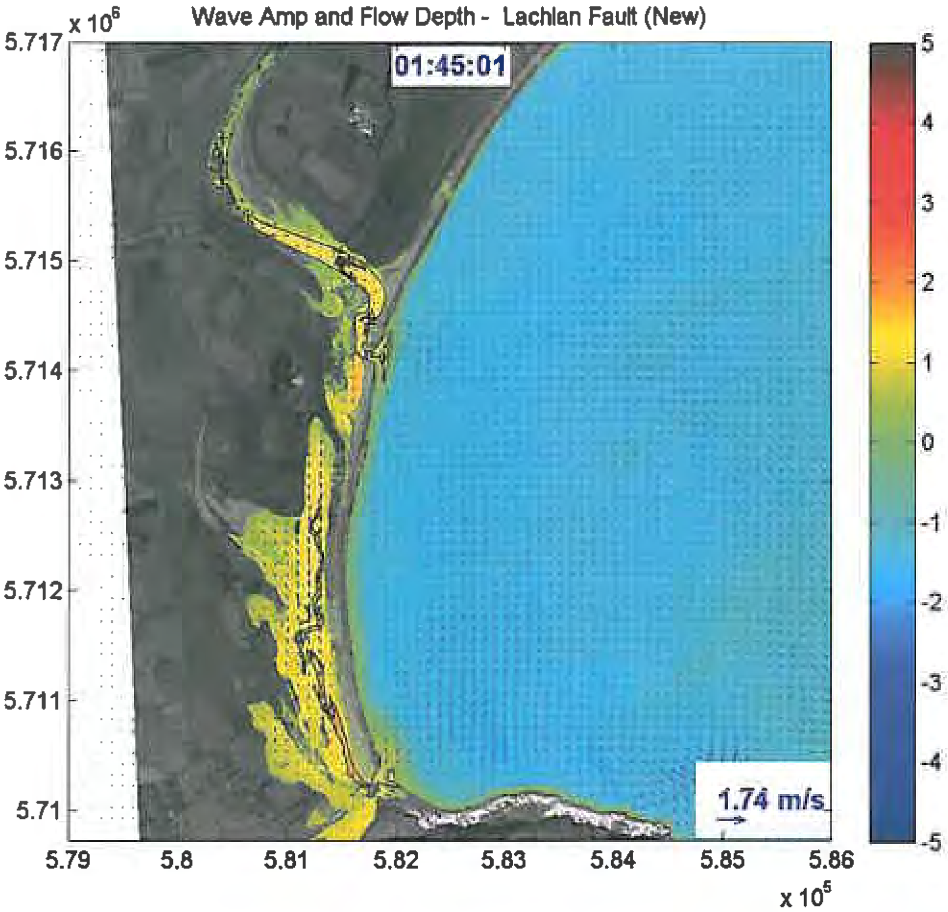

Figure 8.2.4-8 Snapshot of tsunami waves at 1 hour 45 minutes after the earthquake shows that the waves have already retreated back into the bay; however large amounts of water are being left behind the sand dunes and are continuously moving northward along Wherowhero Stream, and are inundating more low-lying areas nearby. The arrow in the lower right corner shows the scale for the velocity vectors. The scale bar is in metres.

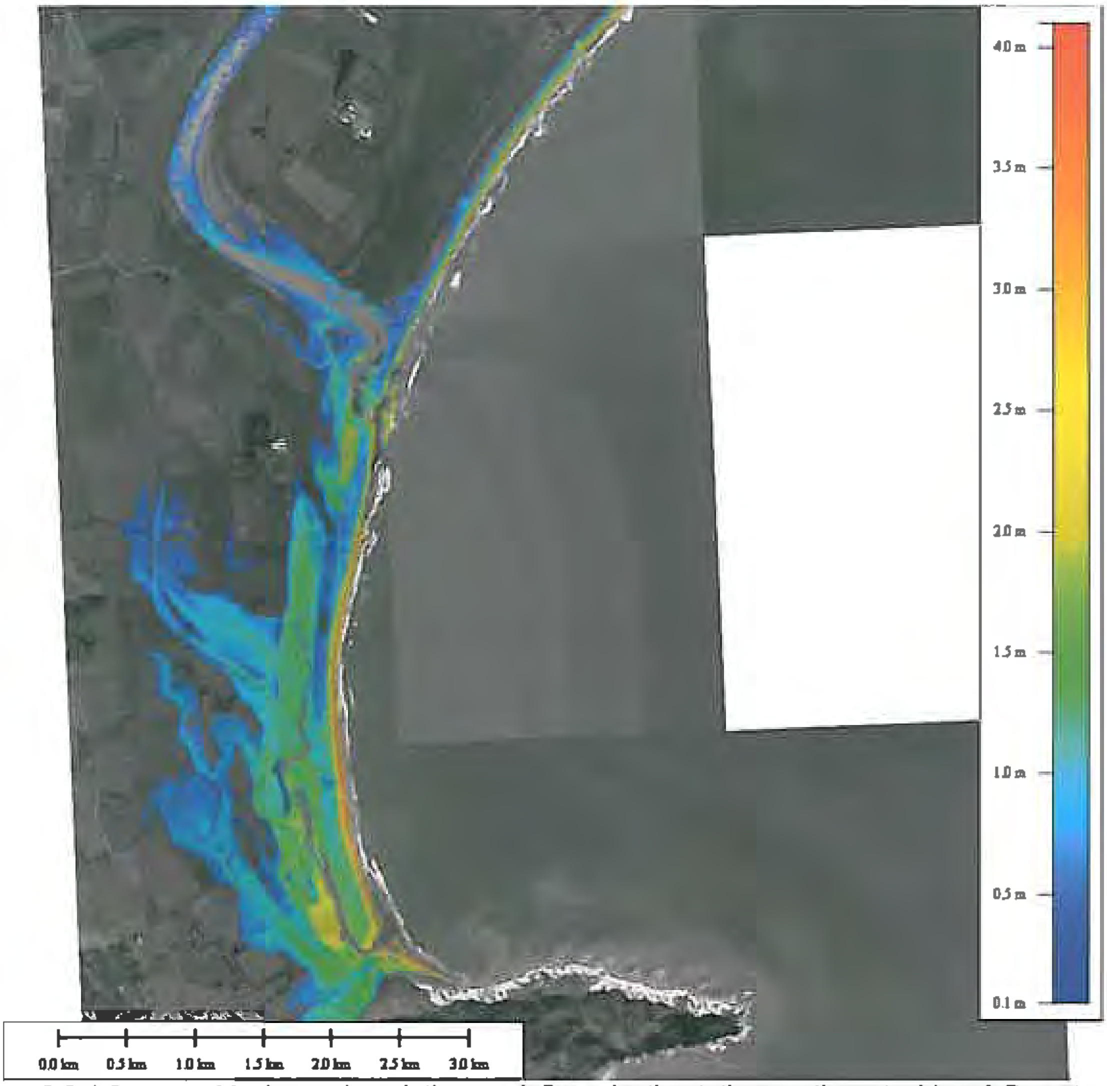

Figure 8.2.4-9 Maximum inundation and flow depth at the southwest side of Poverty Bay (Lachlan Fault with deeper plate interface rupture).

In addition to the tsunami at mean sea level, the tsunami at high tidal level (+0.75 meters) was also modelled for this earthquake. Although both wave profiles and flooding patterns are similar to the modelling results at mean sea level, this scenario (i.e., tsunami over high tides) results in a much larger inundation area in both the city centre of Gisborne and the southwest side of Poverty Bay as shown in Figure 8.2.4-10.

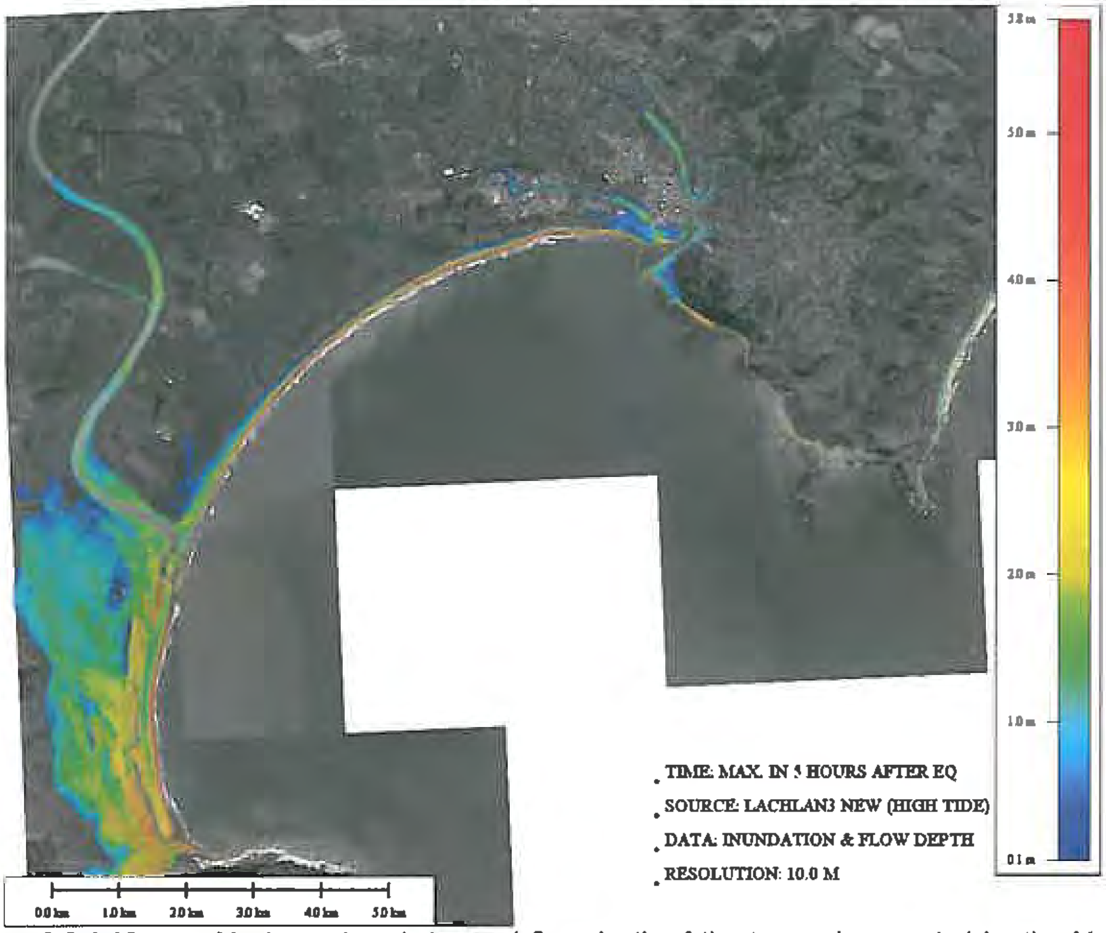

Figure 8.2.4-10 Maximum inundation and flow depth of the tsunami generated by the M_W 7.9 earthquake event at Lachlan Fault with deeper plate interface rupture (high tidal level, +0.75m). This tsunami results in inundation areas much larger than the one over mean tidal level in both Gisborne city centre and the southwest side of the Poverty Bay.

In the Gisborne City area, the modelling results reveal flooding in the area close to the banks of Waikanae Creek and Turanganui River. In this scenario, the southeast side of the Victoria area, most parts of the wharf and the Port, and its neighbouring area including Esplanade Road are submerged under about 0.5~1.5 m of water (Figure 8.2.4-11).

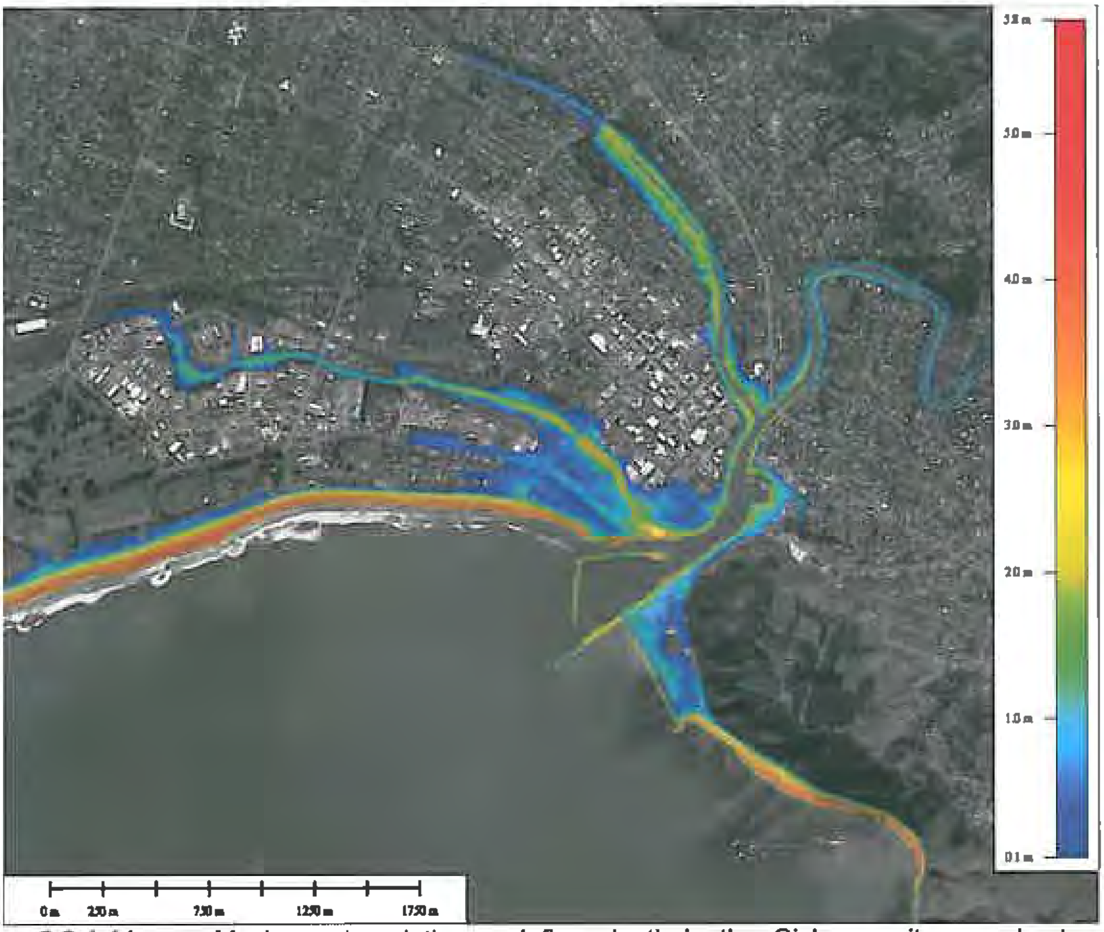

Figure 8.2.4-11 Maximum inundation and flow depth in the Gisborne city area by tsunami generated by the M_W 7.9 earthquake event at Lachlan Fault with deeper plate interface rupture (over high tidal level, +0.75m).

In the southwest side of Poverty Bay, the tsunami at high tidal level causes a much larger inundation area than the one at mean sea level. Most areas below 3.0 meters in elevation are flooded. The inundation reaches as far as 2.5 km inland south of the mouth of the Waipaoa River. 1.0~3.0 meter flow depth can be observed in most flooded areas (Figure 8.2.4-12).

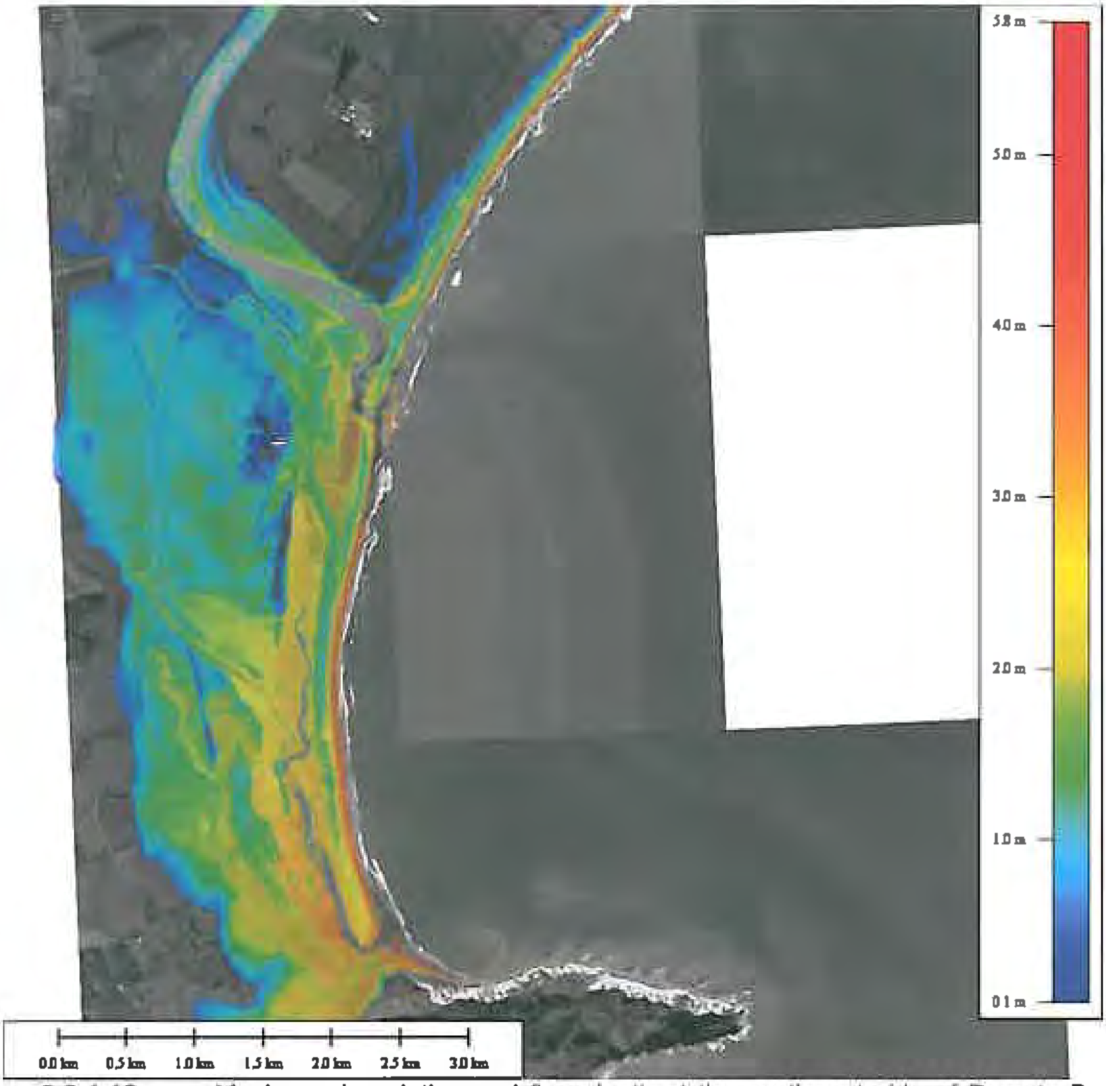

Figure 8.2.4-12 Maximum inundation and flow depth at the southwest side of Poverty Bay by the tsunami generated by the M_W 7.9 earthquake event at Lachlan Fault with deeper plate interface rupture (at high tidal level, +0.75m).

8.2.5 Whole Margin Plate interface M_W 9.0

For this scenario, two sea levels related to tidal conditions are considered in the model simulation. First, the model runs using Mean Sea Level (MSL) and secondly the model runs during the High Tide condition (HT).

8.2.5.1 Model Results (scenario at Mean Sea Level (MSL))

The extent of maximum inundation for this scenario is shown in Figure 8.2.5.1.1 with the time histories in Figures 8.2.5.1.2 and 3. The location and orientation of the initial deformation of this scenario provides a minor subsidence to the Port areas and further inland to the east coast, while the coastal areas at Muriwai were less affected by the initial deformation. The initial deformation creates a negative leading wave that propagates into Poverty Bay (Figure 8.2.5.1.4.a). Within 25 minutes after the earthquake, the tsunami elevation along the Wainui coast reaches more than 8 m while a major leading tsunami wave enters Poverty Bay with an elevation of ~ 5.0 m. Thirty minutes after the earthquake (Figure 8.2.5.1.4.b), the first leading wave with a height up to 2.0 m arrives along the coast of Poverty Bay, followed by the second wave about an hour later with a height up to 4.0 m, and the third and the fourth waves with reduced wave height (~ 1.0 m). Within this time most of the east coast including the coastal area of Wainui, has been hit by tsunami waves nearly 10m in height.

The tsunami inundates most of the coastal areas along Poverty Bay, to a distance inland that ranges from 1 to 3 km, and overtops most of the sand dunes along the coast with flow velocities up to 15.0 m/s, and through the Turanganui River and Waikanae Creek further upstream (Figure 8.2.5.1.4.c). The sand dunes along the coast apparently play a significant role in reducing the impact of tsunami along the Poverty Bay coast. The coastal areas such as Muriwai (Section D) where there are no sand dunes, and the areas surrounding the Waipaoa River (Section C) with relatively low elevation of sand dunes were heavily affected by the tsunami. At section B where the sand dunes are relatively high (4.0 – 5.0 m), the seawater could not retreat back to the sea once it had overtopped dunes, and instead continued to flow further inland as gravity driven flows follow the local terrain (Figure 8.2.5.1.4.d.). The flow is also relatively slow in this section compared to other sections (Section A, C and D). Further analyses are made for Gisborne City, Wainui and Muriwai.

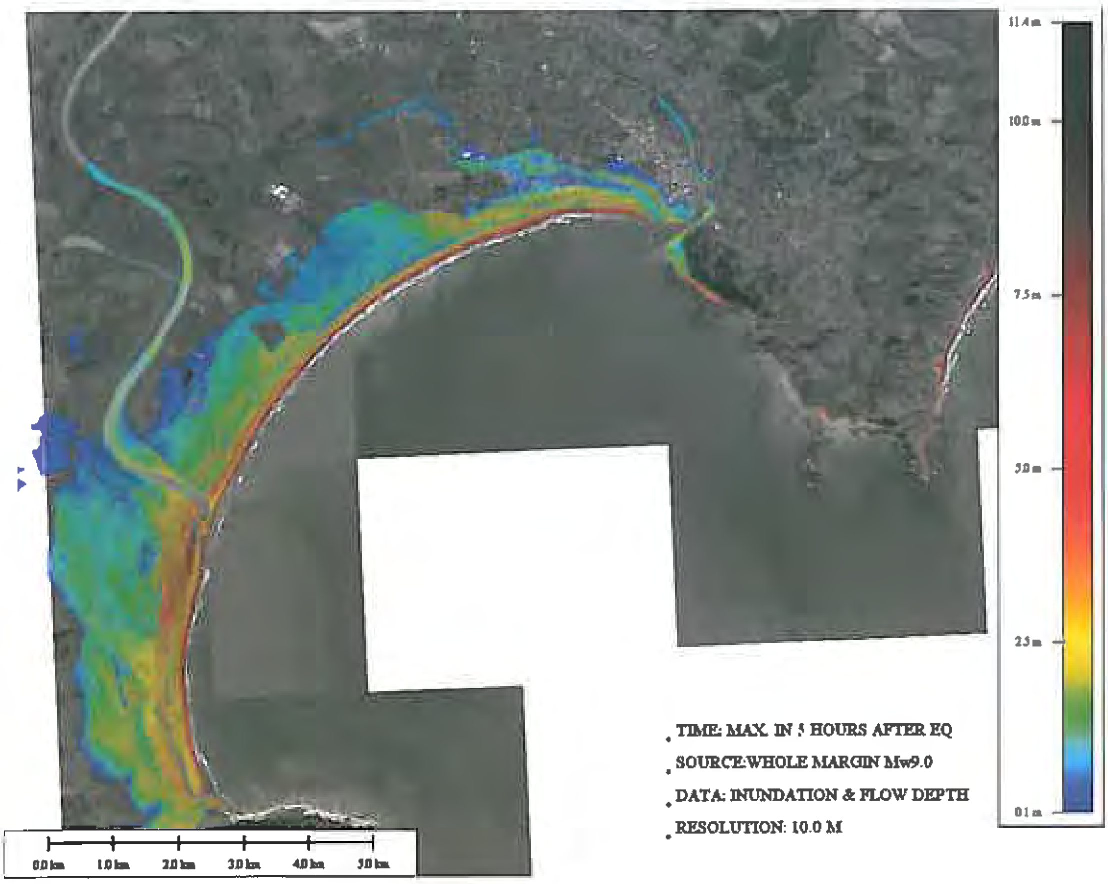

Figure 8.2.5.1-1 Maximum tsunami inundation and flow depth around Poverty Bay (Mean Sea Level, Whole Margin Plate Interface, M_W 9.0).

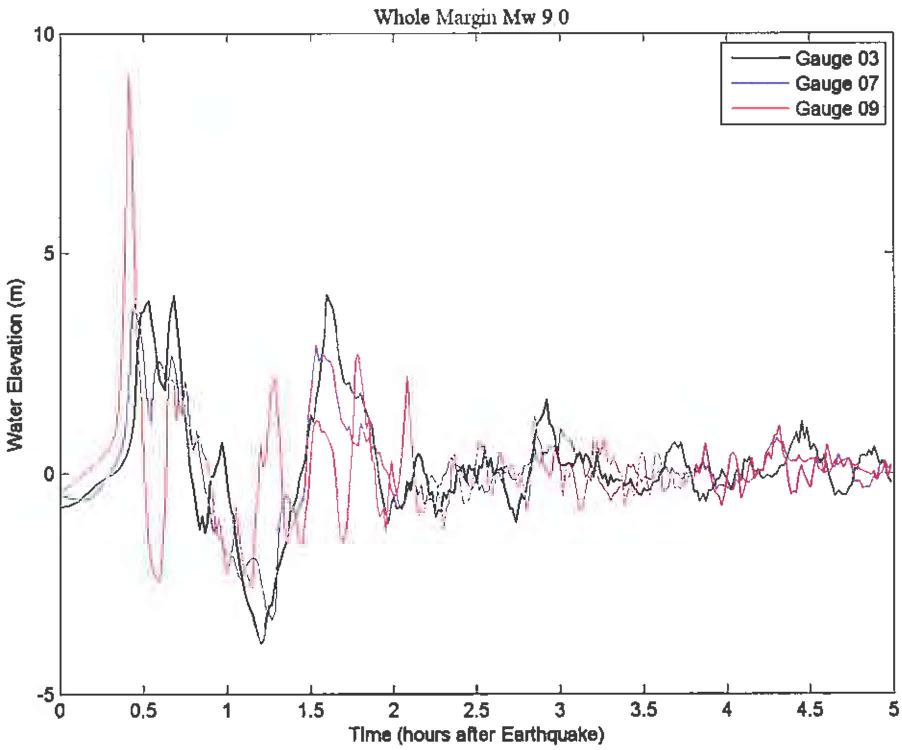

Figure 8.2.5.1-2 Water level fluctuations at virtual tidal gauges 03, 07 and 09 (Mean Sea Level, Whole Margin Plate Interface, M_W 9.0) from the coast to offshore in the middle of Poverty Bay. The results indicate an exceptional water level of about 9.0 meters high near the Wainui coast (Gauge 09).

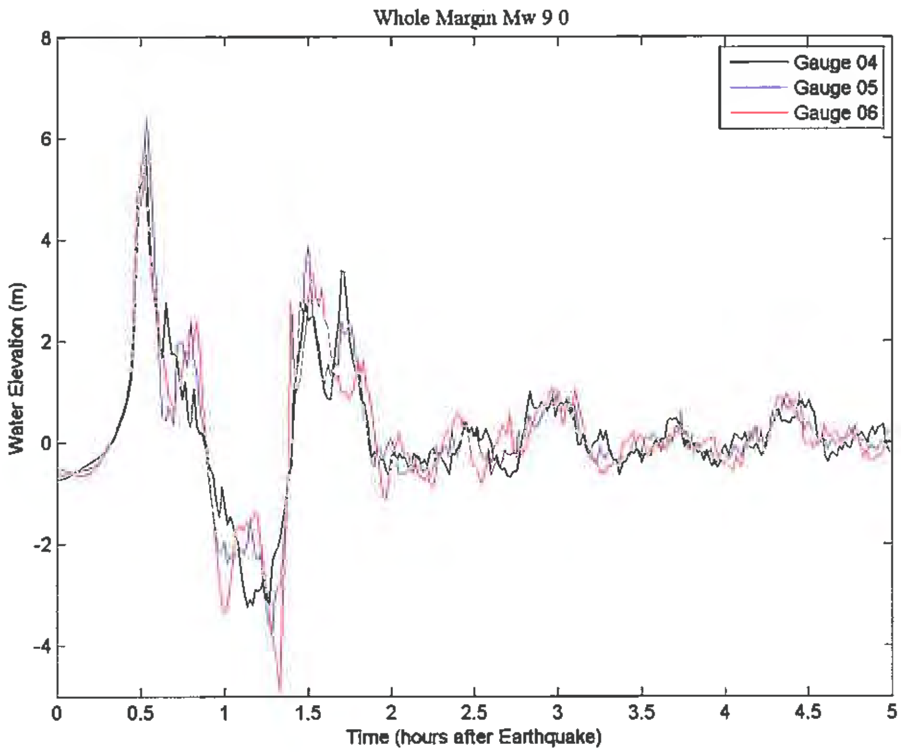

Figure 8.2.5.1-3 Water level fluctuations along the coast of Poverty Bay at virtual tidal gauges 04, 05 and 06; these show the waves arrive almost at the same time along the coast with almost the same height (Mean Sea Level, Whole Margin Plate Interface, M_W 9.0).

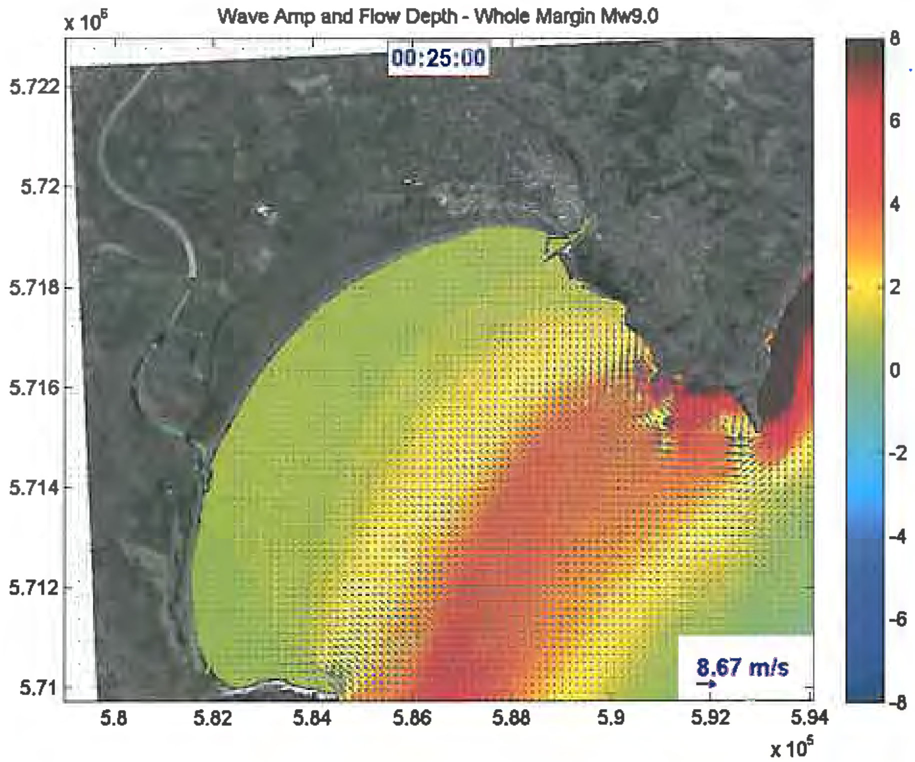

Figure 8.2.5.1-4.a Snapshot of tsunami propagation shows the first wave hitting the Wainui area and entering Poverty Bay. The arrow in the lower right corner shows the scale for the velocity vectors. The scale bar is in metres.

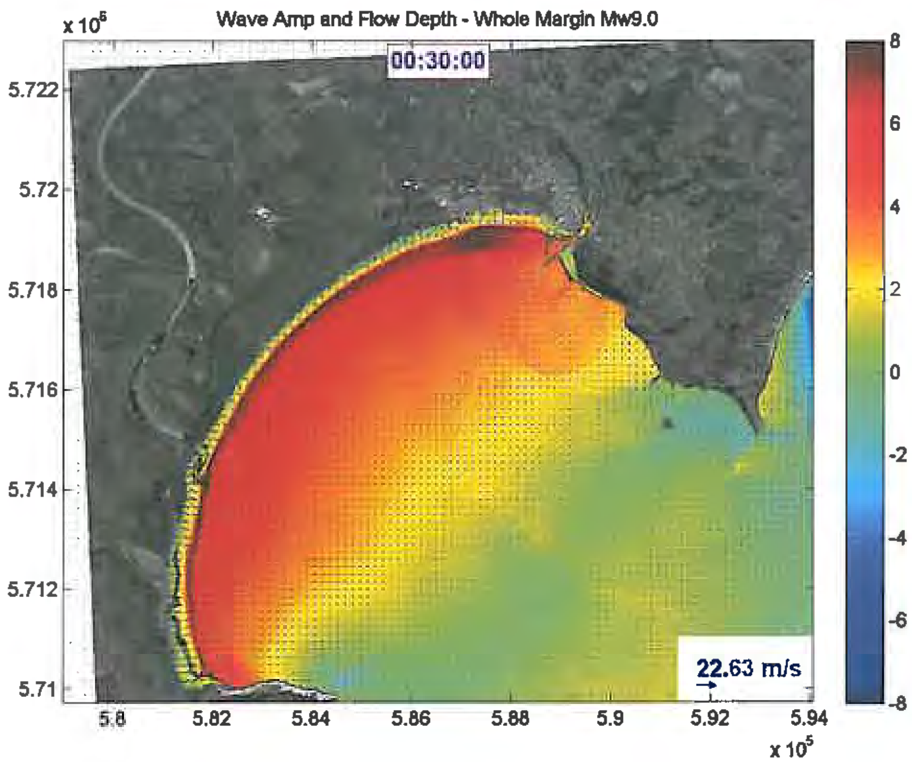

Figure 8.2.5.1-4.b Snapshot of tsunami propagation inside Poverty Bay when the first wave starts to overtop the sand dune. The arrow in the lower right corner shows the scale for the velocity vectors. The scale bar is in metres.