Appendix 1 – Comparison of erosion and siltation before and after Port development

Introduction

1. This appendix addresses changes that have occurred within Te Awanui in relation to erosion and siltation before September 2022, because of Port development and as compared to the period before the dredging of the main channel occurred. It is focussed on locations identified in the Environment Court hearing for Stella Passage as locations of particular interest to Mana Whenua.

2. Episodic erosion on the seaward margin of Panepane occurs during a combination of large storm waves from a narrow range of directions, and a rising tide enhanced by a storm surge, allowing waves to erode the foredunes normally not exposed to wave action. This combination of conditions occurs rarely and has occurred before and after port development occurred with similar effects. The major difference between pre-development and post development erosion is the changed location of the shoreline due to accretion between erosion episodes.

Background

3. The Port of Tauranga was officially established on 1 September 1873, with the Tauranga Harbour Board being formed to control wharves within Te Awanui on 26 October 1912[1]. A wharf was constructed at Mount Maunganui in 1910 (Railway or D Wharf) for the handling of materials for the construction of the East Coast railway Tauranga-Te Puke section. Although it was intended as a temporary structure, it remained until demolished in 1936. A new railway wharf was constructed at Tauranga (Town Reach) starting in 1924. This wharf was primarily used for coastal shipping until October 1948 when the first international vessel arrived to load logs.

[1] Port of Tauranga 2013. *Port History to Modern Day*. 20 pp.

4. To handle the growing international trade, the present-day Port of Tauranga started with the construction of a 373 m wharf starting in late 1953 (Figure 1), with 1954 generally considered the start of modern port development. Therefore, this assessment takes 1954 as the boundary between pre-development and development phases for the Port of Tauranga.

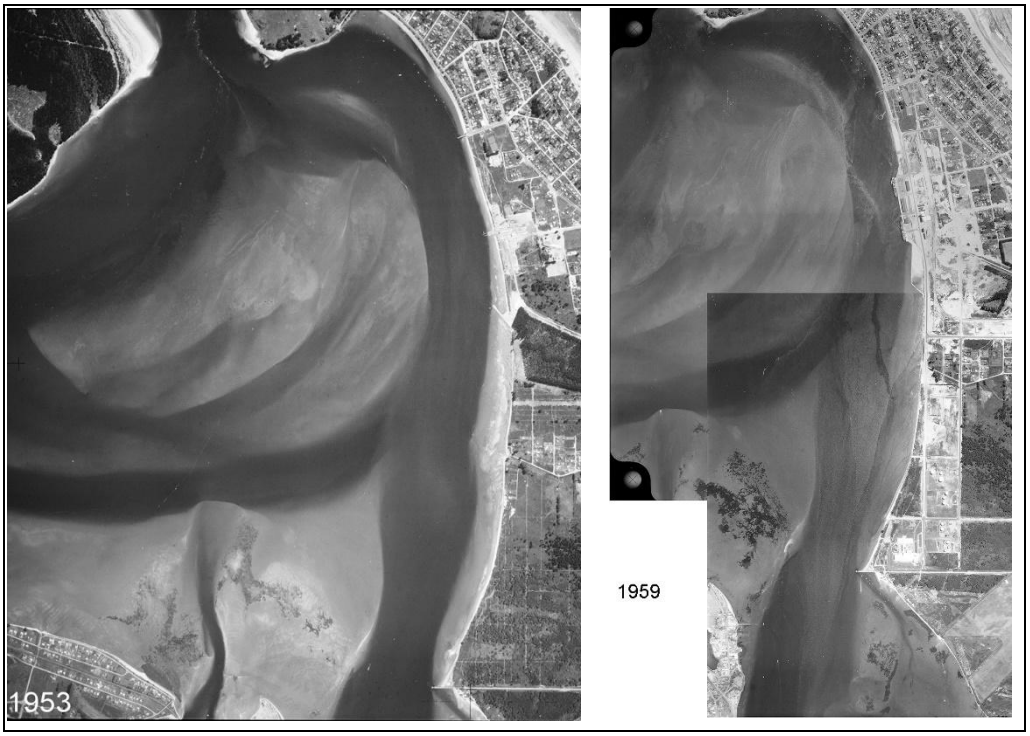


Figure 1 – Comparison of aerial photographs of the port area from 21 January 1953 (Crown 827-2227/3) and 17 January 1959 (Crown 1218-3006/29 & 1218-3007/28).

5. After construction of the first wharf, the Hydraulics Research Station at Wallingford UK, was commissioned by the Tauranga Harbour Board in 1958 to plan future development and assess the impacts of different potential scenarios. The successors to the Tauranga Harbour Board – Bay of Plenty Harbour Board from August 1970 to April 1988, and Port of Tauranga Ltd (**POTL**) since then – have followed the practice of undertaking research into effects of different scenarios prior to undertaking further port development.

6. Consequently, Te Awanui is the most intensively studied harbour in New Zealand, with the earliest studies focussed on physical processes starting in the early 1960s and increasingly including other aspects such as chemistry and ecology towards the present. Te Awanui is an unusual harbour compared to others around New Zealand, with Ohiwa

Harbour in the Bay of Plenty being the most similar. The unusual feature of these two harbours is the distribution of intertidal flats and sub-tidal channels, and the shape of the channel systems, which indicates that both are less infilled with sediment than most barrier lagoons around New Zealand. Both harbours appear to have areas of active subsidence associated with faulting, with both having had local earthquake induced subsidence over the last 800 years. Te Awanui differs from Ohiwa Harbour due to a much lower sedimentation rate, which reflects a low input of sediment into the system from marine and terrestrial sources.

7. Assessing actual and potential anthropic impacts on Te Awanui has been a key objective throughout the research conducted by the University of Waikato and others. This focus led to the establishment of the InterCoast (Integrated coastal zone and shelf-sea research) Graduate Programme, which was a collaboration between the Universities of Waikato and Bremen (Germany) between 2009 and 2018[2]. The research involved 35 PhD students, supported by a similar number of MSc students, and was largely focussed on Te Awanui specifically and the Bay of Plenty more generally.

8. However, for the students examining the anthropic impacts on sedimentation (and associated contamination) and hydrodynamics, it was necessary to shift the focus to other locations, such as the Hauraki Gulf, as their initial fieldwork showed that there was little to no evidence of these types of anthropic impacts beyond the immediate area of the port and the urban areas of Tauranga and Mt Maunganui. These results were consistent with studies conducted before or since InterCoast.

9. Dredging may result in adverse impacts during three phases: during the excavation of the seabed; during the disposal of the extracted sediment (which includes reclamation utilising the sediment); and during the post-dredging recovery. This assessment is focussed on the impacts of past dredging in terms of the excavation and post-dredging phases, although the large-scale reclamation of Sulphur Point and smaller wharf reclamations are considered.

[2] Huhn, K, & Bryan, KR, 2020. Introduction to the special issue of the INTERCOAST graduate training group on coastal and shelf seas in New Zealand and Germany. *Geo-Marine Letters* 40:115 https://doi.org/10.1007/s00367-020-00645-9.

10. During the excavation phase, the main potential impacts are the excavation of benthic biota, and the release of potential contaminants into the water column including suspended sediment (turbidity) and dissolved or absorbed materials such as heavy metals, hydrocarbons and pesticides. These impacts are temporary and can be avoided or mitigated by using appropriate dredging techniques. Due to the temporary nature of these impacts, they tend not to have effects that can be observed in a comparison between pre- and post-development conditions, unless there is a cumulative effect.

11. During the post-dredging phase, the main potential impacts are changes to the tidal circulation and sediment transport within the harbour, which may include changes to the shape of the tidal curve (affecting tidal range, the timing of high and low tide, the duration of flood and ebb tidal flows, and tidal flushing); changes to the behaviour of depth dependent phenomena, such as waves and storm surges; and changed patterns of erosion and accretion. These changes may be permanent, or persistent for more than a year.

12. The effects of a disturbance within an estuary are attenuated with distance: contaminants and conservative properties such as salinity are diluted due to mixing with an increased volume of water; and physical impulses decline due to dissipation and frictional effects. Hence, the maximum impact is at source, and at some point the impact is too small to be of practical significance even if it may be theoretically present. For Te Awanui, a combination of physical and numerical models with direct measurements of key parameters such as water level, current velocity, and sediment characteristics have been used to assess the extent of effective impacts since the early 1960s.

13. The coincident occurrence of some effect with a disturbance due to port development is not proof of a causative link. Further, in my opinion, if an effect is observed further away than the distance at which the disturbance is detectable, it is most likely not a consequence of the disturbance.

Erosion at the southern end of Matakana Island

14. Mana Whenua have raised concerns about coastal erosion at various locations around Te Awanui. Some locations, such as Motuhoa and Rangiwaea Islands, are too far from the port areas dredged and reclaimed for any detectable changes in physical processes due to port development. Erosion for distal areas is driven by local processes unconnected to port development. However, closer to the port area, the impacts of dredging and reclamation on currents and sediment transport could contribute to coastal erosion and accretion.

15. Various studies have examined the effects of dredging and reclamation on the hydrodynamics and evolution of Te Awanui, which has specifically included the impacts on southeastern Matakana Island, Paritaha, and tidal channels within the Tauranga basin. The study by Brannigan (2009)[3], the paper by de Lange et al (2015)[4], and the recent report on erosion at Panepane (de Lange, 2022)[5] are the most relevant with respect to erosion of southern Matakana Island.

16. The south-eastern part of Matakana Island was severely eroded by a tsunami in the early 15th Century resulting of the loss of >2 km of the island and forming the Purakau shoreline, and the Kaharoa shoreline at the northwestern end of the island (Figure 2)[6]. Subsequently, the island has undergone a long-term trend of accretion, predominantly towards the southeast and seaward (Figure 4C).

[3] Brannigan AM, 2009. *Change in geomorphology, hydrodynamics and surficial sediment of the Tauranga Entrance tidal delta system.* MSc Thesis, The University of Waikato, Hamilton, New Zealand.
[4] de Lange WP, Moon VG, & Johnstone R, 2015. *Evolution of the Tauranga Harbour Entrance: Influences of tsunami, geology and dredging.* Proceedings of the Australasian Coasts and Ports Conference, 15-18 September 2015, Auckland, New Zealand.
[5] de Lange WP, 2022. Morphological changes for southeastern Matakana Island (Panepane Point) and Matakana Banks (ebb tidal delta) 2016-22. Report to the Port of Tauranga Ltd. August 2022. 15 pp.
[6] Shepherd MJ, McFadgen BG, Betts HD, & Sutton DG, 1997. *Formation, landforms and palaeo-environment of Matakana Island and implications for archaeology*. Science & Research Series No.102, Department of Conservation, Wellington. 102 pp.

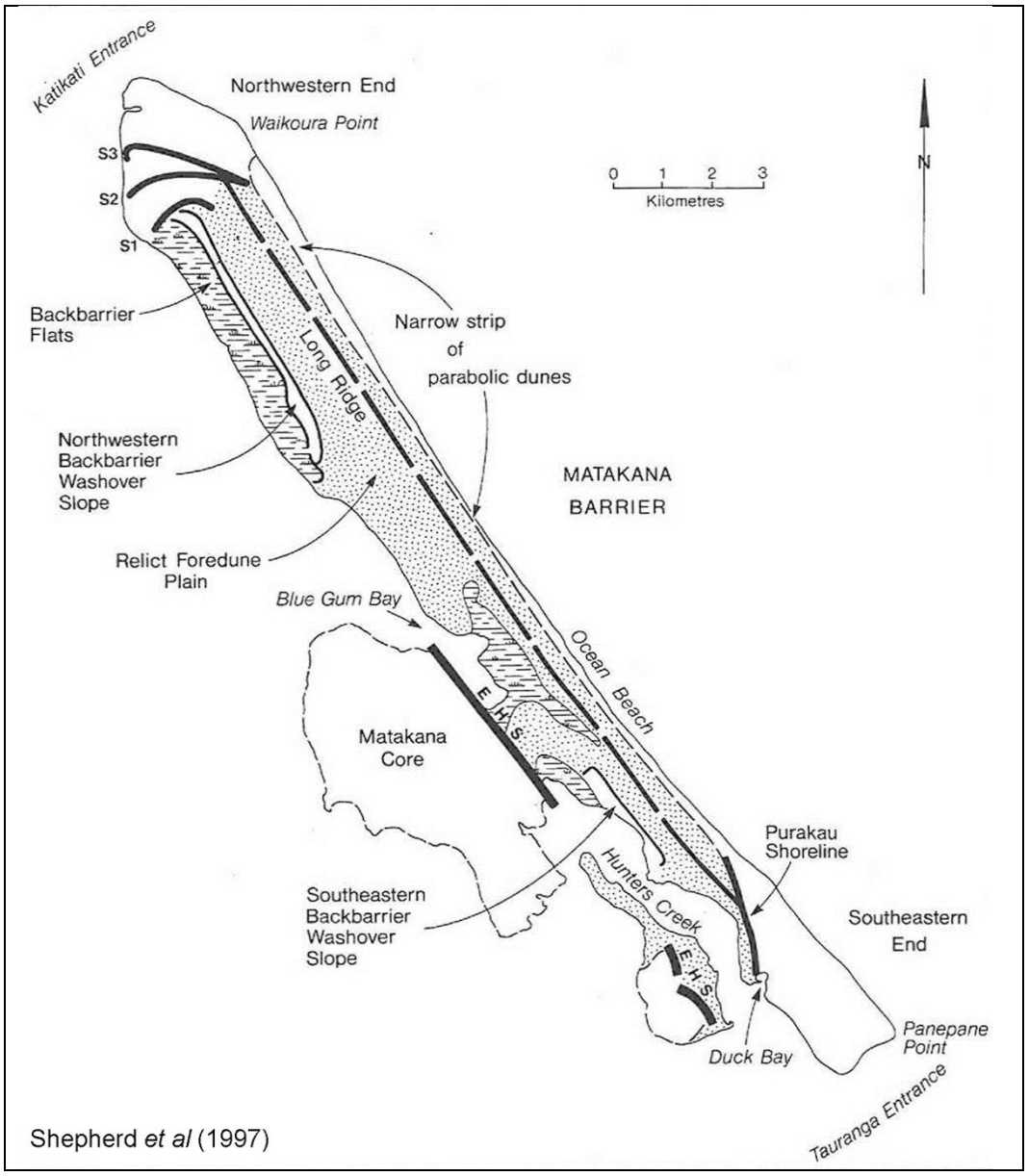


Figure 2 - Map of Matakana barrier island showing landforms and former shorelines. EHS = earliest Holocene shoreline (~7200 BP); S1 and S2 = eroded shorelines; S3 = Kaharoa shoreline. Figure 7 from Shepherd *et a*l (1997).

17. The south-eastward extension of the island is limited by the currents within the tidal inlet (Tauranga Entrance) and the presence of Mauao, which prevents eastward migration of the tidal inlet. Successive hydrographic surveys from 1852 to 1954 (Figures 3 & 4) show that the tidal inlet has progressively narrowed and deepened over time; relatively steadily until the 1970s, but at a decreasing rate since then due to the resistance to erosion of harder layers exposed as the channel deepened.

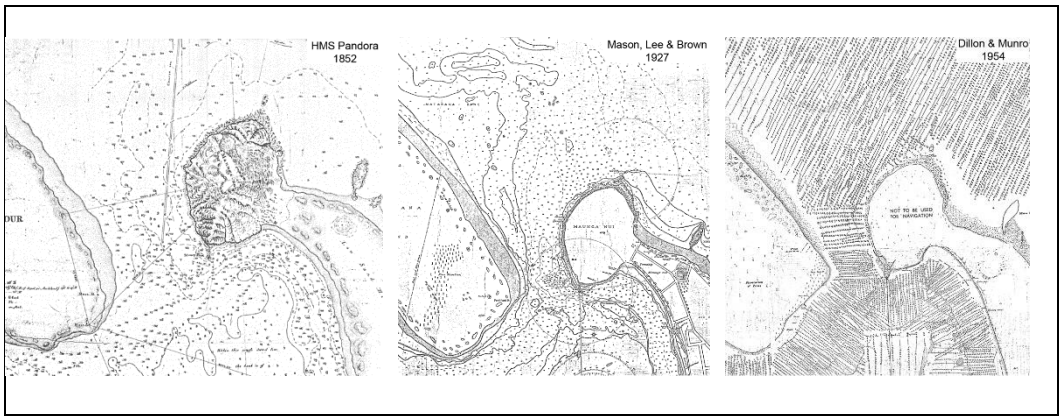


Figure 3 – Hydrographic charts for the Tauranga Entrance to Te Awanui showing the accretion of Panepane and southeastern Matakana Island from 1852 to 1954, prior to the start of the port development. Original charts provided by the Port of Tauranga.

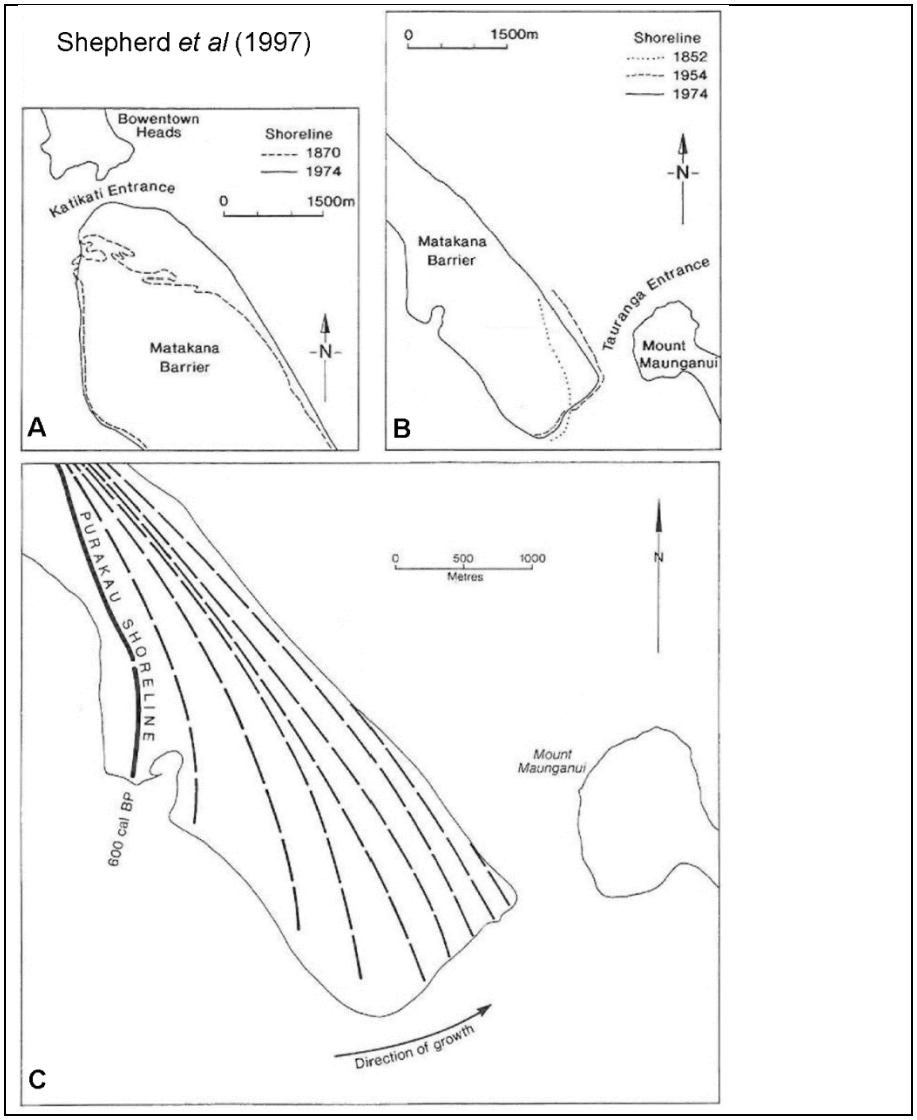


Figure 4 – Prehistoric and historical changes at either end of Matakana Island: A – northwestern end between 1870 and 1974 based on charts; B – southeastern end between 1852 and 1974 (1954 also shown for comparison with Figure 3) based on

charts; C – southeastern end since 15th Century based on parallel dune ridges marking former shorelines.

18. Brannigan (2009) documents the changes over time based on hydrographic survey data, and provides summary diagrams (Figure 5). The time periods shown correspond to the specific years that were modelled to determine the changes to harbour circulation by Brannigan (2009) and other studies he references.

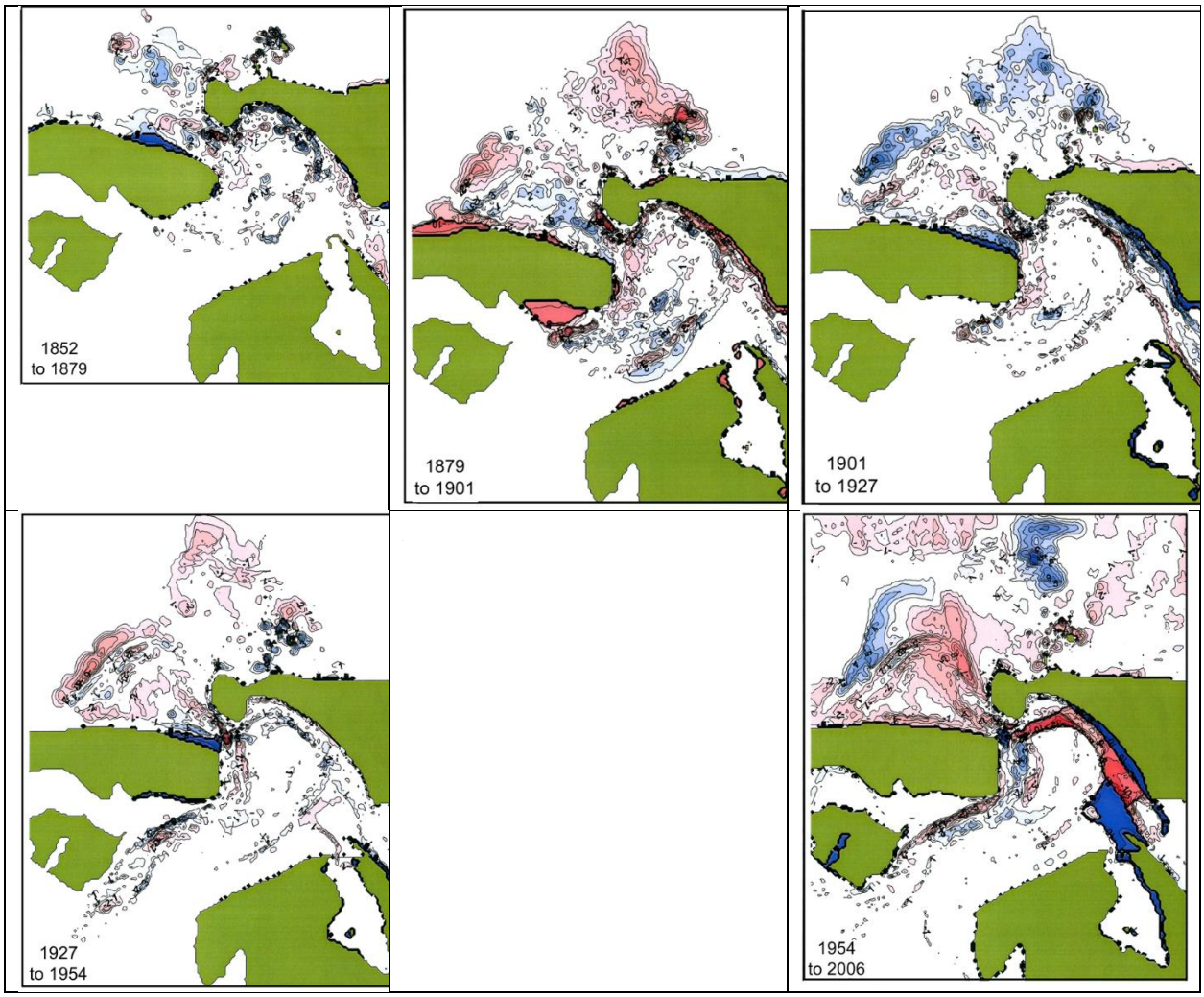


Figure 5 – Contours of elevation changes between hydrographic surveys of the ebb-flood tidal system of the Tauranga Entrance to Te Awanui (Brannigan, 2009). Areas of accretion and erosion are shaded blue and red respectively. The final panel 1954-2006 highlights the areas that have changed since port development began in 1953 (Table 1), but does not include the extension of the Sulphur Point wharf in 2013, and the 2015-2016 Capital Dredging Programme. The darkest blue areas in the final panel represent reclamation for the port and other transport infrastructure, apart from the sedimentation within Rangiwaea Island.

19. The shape of the southeastern end of Matakana Island is due to the combined effects of tidal currents and waves, particularly on the seaward side, and the availability of sediment. There is no evidence for a reduction in the availability of sediment, and some evidence for an increased supply due to port development in relation to changes to tidal currents and wave behaviour as discussed further below.

20. Although the low temporal resolution of historical surveys and proxy indicators of shoreline positions before 1954 suggest accretion has been steady, there is evidence that there have been phases of erosion. Shepherd et al (1997) discuss the existence of 3 phases of wind erosion forming parabolic dunes. This indicates periods of significant loss of vegetation from parts of the parallel dune ridges. One phase occurred ~4000 BP, while the other two were associated with anthropic factors 600-800 years BP, and in the late 1800s. All 3 phases appear to have involved a temporary loss of sediment from the shoreline as sand moved inland.

21. Erosion associated with severe storms is evident since aerial photographs became available in the 1940s. Two distinct patterns have been observed (Figure 6): quite frequent localised embayments occurring at relatively fixed positions along the shoreline due to focussing of waves by swash bars on the ebb tidal delta (Matakana Banks); and rarely an extensive zone of erosion on the seaward side of Panepane associated with the formation of a wide shallow flood marginal channel, which occurs when ENE storm waves refract and diffract around Mauao during a flood tide, focussing wave energy on the foredunes near high tide. The localised embayments rapidly recover (weeks to months), but the erosion associated with the flood marginal channel takes longer (several years).

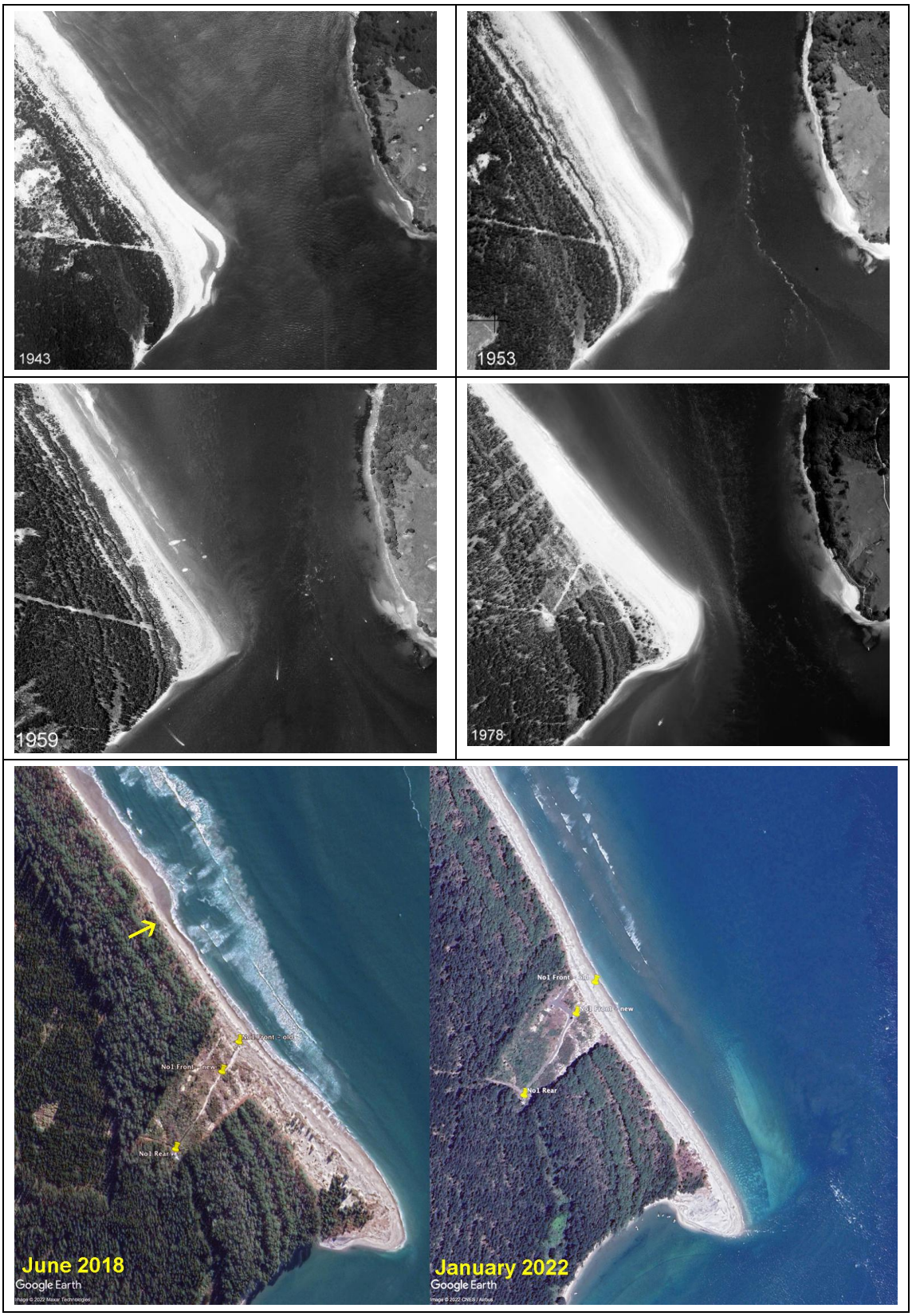


Figure 6 - Aerial photographs for 1943-1978, and Google Earth images for June 2018 and January 2022, of the entrance to Tauranga Harbour showing changes to Panepane associated with the formation and burial of a marginal flood channel on the seaward side of the spit. Note the typical erosion associated with swash bar focussing at the location marked by an arrow in June 2018, and the marginal flood channels present at the spit tip in 1959 and January 2022.

22. The SO 22298 (1922) MHWM Water Boundary is used to mark the seaward boundaries of properties at the southeastern end of Matakana Island.

23. Considering all of the port developments since 1954, two specific changes to the bathymetry of the ebb tidal delta and tidal inlet appear to have impacted the development of Panepane since the early 1970s (de Lange et al, 2015) based on modelling by Brannigan (2009), Speirs et al (2009)7, Speirs (2013)8, and Ramli (2016)9. These changes were due to the dredging of the Entrance Channel in 1971 and lowering of Tanea Shelf in 1972.

24. The creation of the Entrance Channel resulted in a change to the orientation of the ebb tidal jet and associated ebb-tidal eddies, which caused a change from a predominantly bar-bypassing system to a tidal bypassing system. Increased tidal bypassing involves a higher volume of marine sediment transported into the harbour along the western margin of the tidal inlet (Panepane foreshore) during flood tide. Most of the sediment is then exported out of the entrance through the Entrance Channel at ebb tide.

25. The volume of sediment transported per annum is 50,000 m^3 to 100,000 m^3 (Healy and de Lange, 2014)[10]. It is unclear what proportion of sediment transported by the flood tide is retained within the harbour. However, the impact on Panepane was to increase the rate of accretion due to the higher sediment availability, but the effect was limited by the tidal flows through the entrance.

26. Lowering Tanea Shelf resulted in an increase in the cross-sectional area of the tidal inlet between Panepane and Mauao, which reduced the current velocities. Lower tidal velocities allowed the western margin (Panepane) to accrete further eastward than it

[7] Spiers KC; Healy TR; & Winter C, 2009. Ebb-Jet Dynamics and Transient Eddy Formation at Tauranga Harbour: Implications for Entrance Channel Shoaling. *Journal of Coastal Research*, 25: 234-247.
[8] Spiers K, 2013. *Investigation of access channel sedimentation processes and the impact of capital dredging on harbour circulation patterns.* PhD Thesis, The University of Waikato, Hamilton, New Zealand.
[9] Ramli AY, 2016. *The Impact of Dredging on the Stability of Matakana Banks Ebb-Tidal Delta*. PhD Thesis, University of Waikato, Hamilton, New Zealand.
[10] Healy TR, & de Lange WP, 2014. Reliability of geomorphic indicators of littoral drift: Examples from the Bay of Plenty, New Zealand. *Journal of Coastal Research*, 30: 301-318

would otherwise have done. This continued until the pre-lowering velocities were re-established. The same effect occurred in response to further (but smaller) removal of Tanea Shelf during the 1991-92 Capital Dredging Programme.

27. Therefore, the overall impact of port development on Panepane was to temporarily enhance the natural accretion trend and to allow the harbour entrance to become narrower (a few 10s of metres) than it would have become naturally. Panepane now appears to be back in equilibrium with the supply of sediment driving accretion, which makes the erosion associated with episodic storms more evident (e.g. de Lange, 2022). With Panepane in equilibrium, a higher proportion of the marine sand transport into Te Awanui is likely to be deposited within the Lower Western Channel and on Paritaha.

Siltation of channels

28. Siltation within Te Awanui tidal channels occurs in response to sediment supplied from one, or both, of two sources: marine sediment transported into Te Awanui by waves and tidal currents; and terrestrial sediment from freshwater catchments and shoreline erosion, reworked and transported by waves and tidal currents within the harbour. The sediment source within the port area is predominantly marine and associated with the ebb and flood tidal delta system (MacPherson *et al*, 2017)[11]. Further into Te Awanui, the sediment sources are predominantly terrestrial (Pritchard *et al*, 2009[12]; Hancock *et al*, 2009[13]).

29. The boundary between marine-dominated and terrestrial-dominated is not static: it varies with the changing magnitude of tidal flows over spring-neap cycles, magnitude of freshwater inflows, and the influence of storms through storm surges and floods. In the long-term, as the harbour matures, the boundary moves seaward as the harbour naturally infills with sediment.

[11] MacPherson D, Fox BRS & de Lange WP, 2017: Holocene evolution of the southern Tauranga Harbour, *New Zealand Journal of Geology and Geophysics* 60: 392-409.
[12] Pritchard M, Gorman R, & Hume T, 2009a. Tauranga Harbour Sediment Study: Hydrodynamic and Sediment Transport Modelling. NIWA Client Report: HAM2009-032, February 2009.
[13] Hancock N, Hume T, & Swales A, 2009. Tauranga Harbour Sediment Study: Harbour bed sediments. NIWA Client Report: HAM2008-123, March 2009.

30. Analysis of historical hydrographic charts and numerical modelling shows that before 1954, in conjunction with the accretion of southeastern Matakana Island, the Lower Western Channel (ebb channel) has migrated and infilled with sediment, and Paritaha (flood tidal delta) has shoaled (Figures 3 and 5). The maximum accretion within the harbour was closest to the Matakana shoreline, and decreased eastwards towards the eastern ebb channel (now known as Maunganui Roads).

31. The shoaling of Lower Western Channel was one of the factors that led to the eastern ebb channel being favoured for a port, although the Lower Western Channel was used for mooring vessels with hazardous cargoes (e.g., ammunitions). Shoaling of the Lower Western Channel also progressively diverted the ebb flow from the western arm of the Tauranga Basin into the Otumoetai Channel. Figure 1 shows the remnants of a series of shallow ebb channels across Te Paritaha in 1953 and 1959 that track the progressive eastward migration of ebb discharge from the western arm.

32. Te Paritaha has also shoaled over time. However, as the earliest surveys concentrated on measuring the channels, the data for the shallows of the flood tidal data are sparse (Figure 3) making it more difficult to assess. Since the earliest surveys, areas on Te Paritaha were recorded as drying, as shown by the HMS Penguin survey of Te Awanui undertaken between 1901 and 1902 (which also shows the presence of a single shallow ebb channel on Te Paritaha).

33. Between 1879 and 1962 the area drying on Te Paritaha decreased from ~92,000 m^2 to ~56,000 m^2. During the same period the area shallower than 2 m increased from ~2,206,000 m^2 to ~2,890,000 m^2. The additional area was created by an eastward extension of the ebb shield on the southern flank of Te Paritaha, associated with the diversion of more ebb flow into the Otumoetai Channel as the Lower Western Channel shoaled.

34. Within Te Awanui, after 1954 the largest change to tidal currents and sediment transport patterns due to port development occurred when the Cutters Channel was dredged in

1968. This channel was formed by deepening and lengthening an existing blind flood channel that took a portion of the flood flow on the margins of the flood jet. Measurements and numerical modelling indicate that there were two direct impacts on circulation over and around the flood tidal delta (Te Paritaha), which affected sediment transport patterns.

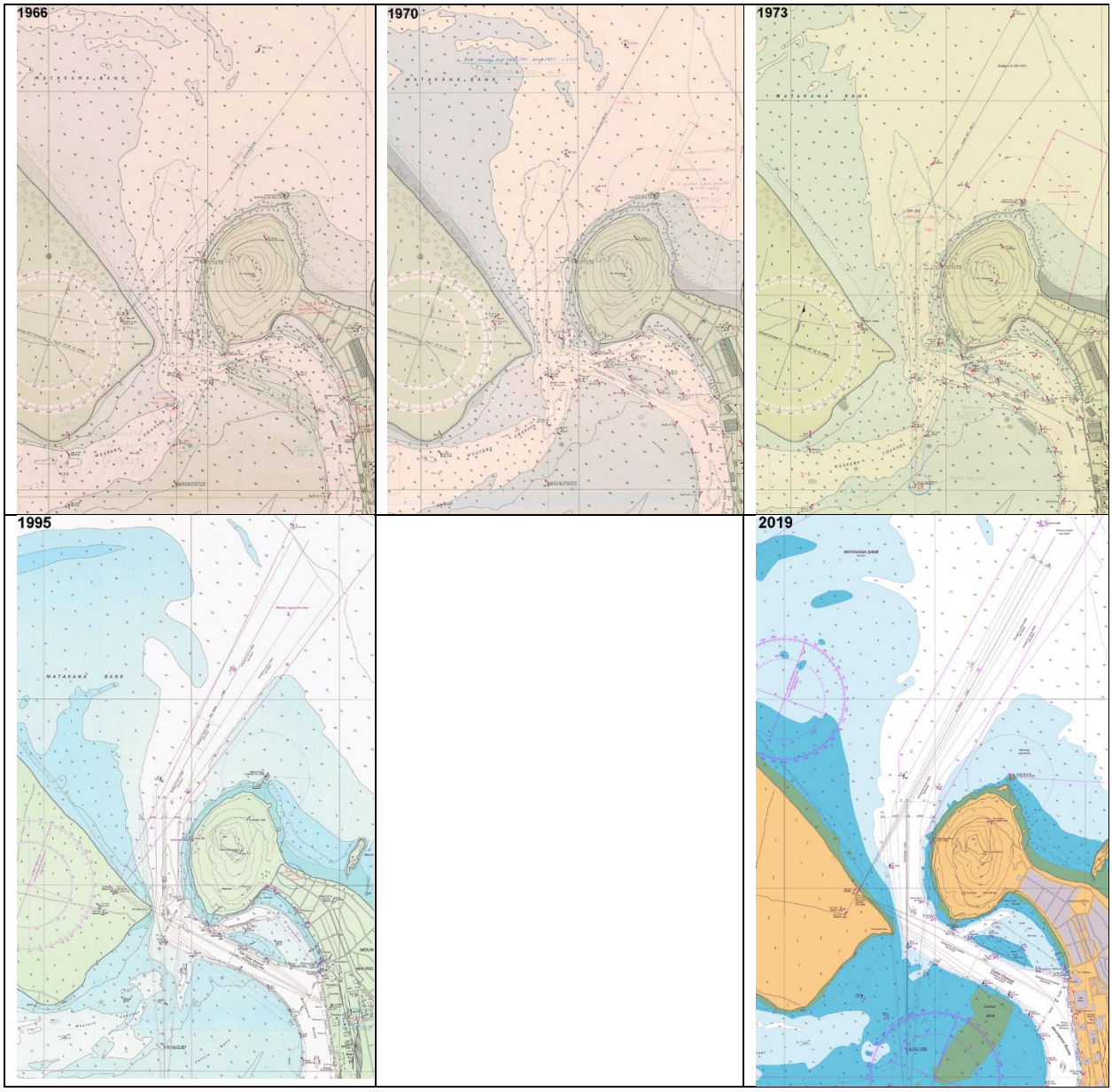


Figure 7 – Sections of hydrographic chart 5412 for 1966, 1970, 1973, 1995 and 2019 that show the changes to the shipping channels, port infrastructure and surrounding harbour bathymetry for the northern port area. The charts are the closest available to provide before and after coverage of major port developments as summarised in Table 1. The harbour bathymetry is unchanged between the 2021 and 2019 charts, so the most recent chart is not included. Note that standard practice for hydrographic charts is to frequently issue updates via Notices to Mariners that cover minor changes; less frequently publish revised charts with major changes, such as alterations to dredged channels and wharves; and rarely publish new charts incorporating all hydrographic data collected since the last new chart. New charts were published in October 1966 (largely using data collected in 1954), January

1975, January 1992, May 2015 (new edition with different colour scheme), August 2019 (new edition), and April 2021 (new edition). Over time the resolution of hydrographic data has improved with the introduction of better technology for position-fixing and depth measurement. Hence, the lack of obvious changes between older charts may be due to the lack of updated data between charts, rather than due to stable conditions.

35. On the northern side of Te Paritaha, Cutter Channel diverted some of the flood flow from the flood ramp, and a significant proportion of the flood flow from the Pilot Bay Channel. Also, during mid- to late-flood tide, an eddy was established that reversed the tidal flow in Pilot Bay from flow to ebb directed.[14] The dredged channel also diverted most of the ebb flow from the Pilot Bay Channel. Therefore, within Pilot Bay Channel the tidal conditions changed to more ebb dominant due to the longer duration of ebb-directed flow, but the peak magnitude of the tidal currents was reduced by around 50-60%.

36. Due to the low availability of sediment for transport due to the presence of shell lag armouring, there was no measurable erosion or accretion of the flood ramp or Pilot Bay Channel. However, there was an increased potential to transport sediment along Pilot Bay beach from then Salisbury Wharf towards Mauao. Also, sediment transported around the eastern margin of Te Paritaha by ebb currents was deposited into the shipping channels at the junction of the Cutter Channel and Maunganui Roads, instead of moving onto the Pilot Bay bank. This sediment deposition has required ongoing maintenance dredging and was used to restore Pilot Bay beach (de Lange, 1988).

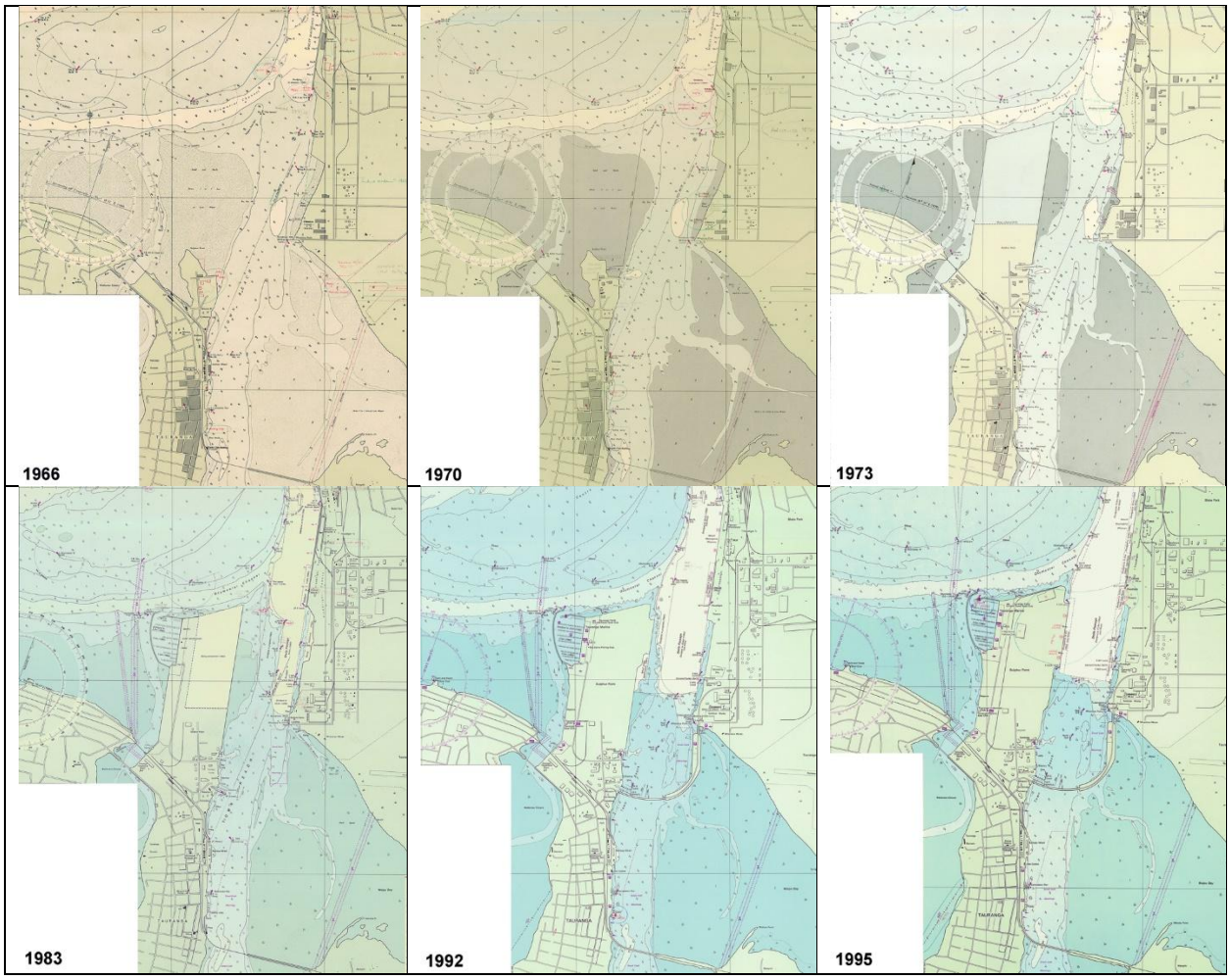
37. On the southern side of Te Paritaha, the increased ebb flow through Cutter Channel appears to have enhanced the pre-development trend of increasing ebb flow through the Otumoetai Channel. This coincided with eastward growth of the ebb shield evident between 1966 and 1973 (Figure 8).

38. Subsequent port development, including reclamation of Sulphur Point and the 1991-92 and 2015-2016 Capital Dredging programs, have not produced significant changes to tidal circulation or sedimentation patterns for the flood tidal delta (Te Paritaha) and adjacent

[14] de Lange WP, 1988. *Wave climate and sediment transport within Tauranga Harbour, in the vicinity of Pilot Bay*. DPhil Thesis, The University of Waikato, Hamilton, New Zealand.

channels. However, the Capital Dredging programmes did remove some material from the flanks of Te Paritaha to widen the channels.

39. Considering Figures 7 and 8, the drying area on Te Paritaha increased between 1962 and 2021 from ~56,000 m^2 to 251,000 m^2; predominantly after Panepane reached equilibrium suggesting that the sediment supply that was contributing to the accretion of Panepane was then transported onto Te Paritaha. During the same period, the area shallower than 2 m depth decreased from 2,890,00 m^2 to 2,177,000 m^2 due primarily to the dredging of the Cutter Channel in 1968, and the 1991-92 channel deepening. The more recent 2015-2016 channel widening and deepening had a lesser impact than the earlier dredging programmes.



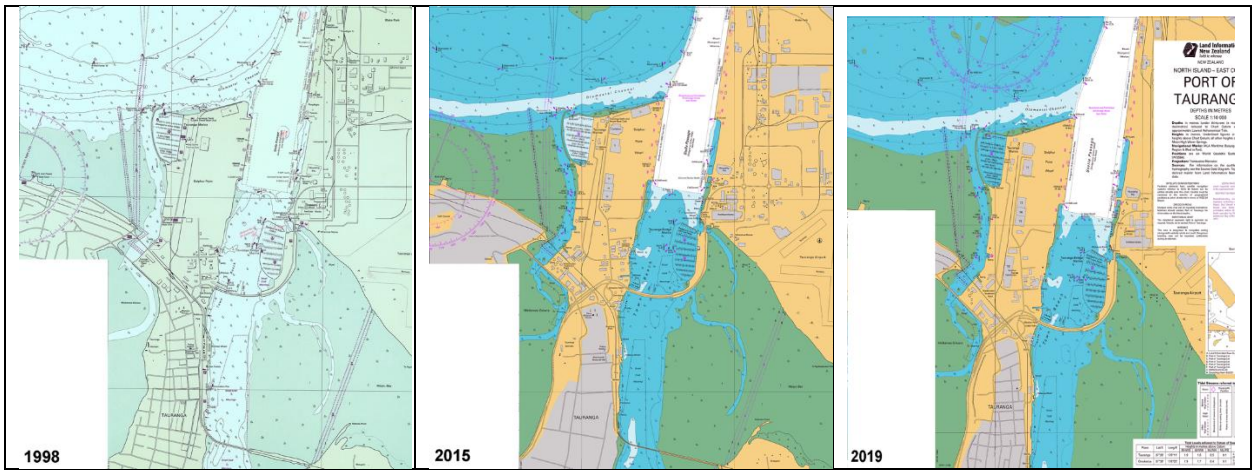


Figure 8 – Sections of hydrographic chart 5412 for 1966, 1970, 1973, 1995 and 2019 that show the changes to the shipping channels, port infrastructure and surrounding harbour bathymetry for the southern port area. The charts are the closest available to provide before and after coverage of major port developments as summarised in Table 1. The harbour bathymetry is unchanged between the 2021 and 2019 charts, so the most recent chart is not included. See caption for Figure 7 for more details about the charts.

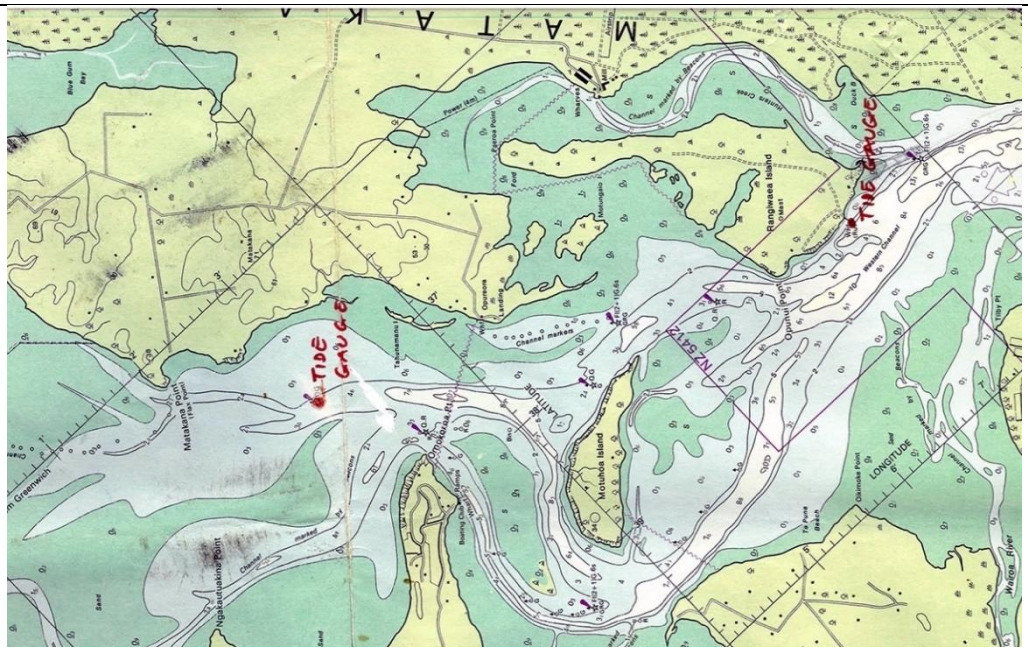
40. The other channels potentially affected by siltation that may be directly linked to port activities are the channels entering Waipu Bay, Town Reach, and the channel entering the Waikareao Estuary. Comparisons of hydrographic charts and aerial photographs for these areas do not show trends for channel depths at the resolution of these data before or after 1954. However, there has been some modification to the locations of the channels due to the development of causeways and armouring of shorelines. These developments were not part of the port development since 1954, with most associated with the construction of road and railway infrastructure since the 1900s.

41. Reclamation of Sulphur Point occurred on the intertidal flats between the Waikareao Estuary channel and Stella Passage. The channel has migrated eastward and now runs along the western confining bund of the reclamation and the breakwater enclosing the Sulphur Point Marina. This has not been associated with siltation.

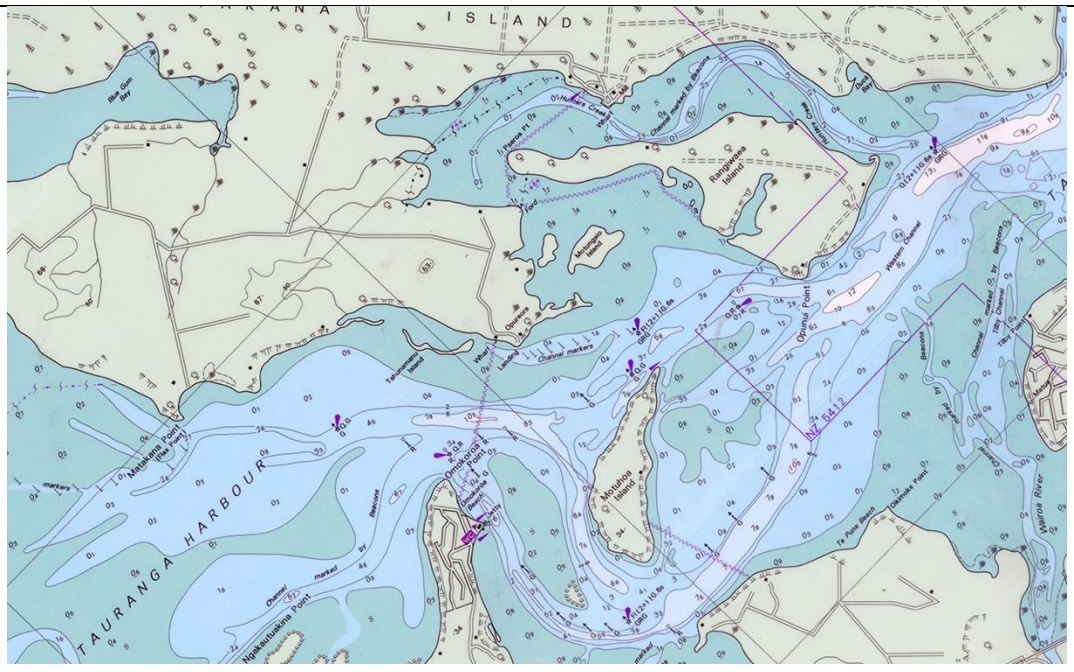
42. The areas beyond the port area where Mana Whenua have raised issues about siltation affecting boat access, such as the Opureora and Rangiwaea/Otapu (Hunters Creek) Channels, are dominated by locally sourced terrestrial sediment. By way of explanation, the siltation of the Opureora and Rangiwaea/Otapu Channels are addressed below. The locations of these channels and available hydrographic charts are shown in Figure 9,

where the Opureora Channel connects the Opureora wharf to the upper Western Channel, and the Rangiwaea/Otapu Channel is marked as Hunters Creek between Rangiwaea and Matakana Islands.

1975



1993



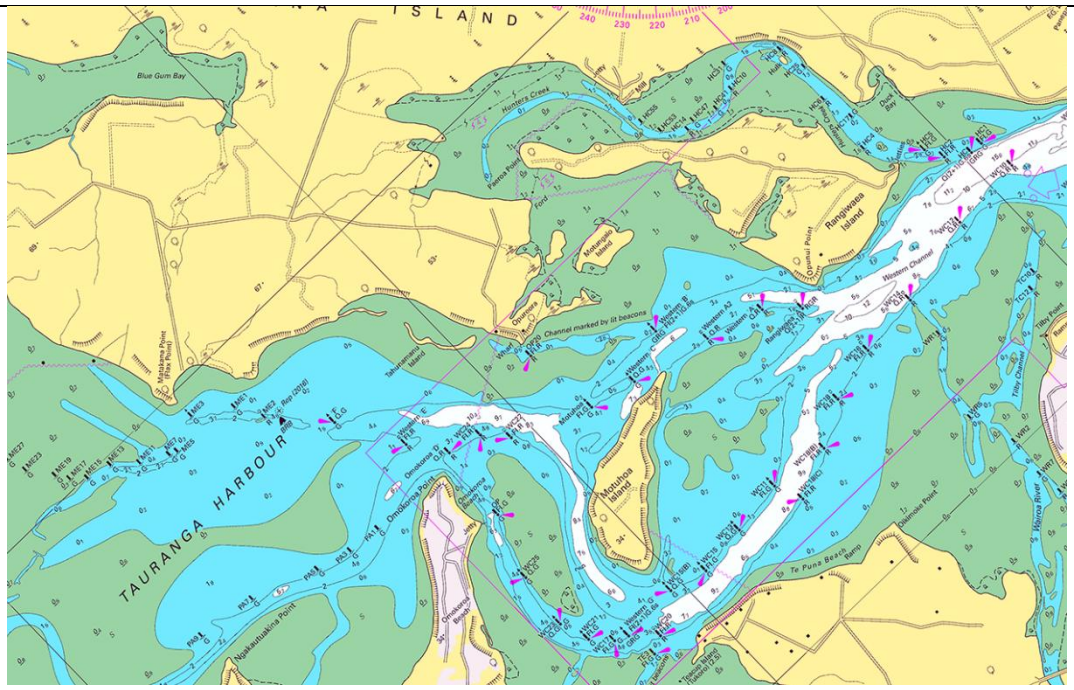


Figure 9 – Sections of hydrographic chart 5411 for 1975, 1993 and 2015 showing the upper Western Channel and western arm of the Tauranga Basin of Te Awanui. The Opureora Channel runs horizontally in the middle of each image, and the Rangiwaea/Otapu Channel (labelled Hunters Creek) runs between Rangiwaea and Matakana Islands.

43. Figure 10 shows mosaics of aerial photographs from 9 February 1943 and 16 January 1959, which are the best two datasets available to cover the period before 1954. The main infrastructural change evident is the establishment of a timber mill and airstrip on Matakana Island on the shore of the Rangiwaea/Otapu Channel. There has also been development of a small subdivision at Omokoroa. The changes to the two channels being considered are discussed below.

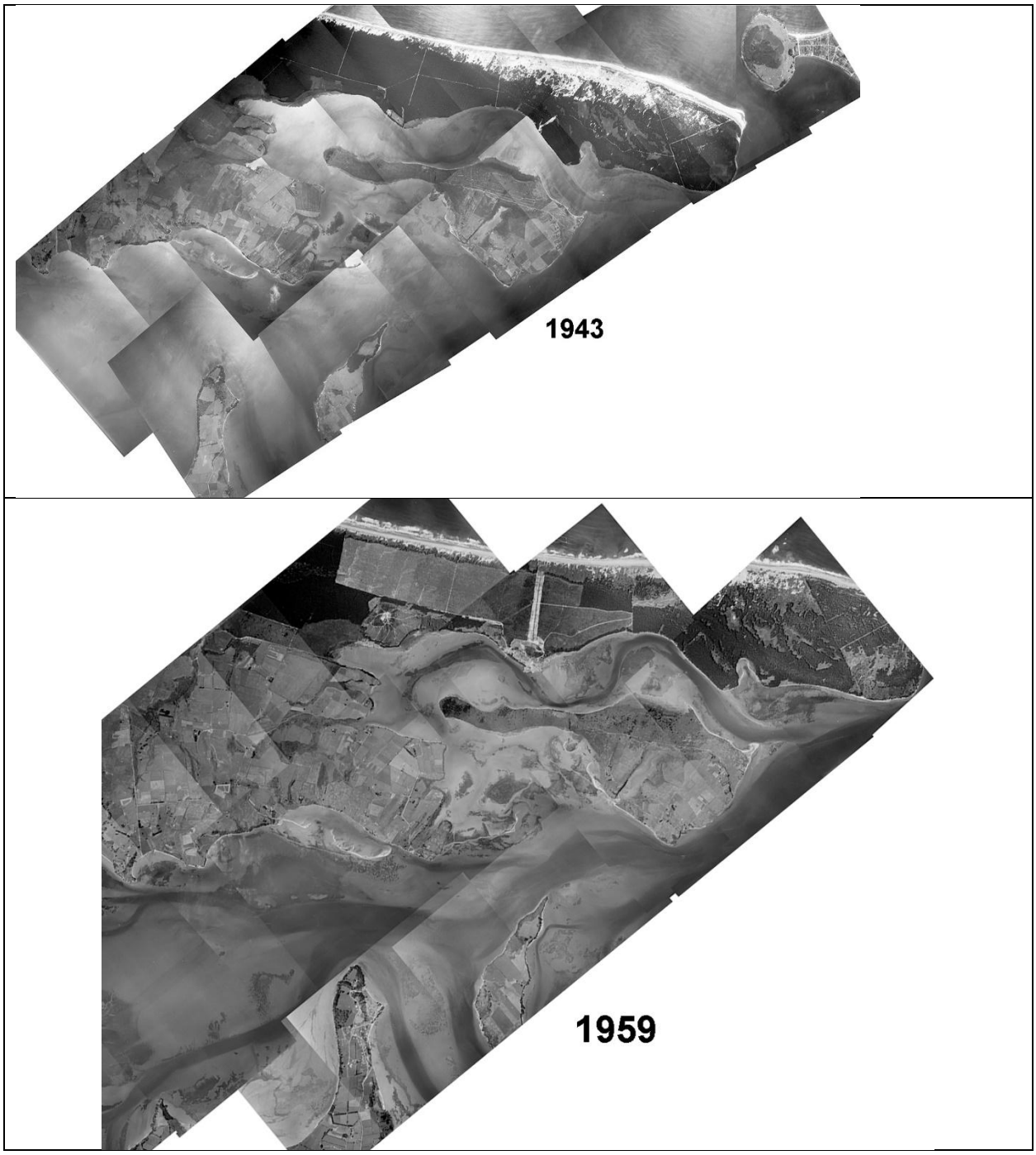


Figure 10 – Mosaics of aerial photographs of the Upper Western Channel area of Te Awanui taken in 1943 (Crown 229-496 & 229-497) and 1959 (Crown 1218-3003, 1218-3004, & 1218-3005).

44. The Opureora Channel is used for a vehicular ferry service between Omokoroa and Opureora, Matakana Island. The Channel has undergone long term siltation that affected

the operation of the ferry[15], resulting in dredging of the channel by the Bay of Plenty Regional Council in September 2017. Siltation within the channel is a consequence of wave action and ebb tidal flows transported sediment eastward over a shallow shoal located on the western side of the channel (Figures 10 and 11).



Figure 11 – Google Earth images of the Opureora Channel and surrounds for March 2003 to April 2022 showing the migration of sediment as sand waves and changes to small islands and spits.

[15] Boffa Miskell Ltd, 2005. *Opureora Channel Capital and Maintenance Dredging: Assessment of Environmental Effects.* Report prepared for Environment Bay of Plenty – Navigation and Safety Section. 36 pp.

45. Parts of the shoal are subaerial shelly sand banks that are partially stabilised by vegetation to form small islands, including Tahuna a Manu. The locations, shapes and areal extent of these islands have continually changed over the available historical record. The Google Earth images (Figure 11) also show the presence of migrating sand waves that overrun seagrass beds. Christophers (2015)[16] investigated the sediment sources for minor siltation affecting the vehicular ferry ramp at Omokoroa and identified the erosion of cliffs around the Omokoroa Peninsula and in situ biogenic production from the intertidal flats as the only viable sources of the sediments deposited.

46. Podrumac (2016)[17] investigated sedimentation in the Upper Western Channel of Te Awanui/Tauranga Harbour between Opunui Point, Rangiwaea Island, and Matakana (Flax) Point, Matakana Island. He identified 5 zones of active sand waves, that were linked to eroding cliffs around the Omokoroa Peninsula; and on Motuhoa, Matakana and Rangiwaea Islands. One of the zones lay in the Upper Western Channel just to the west of the Opureora Channel junction and is linked to erosion of cliffs east of Matakana Point. As reported by various studies (*viz*. Healy *et al,* 2010[18]; Garae, 2015[19]; OPUS, 2015[20]; Tonkin and Taylor Ltd, 2018[21]), cliff erosion around the shores of Te Awanui is primarily driven by subaerial processes, primarily rainfall, with marine processes such as waves and tidal currents eroding and transporting landslide debris away after it falls onto intertidal flats or into channels. This pattern of behaviour has not been affected by port development.

47. The material excavated from the Opureora Channel by a cutter-suction dredge in September 2017 was pumped ashore and used to renourish the beach below Opureora

[16] Christophers A, 2015. *Paleogeomorphic reconstruction of the Omokoroa Domain, Bay of Plenty, New Zealand*. MSc thesis, The University of Waikato, Hamilton, New Zealand.
[17] Podrumac A, 2016. *Holocene evolution of the Upper Western Channel within Tauranga Harbour*. MSc Thesis, The University of Waikato, Hamilton.
[18] Healy TR, Scarfe B, & Schimmel A, 2010. *Eastern Tauranga Harbour historical erosion assessment: Aerial photograph GIS.* Report by Coastal Marine Group, Department of Earth Sciences, The University of Waikato, Hamilton, New Zealand.
[19] Garae CP. 2015. *Estimating patterns and rates of coastal cliff retreat around Tauranga Harbour.* MSc Thesis, The University of Waikato, Hamilton, New Zealand.
[20] OPUS, 2015. *High level coastal erosion study: Coastal erosion risk, cost benefit analyses and site proritisation*. Tauranga Inner Harbour Contract 14-1011. 48 pp.
[21] Tonkin and Taylor Ltd, 2018. *Tauranga Harbour coastal hazards study: Coastal erosion hazard assessment*. Report prepared for Bay of Plenty Regional Council. 41 pp.

Marae, despite being assessed as being unsuitable for the purpose[22]. The issue identified is that the material was likely to be rapidly dispersed by the waves and tidal currents, resulting in the loss of at least 80% of the volume deposited. The dredging and renourishment were completed in October 2017[23].

48. The renourished beach extending from the marae to the end of the spit, and narrow dredged channel at the northern end of Opureora Channel close to the ferry ramp, are visible in the Google Earth image for September 2018 (Figure 11). In April 2022 (Figure 12), the renourished sediment is moving eastward towards the end of the spit, consistent with the direction of longshore movement evident in time series of images in Figures 10 and 11. The dispersal of sediment sourced from erosion of the cliffs on the Matakana shoreline and shells from the intertidal areas, is driven by the locally generated wind waves and the ebb tidal currents associated with the Upper Western Channel. Neither of these processes have been affected by port development, so in my opinion port development has not caused siltation of the Opureora Channel.



[22] Tonkin and Taylor Ltd, 2014. *Opureora Dredging Spoil Disposal Assessment*. Report prepared for the Bay of Plenty Regional Council. 61 pp.
[23] Bay of Plenty Regional Council, 2018. *Tauranga Moana Programme Annual Report 2017/2018*. 33 pp.



Figure 12 – Google Earth images for the junction between the Rangiwaea/Otapu Channel and Upper Western Channel between March 2003 and February 2022 showing the accretion of spits and variations in seagrass cover.

49. The Rangiwaea/Otapu Channel lies between Rangiwaea Island and Matakana Island. Shepherd *et al* (1997) inferred that this channel previously was directly connect to the sea through a tidal inlet located in the area of washover deposits (Figure 2) formed as the inlet either migrated southeast to the present Tauranga Entrance, or closed, as Matakana Island accreted. The Rangiwaea/Otapu Channel drains very shallow backbarrier flats (Figure 10).

50. Hancock *et al* (2009) reviewed studies of sedimentation rates for Te Awanui. The Rangiwaea/Otapu Channel was classified as a low energy zone (low wave and medium tidal energy) with medium mud content (8.5-10.8%). This represents a higher level of fine sedimentation than most of Te Awanui, except for sheltered muddy embayments that are low to very low energy (low wave energy and low to very low tidal energy) with high mud content (10.8-48.1%).

51. The other areas within Te Awanui that have medium to high mud contents are associated with freshwater catchments that discharge fine sediment (Hancock et al, 2009; OPUS, 2011[24]; Park *et al*, 2022[25]). However, the freshwater catchment for the Rangawaea/Otapu Channel is negligible, and freshwater sediment contributions from Matakana and Rangiwaea Islands are not identified as causing sedimentation issues (Park *et al*, 2022). The sedimentation rate for the intertidal flats at Paeroa Point at the northeastern end of Rangiwaea Island was 1.33 $mm.y^{-1}$ over 23 years based on a single core (Hancock et al, 2009), which is average for Te Awanui and low for New Zealand.

52. Unlike the Opureora Channel, there is not a local source of medium to coarse sandy sediment for most of the Rangiwaea/Otapu Channel, apart from the southern end of the channel at the junction with the Upper Western Channel (Figure 12), where material eroded from cliffs between Opunui Point and Rangiwaea Marae is deposited. This deposition has progressively built a series of spits that extend into the channel (Figures 10 & 12) and has occurred throughout the period data are available from 1943 to 2022.

53. Port development since 1954 has not resulted in changes to the rate of sediment supply. The rate of cliff erosion for southern Rangiwaea Island, which determines the volume of sediment available at source, varied along the shoreline from 0.01 to 0.39 $m.y^{-1}$ between 1943 and 2002 (Healy *et al*, 2010) in response to weather events. The sediment transport rate from source depends on the available wave and tidal energy, and there is no evidence that this has changed since 1943.

[24] OPUS, 2011. *Tauranga Harbour Sediment Management Review.* Report prepared for Bay of Plenty Regional Council. 75 pp.
[25] Park S, Crawshaw J, & Fox E, 2022. *Setting sediment load limits to protect ecological values of Tauranga Harbour sub-estuaries.* Bay of Plenty Regional Council Environmental Publication 2022/04. 131 pp.

54. Sediment for the upper reaches appears to be derived from three main sources: fine sands blown inland from the dunes on Matakana Island, particularly during periods of vegetation disturbance such as tree-felling (Figure 10); in situ production of shell material from the intertidal flats; and transport of fine sediment into the area. Based on the numerical modelling undertaken for the Tauranga Harbour Sediment Study, Hume *et al* (2010)[26] concluded that the fine sediment deposited in the upper reaches of the Rangiwaea/Otapu Channel was predominantly sourced from the Wairoa River, particularly during storms.

55. There are no mechanisms whereby port development since 1954 can affect the frequency and magnitude of storm discharges from the Wairoa River. Fine sediment produced by dredging activities associated with port development (turbidity) has been short duration, and very low volumes, compared to the discharges from freshwater catchments. Numerical modelling also has shown that turbidity generated by the Port has not been transported into the Lower Western Channel (Pritchard *et al*, 2009). Therefore, in my opinion, port development has not had an impact on sedimentation between Rangiwaea and Matakana Islands and siltation of the Rangiwaea/Otapu Channel.

Seagrass bed changes

56. Published studies with the longest temporal coverage use 1959 as their baseline, as earlier aerial photographs do not provide adequate coverage for all of Te Awanui. Therefore, they do not allow any assessment of natural changes in the absence of port development before 1954 for all of Te Awanui. However, some areas do have data for 1940, 1943, 1951, and/or 1953. For these areas, some analysis is possible but may not be representative of long-term trends.

57. Aerial photographs of Sulphur Point for 1943, 1951 and 1959 taken before the reclamation undertaken as part of the port development between 1969 and 1989. These

[26] Hume TM, Green MO, & Elliot S, 2010. Tauranga Harbour Sediment Study: Assessment of predictons for management. NIWA Client Report: HAM2009-139, May 2010

show a decline in seagrass beds, some of which is clearly due to burial within a reclamation associated with the New Zealand Railways workshop and causeway across the Waikareao Estuary. The cause of the remaining decline is not clear, partly due to the apparent extent of the seagrass depending on tidal elevation, water clarity, and sun glint at the time the images were taken (Figures 15 & 16).

58. There is also a seasonal variation, with seagrass cover increasing during November to February (summer growth), and declining relatively during February and March (autumn degradation), with a further decline between April and September during wind events[27,28]. This implies that images should be taken during matching seasonal conditions to assess seagrass cover, and this wasn't done as the primary purpose of the imaging was for mapping topography. The analysis of Ha *et al* (2021[29]) derived from satellite imagery, also uses images taken from different seasons, which may explain some of the variability they reported.

59. Natural and anthropic causes for seagrass decline (or expansion) are unclear, and a variety of causes have been suggested as being responsible for these changes in Te Awanui/Tauranga Harbour (*viz*. Turner & Schwarz, 2006[30]; BOPRC, nd[31]; Dos Santos, 2011[32]), including: sedimentation; turbidity; herbicides, pesticides, and other contaminants; excess nutrients; growth of algae impacting on seagrass photosynthesis; dredging and reclamation; anthropic disturbance; and grazing by black swans. Direct removal of seagrass by excavation during dredging, and burial by reclamation, clearly do impact seagrass extent. Most of the other potential drivers of seagrass decline have been investigated for New Zealand and Australia, including specifically for Tauranga Harbour

[27] Martin R, Ellis J, Brabyn L, & Campbell M, 2020. Change-mapping of estuarine intertidal seagrass (*Zostera muelleri*) using multispectral imagery flown by remotely piloted aircraft (RPA) at Wharekawa Harbour, New Zealand. *Estuarine, Coastal and Shelf Science* 246: 107046. 13 pp.
[28] Ramage DL, & Schiel DR, 1999. Patch dynamics and response to disturbance of the seagrass *Zostera novaezelandica* on intertidal platforms in southern New Zealand. *Marine Ecology Progress Series* 189: 275-288.
[29] Ha N-T, Manley-Harris, M, Pham T-D, & Hawes I, 2021. Detecting multi-decadal changes in seagrass cover in Tauranga Harbour, New Zealand, Using Landsat Imagery and Boosting Ensemble Classification Techniques. *International Journal of Geo-Information* 10: 371, 23 pp.
[30] Turner S, & Schwarz A-M, 2006. *Management and conservation of seagrass in New Zealand: An introduction*. Science for conservation 264, Science & Technical Publishing, Department of Conservation, Wellington, New Zealand.
[31] BOPRC, nd. *Seagrass*. Bay of Plenty Regional Council Fact Sheet. 2 pp.
[32] Dos Santos VM, 2011. *Impact of black swan grazing an anthropogenic contaminants of New Zealand seagrass meadows.*

by a series of research student projects (viz. Dos Santos, 2011; Coppede Cussioli, 2018[33]; Sørensen, 2020[34]; Ha, 2021[35]; Zabarte-Maetztu, 2021[36]).

60. In relation to the distribution of seagrass before and after 1954 for all of Te Awanui, additional aspects need to be considered beyond the effects of turbidity:

(a) Grazing by herbivores, particularly Black Swans in Te Awanui, results in significant degradation of seagrass beds that may contribute to a long-term decline (Dos Santos, 2011; Dos Santos *et al*, 2012[37]), and in my opinion is a likely factor in the observed seagrass decline in localised areas of the harbour;

(b) Anthropic disturbance, such as trampling by pedestrian traffic, exercising horses, and vehicles, damages seagrass beds and can result in long-term decline (viz. Travaille *et al*, 2015[38]). Based on my observations, in my opinion this is associated with localised damage to seagrass in areas of high use within Te Awanui;

(c) The factsheet produced by the Bay of Plenty Regional Council (BOPRC, nd) states that "Higher amounts of nutrients in the water column are also related to the decline, as this causes increased algal growth which also reduces the amount of available light". No evidence is provided in the fact sheet to support this claim. The published literature is equivocal on the impact of algal growth on seagrass (e.g. Thomsen *et al*, 2012[39]), with studies suggesting seagrass outcompetes algae, unless suppressed by other environmental stresses (*viz*. Davis & Fourqurean,

[33] Coppede Cussioli M, 2018. *Ecological effects of turbidity variations in and around dredging areas in the Port of Tauranga*. PhD Thesis, The University of Waikato, Hamilton, New Zealand.
[34] Søresen ST, 2020. *New Zealand seagrass (Zostera muelleri) response to acute sedimentation: Linking non-structural carbohydrate reserves to resilience***.** PhD Thesis, The University of Waikato.
[35] Ha N-T, 2021. *Remote sensing dynamics and aboveground biomass of seagrass in Tauranga Harbour (Bay of Plenty, New Zealand*. PhD Thesis, The University of Waikato, Hamilton, New Zealand.
[36] Zabarte-Maetztu I, 2021. *Sediment-effects on seagrass Zostera muelleri in New Zealand.* PhD Thesis, The University of Waikato, Hamilton, New Zealand.
[37] Dos Santos VM, Matheson FE, Pilditch CA, & Elger A, 2012. Is black swan grazing a threat to seagrass? Indications from an observational study in New Zealand. *Aquatic Biology* 100: 41-50.
[38] Travaille KL, Salinas-de-León, & Bell JJ, 2015. Indication of visitor trampling impacts on seagrass beds in a New Zealand marine reserve. *Ocean & Coastal Management* 114: 145-150.
[39] Thomsen MS, de Bettignies T, Wernberg T, Holmer M, & Debeuf B, 2012. Harmful algae are not harmful to everyone. *Harmful algae* 16: 74-80.

2001[40]; Höffle *et al*, 2012[41]; Pereda-Briones *et al*, 2019[42]) or at high levels of burial by macroalgal detritus that also impacts benthic fauna (*viz*. Bishop & Kelaher, 2013[43]; Bittick *et al*, 2018[44]). Based on my observations, in my opinion it is likely that episodic sea lettuce (*Ulva* sp.) blooms within Te Awanui cause localised losses in seagrass beds, but that this is not necessarily contributing to a long-term decline due to recovery between blooms;

(d) Excess nutrients have been linked to seagrass decline through various mechanisms, including the impacts of macroalgal blooms as discussed above. The key nutrients considered are nitrogen and phosphorous (Matheson & Schwartz, 2007[45]); with elevated levels of these attributed to eutrophication associated with freshwater and groundwater nutrient inputs (Li *et al*, 2019[46]). Within Te Awanui, nitrogen appears to be the critical nutrient, with high levels associated with seagrass decline (Dos Santos, 2011; Robertson and Savage, 2021[47]). In contrast, elevated phosphorus levels appear to enhance seagrass growth in Te Awanui (Kohlmeier et al, 2014[48]). Overall, the effects of nutrients (eutrophication) are dependent on seagrass biomass, with resilience increasing as biomass increases (Gladstone-Gallagher, 2018[49]). In my opinion, nitrogen loading is likely to be an important contributor to seagrass decline, as reported by Robertson and Savage (2021) for Ohiwa Harbour;

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[40] Davis BC, & Fourqurean JW, 2001. Competition between the tropical alga, *Halimeda incrassate*, and the seagrass, *Thalassia testudinum*. *Aquatic Botany*. 71: 217-232.

[41] Höffle H, Wernberg T, Thomsen MS, & Holmer M, 2012. Drift algae, an invasive snail and elevated temperature reduce ecological performance of a warm-temperate seagrass, through additive effects. *Marine Ecology Progress Series*. 450: 67-80.

[42] Pereda-Briones L, Terrados J, & Tomas F, 2019. Negative effects of warming on seagrass seedlings are not exacerbated by invasive algae. *Marine Pollution Bulletin*. 141: 36-45.

[43] Bishop MJ, & Kelaher BP, 2013. Replacement of native seagrass with invasive algal detritus: impacts to estuarine sediment communities. *Biological invasions*. 15: 45-59.

[44] Bittick SJ, Sutula M, & Fong P, 2018. A tale of two algal blooms: Negative and predictable effects of two common bloom-forming macroalgae on seagrass and epiphytes. *Marine Environmental Research* 140:1-9.

[45] Matheson FE, & Schwarz A-M, 2007. Growth responses of *Zostera caprivcorni* to estuarine sediment conditions. *Aquatic Botany*. 87: 299-306.

[46] Li M, Lundquist CJ, Pilditch CA, Rees TAV, & Ellis J, 2019. Implications for nutrient enrichment for the conservation and management of seagrass *Zoster muelleri* meadows. *Aquatic Conservation: Marine Freshwater Ecosystems*. 29: 1484-1502.

[47] Robertson BP, & Savage C, 2021. Thresholds in catchment nitrogen load for shifts from seagrass to nuisance macroalgae in shallow intertidal estuaries. *Limnology and Oceanography* 66: 1353-1366.

[48] Kohlmeier D, Pilditch CA, Bornman JF, & Bischof K, 2014. Site specific differences in morphometry and photophysiology in intertidal *Zostera muelleri meadows*. *Aquatic Botany*. 116: 104-109.

[49] Gladstone-Gallagher RV, Hughes RW, Douglas EJ, & Pilditch CA, 2018. Biomass-depandent seagrass resilience to sediment eutrophication. *Journal of Experimental Marine Biology and Ecology*. 501: 54-64.

(e) Herbicides, particularly those that affect photosynthesis, and some pesticides heavy metals have been linked to seagrass decline (Macinnis-Ng & Ralph, 2004[50]; McMahon *et al*, 2005[51]; Dos Santos, 2011; Negri *et al*, 2015[52]; Wilkinson *et al*, 2015[53]; Gamain *et al*, 2018[54]). These contaminants are normally absorbed onto fine sediments, so their effects on seagrass are often combined with any adverse effects due to turbidity (Negri et al, 2015). The concentration of these contaminants is increased by the presence of organic matter in the sediment (Dos Santos, 2011), and is also affected by the temperature, salinity and light levels. For example, uptake of copper by *Zostera muelleri* increases with decreasing salinity and light levels (Skillington *et al*, 2020[55]). The investigation of Dos Santos (2011) found that there was no conclusive evidence that the decline of seagrass beds in Te Awanui is linked to the presence of herbicides and other contaminants;

(f) Turbidity affects photosynthesis by reducing ambient light levels (Bulmer *et al*, 2016[56]). Turbidity generated by dredging and reclamation is short duration, does not travel far, and does not reduce light levels to the point where adverse impacts will occur for existing seagrass beds. The potential impacts of turbidity are also reduced by the low mud content of the sediments for seagrass beds close to the port area due to decreasing sensitivity to low irradiance with decreasing muddiness (Zabarte-Maeztu, 2021; Zabarte-Maeztu *et al*, 2021[57]). For Te Awanui, natural turbidity produced by floods and wave action within the harbour, are

[50] Macinnis-Ng CMO, & Ralph PJ, 2004. In situ impact of multiple pulses of metal and herbicide on the seagrass, *Zostera capricorni*. *Aquatic Toxicology*. 67: 227-237.
[51] McMahon K, Bengston Nash S, Eaglesham G, Müller JF, Duke NC, & Winderlich S, 2005. Herbicide contamination and the potential impact to seagrass meadows in Hervey Bay, Queensland, Australia. *Marine Pollution Bulletin*. 51: 325-334.
[52] Negri AP, Flores F, Mercurio P, Mueller JF, & Collier CJ, 2015. Lethal and sub-lethal chronic effects of thre herbicide diuron on seagrass. *Aquatic toxicology*. 165: 73-83.
[53] Wilkinson AB, Collier CJ, Flores F, & Negri AP, 2015. Acute and additive toxicity of ten photosystem-II herbicides to seagrass. *Scientific Reports*. 5: 17443, 10 pp.
[54] Gamain P, Feurtet-Mazel A, Maury-Brachet R, Auby I, Pierron F, Belles A, Budzinski H, Daffe G, & Gonzalez P, 2018. Can pesticides, copper and seasonal water temperature explain the seagrass *Zostera noltei* decline in the Arcachon bay? *Marine Pollution Bulletin*. 134: 66-74
[55] Skillington A, Flint N, Anastasi A, Dwane G, & Jackson EL, 2020. Influence of variable salinity and low light on copper accumulation in the potential seagrass bioindicator, *Zostera muelleri*. *Marine Pollution Bulletin*. 160: 11602, 8 pp.
[56] Bulmer RH, Kelly S, & Jeffs AG, 2016. Light requirments of the seagrass, *Zostera muelleri*, determined by observations and the maximum depth limit in a temperate estuary, New Zealand. *New Zealand Journal of Marine and Freshwater Research*. 50: 183-194.
[57] Zabarte-Maetzu I, Matheson FE, Manley-Harris M, Davies-Colley RJ, Oliver M, & Hawes, I, 2020. Effects of fine sediment on seagrass meadows: A case study of *Zostera muelleri* in Pāuatahanui Inlet, New Zealand. *Journal of Marine Science and Engineering* 8: 645, 20 pp.

more extensive and longer duration than the plumes produced by port development. Turbidity pulses associated with anthropic activities, particularly land use changes, appear to have similar characteristics to natural events. However, there are no reports of any adverse effects because of turbidity associated with these events to date. In my opinion, turbidity levels in Te Awanui are not a significant factor contributing to historical seagrass decline; and

(g) Sedimentation involves the deposition of materials ranging in size from boulders to clays. However, in relation to seagrass, many studies consider sedimentation to only involve fine materials consisting only of silts and clays (Sørensen,2020; Zabarte-Maetzu et al, 2020; Zabarte-Maetzu, 2021), which are also referred to as muds. In my opinion, adverse impacts on seagrass beds in Te Awanui associated with the deposition of fine sediment are due to the contaminants and nutrients adsorbed primarily to the clays, and not directly due to partial burial by fine sediment, or changing sediment texture as discussed below.

61. Kohlmeier *et al* (2014) evaluated the spatial differences in seagrass density within Te Awanui in response to environmental conditions including: ambient light levels; water/air temperature; sediment texture after removal of organic matter; and pore water nutrients. The sites sampled displayed marked differences in environmental conditions from sandy and exposed to wave action, to muddy with limited waves and currents. They found that *Zostera muelleri* displayed the ability to adjust growth forms and metabolic processes to enable growth in a wide range of conditions. Overall, their study indicated that the most beneficial conditions for growth were intermediate light levels, high mud content (contrary to common perceptions), and high phosphate concentrations.

62. Crawshaw (2020[58]) assessed seagrass health within Te Awanui and found significant spatial and temporal changes, including a strong seasonal variation that highlights a difficulty for interpreting aerial photograph data for seagrass coverage as noted above. She found that there were variations in seagrass growth forms and metabolic processes

[58] Crawshaw J, 2020. *Seagrass health monitoring in Tauranga Harbour*. Bay of Plenty Regional Council Environmental Publication 2020/08. 53 pp.

in response to environmental conditions, consistent with the findings of Kohlmeier et al (2014). She identified eutrophication stress, characterised by organic matter, muddiness and ambient light levels, as a contributor to seagrass decline.

63. Crawshaw (2020) applied an international seagrass health grading system known as the Ecological Quality Status (**EQS**) to the sites sampled.[59] The sites with the worst health (poor EQS) were Waiau (Anthenree) and Matahui in the Katikati Basin of Te Awanui, and the healthiest site (very good EQS) was Otumoetai, close to the Port of Tauranga (Figure 13).

64. Crawshaw (2020) defined an environmental gradient based on the organic matter and mud content of the sediment, and ambient light levels. In my opinion, the results in Figure 13 suggest that this environmental gradient is not a good predictor of seagrass health.[60]

[59] EQS is a descriptive classification based on the Ecological Quality Ratio (**EQR**), derived from a principal component analysis of the environmental characteristics sampled.

[60] The apparently good correlation for the upper regression line (Figure 13) is due to the influence of a single Otumoetai outlier, after omitting the Matahui, Waimapu, Tuapiro and Waiau sites. Undertaking a regression analysis for the full dataset (note the CI data in Figure 13 is from Table 8 in Crawshaw, 2020, and not Table 11 that is presented in the Crawshaw report with the two plots shown here in Figure 13). The trend line for all the data is y = 0.52-0.02x with r2 = 0.02, indicating there is no meaningful relationship between seagrass health and the environmental gradient as defined by Crawshaw (2020).

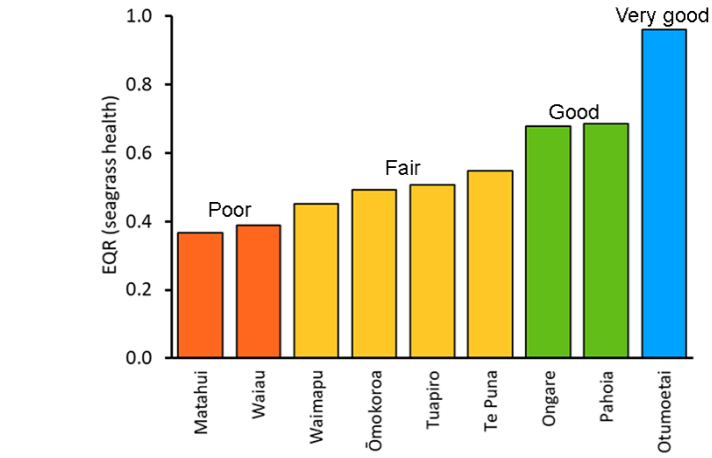


Figure 16 *Seagrass health grading (EQR) from low to high.*

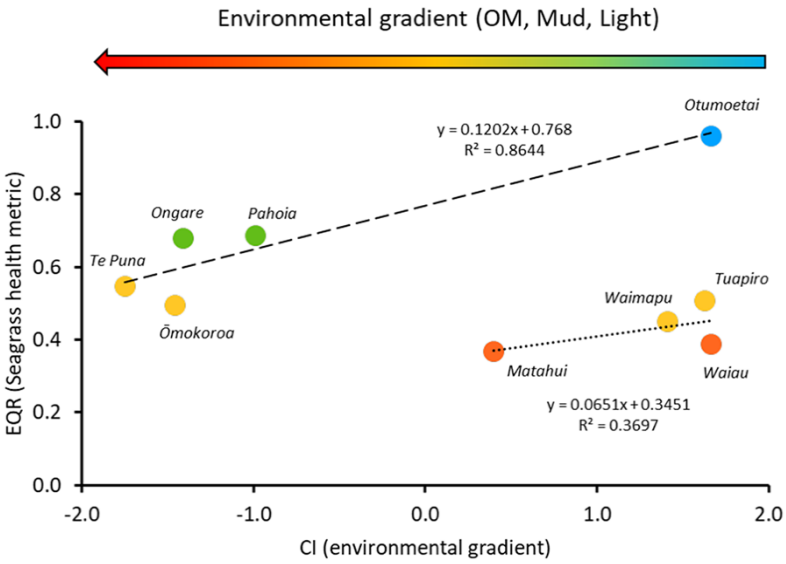


Figure 17 *Relationship between the seagrass health EQR and the environmental gradient CI scores. More negative CI scores indicate a lower environmental quality indicative of eutrophication. Site colour coding represents EQS (ecological quality status).*

Figure 13 – Figures 16 and 17 from Crawshaw (2020) showing the EQS scores for 9 sites monitored for seagrass health in Te Awanui. The EQS classifications have been added to Figure 16 for clarification.

65. An assessment of the sensitivity of Te Awanui by Crawshaw *et al* (2022[61]) recognises that nutrients sourced from freshwater discharges are significant contributors to declining ecological states within the harbour. They also report that modelling of nutrient inflows using the CLUES model by Stewart (2021)[62] over-estimates the nutrient concentrations

[61] Crawshaw J, Park S, & Fox E, 2022. *Tauranga Harbour sensitivity to freshwater inflows and ecological state assessment*. Bay of Plenty Regional Council Environmental Publication 2022/07

[62] Stewart, BT, 2021. *Investigating groundwater derived nutrient fluxes within Tauranga harbour, New Zealand*. PhD Thesis, University of Waikato, Hamilton, New Zealand. 166 pp.

within the harbour. This implies that the eutrophication risk to the harbour is lower than previously thought.

66. There is limited information published about long term trends for seagrass abundance around New Zealand, with most seagrass studies referring to a review by Inglis (2003[63]) based on anecdotal evidence and historical photographs that reported a decline in seagrass. The timing of the onset of decline varied around New Zealand, with some areas experiencing losses from the late 1800s, and others, such as Te Awanui, starting in the 1960s and 1970s. Inglis (2003) also noted that since the 1970s seagrass abundance had been increasing for a growing number of areas affected by declines. This recovery was attributed to improving water quality. However, the quality of the data used by Inglis, particularly before aerial photography, is poor temporally and spatially, and reliant on anecdotal evidence.

67. Matheson *et al* (2011)[64] objected to the IUCN Red List classification of *Zostera muelleri* as of "Least Concern", as the then current distribution of seagrass was less than historical levels indicated by Inglis (2003), despite recovery evident in some locations. Matheson *et al* also suggested improving water quality as driving recovery.

68. Booth (2019[65]) quantitatively tracked the extent of subtidal seagrass for the eastern Bay of Islands from the 1930s to the 2010s using aerial photographs. He identified low abundance before the early 1950s, that was attributed to land clearance from the late 1800s. Seagrass abundance then increased to a peak abundance from the 1960s to the 1980s, followed by a decline of some beds for the next 2 decades. This century the abundance increased up to the point his study concluded. Although Booth (2019) attributes the observed trends to water quality changes (particularly clarity), he also notes that there appears to a cyclic variation that he suggests is due to oceanic and/or climate factors.

[63] Inglis GJ, 2003. The Seagrasses of New Zealand. In Green EP & Short FT, eds. *World atlas of seagrasses*. Berkley, University of California Press, p. 134-143.
[64] Matheson FE, Lundquist GJ, Gemmill CEC, & Pilditch CA, 2011. New Zealand seagrass – More threatened than IUCN review indicates. *Biological Conservation* 144: 2749-2750.
[65] Booth J, 2019. Recent (post-1930) changes in the extent of subtidal seagrass (*Zostera muelleri*) beds of the eastern Bay of Islands, New Zealand.

69. As noted above there is limited data on the distribution of intertidal seagrass in Te Awanui before port development commenced in 1954, and the available data does not indicate the health of the seagrass beds. There is also no data to indicate that, apart from fringing areas of intertidal flats, subtidal seagrass beds were previously present in channels, and none were found during the seabed mapping sampling for both the Wallingford Hydraulics Research Station studies beginning in 1958 (Hydraulics Research Station, 1963[66]), and the Tauranga Harbour Study beginning in 1981 (Healy, 1985[67]). Surveys of seagrass around New Zealand suggest that within estuaries subtidal seagrass typically occurs as a fringe associated with intertidal beds (Turner, 2007[68]), and deeper subtidal beds occur offshore.

70. Based on aerial photograph coverage of Te Awanui several studies identified a decline in seagrass coverage between 1959 and 2011 (Park, 1999a[69], 1999b[70], 2016[71]; Nielsen, 2000[72]). The decline was most marked in areas near the mouths or rivers and streams, and least in areas close to the harbour entrances, particularly the area around the port in the Tauranga Basin.

71. Although it is not possible to determine seagrass coverage trends for all of Te Awanui before port development commenced in 1954, it is possible to do so for the immediate area around the port, which is most likely to be affected by the development. Examining aerial photo coverage of the port area including Paritaha and Waipu Bay for 1940, 1943, 1947, 1951, 1953 & 1959, there is a gradual decline in seagrass coverage in some areas, particularly in Waipu Bay and the Otumoetai foreshore, and an increase in others (Sulphur

[66] Hydraulics Research Station, 1963. *Tauranga Harbour Investigation. Report on First Stage*. Report No. 201. Hydraulics Research Station, Wallingford, England. 69p.
[67] Healy TR, 1985. *Tauranga Harbour Study: A report for the Bay of Plenty Harbour Board. Parts II & V Field data collection programme and morphological study.*
[68] Turner SJ, 2007. Growth and productivity of intertidal *Zostera capricorni* in New Zealand estuaries. *New Zealand Journal of Marine and Freshwater Research* 41: 77-90.
[69] Park SG, 1999a. *Changes in the abundance of seagrass (Zostera marina) in Southern Tauranga Harbour*. Environmental Report 99/12, Environment Bay of Plenty. July 1999.
[70] Park SG, 1999b. *Changes in abundance of seagrass (Zostera spp.) in Tauranga Harbour from 1959-96*. Environmental Report 99/30, Environment Bay of Plenty. November 1999.
[71] Park SG, 2016. *Extent of seagrass in the Bay of Plenty in 2011*. Environmental Publication 2016/03, Bay of Plenty Regional Council, February 2016.
[72] Nielson K, 2000. *Seagrass abundance in Tauranga Harbour*. Special topic report, The University of Waikato, Hamilton, New Zealand.

Point). However, there were no seagrass beds in the area affected by the wharf development (Figure 1).

72. After 1954, port development potentially affected seagrass coverage through increased turbidity restricting ambient light levels. Concern is focussed on turbidity associated with dredging and reclamation, as turbidity levels during normal port operations are negligible to low, and much less than that caused by storm water and freshwater discharges into the harbour.

73. Due to the greater volumes of sediment involved, capital dredging has the potential to cause the largest increases in turbidity within the harbour. However, this is dependent on the fine sediment (silt and clay) present, particularly the clay content as clays tend to remain in suspension for longer and can have a greater effect on water clarity through light scattering.

74. Within the areas dredged in Te Awanui, the fine sediment content increases with the age of the materials due to increase weathering (Jorat *et al* 2016[73]; MacPherson *et al*, 2017). The age of the materials increases with depth below the surface, so there is a general trend of increasing fines with increasing excavation depth. However, this trend is site specific as the youngest (Holocene) have been deposited on a dissected surface of varying relief (Moon & de Lange, 2019[74]). This means that the turbidity generated by capital dredging varies with location and excavation depth.

75. The initial Capital Dredging between 1968 and 1978 involved excavation of Holocene sands and shells, with negligible to very low fines content, apart from the matrix surrounding boulders on the Tanea Shelf. Therefore, apart from Tanea Shelf, turbidity caused by dredging should have been negligible and there are no published reports of any turbidity being reported. The 1972 dredging of Tanea Shelf primarily involved removing

[73] Jorat ME, Moon VG, Hepp DA, Kreiter S, de Lange WP, Feldmann S, & Mörz T, 2017. Subseafloor Investigation of Sediments at Southern Tauranga Harbour, New Zealand, before Capital Dredging. *Journal of Coastal Research* 33: 227-242.

[74] Moon VG, & de Lange WP, 2019. Characteristics of sub-surface sediments in southern Stella Passage, Tauranga Harbour. *Environmental Research Institute Report No 133*. Client report prepared for Port of Tauranga. Environmental Research Institute, The University of Waikato, Hamilton. 62 pp.

boulders. My observations of the Tanea Shelf in 1982-83 indicated that removal of the boulders resulted in scouring of the matrix that surrounded and supported the boulders. This would have resulted in some fine sediment being released to cause turbidity. However, due to the high turbulence over the Tanea Shelf, the suspended sediment would have been rapidly diluted. No published reports indicate that turbid plumes were observed from this location.

76. The 1991-92 Capital Dredging primarily excavated Holocene sediments, although some older Pleistocene materials were encountered, predominantly at the southern end of the Stella Passage excavation along the western side of the channel. The Stella Passage material included some 5-10% fines consisting mostly of white silts that produced highly visible plumes within the dredged channels between the source and the ocean (Figure 14). These plumes resulted in complaints by members of the public who viewed the harbour from elevated locations.





Figure 14 – Turbid plume produced by dredging silty weathered Pleistocene sediments in Stella Passage during the 1991-92 Capital Dredging Programme. Photographs by Prof T.R. Healy.

77. Coppede Cussioli (2018[75]) specifically investigated the impacts of this white material as part of her PhD thesis as pre-dredging investigations for the 2015-16 indicated that more of the same material was likely to be encountered. Her work showed that while the plume was very visible due to scattering, the impact on ambient light levels was insufficient to affect seagrass. Observations of the 1991/92 plumes also indicated that while the silty sediment took 30-60 minutes to settle, probably due to aeration of the overflow, the plume was largely confined to the shipping channels and removed from the harbour by the ebb tidal currents. There was no reported negative impact on seagrass or shellfish from turbidity during this Capital Dredging programme.

[75] Coppede Cussioli, M, 2018. *Ecological effects of turbidity variations in and around dredging areas in the Port of Tauranga*, PhD Thesis, The University of Waikato, Hamilton, New Zealand.

78. Reclamation of Sulphur Point between 1969 and 1989 involved discharge of water into Stella Passage from a dewatering pond, and the pumping of dredged sediment from a Cutter Suction dredge operating in the southern Maunganui Roads and Stella Passage. No turbidity issues were reported, and my personal observations from 1981-1989 while undertaking fieldwork are that no turbid plumes were visible from the dredge or the dewatering pond discharge.

79. For the 2015/16 Capital Dredging programme, the locations of Pleistocene materials that could generate elevated turbidity were identified by shallow seismic reflection profiles and coring (de Lange *et al*, 2014[76]). The dredging was scheduled to maximise dilution with the dredge hopper of the siltier sediment with material having a negligible to low fines content, and variable overflow height and green valve technology was used to minimise aeration and entrainment of fines into the overflow. The siltiest sediment was also associated with iron pan layers, so was removed by a barge mounted excavator that minimised turbidity. There were no complaints concerning turbidity by the public or iwi observers who were located on the dredges. The Port's turbidity sensor array did not record any levels exceeding the consented thresholds.

80. Figures 15 and 16 show changes in seagrass extent for the Whareroa Marae foreshore and Waipu Bay at different timescales. Seasonal changes, and the effects of water depth and position of the sun relative to the camera, are evident. Overall, there is little change in seagrass extent between 1947 and 1978, followed by a decline predominantly along the banks flanking the Town Reach Channel between 1978 and 1994.

[76] de Lange WP, Moon VG, & Fox BRS, 2014. Distribution of silty sediments in the shallow subsurface of the shipping channels of Tauranga Harbour. *Environmental Research Institute Report 28*. Client report prepared for Port of Tauranga. Environmental Research Institute, Faculty of Science and Engineering, The University of Waikato, Hamilton, New Zealand. 76 pp.

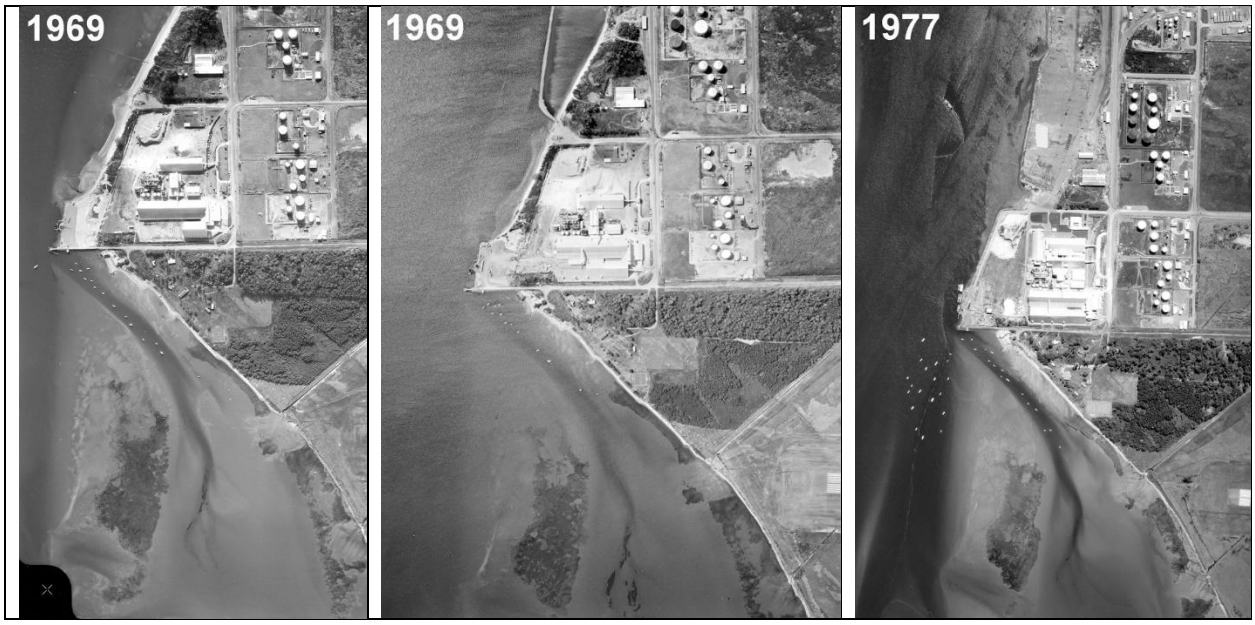
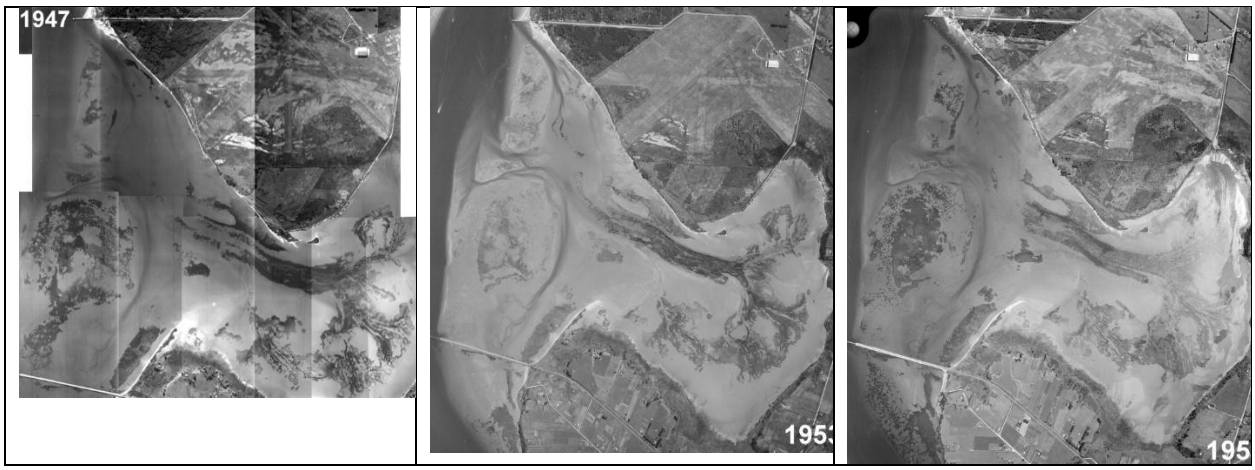


Figure 15 – Aerial photographs of Whareroa Point taken on (left) 16 May 1969 (Crown 3166-A/1), (middle) 4 November 1969 (Crown 3215-A/4), (right) 13 October 1977 (Crown 5151-A/6). The May 1969 photo corresponds to autumn and was taken about quarter of an hour before low tide. The November 1969 photo corresponds to spring and was taken about quarter of an hour after high tide. The October 1977 photo corresponds to spring and was taken about one and a quarter hours before low tide. In November 1969 the bund for reclamation as part of the Mt Maunganui wharf extensions has been completed, and in October 1977 the reclamation is in use. There appears to be a decline in seagrass abundance, particularly in the immediate vicinity of drains discharging from the Tauranga aerodrome.



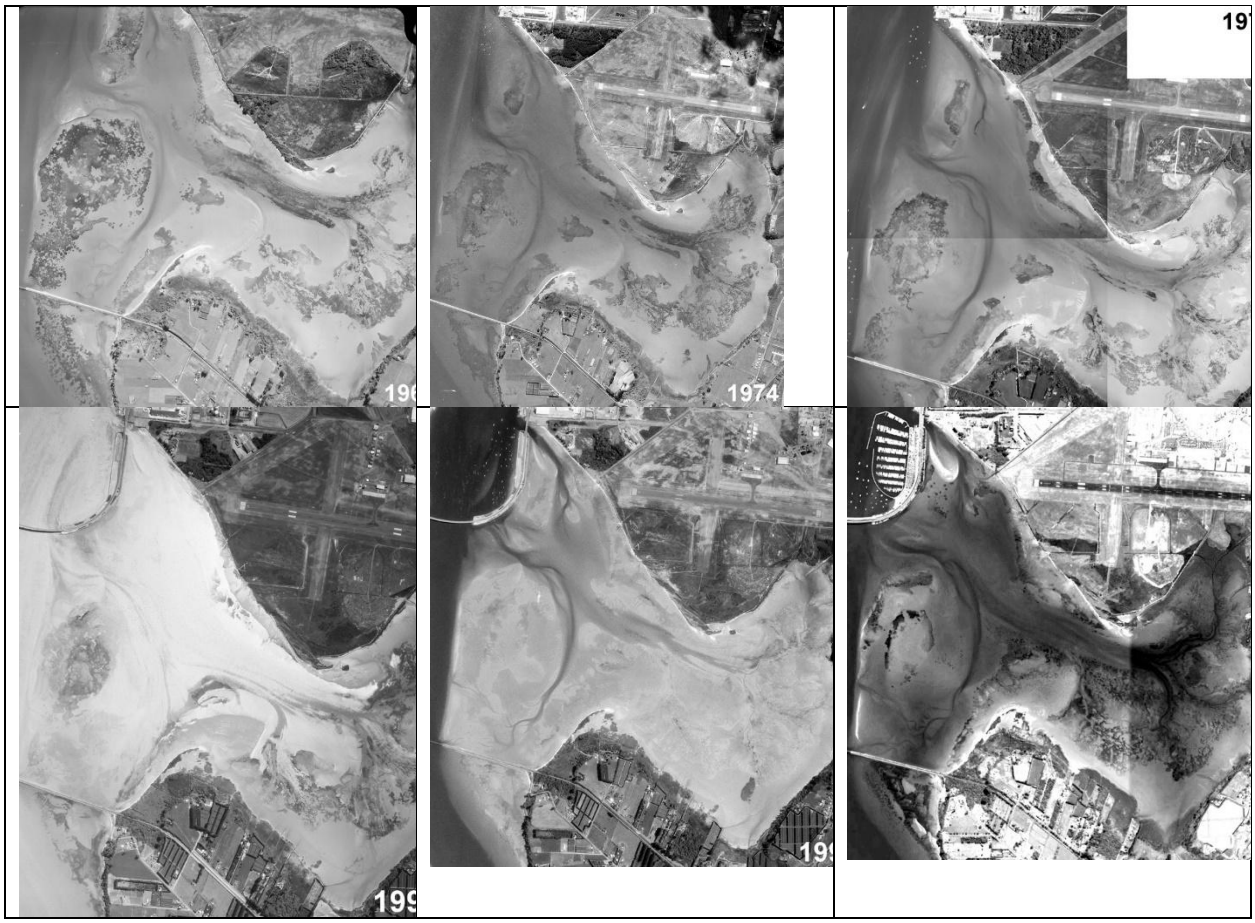


Figure 16 – Aerial photographs (1947-1994) and Google Earth image (2022) of Waipu Bay showing changes to infrastructure. channels and seagrass coverage.

81. The decline appears to be largely due to the construction of the Tauranga Harbour Crossing, although the 1991-92 Capital Dredging Programme also occurred at this time. The 1994 aerial photograph was taken at an altitude of 25,000 feet, while the earlier photographs were from lower altitudes (e.g. 12,500 feet in 1992). Combined with the tide and lighting this makes it more difficult to observe the seagrass beds in Figure 16. Careful examination of the full-scale photograph shows that the distribution in 1994 was very similar to that depicted in 1992.

82. By 2022, the seagrass extent had increased, and apart from areas buried by the Tauranga Harbour Crossing and associated accretion, the overall seagrass coverage is similar to 1947.

83. In my opinion, based on the available evidence, turbidity resulting from port development since 1954 has involved short duration events with no lasting immediate or cumulative

impact on seagrass. It appears that seagrass within Te Awanui are capable of rapidly recovering from sedimentation events.

Tidal flow characteristics and flushing

84. Based on numerical modelling and measurements before and after capital dredging campaigns and other major changes to the bathymetry in the port area (*viz*. Mathew, 1997[77]; McKenzie,2014[78]; Watson, 2016[79]), there is no evidence that port development has resulted in detectable changes to tidal characteristics beyond the immediate area of development.

85. The concerns raised by Tangata Whenua related to the harvesting of kai moana, can also be caused by relative sea level changes involving either a change in the seabed elevation due to vertical land movement or sedimentation, or a rise or all in the absolute or global sea level, or a combination of both.

86. It is evident that relative sea levels have changed within Te Awanui over time, but the changes are site specific with some locations experiencing a relative sea level fall, and most experiencing a rise. Tidal characteristics are a function of the water depth the tidal waves propagate through. In my opinion, changes to tidal behaviour at sites beyond the immediate port area are due to the observed changes in relative sea level, which are a combination of a rise in absolute sea level around New Zealand and local changes in the seabed elevation due to vertical land movement and sedimentation. These changes are not a consequence of port development.

87. Tidal flushing within estuaries, such as Te Awanui, depends on the tidal range, freshwater discharge, wind stress on the water surface, and rainfall on the estuary. Stewart (2021)[80]

[77] Mathew J, 1997. *Morphologic changes of tidal deltas and an inner shelf dump ground from large scale dredging and dumping, Tauranga, New Zealand*. PhD Thesis, The University of Waikato, Hamilton, New Zealand.
[78] McKenzie JS, 2014. *Predicted hydrodynamic and sediment transport impacts of breakwater construction in Tauranga Harbour, New Zealand.* MSc Thesis, The University of Waikato, Hamilton, New Zealand.
[79] Watson HM, 2016. *Potential impacts of wharf extensions on the hydrodynamics of Stella Passage and upstream regions of Tauranga Harbour, New Zealand*. MSc Thesis, The University of Waikato, Hamilton, New Zealand.
[80] Stewart, BT, 2021. *Investigating groundwater derived nutrient fluxes within Tauranga harbour, New Zealand*. PhD Thesis, University of Waikato, Hamilton, New Zealand. 166 pp.

is the most recent study investigating tidal flushing within Te Awanui using a combination of isotopic tracers and numerical modelling. His study considered a range of scenarios to investigate the influences of these factors in response to climate change. Despite this focus, his results are also useful for assessing the impacts of port development.

88. Stewart (2021) found that tidal flushing within Te Awanui is correlated with the Southern Oscillation Index (SOI) with statistical significance of r^2=0.43 with p≤0.001. This indicates that in the long term, changes in tidal flushing are predominantly a function of weather patterns affecting rainfall and wind stress. As discussed above, port development potentially only affects the tidal range within, and in close proximity to, the port area.

89. Figure 17 shows the annual average flushing times for the Tauranga Basin of Te Awanui, and it highlights that flushing time is primarily a function of the distance from the harbour entrance. However, flushing time is modified by freshwater discharges, so it is also a function of the proximity to rivers and streams around the harbour. These geographic factors have not changed beyond the port area because of port development. Therefore, in my opinion, port development has not changed the average flushing times. However, as discussed above, small, localised changes may have occurred due to relative sea level changes since 1954. The impacts of sea level rise on flushing times does not appear to have been investigated for Te Awanui.

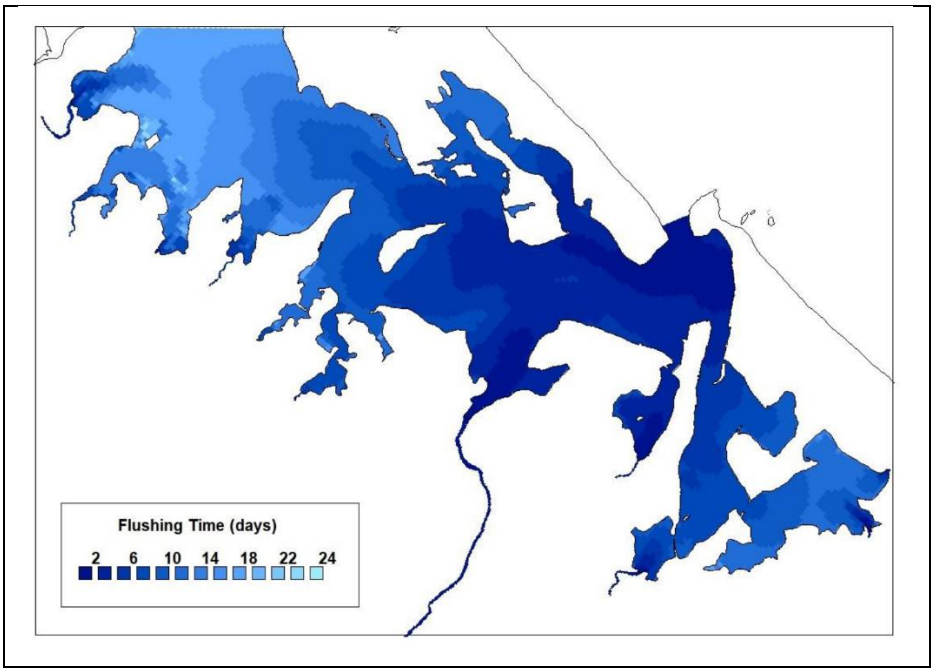


Figure 17 – Annual average flushing time for the Tauranga Basin of Te Awanui. Figure 3.7 from Stewart (2021).

Erosion of Whareroa foreshore

90. Beach erosion in front of Whareroa Marae has been linked to the Tauranga Harbour Crossing by previous studies including Healy (1994) [81] and Tonkin and Taylor (2009)[82]. My opinion is that this interpretation is correct.

91. However, Figures 1, 15 & 16 suggest that erosion may also have occurred due to the construction of a jetty at Whareroa Point during World War II. Figure 18 shows the Whareroa Point and the Whareroa Marae foreshore in 1940 and 1943. Comparing these two photos indicates that there were several metres of erosion affecting the Marae, resulting in the loss of several large trees close to the 1940 shoreline. At the same time, sediment accumulated around the structure built at Whareroa Point. In my opinion, there was a phase of erosion associated with the realignment of the shoreline in response to the structure.

[81] Healy TR, 1994. *Harbour shoreline erosion fronting Whareroa Marae; causes and possible remedies*. Technical report prepared for Tauranga District Council, December 1994.
[82] Tonkin and Taylor, 2009. *Whareroa Marae – Foreshore erosion*, Tonkin & Taylor Ltd, Report 851261, June 2009.

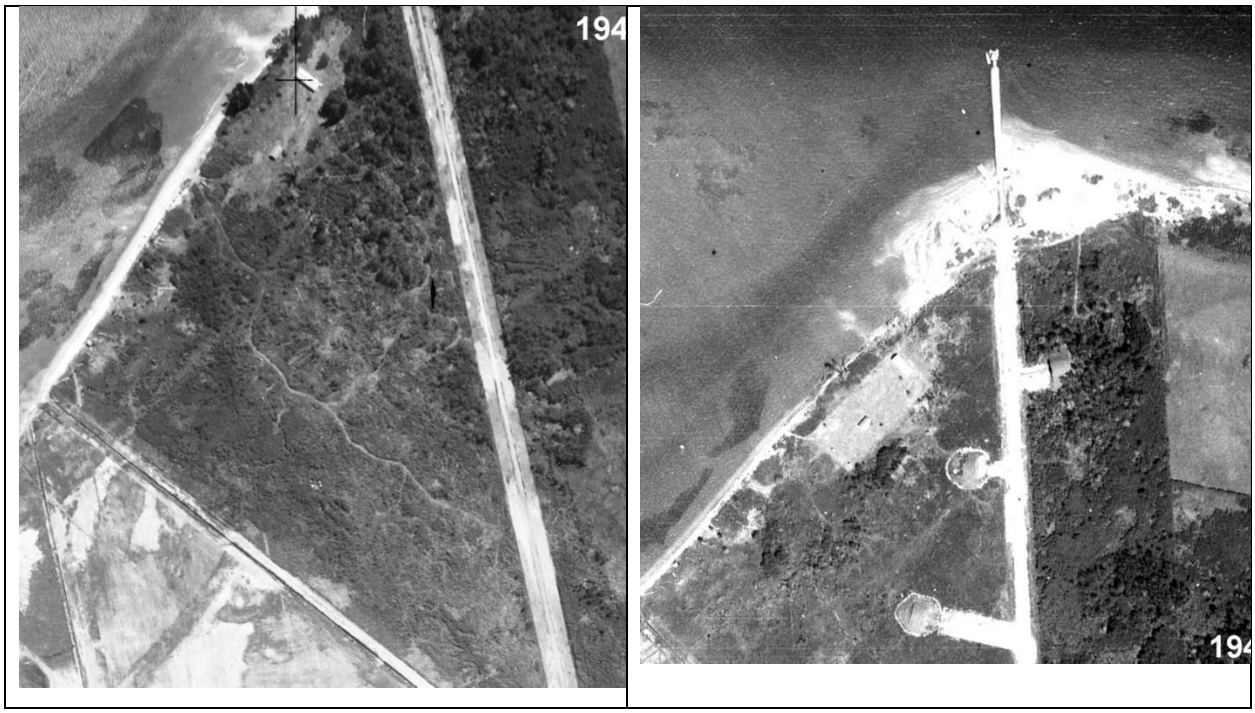


Figure 18 – Aerial photographs of Whareroa Marae and Point on 19 February 1940 (Crown 140-C/2) and 9 February 1943 (Crown 229-499/45) showing erosion of the foreshore resulting in the loss of two clusters of large trees. The erosion may be linked to the accumulation of sediment at Whareroa Point associated with the construction of the jetty and other infrastructure during World War II.

92. Comparison of the locations of buildings and the shoreline for all the available aerial suggests that the most severe erosion of the Whareroa Marae foreshore occurred during World War II and continued until the early 1950s, prior to port development. The shoreline subsequently was stable within the resolution of the aerial photographs until construction of the Tauranga Harbour Crossing, as reported by Healy (1994). A further realignment of the shoreline was triggered by the impacts of the causeway on the tidal circulation and wave conditions near Whareroa Marae. Therefore, in my opinion port development is not responsible for the observed erosion of the Whareroa Marae foreshore.

93. The effects of erosion are currently being mitigated by T-groynes and renourishment, which appears to be effective. This mitigation is focussed on maintaining the shoreline at the position it occupied in about 1990. Further work would be required to more accurately determine pre-1990 shorelines and assess the impacts of those shorelines combined with the Tauranga Harbour Crossing on circulation within Waipu Bay, if it is deemed necessary to restore the shoreline to an earlier position.

94. For Te Awanui, the key environmental stressors are assumed to be sedimentation and excess nutrients (eutrophication). As discussed above, the sources of these stressors are the local catchments within the harbour. The Bay of Plenty Regional Council in conjunction with local territorial authorities has embarked on a programme to reduce the discharges of sediments, nutrients, and contaminants into the harbour (*viz*. Crawshaw *et al*, 2022).

Timeline of events

95. The following table summarises the predevelopment conditions, and the sequence of development and associated changes observed.

Port Development	Changes in shellfish beds	Changes in sea grass abundance	Erosion at the southern end of Matakana Island	Siltation of harbour channels affecting boat access
Pre-development – taken as the period before 1954 when construction of the first section of the Mt Maunganui wharves began.	There are no known maps of shellfish bed extent before 1954. Shellfish of relevance to this summary include channel floor (subtidal) populations of hururoa/kūkukuroa (horse mussel), *Atrina pectinata zelandica* and kuakua/tipa/tupa (scallop) *Pecten novaezelandiae*; and intertidal or shallow subtidal populations of tuangi (cockle) *Austrovenus stutchburyi*, and pipi, *Paphies australis*.	Aerial photo coverage of the port area including Paritaha and Waipu Bay for 1940, 1943, 1947, & 1951, indicate there was a gradual decline in seagrass coverage in some areas, particularly in Waipu Bay and the Otumoetai foreshore, and an increase in others (Sulphur Point). No data exists for the presence or absence of subtidal seagrass beds. Aerial photographs suggest that subtidal seagrass was only present as a subtidal fringe to intertidal seagrass beds.	Matakana Island has undergone long-term accretion at both the northwestern and southeastern ends since erosion by a major tsunami in the early 15th Century. At the southern end, the extent of erosion is marked by the Purakau shoreline, which is >2 km from the present-day location of the spit tip of Panepane. Hydrographic and cadastral surveys show accretion continued from 1852 to the commencement of port development, with episodic reversals due to storm erosion.	Analysis of historical hydrographic charts and numerical modelling shows that before 1954, in conjunction with the accretion of southeastern Matakana Island, the Lower Western Channel (ebb channel) has migrated and infilled with sediment, and Paritaha (flood tidal delta) has shoaled. Hydrographic surveys indicate the shallows of Te Paritaha varied in elevation and increased in area before port development. The maximum accretion within the harbour was closest to the Matakana shoreline, and decreased eastwards towards the eastern ebb channel (now known as Maunganui Roads). The shoaling of Lower Western Channel was one of the factors that led to the eastern ebb channel being favoured for a port, although the Lower Western Channel was used for mooring vessels with hazardous cargoes (eg. ammunitions). The Stella Passage channel was much shallower than the Otumoetai Channel.

Port Development	Changes in shellfish beds	Changes in sea grass abundance	Erosion at the southern end of Matakana Island	Siltation of harbour channels affecting boat access
1953 – first stage of wharf development, midway along the current Mount wharves.	No data	Published studies with the longest temporal coverage use 1959 as their baseline as earlier aerial photographs do not provide adequate coverage for all of Te Awanui. Figure A6.2 includes aerial photographs for 1943, 1951 and 1959. These show a decline in seagrass beds at Sulphur Point, some due to burial within a reclamation associated with the Railways workshop and causeway. Examining aerial photo coverage of the port area including Paritaha and Waipu Bay for 1940, 1943, 1947, 1951, 1953 & 1959, there is a gradual decline in seagrass coverage in some areas, particularly in Waipu Bay and the Otumoetai foreshore, and increase in others (Sulphur Point). However, there were no	Various studies have examined the effects of dredging and reclamation on the hydrodynamics and evolution of Te Awanui. The study by Brannigan (2009)[83], the paper by de Lange et al (2015)[84], and the recent report on erosion at Panepane (de Lange, 2022)[85] are the most relevant. The southeastern of Matakana Island was severely eroded by a tsunami in the early 15th Century resulting of the loss of >2 km of the island and forming the Purakau shoreline, and the Kaharoa shoreline at the northwestern end of the island (Figure 2). Subsequently, the island has undergone a long-term trend of accretion, predominantly towards the southeast and seaward (Figure 4C).	Siltation within harbour channels occurs in response to sediment supplied from one, or both, of two sources: marine sediment transported into Te Awanui by waves and tidal currents; and terrestrial sediment from freshwater catchments and shoreline erosion, reworked and transported by waves and tidal currents within the harbour. The sediment source within the port area is predominantly marine and associated with the ebb and flood tidal delta system. Further into Te Awanui, the sediment sources are predominantly terrestrial. The boundary between marine-dominated and terrestrial-dominated is not static: it varies with the changing magnitude of tidal flows over spring-neap cycles, magnitude of freshwater inflows, and the influence of storms through

[83] Brannigan AM, 2009. *Change in geomorphology, hydrodynamics and surficial sediment of the Tauranga Entrance tidal delta system.* MSc Thesis, The University of Waikato, Hamilton, New Zealand.
[84] de Lange WP, Moon VG, & Johnstone R, 2015. *Evolution of the Tauranga Harbour Entrance: Influences of tsunami, geology and dredging.* Proceedings of the Australasian Coasts and Ports Conference, 15-18 September 2015, Auckland, New Zealand.
[85] de Lange WP, 2022. Morphological changes for southeastern Matakana Island (Panepane Point) and Matakana Banks (ebb tidal delta) 2016-22. Report to the Port of Tauranga Ltd. August 2022. 15 pp.

Port Development	Changes in shellfish beds	Changes in sea grass abundance	Erosion at the southern end of Matakana Island	Siltation of harbour channels affecting boat access
		seagrass beds in the area affected by the wharf development (Figure 1). Note that the apparent seagrass extent determined from aerial photographs may not be reliable as seagrass presence may be obscured if the beds are submerged, and there can be significant variations within a single year (Figure 9), possibly due to seasonal factors, that suggest the time of year the photo is taken may affect the results. No data exists for the presence or absence of subtidal seagrass beds.	The south-eastward extension of the island is limited by the tidal inlet (Tauranga Entrance) and the presence of Mauao, which prevents eastward migration of the tidal inlet. Successive hydrographic surveys from 1852 to 1954 (Figures 3 & 4) show that the tidal inlet has progressively narrowed and deepened over time; relatively steadily until the 1970s, but at a decreasing rate since then due to the resistance to erosion of harder layers exposed as the channel deepened. Brannigan (2009) documents the changes over time based on hydrographic survey data and provides summary diagrams (Figure 5). The time periods shown correspond to the specific years that were modelled to determine the changes to harbour circulation by Brannigan (2009) and other studies he references. The shape of the southeastern end of Matakana Island is due to the combined effects of tidal currents and waves, particularly	storm surges and floods. In the long-term, the boundary moves seaward as the harbour naturally infills with sediment. Analysis of historical hydrographic charts and numerical modelling shows that before 1954, in conjunction with the accretion of southeastern Matakana Island, the Lower Western Channel (ebb channel) has migrated and infilled with sediment, and Paritaha (flood tidal delta) has shoaled (Figures 3 and 5). The maximum accretion within the harbour was closest to the Matakana shoreline, and decreased eastwards towards the eastern ebb channel (now known as Maunganui Roads). The shoaling of Lower Western Channel was one of the factors that led to the eastern ebb channel being favoured for a port, although the Lower Western Channel was used for mooring vessels with hazardous cargoes (eg. ammunitions). The areas beyond the port area where Mana Whenua have raised issues about siltation affecting boat

Port Development	Changes in shellfish beds	Changes in sea grass abundance	Erosion at the southern end of Matakana Island	Siltation of harbour channels affecting boat access
			on the seaward side, and the availability of sediment. There is no evidence for a reduction in the availability of sediment. However, there have been changes to tidal currents and wave behaviour as discussed further in the table below. Although the low temporal resolution of historical surveys and proxy indicators of shoreline positions before 1954 suggest accretion has been steady, there is evidence that there have been phases of erosion. Shepherd et al (1997) discuss the existence of 3 phases of wind erosion forming parabolic dunes. This indicates periods of significant loss of vegetation from parts of the parallel dune ridges. One phase occurred ~4000 BP, while the other two were associated with anthropic factors 600-800 years BP, and in the late 1800s. All 3 phases appear to have involved a temporary loss of sediment from the shoreline as sand moved inland.	access are dominated by locally sourced terrestrial sediment. The channels potentially affected by siltation that may be linked to port activities are the channels entering Waipu Bay, Town Reach, and the channel entering the Waikareao Estuary. Comparison of the aerial photographs from 1953 and 1959 (Figure 1) shows that the Waikareao Estuary at that time was exporting sediment to form a delta entering the Otumoetai Channel. The channels entering Waipu Bay and Town Reach show no evidence of sediment transport at the scale of the photographs. There is also no evidence of siltation for any of the channels. This is unsurprising as the first stage of development is restricted to construction over a short length of shoreline with negligible on tidal flows within Te Awanui. However, the port structures would have disrupted longshore transport of sediment at the shoreline by waves. The aerial photographs suggest that there was

Port Development	Changes in shellfish beds	Changes in sea grass abundance	Erosion at the southern end of Matakana Island	Siltation of harbour channels affecting boat access
			Erosion associated with severe storms is evident since aerial photographs became available in the 1940s. Two distinct patterns have been observed (Figure 6): quite frequent localised embayments occurring at relatively fixed positions along the shoreline due to focussing of waves by swash bars on the ebb tidal delta (Matakana Banks); and rarely an extensive zone of erosion on the seaward side of Panepane associated with the formation of a wide shallow flood marginal channel, which occurs when ENE storm waves refract and diffract around Mauao during a flood tide, focussing wave energy on the foredunes near high tide. The SO 22298 (1922) MHWM Water Boundary is used to mark the seaward boundaries of properties at the southeastern end of Matakana Island and marks the limit of permissible erosion before the Port of Tauranga is required to initiate mitigation	reduction in the supply of sand to the beach within Pilot Bay.

Port Development	Changes in shellfish beds	Changes in sea grass abundance	Erosion at the southern end of Matakana Island	Siltation of harbour channels affecting boat access
			measures under the consent issued for the 2015-2016 Capital Dredging.	
1968 – dredging of Cutters Channel by trailer suction hopper dredge to eliminate the need to use the Pilot Bay channel, cutting through a bar along the margin of the Maunganui Roads channel into a partly existing blind channel.	No data Would have removed shellfish beds within the area dredged. My personal observations during the Tauranga Harbour Study were that Pilot Bay experienced a significant reduction in flood and ebb tidal flows that resulted in the cessation of reworking of the shell lag within the Pilot Bay Channel. By 1982 the shells were heavily encrusted and overgrown with barnacles, sponges etc. Similarly, the horse mussels that were still present were heavily overgrown. There were high concentrations of turret shells that weren't present in higher flow channels.	No change within the port area, including Waipu Bay (Figure 10). However, declining abundance, based on areal coverage in aerial photographs was reported from shallow intertidal areas further into the harbour. No data exists for the presence or absence of subtidal seagrass beds.	Continuing accretion of southeastern end of Matakana Island (Figure 7 – 1966 and 1970 hydrographic charts). Note the existence of a slight embayment extending ~800 northwest along the Matakana Island shoreline from Panepane Pt. This indicates that waves combined with the marginal flood tidal flow restrict seaward accretion of the shoreline in this area.	Continuing shoaling of Lower Western Channel and Paritaha (Figure 7 – 1966 and 1970). Pilot Bay Channel became more ebb dominant as more marginal flood tidal flows were transferred to the Cutter Channel compared to the pre-dredging blind flood tidal channel, resulting in the formation of a late flood tidal eddy driving ebb flow within Pilot Bay (de Lange, 1988)[86]. The changed flow within Pilot Bay didn't result in channel accretion or erosion but did contribute to erosion of Pilot Bay beach.
1971 – dredging carried out in the entrance channel using trailing suction hopper dredging.	No data Dredging would have removed shellfish beds within the area dredged, but shellfish beds were present in 1982 during the Tauranga Harbour Study	No change within the port area, including Waipu Bay (Figure 10). No evidence for the existence of seagrass beds on the ebb tidal delta prior to, or after, dredging.	Continuing accretion of southeastern end of Matakana Island (Figure 7 – 1970 and 1973 hydrographic charts).	Ongoing shoaling of Lower Western Channel and Paritaha(Figure 7 – 1970 and 1973). The creation of the Entrance Channel resulted in a narrower and stronger ebb jet, and a change to a predominantly tidal

[86] de Lange WP, 1988. *Wave climate and sediment transport within Tauranga Harbour, in the vicinity of Pilot Bay*. DPhil Thesis, The University of Waikato, Hamilton, New Zealand

Port Development	Changes in shellfish beds	Changes in sea grass abundance	Erosion at the southern end of Matakana Island	Siltation of harbour channels affecting boat access
				bypassing inlet, compared to the predominantly bar-bypassing system prior to dredging (Ramli, 2016)[87]. A consequence of this change is accretion on the western side of the ebb tidal delta, with the formation of a new terminal lobe (Figure 5 - 1954 to 2006). This may have accelerated the existing trend of accretion of southeastern Matakana Island and shoaling of the Lower Western Channel and Paritaha. One question that hasn't been answered to date, is where the extra sediment was sourced from. The most likely source is the inner shelf.
1972 – deepening and widening of Tanea Shelf. The material was a boulder field overlaying predominantly cemented silt and sand. Dredging method was by bucket conveyor dredge.	The boulders covering the ignimbrite forming Tanea Shelf were blasted to reduce their size to allow removal by bucket conveyor dredge. Some rolled deeper into the inlet channel. Overall, there was a reduction in the quantity of hard substrate present on the flanks of Mauao. Subsequent dredging of Tanea Shelf has	No change within the port area, including Waipu Bay (Figure 10).	Continuing accretion of the southeastern end of Matakana Island (Figure 7 – 1970 and 1973). Deepening and widening of Tanea Shelf resulted in a reduction in tidal velocities due to the increase in cross-sectional area within the tidal inlet at the narrowest point. This would have contributed to the accretion of Panepane to	No siltation of harbour channels resulted from dredging of Tanea Shelf. However, the existing trend of shoaling of the Lower Western Channel and Paritaha continued (Figure 7 – 1970 and 1973).

[87] Ramli AY, 2016. *The Impact of Dredging on the Stability of Matakana Banks Ebb-Tidal Delta*. PhD Thesis, University of Waikato, Hamilton, New Zealand.

Port Development	Changes in shellfish beds	Changes in sea grass abundance	Erosion at the southern end of Matakana Island	Siltation of harbour channels affecting boat access
	involved transferring the boulders to shallower areas flanking Mauao to provide additional hard substrate habitat. No effects to soft substrate habitats within the harbour should have resulted.		evident as the changed orientation of the spit tip in 1973 compared to 1970.	
1974 and 1978 – further smaller trailing suction hopper dredging projects resulting in a final port draught of 10.7 metres at high water (depth of 10.4m inside and 11.3m outside of the harbour).	Removal of shellfish beds from channel floor areas dredged (which had re-established before Dr de Lange sampled the Port area in 1982), and loss of shellfish beds covered by the Sulphur Point reclamation (Figure 8 – 1970, 1973 & 1983).	The sediment dredged was used for the Sulphur Point reclamation (Figure 8 – 1970, 1973 & 1983). This resulted in the loss of the seagrass beds on the intertidal flats (Figure 1) that were buried by the reclamation. Otherwise, there were no significant changes in the port area, including Waipu Bay (Figure 10). Elsewhere within Te Awanui, seagrass declined, most likely due to local factors as noted by various studies.	Continued accretion of the southeastern end of Matakana Island (Figure 7 – 1973 and 1995).	Continued shoaling of Lower Western Channel and Paritaha (Figure 7 – 1973 and 1995). The shoaling of Lower Western Channel has resulted in a shallow channel limiting the draft of vessels that can use it. A comparison of hydrographic charts (Figure 8 – 1970 and 1973) suggest shoaling occurred in Waipu Bay reducing the size of the two main tidal channels. However, the 1970 chart used mostly HMS Lachlan 1954 data supplemented with Tauranga Harbour Board data up to 1967 for this area. Whereas the 1973 chart used HMS Lachlan 1954 and 1970 data, supplemented with Tauranga Harbour Board data up to 1972. Aerial photographs indicate that the differences in Waipu Bay shown by the charts are

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				primarily a result of poor data quality before 1973.
1978 – stand-alone tanker berth built, south of the Mount wharves.	No, to negligible, impact as the structure is supported on piles. The Tauranga Harbour Study found a large bed of juvenile pipi underneath and surrounding this berth in 1982.	No change within the port area, including Waipu Bay (Figure 10). There does not appear to have been a seagrass bed present at the site. Isolated seagrass clumps were noted in the shallow intertidal strip between the Tanker and No 11 berths during the Tauranga Harbour Study.	Continued accretion of the southeastern end of Matakana Island (Figure 7 – 1973 and 1995).	Continued shoaling of Lower Western Channel and Paritaha (Figure 7 – 1973 and 1995).
1969 - 1989 – Sulphur Point reclamation, material dredged between 1969 – 1989 from the Maunganui Roads channel and Stella Passage and pumped ashore via pipelines to form the reclamation.	Shellfish beds present in the intertidal area covered by the Sulphur Point reclamation (Figure 8 – 1970, 1973 & 1983) would have been lost. It is not known what species were present, and their relative abundances.	The seagrass beds present on the intertidal flats (Figure 1) were buried by the reclamation. Otherwise, there were no significant changes in the port area, including Waipu Bay (Figure 10). Elsewhere within Te Awanui, seagrass declined, most likely due to local factors as noted by various studies.	Continued accretion of the southeastern end of Matakana Island (Figure 7 – 1973 and 1995).	Continued shoaling of Lower Western Channel and Paritaha (Figure 7 – 1973 and 1995).
1960's, 70's and 80's – progressive wharf extensions at Mount Maunganui, with the last extension carried out in 1988 to create the	Any shellfish beds present in the intertidal area covered by wharf reclamations would have been lost. It is not known what species were present, and their relative abundances.	No seagrass beds appear to have been present in the areas directly affected by the wharf reclamations. There were no significant changes in the	Continued accretion of the southeastern end of Matakana Island (Figure 7).	Continued shoaling of Lower Western Channel and Paritaha (Figure 7).

Port Development	Changes in shellfish beds	Changes in sea grass abundance	Erosion at the southern end of Matakana Island	Siltation of harbour channels affecting boat access
2060 metres of the continuous wharf that exists today.		remained port area, including Waipu Bay (Figure 10).		
1991 – construction of 600m of wharf at Sulphur Point.	Any shellfish beds present in the intertidal area covered by wharf reclamations would have been lost. It is not known what species were present, and their relative abundances.	No seagrass beds appear to have been present in the areas directly affected by the wharf reclamations. There were no significant changes in the remained port area, including Waipu Bay (Figure 10).	Continued accretion of the southeastern end of Matakana Island (Figure 7).	Continued shoaling of Lower Western Channel and Paritaha (Figure 7).
1991 – 1992 – channel deepening and widening following the reclamation, to establish the container terminal, deepened by approximately three metres and channels widened by 30 – 40 metres at various points to ease corners.	Any shellfish within the dredged areas would have been removed by the dredges. However, the shellfish beds rapidly were re-established.	There were no significant changes in port area, including Waipu Bay because of this dredging (Figure 10). Note that there appears to have been a decline in seagrass cover within Waipu Bay following the construction of the Tauranga Harbour crossing (Figure 10 – 1992 to 1994). It is not clear if the seagrass completely disappeared, or if rhizomes were still present. The seagrass rapidly recovered after 2000, and in 2022 seagrass extent was like conditions from 1947-1992.	Continued accretion of the southeastern end of Matakana Island (Figure 7 - 1995).	Continued shoaling of Lower Western Channel and Paritaha (Figure 7 -1995). Note that there has been no shoaling of channels in Waipu Bay during port development up to 1992 (Figures 8 and 10). Hydrographic surveys suggest the northern channel may have deepened slightly, but data are sparse. After construction of the Tauranga Harbour Crossing, the northern channel has deepened close to Whareroa Point. There has been shoaling of the intertidal flats immediately east of the causeway (Figure 10).

Port Development	Changes in shellfish beds	Changes in sea grass abundance	Erosion at the southern end of Matakana Island	Siltation of harbour channels affecting boat access
2013 – northern extension to extend Sulphur Point wharves to a length of 770m, with a mooring dolphin structure constructed approximately 31 meters north of the end of the wharf.	Any shellfish beds present in the intertidal area covered by wharf reclamations would have been lost, but the area involved is small. The dolphin structure had negligible impact It is not known what species were present, and their relative abundances.	There were no significant changes in port area, including Waipu Bay because of this extension. Seagrass extent elsewhere in Te Awanui appears to have been increasing, but is not linked to this development	Continued accretion of the southeastern end of Matakana Island (Figure 7).	Continued shoaling of Lower Western Channel and Paritaha (Figure 7).
2015 – 2016 - capital dredging involving deepening of entire existing channel by 1.5m inside and 1.7 m outside of the harbour, widening occurring along the Maunganui Roads and Cutters Channel into Te Paritaha and in to the ebb tide delta in the Number 2 reach, carried out primarily by trailing suction hopper dredge. Deepening at Tanea Shelf (Mauao) and a hard patch in the	Any shellfish within the dredged areas would have been removed by the dredges. However, the shellfish beds rapidly were re-established.	There were no significant changes in port area because of this dredging. Seagrass extent in Waipu Bay increased, and elsewhere in Te Awanui appears to have been increasing, but is not linked to the dredging	Continued accretion of the southeastern end of Matakana Island. However, erosion has occurred on the seaward side of Panepane since 2019 in response to several northeasterly storm events. This is likely to be temporary.	Shoaling of the Lower Western Channel largely ceased, and shoaling of Paritaha has continued (Figures 7 & 8)

Port Development	Changes in shellfish beds	Changes in sea grass abundance	Erosion at the southern end of Matakana Island	Siltation of harbour channels affecting boat access
entrance carried out by Backhoe Dredge.				