Feasibility Study:

Opotiki Entrance Navigation Improvements

Report prepared for Opotiki District Council

November 2002

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Executive Summary

This report was commissioned by Opotiki District Council to assess and report on the feasibility of options for improving navigability at the mouth of the Tara and Waioeka Rivers.

The study was developed in a number of stages. First, a synthesis of existing technical reports on coastal and river processes and changes in entrance morphology. Findings show that:

- Opotiki Entrance is dominated by ebb-tide flows and can experience extreme short-term variations in discharge controlled by seasonal and storm-driven changes in river flow that range between 5 and 2000 m^3/s.
- The entrance experiences low to moderate wave energy with maximum wave energy experienced during episodic storm events. Marine influences dominate entrance hydrodynamics only during periods of low river flow.
- The Opotiki Entrance is situated on a low drift coast. Net alongshore sediment transport is in a westward direction at the Opotiki Entrance. Sediment is transported past the entrance through the process of bar-bypassing.
- Estimates of net alongshore sediment transport range from 6 000 to 8000 m^3 per year.
- Delivery of river sediment to the entrance is estimated at 15 000 m^3 per year. However, the volume of sediment is likely to be controlled by frequency of river floods.
- Combining estimates of sediment delivery from both sources approximately 23 000 m^3 of sediment may be delivered to the Opotiki Entrance on an annual basis. This value is used as a ‘best estimate’ in the study to examine the environmental effects of options to improve navigability.

Results of this synthesis show there is a dearth of information on coastal processes and morphological change at the Opotiki Entrance. This will need to be remedied should Council wish to proceed to the detailed design stage of any preferred option.

The second stage of the report reviews scientific and engineering literature on the morphological behaviour of river entrances. This review is combined with the process information to develop a conceptual model of the processes that control changes in the entrance and channel morphology (cross-sectional area, depth and location) and the time and space scales of these changes. In lieu of detailed information at the Opotiki Entrance the model relies heavily on results from investigations at other ebb tide deltas in New Zealand (e.g. Dahm, 1983), investigations at similar-sized entrances (e.g. Weipa, Kench and Parnell (1991) and Rangitaiki, Coastal Consultants (2001)), and use of empirical models.

Key results of this analysis indicate:

- The morphology of the Opotiki Entrance and bar is controlled by the balance between marine and river processes. Under extreme river discharges, tidal prism and peak entrance discharges scour and enlarge the entrance cross-section. Conversely, entrance cross-section reduces when marine processes dominate the entrance (under low river discharge periods and during periods when storms generate significant wave energy at the coast).
- Analogues from similar-sized entrances and empirical modelling suggest that the Opotiki entrance dimensions can potentially vary from 70 m^2 under low discharge periods, 110 m^2 under mean discharges, and up to 1320 m^2 during severe floods.
- Changes in entrance morphology occur over short timeframes (days to months). Seasonal variations in river discharge promote winter widening and summer shallowing (when wave processes exert a stronger influence). However, individual river floods also exert short-term but significant changes in entrance morphology.
- The ebb delta at the Opotiki entrance is the major subtidal sediment sink within the entrance system. The delta experiences seasonal and event-driven changes in position of the channel that flows across the delta.
- During periods of mean and low river discharge the channel assumes an oblique angle to the coast. Under extreme floods the channel assumes a more perpendicular orientation to the coast, thereby cutting-off a section of the bar that is able to weld to the western shoreline. This cyclic channel migration and bar splitting provides the mechanism for westward alongshore sediment transfer.

- The gross rate of sediment flux on the ebb delta is considered to be at least an order of magnitude larger (10^5 m^3/yr) than the net rate of sediment transport at the entrance (10^4 m^3/yr).

The conceptual model provides first order approximations of the nature of processes and spatial and temporal scale of entrance and bar morphological change. This conceptual model is used to assess likely effects of a range of options to improve navigation.

The study then reviews scientific and engineering literature related to improving the navigability of river and tidal entrances. This review identifies: the range of possible options used to improve navigation at river entrances; design implications for each option; and highlights the range of environmental effects typically encountered with each option. In the final stage of the study the possible range of options to improve navigation at the river entrance are evaluated for the Opotiki Entrance with regard to: practicability; environmental effects; sustainability of navigation improvements including maintenance requirements, operational availability and the potential lifetime of any improvements; costs (capital and maintenance); and risks and mitigation.

The outcomes of this analysis are summarised in the following table. It is not the purpose of this report to prescribe which option, if any, should be chosen. Rather the findings indicate what is practicable at the Opotiki Entrance. Each option carries a range of capital and maintenance costs as well as environmental effects. The results provide Opotiki District Council with an objective summary of the benefits and costs of each option with which to make an informed decision of how best to proceed.

SUMMARY OF OPTIONS

OPTION	Likelihood of Improving Entrance Depths & Navigability	Practical to Implement at Opotiki	Operational Availability for Vessels	Life Expectancy of Navigational Improvements	Effects on Coastal Processes	Effects on Flooding at Opotiki	Maintenance Requirements	Estimated Capital Costs $ Millions	Estimated Maintenance Costs $ Millions/yr
STAUS QUO (no intervention)	NO	YES	No Change in operating conditions	N.A.	NIL	NIL	LOW	0.1 – 0.2	0.05 – 0.07
STAUS QUO & MINOR DREDGING	LIMITED TO BAR CREST	YES	IMPROVE - minor	SHORT (days – weeks) - Gross sediment transport will deposit sediment in dredged area	NOT SIGNIFICANT	MARGINALLY BENEFICIAL	MODERATE	0.1 – 0.2	0.4 – 1.0
MECHANICAL DREDGING OF CHANNEL	YES	YES	IMPROVE	SHORT (days – months) - Gross sediment transport on ebb delta will deposit sediment in channel	SIGNIFICANT -Alter wave processes & will deplete sediment reserves promoting alongshore erosion	IMPROVE - Increased channel depth will evacuate flood waters more efficiently	HIGH - monitoring and repeat dredging likely on a regular basis (monthly)	1.8 – 2.2	1.0 - 3.4

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FLUIDISATION (insertion of pipes along channel axis to artificially suspend sediment)	UNKNOWN This technique is untested in environments as dynamic as the Opotiki Entrance.	NO - Sediment size, the length and number of pipes & platform requirements for pumps make this option impractical	-	-	-	-	-	-	-
SINGLE MOLE (rock wall inserted perpendicular to shoreline on one side of entrance extending 600m from shore)	YES	YES	IMPROVE - Navigation may still be difficult due to channel movement & wave action on unprotected side.	MEDIUM (months – years) - Alongshore and gross sediment transport will promote deposition in channel.	SIGNIFICANT - Alter river, wave and sediment transport processes. - May promote alongshore erosion. - Will significantly alter natural character.	POSSIBLE MINOR IMPROVEMENT	HIGH - Monitoring and repeat dredging are likely to be needed on a sub-annual basis - Ongoing maintenance of mole	5.8 – 7.5	0.4 – 4.2
DUAL MOLES (rock walls inserted perpendicular to shoreline on either side of entrance & extending 600m from shoreline)	YES	YES	IMPROVE - Entrance likely to be navigable under most sea conditions	LONG (decade – century) - Improvements will endure until bar re-establishes at the end of moles. This is likely to take more than 50 years.	SIGNIFICANT - Alter wave, tide and littoral processes. - promote updrift accretion and downdrift erosion of shoreline. - Will significantly alter natural character.	POTENTIALLY ADVERSE - Careful design of entrance cross-section will be required to avoid exacerbating flooding at Opotiki and breaching of spit.	MODERATE - Is likely to require sand bypassing on an annual or interannual basis. - Ongoing maintenance of the moles will be required.	9.8 – 11.5	0.2 – 2.4

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1. INTRODUCTION

This report was commissioned by Opotiki District Council to assess and report on the feasibility of options for improving navigability at the mouth of the Otara and Waioeka Rivers. The shallow bar at the entrance to these rivers (hereafter referred to as the Opotiki Entrance) currently presents significant obstacles to use and development of Opotiki Harbour.

1.1 Background and Previous Work

Opotiki is located between the lower, estuarine reaches of the Waioeka and Otara Rivers in the Eastern Bay of Plenty (Figure 1). The rivers join on the seaward side of the town and discharge to sea through the Opotiki Entrance approximately 1.75km further downstream.

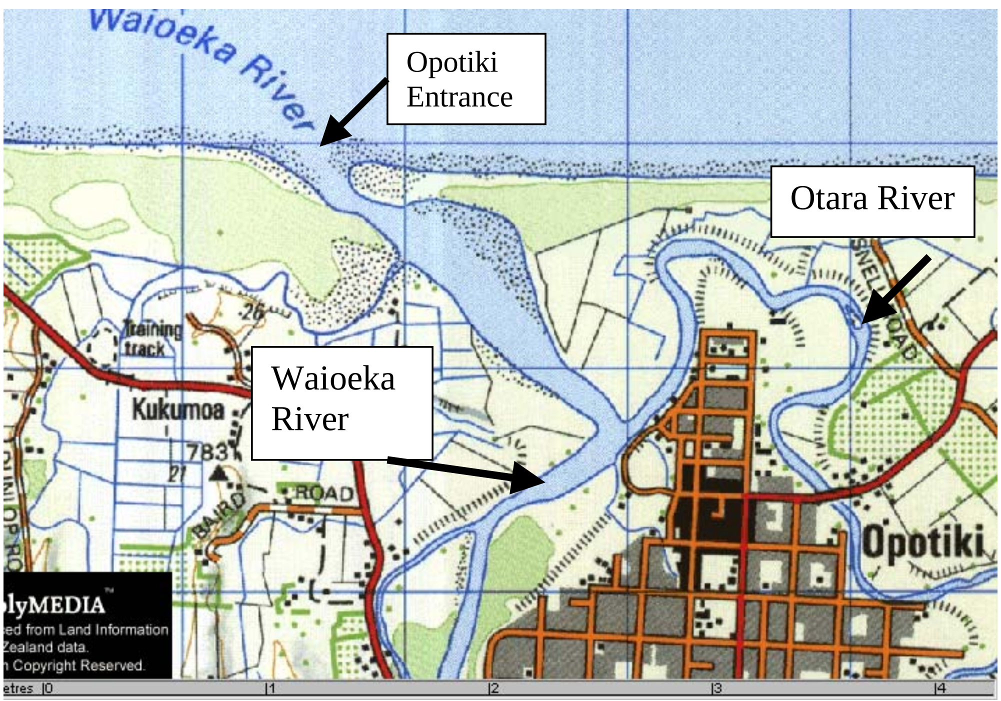

Figure 1: Location diagram (Note: Grid lines are at 1km spacing).

Recent investigations have highlighted that improvement of the harbour entrance has the potential to bring significant benefits to the economy of the district, particularly in respect to recreational fishing and aquaculture (Tonkin and Taylor, 1996; ODC, 2002). However, the sand bar immediately seaward of the entrance typically has depths of only 1.8-2.4 metres at high tide and has always presented navigation difficulties, particularly during periods of significant wave action and after periods of sustained low river flows (Croad et al., 1993). These difficulties are a major impediment to use and development of the harbour.

Various previous reports have considered options for improvement of the harbour entrance (Croad et al., 1993; Tonkin and Taylor, 1996 and 2001; ODC, 2002). In a report commissioned to investigate the feasibility of a barge port facility at Opotiki, Croad et al (1993) concluded that twin moles, extending approximately 600m out to sea on either side of the entrance channel, were "the only sensible engineering option" to maintain navigability of the harbour entrance.

Tonkin and Taylor (1996) considered four options for maintaining navigability. Two options, an unprotected harbour and fluidisation were not considered effective. The remaining options (throat restrictions and twin moles) were likely to have significant effects on the existing environment. A further study concluded that fluidisation was unlikely to be a cost-effective solution to maintain navigable depth but noted local factors that may enable a partial fluidisation scheme to be effective (Tonkin and Taylor, 2001).

Options available to improve the harbour entrance were also reviewed by ODC (2002). Moles were considered to present the best surety of outcome but also had significant capital and ongoing costs. Dredging alone was also identified as a possible option that could be trialled. However, this option is likely to provide less surety of channel location, safety and wave shelter than moles.

2. METHODS

The study was undertaken in three stages.

2.1 Review of existing information

Stage one involved review of existing information, which was divided into two parts. First, technical reports related to the Opotiki River and coastal environment.

This information was essential in order to develop an understanding of the broad environmental processes such as sediment transport, tidal and river flows and to identify morphological components of the river entrance.

Second, a review was undertaken of the scientific and engineering literature related to improving the navigability of river and tidal entrances. This review identified: the range of possible options used to improve navigation at river entrances and tidal inlets to be evaluated at Opotiki; the design implications for each option; and highlighted the range of environmental effects typically encountered with each option.

2.2 Conceptual model of entrance dynamics

A conceptual model of the processes and dynamics controlling the morphological behaviour of the river entrance was developed. This model was then used to assess the effectiveness and environmental effects of the various options for improving navigability at the Opotiki Entrance.

In the absence of any detailed studies of the entrance, the conceptual model was developed based on the review of coastal and river processes combined with known behaviour of tidal and river entrances from scientific literature. This model was calibrated against similar-sized and small river entrances in which detailed studies have been undertaken. These include the Rangitaiki and Maketu entrances (Bay of Plenty) and the Waipu River entrance (Northland).

2.3 Evaluation of options to improve navigation

The final section of the report critically evaluates the various options to improve navigation at the Opotiki entrance. Options were evaluated in terms of:

- Practicability.
- Environmental effects including: changes to wave, tide and sediment transport processes; changes in form of the ebb delta; and impact on flooding in lower reaches of the Otara and Waioeka Rivers.

- Sustainability of navigation improvements, including maintenance requirements, operational availability and the potential lifetime of any improvements.
- Cost - including capital and maintenance costs.
- Risks and risk mitigation.

The study summarises the benefits and disadvantages of each option to assist Council decide which, if any, option to pursue. A summary table has also been included in the Executive Summary.

3. REVIEW OF COASTAL AND RIVER PROCESSES

3.1 Waves

New Zealand lies in a westerly wind system with prevailing deep-water waves approaching from the south to westerly quarter. As these swells refract around the South and North Islands, East Cape acts as an effective barrier that strongly transforms swell energy entering the Bay of Plenty.

The east coast and in particular, the Opotiki entrance is on a leeward shore with prevailing winds blowing offshore. As a consequence prevailing winds have no role in generating waves that impact on the Opotiki coast.

There are no wave records from the vicinity of the Opotiki entrance. At the regional scale Pickrill and Mitchell (1977) report wave observations at Hicks Bay (East Cape), Tauranga Harbour and Waihi (Table 1). Recent wave hindcast modelling covering the last 20 years (undertaken by NIWA for the entire New Zealand coastline) confirm the region-wide wave statistics presented in Table 1.

Table 1. Summary wave characteristics – Bay of Plenty. After Pickrill and Mitchell (1979) and Heath (1985).

Location	Significant Wave Height (m)	Wave Period (sec)
Hicks Bay – deep water	1.36	6.47
Hicks Bay – nearshore	0.49	1.17
Tauranga	0.96	-
Waihi	0.39	11.13

The predominant wave approach is from the north through east. Northeasterly waves are generated by tropical depressions moving down from the northwest (north of New Zealand). Consequently storm events are considered to dominate the wave climate in the Bay of Plenty (Pickrill and Mitchell, 1979). The frequency of such events is difficult to predict. Pickrill and Mitchell (1977) also note there appears to be no seasonality in wave conditions in the Bay of Plenty.

3.2 Tides

Bay of Plenty experiences low mesotidal to microtidal conditions (Table 2). The tidal range at the Opotiki Wharf ranges from 1.29 m to 1.76 m for neap and spring tide conditions respectively. However, maximum water level at the Opotiki Wharf is determined by flood flows in the Otara and Waioeka Rivers. In particular, flows in the Waioeka River act to block discharge from the Otara River super-elevating water levels at Opotiki Wharf. For instance, records from July 1998 indicate that the maximum tide level was 1.44 m R.L. while a flood event raised water level to 2.74 m R.L.

Table 2. Tidal conditions at selected sites in the Bay of Plenty.

	Mean Spring Range (m)	**Mean Neap Range (m)**
Tauranga	1.6	1.2
Ohiwa	1.5	1.3
Ohope Wharf	1.7	1.3
Whakatane	1.6	1.2
Opotiki Wharf*	1.76	1.29
Hicks Bay	1.7	1.2

* Based on short-term observations at the Opotiki Wharf.

No measurements have been made of the tidal prism – the total volume of water passing through the Opotiki Entrance on the flood and ebb tide. However, Williams et al. (1988) provide a first order estimate of the spring tide prism of 0.95 x 10^6 m^3 based on tidal range and intertidal area of the lower river.

3.3 River Flows and Flooding

The Waioeka and Otara catchments encompass an area of 1130km^2, which is largely steep and forested hill country. There is no flow information available for the short reach of the river system from the confluence to the sea, but reasonable estimates of flows are available for each of the separate river systems.

Table 3 details best present estimates of flood flows in each of the river systems. The peak flows in the reach below the confluence are unknown. However, in flood modelling it has been assumed that the chance of experiencing a 1% AEP event in each river simultaneously is extremely remote and a combination of the 1% and 5% AEP (annual exceedance probability) events from each river have been used (Wallace, 1999). This suggests that in rare and major floods (i.e. 1-2% AEP events), peak entrance discharges are probably of the order of 2200-2500 m^3/s. Flood discharges of 1500-2000 m^3/s are expected to be more common, probably having an annual probability of 5-10%. Peak annual flows are likely to be in the range of 800-1200 m^3/s.

Table 3. Predicted flood sizes in the Waioeka and Otara Rivers (Wallace 1999).

AEP (%)	Waioeka River at Cableway Discharge (m^3/s)	Otara River at Browns Bridge Discharge (m^3/s)
50	656	327
20	904	463
10	1074	562
5	1279	666
2	1583	812
1	1845	932
0.5	2140	1062

Flooding is a serious problem in Opotiki with the town experiencing major flooding on a number of occasions. Existing stopbanks are designed to provide protection for events up to and including the 1% AEP events. However, these stopbanks have been found to offer a significant lesser standard of protection because of excessive energy losses that occur at the confluence of the Otara and Waioeka Rivers, super-elevating water levels in the Otara River (Wallace, 1999). Any alteration in river entrance configuration that could affect flood levels will require thorough investigation.

Low and mean flow estimates for the Waioeka and Otara River systems are detailed in Table 4.

It can be seen that extreme low flows are only 1-5 m^3/s in both rivers. Under these conditions, entrance discharges are likely to be dominated by tidal flows. Estimates of peak entrance discharge using the methods outlined in the US Army Corps of Engineers Coastal Engineering Manual (2001) suggest that peak entrance discharges are in the order of 60-70 m^3/s during spring tides with low river flows.

Table 4. Low and mean flows in the Waioeka and Otara Rivers (data supplied by EBoP). The "combined" flow column provides indicative estimates of low and mean river flows for the area below the confluence.

Flow Parameter	**Waioeka (m^3/s)**	**Otara (m^3/s)**	**Combined (m^3/s)**
Mean annual 7-day low Flow	4.54	1.40	6
5-Year low Flow	3.47	1.28	5
Mean Flow	31.77	11.71	43
Median Flow		6.07	
Mean Summer Flow	21.55	8.94	31
Mean Autumn Flow	24.70	9.45	34
Mean Winter Flow	44.64	16.18	61
Mean Spring Flow	35.44	12.17	48

Mean flows in both rivers show a strong seasonal variation, with combined discharges probably varying from about 30m^3/s in summer to about 60m^3/s in winter (Table 4). We estimated peak discharges of 100-150 m^3/s for the range of mean river flow conditions, consistent with model simulations which indicate peak spring ebb-tide entrance discharge is about 120 m^3/s (pers. comm., Mr P. Blackwood, EBoP, October, 2002).

In contrast, our preliminary estimates indicate that peak flood-tide flows are greatly reduced under mean river flow conditions, peak inflows probably being less than 20-30 m^3/s under such conditions. The associated peak velocities would be barely competent to move local sediments. Therefore, in terms of water and sediment fluxes, the harbour and entrance channel are strongly ebb-dominated.

Overall, the entrance experiences a wide variation in peak discharges, ranging from 50-70 m^3/s at low flows and 100-150 m^3/s under mean river flow conditions to discharges of at least 2000-2500 m^3/s during 1-2% AEP flood events.

3.4 Sediments and Sediment Supply

3.4.1 River sediments

The Otara and Waioeka Rivers are considered to transport large quantities of gravel (Griffiths, 1982). However, most gravel is retained in the lower reaches of the

Otara and Waioeka Rivers and upstream of the confluence. These lower reaches have exhibited significant aggradation in recent years due to gravel deposition (Wallace, 1999). For example, between 1996 and 1998, 46 800 m^3/yr of gravel was deposited in the Otara River downstream of Browns Bridge while the Waioeka River aggraded at 60 400 m^3/yr between the start of the Waioeka gorge and the confluence (Wallace, 1999).

No detailed sedimentological study has been undertaken on the lower reaches of the Otara and Waioeka Rivers. Williams et al. (1988) broadly mapped the sediments downstream of the confluence and noted that medium-size sands dominate the entrance and lower reaches of the river, whereas the intertidal flanks of the lower river and Huntress Creek contain increased proportions of silt and clay-size sediments.

Consequently, the rivers are believed to discharge only sand-size (and finer) material to the coast (Williams et al., 1988; Croad et al., 1993; Tonkin and Taylor, 1996). The total load of sediment to the open coast is estimated at 15 000 m^3/yr (Croad et al., 1993). This value is based on crude scaling of the sediment load in the Motu River and can be considered a first order estimate.

3.4.2 Coastal sediments

The Opotiki entrance joins the open coast on a large drift-aligned embayment. Sediments along this coast are comprised of quartz/feldspars with additions of lithics, pumice, obsidian and shell. The beach sands to the east and west of the Waioeka River entrance are primarily fine to medium sands, with mean grain sizes typically varying from about 0.2-0.3 mm (Healy, *et al*, 1977; Smith, 1986).

There has been no detailed investigation of sediments of the entrance and ebb delta. Such work will be important to support detailed design of options to improve navigation at the entrance. However, Croad et al. (1993) reported a mean grain size of 0.5-0.6 mm in 3 samples taken below low tide on the immediate eastern side of the river entrance (i.e. the extreme western end of the spit). They also noted maximum particle sizes of 3.4 to 7 mm in samples. Tonkin and Taylor (2001) presented sediment size data for 5 samples taken from the outer bar. These sediments were primarily medium sands, with about 75% of each sample lying within the size range of 0.2-0.43 mm and a typical d_{50} grain size of about 0.3mm. The samples also contained small amounts of coarser sand and sometimes gravel, typically 5-10% of the sample being coarser than 0.43 mm, with maximum sizes of about 10 mm.

Clearly sediment at the entrance and bar is coarser than alongshore beach sands on either side of the entrance, as also shown by Smith (1986) who examined alongshore trends in sediment texture between the Motu River and Whakatane. The coarsening of sediments is expected in the vicinity of river entrances and is likely to reflect the injection of river sediments to the coast and the effect of increased velocities in the entrance winnowing finer sands from deposits.

3.4.3 Longshore sediment transport

The direction and magnitude of net alongshore sediment transport has been the subject of a great deal of conjecture in the Bay of Plenty. This is attributable to the lack of detailed quantitative studies of sediment fluxes and the relatively long and open coast in which a number of littoral cells are likely to have established.

Healy et al (1977) state that ‘net littoral drift is in a southeastward direction and appears to decrease in magnitude toward the eastern limits of the littoral conveyor system’. Harbour and river entrances, and rocky headlands provide natural disruptions to such simple patterns of littoral drift. Smith (1986) argued that the Whakatane Heads are the eastern boundary of the easterly littoral conveyor system, with westerly drift from Opape to Ohiwa, though others consider that fine sediments from the Whakatane River do supply small quantities of sediment to Ohope Beach with the most eastern part of the easterly drift system terminating at Ohiwa Harbour.

Evidence for westerly drift is found in several complementary sources. The most compelling evidence for westerly drift is found between Opape and the Opotiki entrance where, despite localised variability, there is a general westward decline in size of sediments. The morphology of the Opotiki spit provides further support for westerly littoral drift. In general spits accrete (or extend) in the direction of littoral drift. The Opotiki spit is offset to the west and has deflected the axis of the channel at an oblique angle (NW) to the coastline.

However, the trend for net westward littoral drift does not appear to extend beyond the Waiotahi River entrance. For instance, the eastward extension of the Ohope Spit over the late Holocene (Gibb, 1977) and the development of the spit on the western side of the Waiotahi River entrance suggest that any trend for net littoral drift in these areas is eastward – when averaged over suitably long periods of time.

It is possible that Waiotahi Beach, between the Waiotahi and Waioeka River is a null point – receiving net deposition from the west and east. Evidence supporting this assertion is found through analysis of historical shoreline positions, which shows net progradation along the length of Waiotahi Beach over at least the last 80-100 years (Figure 2). This is the only area of beach between Opape and Ohiwa to have shown a consistent trend for progradation over the last 80-100 years (Coastline and Coastal, in prep).

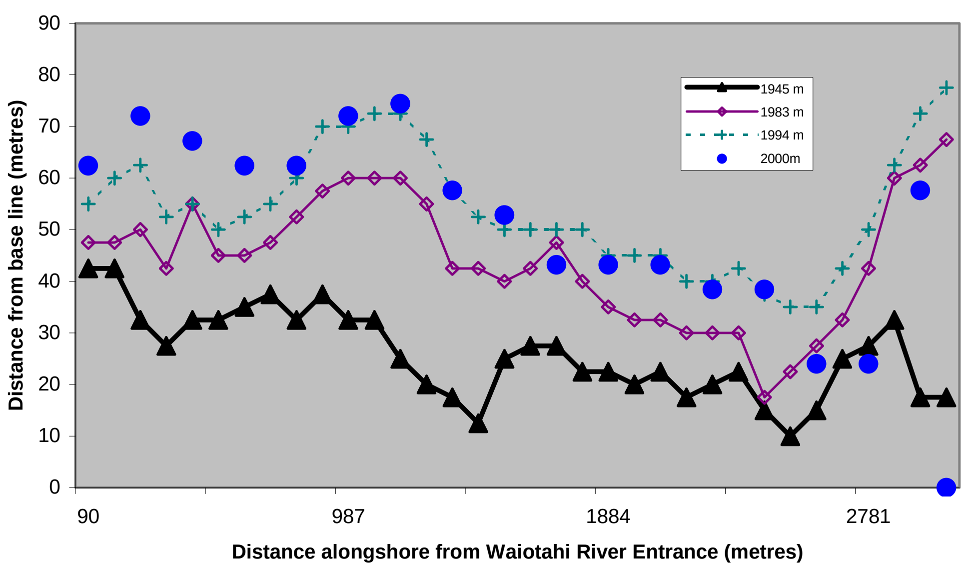

Figure 2. Shoreline change along Waiotahi Beach 1945-2000, indicating general trend for net shoreline progradation.

Estimates of the amount of littoral drift in the Bay of Plenty vary enormously from 70 000 m^3/yr at Katikati, Tauranga and Ohiwa (Healy et al., 1977; Hicks and Hume, 1991) to 5-10 000 m^3/yr in eastern Bay of Plenty (Smith, 1986). The rate of net westward littoral drift is unknown. However, estimates all suggest that net drift is relatively low. Smith (1998) estimated longshore drift of 6 000 m^3/yr in the vicinity of the Opotiki entrance based on analysis of historical change of the coastline. It should be noted this value is low in comparison to other east coast littoral drift systems (e.g. Katikati, Pakiri). It should also be noted that this value is based on net change of the coastline and does not reflect the gross flux of sediment transported along the coast.

3.4.4 Estimates of net sediment supply to Opotiki entrance

On the basis of the preceding sections, available estimates tend to suggest that sediment supply to the entrance area, both from the Waioeka-Otara River system and from net westward littoral drift are low – these amounts estimated to average 15,000 m^3/yr (Croad et al, 1993) and 6,000 m^3/yr (Smith, 1986), respectively. These estimates tend to suggest an average net sediment supply of about 20-25,000 m^3/yr.

In order to validate the estimate of alongshore sediment flux we have estimated the average rate of sediment supply to Waiotahi Beach – adopting the average rate of beach progradation over the last 80 years (about 0.3 m/yr - Coastline and Coastal, *in prep*) and using equilibrium beach theory to estimate the volume of sediment required to produce this progradation. These calculations suggest that, over the last 80 years, the average net deposition along the 4km length of Waiotahi Beach has been of the order of about 8000 cubic metres per year. While indicative only, this figure does tend to support the conclusions of earlier work that the volumes of net littoral drift and river sand supply are relatively low in this area of coast. The figure tends to suggest that net, time-averaged sediment supply to the Waioeka entrance may even be lower than previous estimates suggest. However, the volumes of sediment accumulating at Waiotahi Beach do not account for any sediment losses to local harbours (e.g. Ohiwa and Waiotahi) or to areas offshore.

Therefore, for the purposes of this study we have adopted a figure of 10,000 m^3/yr as a lower bound estimate of net sediment supply in the vicinity of the Opotiki Entrance, a mid-point value of 25,000 m^3/yr and an upper estimate of 40,000 m^3/yr.

3.5 Morphological components of the entrance system and morphological change

The area below the confluence can be subdivided into three morphological zones: i) the harbour area from the confluence to the entrance; ii) the narrow entrance gorge; and iii) the bar at the harbour entrance – which technically is referred to as an ebb tide delta.

3.5.1 Harbour environment

The harbour area varies in width from 200-500m at high tide, though the main channel is typically only 150-200m wide. In the area immediately downstream of the confluence, channel flow is hard against the eastern bank and this area is actively eroding. Further downstream, channel flow affects the western bank and this area has also been gradually eroding over time. For example, based on analysis of historical aerial photographs over a 62-year period between May 1940 (SN 150, Photo A/20, NZAM Ltd) and February 2002 (SN 50110c, Photo No. 23/9, NZAM Ltd), the length of channel immediately downstream of Huntress Creek has experienced net erosion of the western bank of 30-40m. Field inspection indicated that this area is still subject to flow attack, though partially protected by various armouring works. The bank now actually protrudes some distance (up to 40-50m) into the main channel and it is possible that it would have eroded somewhat further over the last few decades had it not been for the armouring measures. The erosion of the western bank has been accompanied by shallowing on the eastern side of the confined channel of the harbour and by accretion of the true eastern bank – which has advanced by up to 100m in places over the last 62 years.

3.5.2 Entrance Gorge

The channel narrows markedly at the entrance gorge. Measurements from aerial photographs indicate that it is typically only 80-90 m wide at mid-tide. However, reconstruction of the gorge cross-section from a 1995 bathymetric survey (Figure 3) shows the entrance was 150 m in width at that time, with a maximum depth of 3.2 m below R.L. These variations in entrance width reflect the highly dynamic nature of river mouths and tidal entrances.

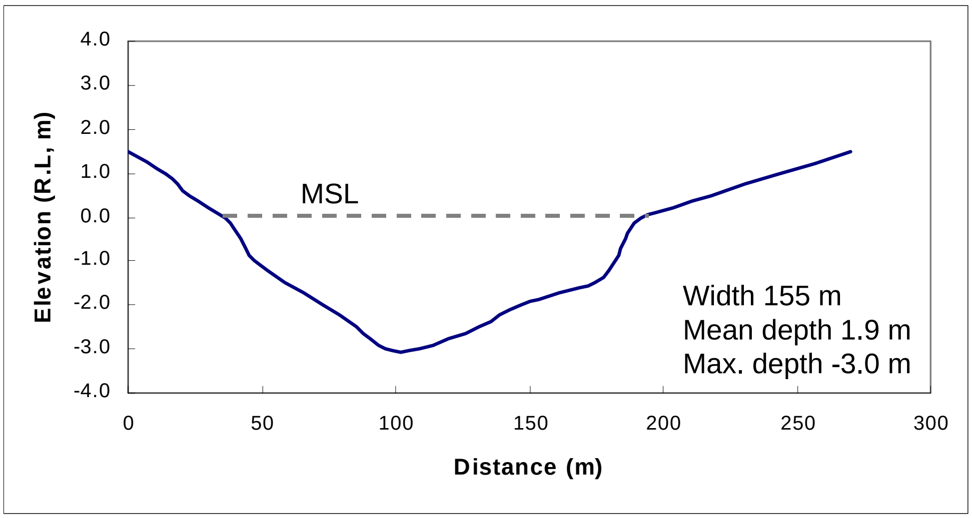

Figure 3. Opotiki entrance throat cross-section.

Critical to this study is an understanding of the spatial and temporal scale of change in the river entrance channel. Naturally occurring river entrances (or tidal inlets) are commonly bounded by sand spits on either side of the channel (as is the case at the Opotiki entrance). Tide, wave and river processes act to transfer energy and materials between the open coast and estuarine environments and control the size of the inlet channel (Bruun, 1978, Walton and Adams, 1976; Hume and Herdendorf, 1992). River entrances are highly dynamic coastal landforms that change their configuration (cross-sectional area, width and depth), and position on the coast continuously in response to changes in river flow, wave and tidal processes (Hume and Herdendorf, 1992; Kench and Parnell, 1991).

At any point in time the dimensions of the gorge reflect the dynamic balance between the forces acting to keep the channel open (i.e. the river and tidal flows) and those forces which act to close the entrance (i.e. sediment carried into the channel by waves and currents). Consequently, as a natural process, river entrances can migrate alongshore and show considerable variation in width, depth and cross-sectional area over time in response to changes in tidal, wave and river processes and sediment supply.

Studies from many larger inlets have shown that a sensitive relationship exists between the tidal prism or peak discharge and channel cross-sectional area (O'Brien, 1931, 1969; Jarrett, 1976; Bruun, 1978). Figure 4 shows this relationship for a number of New Zealand inlet systems. The readjustment of the inlet cross-section occurs almost instantaneously with each tide. In situations where the tidal prism increases a greater erosive force is exerted on the boundary and the cross-sectional area can increase. In contrast, reduction in the tidal prism promotes sedimentation and a decrease in cross-sectional area. In situations where rivers discharge to the coast the tidal prism can change markedly between low and high river flows with consequent dramatic changes in inlet configuration.

Detailed studies of the morphological behaviour of the Opotiki entrance have not been undertaken and will be required to design any improvement to the entrance. However, on the basis of experience elsewhere and theoretical considerations it is probable that the entrance area increases significantly during major flows and contracts during periods of low river flow. For the purposes of this study, we have used data from other similar sized entrances and available empirical models (derived using field data) to better resolve the likely magnitude and temporal scale of entrance dynamics - in order to assess the effects of proposed navigation improvements at the entrance.

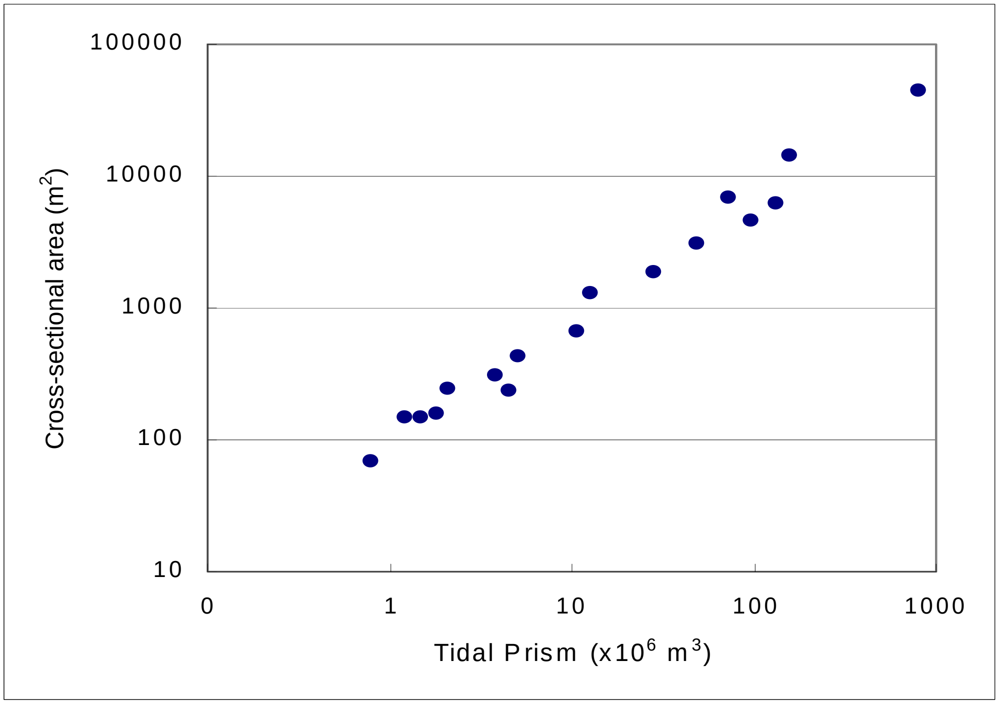

Figure 4. Tidal prism cross-sectional area relationship for New Zealand inlet systems. Source: Coastal Consultants, 2002.

3.5.3 Dynamics of river entrance cross-sections

Table 3 presents summary statistics of the morphological dimensions, river discharge and tidal prisms for a number of North Island east coast inlets. Of note, the Opotiki entrance is small in size and similar in characteristics to the Rangitaiki and Waipu river entrances (Table 3). Significantly these smaller entrances have small tidal prisms and relatively high catchment runoff. During periods of low flow the entrances are almost solely reliant on the tidal prism for flushing. Studies at the Waipu and Rangitaiki River entrances show these small entrances to experience large fluctuations in tidal prism related to the variable nature of river flow. Table 4 summarises changes in tidal prisms at these inlets and indicates that river floods can more than double the tidal prism. As noted in Section 3.3 river flow can vary enormously in the Opotiki system ranging from 5 to more than 2000 m^3/s. Therefore, large variations in “tidal” prism and peak entrance discharge will also be experienced at Opotiki.

Table 3. Morphological, tidal prism and river flow characteristics for east coast tidal inlets and river entrances.

Site	Spring tidal prism (10^6 m^3)	Throat width at HT (m)	Max. throat depth at HT (m)	Throat area at MT (10^3 m^2)	Mean daily runoff (m^3/s)	Ratio runoff to prism
Katikati	95.8	400	25.8	4.7	16	0.17
Ohiwa	28.1	340	12.8	1.95	7	0.25
Tairua	5.02	175	6.5	0.43	9	1.79
Tauranga	131	700	27.6	6.30	37	0.28
Rangitaiki	1.22	70	5.5	0.15	71	58
Waipu	1.82	132	3.5	0.16	5	2.74
*Opotiki	0.95-2.8	150	3.2	0.28	29	30.5

Table 4. Influence of river floods on entrance tidal prisms.

	Spring tide prism (m^3)	Prism enhanced by storm surge (m^3)	Prism enhanced by river flood	Percent increase in prism due to flood
Waipu River*	1 820 532	2 594 402	3 678 000	102%
Rangitaiki River**	1 221 284	-	3 706 912	203%

*Kench 1990, ** Coastal Consultants 2000

Available data indicates that large fluctuations in tidal prism exert a major control on entrance cross-section characteristics. Table 5 and Figure 5 present monitoring records that show the magnitude and rate of change of the Waipu and Rangitaiki entrances. These records show that small river-dominated entrances are able to double in width and cross-sectional area over very short timeframes in response to fluctuations in tidal prism, which are strongly influenced by river discharge.

Table 5. Morphological change in river entrance dimensions.

Waipu River Entrance*			Rangitaiki River Entrance**			
Month 1989	**Width (m)**	**Cross-sectional Area (m2)**	**Month 2001**	**Width (m)**	**Mean Depth (m)**	**Cross-sectional Area (m2)**
May	96	122.5	March	48	3.10	148.3
June	194	187.5	June	67	2.62	175.4
July	160	192	Sept	51	2.90	146.9
August	110	165	Dec	70	3.40	244.0

* Kench 1990, **Coastal Consultants 2001

As the Otara and Waioeka Rivers exhibit marked variations in river discharge it is expected the Opotiki entrance also experiences significant short-term (i.e. daily, weekly, monthly) changes in cross-sectional area and width.

Calculations using empirical procedures underscore the potential for significant scour of the harbour entrance during major flows. For instance, estimates of entrance scour using the procedures developed by the US Army Corps of Engineers (Hughes, 2002) indicate that the cross-sectional area may increase up to about 700 m^2 for a peak flow of 1000 m^3/s and potentially as high as 1300 m^2 for a flow of 2000 m^3/s (i.e. a 1-2% AEP event, see Table 6) – compared to a cross-sectional area of 100-150 m^2 under mean flow conditions. In practice, scour during major flows may be less than indicated by the empirical models due to the relatively short duration of the flood events. Nonetheless, the calculations do indicate that the entrance is likely to be significantly scoured during major river flows – resulting in both deepening and widening of the entrance.

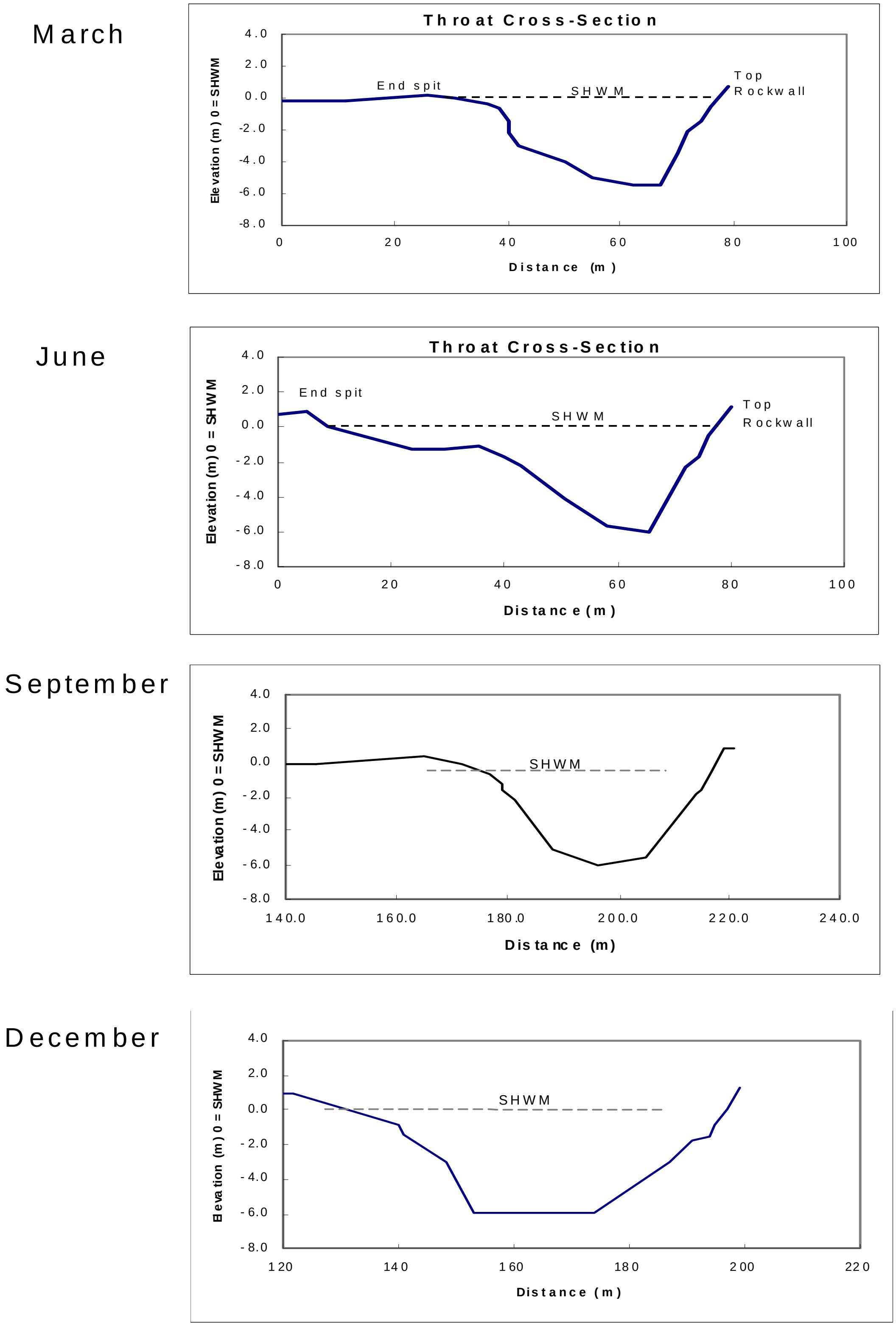

Figure 5. Four monthly cross-sectional surveys of the Rangitaiki River entrance, 2001. Source (Coastal Consultants, 2001). Note large shifts in width and depth between surveys.

Table 6. Estimates of Opotiki entrance hydrodynamics and consequent changes in cross-sectional area.

Discharge (m^3/s)	Mean velocity (m/s)	Max. Velocity (m/s)	Depth (m)	Cross-sectional Area (m^2)
70	1.04	1.17	0.7	70
120	1.11	1.25	1.10	110
1000	1.40	1.58	7.1	710
2000	1.51	1.7	13.2	1320

In the intervening low flow periods the entrance is likely to infill with sediment leading to a decrease in width and cross-sectional area. Calculations suggest that the gorge may contract to a minimum area of only 60-80 m^2 during periods of sustained low river flows (Table 6). Under such conditions marine processes dominate the entrance and wave and flood tide currents transport sediment into the entrance channel.

Overall, the Opotiki entrance is likely to experience periods of river dominance producing entrance widening and deepening and low river flow periods in which marine processes dominate, producing entrance narrowing and shallowing.

It is clear from the above discussion that the entrance gorge is likely to be a very dynamic area, varying in cross-sectional area by one or two orders of magnitude between peak river flows and periods of sustained low flows. However, the above estimates based on data from other sites and available empirical models should be treated as indicative only and it is important that site-specific data is gathered for this entrance. This data will be critical to the design of any training walls for the harbour entrance. It is also important to improve the modelling of flood flows in the lower harbour.

3.5.4. Dynamic behaviour of the Opotiki entrance: throat location

In addition to the dynamic variability experienced in response to varying river flows, the entrance has historically demonstrated a slow but significant trend for westward migration over the period for which records are available. For instance, the earliest available shoreline survey (SO 2810 conducted in 1866) indicates that the entrance gorge lay 900-1100m east of the present position, indicating an average rate of westward migration of about 7.5-9.5 m/yr over this period. This westward migration is continuing but appears to have been slower in recent decades. For instance, comparison of aerial photographs from 1940 and 2002 indicate westward migration of about 170m over the last 62 years, an average rate of migration of about 2.8 m/yr.

The westward migration observed over the last 140 years appears to relate both to river channel changes and to westward growth of the spit on the eastern side of the entrance. Significant river channel changes appear to have been a major factor in the entrance changes between 1866 and the 1940's.

Aerial photographs indicate that while there has been westward extension of the spit, it has become narrower. In 1940, the spit was approximately 155 m wide at its narrowest point - compared to only 90 m in February 2002. The narrowing relates primarily to erosion on the inside (harbour) margin of the spit, probably during floods. It is likely that the spit will eventually be breached by river flows and/or storm wave washover. Breaching is most likely to occur at the narrowest point of the spit, presently located about 300 metres east of the entrance.

3.5.5 Ebb Delta

The sediment eroded from the river entrance during major river flows will be deposited further seaward on the ebb tide delta. Once the major flows cease, wave action and flood tide currents will tend to move sediment from the adjacent beaches and nearshore areas of the delta into the entrance gorge, reducing the entrance area. It is possible that significant deposition may even occur during the falling stages of major river flows.

There is little information on the ebb tide delta at the entrance to Opotiki Harbour, largely limited to a bathymetric survey conducted by the RNZN in 1995 and a partial survey conducted for ODC by Martin McCaulay Morton Ltd in May 2001

(Plan 121045/P, Sheet 1). This data, available aerial photos and field inspection suggest the feature extends about 600 metres offshore (to about 5m below Chart Datum, Fig. 6), with an alongshore extent adjacent to the shoreline of about 1200-1500 metres.

The main morphological features of a typical ebb tide delta are shown in schematic and idealised form in Figure 7. Net sediment transport is normally seaward within the main ebb channel, terminating in a terminal lobe at the seaward end of the channel. Sediment deposited on the terminal lobe and on the shallow platforms adjacent to the main channel is moved landward and entranceward by waves and flood tide currents, often in the form of migrating swash bars (Figure 7). Transport toward the entrance dominates along the landward margin of the ebb tide delta, under the influence of both waves and flood tide currents. These general morphological features and the associated pattern of sediment transport have been widely demonstrated by studies of ebb tide deltas overseas (e.g. Hayes, 1975; Fitzgerald, 1982 & 1988) and within New Zealand (Dahm, 1983).

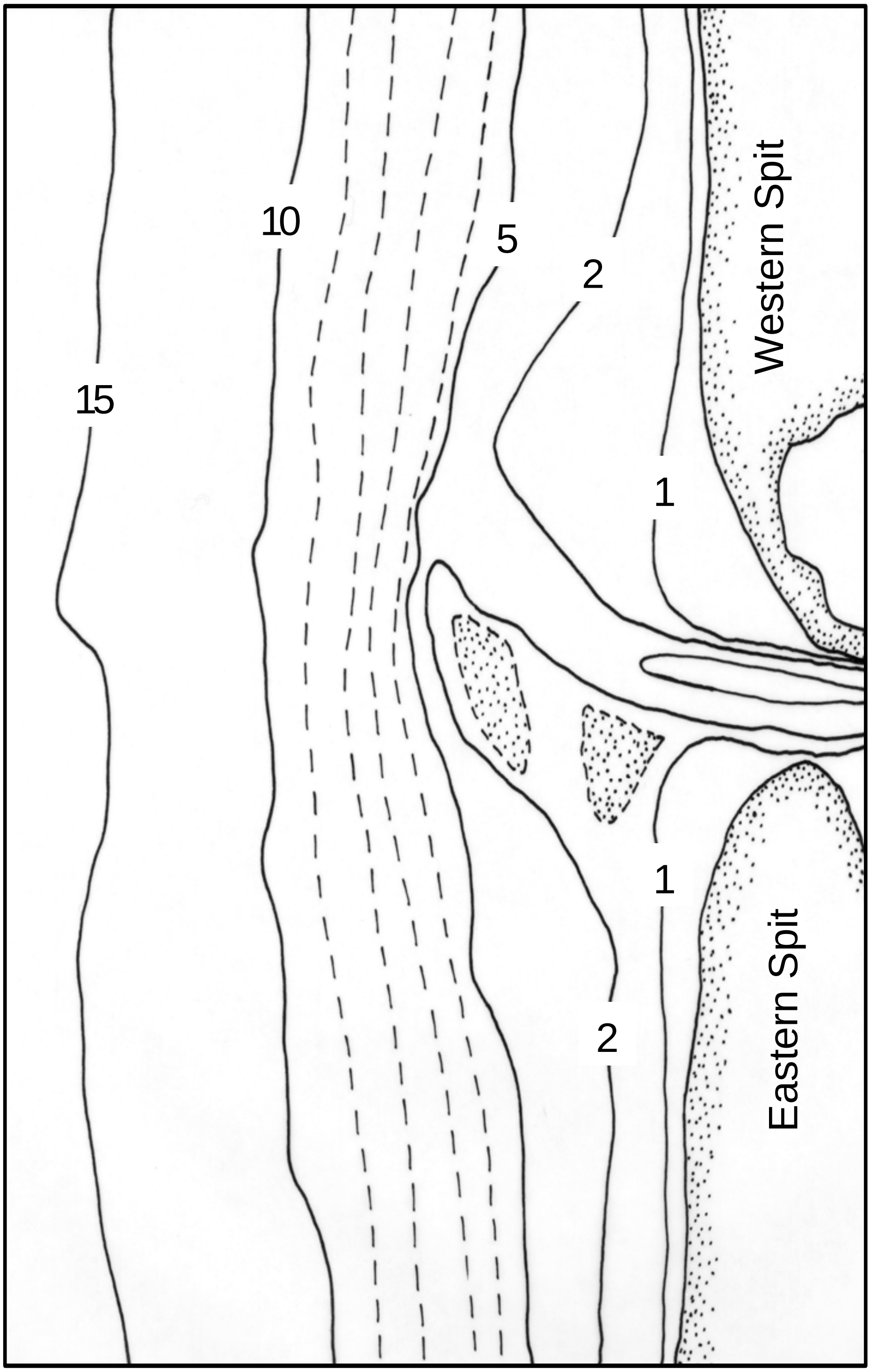

Figure 6. Bathymetry of the Opotiki entrance and nearshore. Planform configuration of the ebb-tide delta as defined by the 5 m contour. Source RNZN hydrographic survey, 1995.

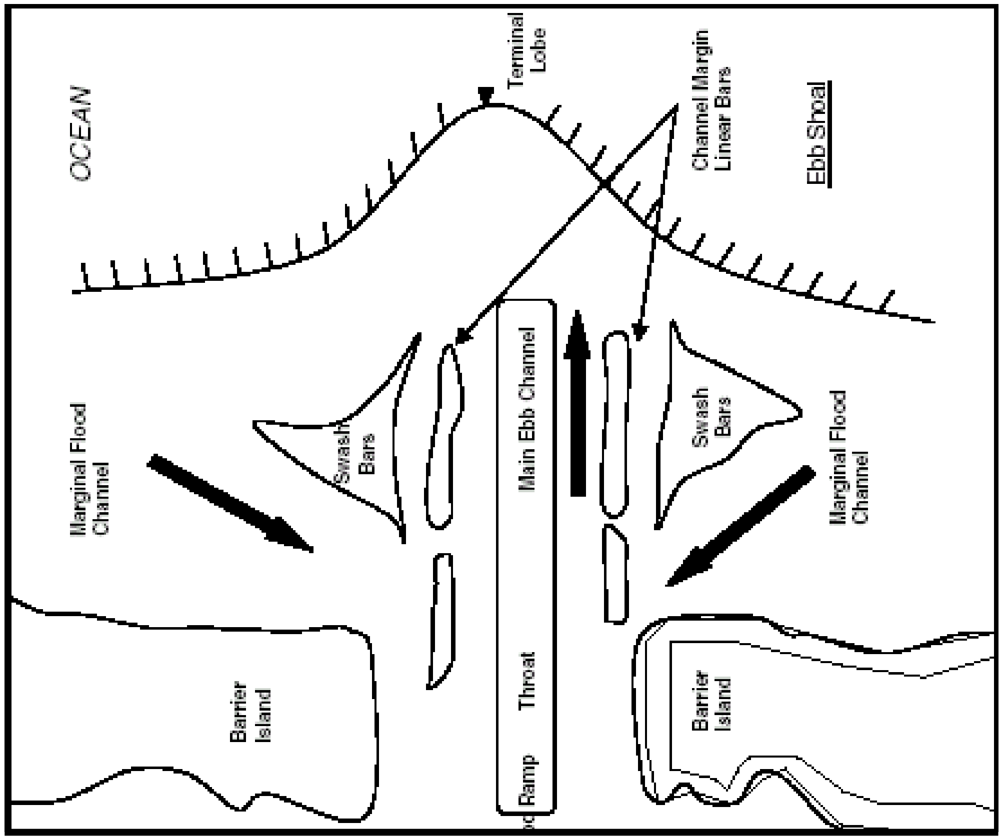

Figure 7. Typical components of an ebb-tidal delta and directions of net transport. (Source: Modified after Militello and Hughes, 2000).

The volumes of sediment recirculating over an ebb tide delta are usually high and these features can be very dynamic. In a feature the size of the Opotiki ebb tide delta, the volumes of sediment being recirculated will be somewhere of the order of 10^5 m^3/yr, much higher than net sediment fluxes.

The ebb tide delta also acts as a “bridge” across the entrance, enabling sediment being moved along the coast to bypass the entrance. The mechanism by which sediment bypasses the entrance can vary (Bruun and Gerritsen, 1959; Fitzgearld, 1982, 1988). However, at entrances like Opotiki the main mechanism is typically a form of bar bypassing known as ebb tide delta breaching (Fitzgerald, 1988).

In ebb tide delta breaching the dominant direction of littoral drift produces a preferential accumulation of sediment on the updrift side of the ebb tide delta, the eastern side at Opotiki. At Opotiki, this sediment accumulation causes a downdrift (i.e. western) deflection of the main ebb channel, evident in the survey conducted by Martin McCaulay Morton Ltd. On some occasions, particularly during very low river flows, the channel can be severely deflected and almost run along the face of the western shoreline. However, during high river flows at Opotiki, the main channel cuts a path directly seaward through the ebb tide delta. This cuts off a large portion of the delta (on the western side of the entrance), which slowly migrates landward welding to Waiotahi Beach - thereby completing the bypassing of the entrance.

A more subtle and longer-term form of bypassing may also operate at Opotiki. This process is known as inlet migration spit breaching (Fitzgerald, 1988). With this mechanism the spit on the updrift side of the entrance gradually extends resulting in alongshore entrance migration – to the west at Opotiki. As the spit extends, it tends to become narrower and is eventually breached by high river flows, forming a new entrance at the point of breaching. The area of the spit cut-off on the downdrift side of the new entrance is thereby bypassed. It is not clear that this form of bypassing has operated at Opotiki. However, the gradual extension and narrowing of the spit on the western side of the entrance suggests this form of bypassing could occur.

It can be seen from the above explanation, that the pattern of bar and channel movements observed at Opotiki entrance are critical to the natural operation of the sediment system, particularly to bypassing of sediment across the entrance. However, this process gives rise to extreme difficulties for navigation. Means used to establish a stable channel for navigation disrupt natural bypassing processes. Therefore, a by-product of navigation improvements is a requirement to artificially bypass sediment.

3.6. Conceptual Model of Opotiki Entrance Dynamics

Given the paucity of process information at the Opotiki Entrance a conceptual model has been developed based on the literature review, investigations at other ebb tide deltas in New Zealand (e.g. Dahm, 1983), investigations at similar-sized entrances, most notably at Waipu (Kench and Parnell, 1991) and Rangitaiki (Coastal Consultants, 2001), and the use of available empirical and conceptual models. The conceptual model provides first order approximations of the nature of processes and spatial and temporal scale of entrance and bar morphological change. This model provides a useful framework to assess the potential impact of options to improve navigation at the entrance.

3.6.1 Process controls on entrance dynamics

- The Opotiki entrance is ebb-dominated with regard to the velocity, duration of flow throughout a tidal cycle and net sediment transport.
- The entrance experiences extreme short-term variations in discharge controlled largely by seasonal and storm-driven changes in river flow that range between 5 to 2000 m^3/s.
- The entrance experiences low to moderate wave energy. Dominant wave energy is experienced during episodic storm events. Marine influences on entrance hydrodynamics are most dominant during periods of low river flow.

3.6.2 Sediment transport at the Opotiki Entrance

- The Opotiki entrance is on a low drift coast. Alongshore transport is in a westward direction at the Opotiki entrance.
- Sediment is transported past the entrance through the processes of bar-bypassing.
- Estimates of net alongshore sediment transport range from 6 000 – 8000 m^3 per year.

- Delivery of river sediment to the entrance is estimated at 15 000 m^3 per year. However, the volume of sediment is likely to be controlled by the frequency of floods.
- Combining estimates of sediment delivery from both sources approximately 23 000 m^3 of sediment may be delivered to the Opotiki entrance on an annual basis. This value is used as a 'best estimate'.
- However, recognising the uncertainty of sediment transport estimates the report also adopts a low value of 10 000 m^3/y and a high value of 40 000 m^3/y, in its assessment of the effects of options to improve navigation, in order to establish the sensitivity of the system to changes in sediment supply.

3.6.3 Morphological change at the entrance

- The morphology of the Opotiki Entrance and bar is controlled by the balance between marine and river processes.
- Under extreme river discharges the tidal prism and peak entrance discharges are likely to significantly increase and give rise to significant scour and enlargement of the entrance cross section.
- Marine processes dominate the entrance under low river discharge periods and during periods when storms generate significant wave energy at the coast. Under these conditions wave-driven currents transport sediment toward the entrance promoting sedimentation and reduction in cross-sectional area.
- Analogues from similar-sized entrances and empirical modelling suggest that the Opotiki entrance dimensions can potentially vary from 70 m^2 under low discharge periods and 110 m^2 under mean discharges up to 1320 m^2 or more under extreme river discharge.
- Changes in entrance morphology occur over short timeframes (days to months). Seasonal variations in river discharge promote winter widening and summer shallowing (when wave processes exert a stronger influence). However, individual river floods also exert short-term but significant changes in entrance morphology.

3.6.4 Ebb delta morphology and morphological change

- The ebb delta at the Opotiki entrance is the major subtidal sediment sink within the entrance system.
- The delta experience seasonal and event-driven changes in position of the channel that flows across the delta.
- During periods of mean and low river discharge the channel assumes an oblique angle to the coast. This is controlled by the extended position of the western spit that promotes northwestward deflection of the channel as it exits the entrance and westward littoral drift.
- Under extreme floods the channel assumes a more perpendicular orientation to the coast, thereby cutting-off a section of the bar that is able to weld to the western shoreline.
- This cyclic channel migration and bar splitting provides the mechanisms for westward alongshore sediment transfer.
- The gross rate of sediment flux on the ebb delta is considered to be at least an order of magnitude larger (10^5 m^3) than the net rate of sediment transport at the entrance (10^4 m^3).

3.7 Implications of Entrance Processes and Morphodynamics for Options to Improve Navigation

3.7.1 Flood release

As noted in Section 3 the Opotiki Entrance is subject to large fluctuations in river discharge. Under such conditions the entrance scours to accommodate large river fluxes. It is paramount that evaluation of options to improve entrance navigation ensures that flooding in the lower reaches of the Otara and Waioeka Rivers is not exacerbated. Consequently, options should allow for maximum scour under river floods and should not markedly slow entrance enlargement - to ensure that flood protection works are not compromised.

3.7.2 Morphological adjustment of throat

Given the requirement to allow for maximum flood scour options should take account of natural and short-term adjustments in channel cross-section. Designs should allow for channel fluctuations between an envelope dictated by the minimum navigation requirement and maximum river discharge.

3.7.3 Morphological changes on delta

Bar bypassing of sediment on the ebb delta implies the channel is able to change its position relatively freely. This is central to the issue for improving navigation, which requires a stable channel (in both position and depth).

3.7.4 Low rate of alongshore drift

Unlike most examples where entrance improvements have been instigated the Opotiki coast has low rates of alongshore sediment transport (approximately 8 000 m^3/yr) and river delivery (15 000 m^3/yr). This is a positive feature of the entrance system as New Zealand and overseas examples indicate that entrances which experience high rates of littoral drift receive only short-term benefits from navigation improvements and they are expensive to maintain.

3.7.5 High gross sediment flux

It is important to note that while rate of net alongshore sediment transport is low in the vicinity of the entrance, the gross sediment flux on the delta is likely to be several orders of magnitude larger. The ebb delta encompasses the surfzone, a zone of intense turbulence and high sediment flux. Consequently, it is likely that cyclic reworking of sediment on the ebb delta is in the order of 10^5-10^6 m^3 on an annual basis.

4. REVIEW OF OPTIONS FOR ENTRANCE IMPROVEMENT

This section reviews and evaluates the various options for improvement of navigability at the entrance to the Waioeka River so that it can function on a long-term basis as a reliable all-weather port for commercial vessels.

The brief provided for this study specifies that the commercial use of Opotiki Harbour would require an entrance channel at least 30 metres wide, with a depth of at least 2.5 metres below mean low water spring tide.

The various options discussed and evaluated are:

- Status quo
- Status quo and minor dredging
- Dredging
- Fluidisation
- Entrance constriction
- Single mole
- Dual moles

The options are evaluated according to their improvement of entrance depths and navigability, operational availability of the port, effects on coastal and river processes and the wider environment, effects on flooding, consent requirements, practicality to implement and maintain, capital and maintenance costs, risks associated with the option and means of mitigating these risks.

4.1 Status Quo

4.1.1 Description

This option involves no action to improve depths over the entrance bar. However, it does involve a number of actions designed to provide improved information for craft using the harbour, including:

- Preparation of a harbour information pack that assists users to understand navigation constraints, similar to the Westport Harbour Information Pack.
- Regular (perhaps weekly) inspection and/or soundings to monitor changes in the position and depths of the channel over the bar, with recommended route for crossing the bar shown on regularly updated chart at the launching ramp.
- Installation of leading lines to delineate the safest routes over the bar, with relevant leads regularly moved to keep up to date with changing conditions.

4.1.2 Practicality to implement and maintain

This option is relatively simple to implement.

4.1.3 Improvement of entrance depths and navigability

This option does not result in any improvement in depths over the entrance bar or any improved shelter from wave effects.

4.1.4 Operational availability

Availability will be totally dependent on natural conditions. At present, there is limited information on closures and depth restrictions at the Opotiki entrance. However, Tonkin and Taylor (1996) note that available statistics suggest the number of days the bar would be closed is similar to Whakatane. Analysis of Whakatane bar closures for the period January 1991 to 30 June 1994 indicated the bar was closed by wave conditions for a total of 222 days in the period (Spake, 1994), about 17% of the time or approximately 1 day in 6.

Consequently, without entrance improvement, it is possible that the entrance can be used by recreational craft for about 80% of the time, though there may occasionally be depth constraints preventing use for some period either side of low tide. Therefore, provided the option was accompanied by improved information about entrance conditions, it may be possible to counter the negative perceptions held by recreational/game fishermen about the Opotiki bar (reported by Tonkin and Taylor, 1996) and facilitate more frequent and safer use of the entrance by recreational users.

As this option does not involve action to improve depths, there will inevitably be lengthy periods when bar depths are inadequate for vessels drawing more than 2 m. Unfortunately, there is insufficient information on bar depths to make any reasonable estimate of the constraint likely to be imposed on commercial use. The uncertainties imposed on commercial use by wave action and occasional depth constraints mean that this option is unlikely to facilitate increased commercial use.

4.1.5 Effects on coastal processes and wider environment

The option does not have any significant effect on natural coastal processes or the wider environment.

4.1.6 Effect on flooding

This option will have no adverse or beneficial effects on flooding.

4.1.7 Capital and maintenance costs

Expenditure Item	Estimated Capital Costs ($2002)	Estimated Annual Maintenance Costs ($/yr: 2002)
Installation of harbour leads	$50-150,000	$10,000
Preparation of harbour information pack	$10,000	$2000
Weekly inspections of bar conditions		$25,000
Miscellaneous		$5-15,000
Total Estimated Costs	**$60-160,000**	**$50-65,000**

4.1.8 Consent requirements

This option is unlikely to have any significant consent requirements.

4.1.9 Risks and risk mitigation

If this option facilitated increased recreational use, there is a risk that the frequency of accidents at the harbour entrance could increase. The major means of mitigation of such effects is likely to be the provision of good, user-friendly information at the boat ramp and preparation of a readily available harbour information pack.

4.1.10 Summary

This option is unlikely to realise the benefits associated with increased commercial use of the harbour, but could be used to increase the level of recreational use.

The option does not have any significant effect on natural coastal or river processes, flooding or the wider environment.

4.2 Status Quo and Minor Dredging

4.2.1 Description

This involves similar actions to the previous option (Section 4.1) with the addition of occasional and localised dredging to increase water depth over the shallowest regions of the bar.

4.2.2 Practicality to implement and maintain

This option requires the availability of suitable dredging equipment and regular monitoring of bar depths. This option will allow the channel to move naturally rather than attempting to fix the channel location. This approach will need to be trialled to establish feasibility and maintenance requirements. The option is dependent on regular monitoring of bar conditions and improved understanding of bar dynamics.

4.2.3 Improvement of entrance depths and navigability

This option will not maintain a navigable channel of the dimensions specified in the brief. Rather it is designed to ease constraints imposed by the bar after periods of sustained low flows. It does not provide any shelter from incident wave effects.

4.2.4 Operational availability

Availability will be largely dependent on natural conditions as with the status quo option (Section 4.1.4). The option is designed to minimise the duration when navigation is limited by severe bar shallowing.

4.2.5 Effects on coastal processes and wider environment

The option will not have any significant effect on natural coastal processes or the wider environment provided the sediment is returned to the local coastal environment.

4.2.6 Effect on flooding

This option will have no adverse effects on flooding. Rather maintenance of greater depth at the bar crest may have minor beneficial impact on flood release.

4.2.7 Capital and maintenance costs

Expenditure Item	Estimated Capital Costs ($2002)	Estimated Annual Maintenance Costs ($/yr; 2002)
Installation of harbour leads	$50-150,000	$10,000
Preparation of harbour information pack	$10,000	$2000
Miscellaneous		$5-15,000
Regular soundings and monitoring of sedimentation		$0.05 – 0.3 million/yr ($0.15 million/yr)
Dredging (cost per operation = $ 0.15-0.3 million)		$0.3 – 0.6 million/yr ($0.45 million)
Total Estimated Costs	**$60-160,000**	**$0.4 – 1.0 million/yr**

4.2.8 Consent requirements

This option is likely to require resource consent for dredging and disposal.

4.2.9 Risks and risk mitigation

If this option facilitated increased recreational use, there is a risk that the frequency of accidents at the harbour entrance could increase. The major means of mitigation of such effects is likely to be the provision of good, user-friendly information at the boat ramp and preparation of a readily available harbour information pack.

There is a risk that the option will not provide sufficient surety of improved depths for commercial vessels. There is also likely to be delays in mobilising dredging equipment. The improvements may also be lost rapidly due to significant wave events following dredging.

4.2.10 Summary

This option may benefit commercial use of the harbour but will need to be tested.

The option does not have any significant effect on natural coastal or river processes, flooding or the wider environment.

4.3 Dredging

4.3.1 Description

This option involves the formation and maintenance of a navigable channel across the bar by regular dredging. The channel is likely to require significant over-dredging to ensure the maintenance of design dimensions between periods of maintenance dredging. Dredging navigation channels in excess of minimum navigation requirements is common practice in situations where serious shoaling may be experienced during extreme climatic events (e.g. river floods or severe wave storms at Opotiki) and where maintenance dredging may be delayed by adverse weather conditions or the availability of suitable dredging equipment. Over-dredging has also be found in many situations to reduce both the frequency of dredging operations (which usually reduces annual costs) and to result in less frequent disruption to navigation (Parchure and Teeter, 2002).

4.3.2 Improvement of entrance depths and navigability

This option can be used to form and maintain a navigation channel of the desired design dimensions to provide for the commercial use of Opotiki Harbour.

4.3.3 Practicality to implement

Wave conditions are likely to complicate both capital and maintenance dredging operations. A significant degree of over-dredging will be required to avoid disruption to navigation and to allow for delays in mobilising maintenance dredging.

The level of over-dredging required to ensure maintenance of design channel dimensions at Opotiki will require detailed consideration of: costs; significance of disruptions to navigation; availability of suitable dredging equipment; and improved information on sediment movements over the bar at the harbour entrance. However, it is probable that the channel will need to be constructed to a width of at least 35 m and a depth of at least 3 m below mean low water springs over a distance of 600 m. Side batter slopes will need to be at least 1:5. The volume of sediment required to be dredged to form this channel is approximately 55-60,000 cubic metres.

Specialised dredged equipment and skilled operators will be required to operate in the wave and current environment prevailing at the entrance. Dredging will also require equipment capable of operating in at least mild wave conditions to enable capital and maintenance dredging to be conducted relatively cost effectively. Advice from dredging operators suggest that a moderate-sized cutter suction dredge should be capable of working in the conditions available in the entrance up to swell heights of about 0.5-0.75m and such equipment is available in Auckland (Mr G Kruuf, Heron Construction Ltd, pers. comm. November 2002). Nonetheless, wave action will limit the days when dredging is possible.

The most cost-effective operation is likely to involve pumping the sediment to an appropriate location, rather than loading to a hopper or barge. Agitation dredging, which involves loosening bed sediment and allowing local currents to transport it away, could be trialled with discharging flows to see if this method can be used to reduce costs. However, it is unlikely to be appropriate due to the length of the channel, the varying direction and strength of the currents and the high probability that the sediment will return to the channel within a short period. Similarly, sidecast dredging (depositing dredged sediment on one or both sides of the navigation channel) is unlikely to be appropriate because the dynamic nature of the ebb tide delta gives rise to a high possibility of the sediment returning rapidly to the navigation channel.

4.3.4 Operational availability

It should be possible to maintain reasonable operational availability, provided that sedimentation problems are closely monitored and maintenance dredging is able to be readily undertaken. However, the unprotected nature of the channel means that wave effects will also make navigation difficult on occasions, especially on an ebbing tide. The entrance is likely to be difficult to use once waves exceed 1.5 m in height (waves between 2.0 m and above are likely to break in the channel, with a depth of 3 m). The wave data available for the Bay of Plenty is not adequate to estimate the frequency of such wave heights with any certainty.

4.3.5 Sustainability of entrance improvements

The conceptual model indicates that gross sediment fluxes in the harbour entrance and bar are likely to be very high (10^5 m^3/yr). Investigations of similar-sized entrances indicate that large volumes of sediment can be moved over short timescales. For instance, fluctuations of +/- 20 000 m^3 were observed between months on the Waipu flood delta (Kench, 1990). Ebb tide deltas are known to be far more dynamic features than flood tide deltas.

Evidence of rapid infill of dredge scour holes at Parengarenga and Pakiri (over a timescale of days) provides further evidence of the efficacy of nearshore wave and current processes to rapidly infill depressions in the seabed.

Therefore, safeguarding design dimensions in the unprotected, dredged channel is likely to require regular and significant maintenance dredging. The volume of maintenance dredging will be controlled by wave and river flow conditions and will vary markedly over time. Significant changes are likely to occur relatively rapidly after major floods and storm wave events.

It is difficult to estimate the average annual volume of maintenance dredging with any certainty, though it is unlikely to be less than 30,000 cubic metres per year and may be much higher – possibly in excess of 100,000 cubic metres.

The likelihood of rapid sedimentation will necessitate frequent monitoring of depths and require the ready availability of suitable dredging equipment.

4.3.6 Effects on coastal processes and wider environment

The removal of large volumes of sediment to form and maintain the navigation channel is likely (over time) to have significant effects on the ebb tide delta and adjacent beaches. For instance, repetitive dredging is likely to result in lowering of the bar and increased wave attack and erosion of adjacent beaches. However, these effects can be mitigated to some extent by placing the dredged sediment on or near the local beaches.

The dredging will also disturb any shellfish or other biota within the confines of the dredged channel and the disposal area for the dredging. Detailed ecological investigations would be required to assess the nature and extent of any biological communities likely to be affected.

4.3.7 Effect on flooding

This option is likely to have beneficial effects on flooding as the dredged channel will facilitate the release of flood flows.

4.3.8 Capital and maintenance costs

Estimated costs are shown in the table below. As per the requirements of the brief, lower and upper limit estimates are provided for maintenance costs, with present best estimates shown in brackets.

Expenditure Item	Estimated Capital Costs ($2002)	Estimated Annual Maintenance Costs ($/yr; 2002)
Design and consenting	$50-150,000	$30,000
Capital Dredging	$1.8-2 million	
Regular soundings and monitoring of sedimentation		$0.05-0.3 million/yr (0.2 million/yr)
Maintenance dredging		$1-3 million/yr ($2 million/yr)
Total Estimated Costs	**$1.85-2.15 million**	**$1-3.4 million/y ($2.2 million/yr)**

Fairly expensive and specialised dredging equipment will be required given the wave conditions, currents and limited depths. Dredging costs assume equipment will have to be brought in from other locations and that establishment and disestablishment costs will be required. The nearest location with dredging equipment capable of meeting requirements is Auckland – where at least one moderate-sized, cutter suction dredge capable of working in low-moderate swell conditions (say 0.5-0.75m) is available. Sands would be discharged via pumping to an appropriate local coastal location, probably on the western side of the entrance. Skilled and experienced dredging operators will be required for a cost-effective operation.

If maintenance dredging requirements prove to be high and rapid changes occur, dredging equipment may have to be purchased to be available at relatively short notice. These costs have not been evaluated but would be considerable. However, the unit rate for dredging may decrease if suitable dredging equipment is ultimately purchased.

There is a high level of uncertainty in regard to the maintenance dredging requirements and therefore maintenance costs for this option.

The annual design costs reflect the need with this option to better understand the nature and rates of sedimentation to enable cost savings to be effected in maintenance dredging. For instance, better understanding of bypassing and of the response of the delta to floods will be required to improve prediction of bar behaviour and operational conditions as well as improved prediction and design of dredging requirements.

4.3.9 Consent requirements

The volume of capital and maintenance dredging associated with this option is a Restricted Coastal Activity under the New Zealand Coastal Policy Statement (NZCPS). As such, it will require a publicly notified consent application, with the Minister of Conservation as the final approving authority. The consent application will require a detailed and extensive assessment of environmental effects and the consent process may be lengthy and have an uncertain outcome.

4.3.10 Risks and risk mitigation

This option involves considerable uncertainties in respect of maintenance dredging costs. These costs are also likely to vary significantly on an annual basis. Trial dredging is likely to be the most effective means of estimating maintenance requirements. Available physical and numerical modelling techniques are not adequate to reliably model and assess these requirements.

The adverse effects of the dredging on the local beaches over time are also difficult to estimate and will probably require detailed modelling.

The scale of the dredging associated with this activity may be controversial and this may result in a (controversial and) lengthy consent process. Consultation with key stakeholders and the wider community will be critical.

4.3.11 Summary

This option is likely to enable commercial use of the harbour but will require expensive ongoing maintenance. Maintenance costs are difficult to estimate with any reliability but are likely to be considerable.

The option has the potential to have significant effects on coastal processes and local beaches over time, but will probably improve flood release.

4.4 Fluidisation and Related Options

4.4.1 Description

This option involves the installation of a series of fluidisers (essentially pipes with small holes) along the path of the proposed channel at the required navigable depth. Hydraulic jets pump water through the pipes on the ebb tide, injecting fluid into the sand and causing the grains to lift and separate. According to theory (e.g. Weisman *et al*, 1996), the discharging flows and/or gravity flow (i.e. downward gradient) then transport the slurry to form the required channel. Alternatively, the slurry can be pumped, as occurs with bypassing systems (Weisman *et al*, 1996).

Preliminary desktop assessment of the use of this option at Opotiki was conducted by Tonkin and Taylor (2001). This work indicated that the fluidisers would need to be buried at 1-1.5m depth along the length of the desired channel, with each length of fluidisers creating a channel width of about 3m. Therefore, a series of at least 10 parallel pipe systems would be required to create the 30m wide channel specified in the brief. These would need to extend for the full 600m length of the channel. A major pumping system would also be required to operate the fluidisers.

4.4.2 Practicality of option for Opotiki

Design manuals have been produced which outline the use and design of fluidisation to maintain dredged channels across entrance bars similar to that at Opotiki (Weisman, *et al*, 1996). The use of this approach to maintain a dredged channel across an entrance bar has also been widely discussed at a conceptual level (e.g. Weisman *et al,* 1982; Bruun and Adams, 1988; Bruun, 1989). However, despite extensive searching of electronic scientific and engineering databases and the Internet, we have found no examples or references to the use of this technology for channel maintenance in environments similar to that at Opotiki. We have also posted an international query on the major coastal engineering internet List and to date have received no details of any applications in environments anywhere near as complex and dynamic as Opotiki.

Collins *et al*, (1987) indicate that the use of fluidisation to maintain channels through sand bars was (only) first proposed in 1969 (Hagyard *et al*, 1969). The recently published design manual for this approach also notes, "*at this time (1996) there have been few field installations from which to gather information*" (Weisman *et al*, 1996, p1). The only example we have identified where fluidisation has been used for the maintenance of an entrance channel is a relatively simple application in an artificial boat channel linking Lake la Vista to Tampa Bay in Florida (Collins *et al*, 1987). This entrance channel is just under 5 m wide and about 1.2m deep at low water and does not involve the complex wave and river dynamics that characterise the Opotiki Entrance. The authors indicate that this installation was the first full-scale application of the technology (Collins *et al*, 1987), indicating the technology is relatively new compared to long-established approaches such as dredging and harbour moles. Recent communications we have had with a local Consultant in Florida indicates that the fluidisation works at Anna Maria were unsuccessful and the works were removed prior to 1992, within just a few years of installation.

Therefore, the use of this approach for the formation or maintenance of navigation channels has not been proven in environments as complex and dynamic as the Opotiki Entrance. Consequently, despite the many publications discussing the potential of this approach for channel maintenance, considerable caution is warranted until the measure has been more widely utilised and proven.

This is further reinforced by the assessment of Tonkin and Taylor (2001), which indicates that fluidisation is unlikely to be a cost effective solution to maintain navigable depth - due to the large physical scale of the required system and the relatively coarse sediment (which reduces the hydraulic efficiency and increases the flow requirement to achieve fluidisation). However, Tonkin and Taylor (2001) did suggest that various factors may support the ability of a partial fluidisation scheme to be effective – including river flows, finer sediment with depth and shorter lengths of fluidisation pipe to localise potential scour rather than fully scour the channel.

ODC (2002) also report reservations about fluidisation, noting that the scale of the system and the pumping requirements are likely to be prohibitively expensive for Opotiki.

On the basis of the conceptual model developed in Section 3, we believe that the network of fluidisers may also be exposed by scour during major river flows, giving rise to the potential for severe damage by the large volumes of timber carried in the Waioeka-Otara River system.

The more seaward elements of the system are also likely to be inundated by the large volumes of sediment carried seaward during major river floods – associated with scour of the entrance and near entrance areas. It is also questionable whether the system could cope with the significant bar and channel movements which occur over the ebb tide delta in association with sediment bypassing. It is quite possible that on occasions, the channel will swing away from the fluidiser network and the system will be swamped by large slugs of sand (i.e. bars) bypassing the entrance.

It is also probable that the rapidly decelerating river flows will, at best, simply transfer fluidised sediment to just beyond the margins of the fluidisation network - from where the sediment is likely to be readily mobilised back into the channel during wave action and flood tidal flows.

Overall, we are not convinced that this approach offers a practical option for the improvement of navigable depths at the Opotiki Entrance. As noted above, the option appears to have been very little tested and we have been able to locate no situations in which it has been used to successfully effect or maintain channel improvements in environments as complex and dynamic as the Opotiki Entrance. The one notable application frequently referenced in the literature actually appears to have failed and been removed soon after installation. We concur with the view in ODC (2002) that other options are likely to yield far better and more certain results for similar costs. We believe that the risks with this option are such that it does not warrant serious consideration.

4.5 Single Entrance Mole

4.5.1 Description

This option involves the installation of a single mole or training wall extending seaward to the desired minimum navigation depth along the alignment of the entrance channel. The length of the wall would depend on the exact alignment, which would need to be determined by detailed design. However, the wall would probably be perpendicular or nearly perpendicular to the shoreline and extend seaward by about 600 metres. An additional length of wall would be required at the landward end to prevent outflanking of the structure by upstream channel changes.

The wall would be designed to deepen the channel over the bar by:

- concentrating river discharges along the length of the mole to optimise scouring;
- reducing sediment deposition in the entrance channel through the interception of littoral drift from one direction.

The mole would also provide increased locational stability for the harbour entrance by preventing or restricting longshore migration. Wave protection would also be provided for waves coming from the direction on the side of the channel on which the mole was installed.

The most appropriate location and orientation of the training wall will need to be determined by detailed design, though (counter-intuitively) a wall on the eastern (i.e. updrift) side of the entrance will probably provide the most effective entrance improvements. Single training walls are normally located on the updrift side of the channel entrance to act as a barrier to the predominant direction of drift, though there are also examples of single moles on the downdrift sides of entrances.

4.5.2 Improvement of entrance depths and navigability

Single entrance moles have been widely used to improve navigability at harbour entrances, including both river and tidal entrances (e.g. Kieslich, 1981; Bruun, 1978; 1989). Overseas experience is that single moles have generally been found to be unsatisfactory and they are no longer recommended by the US Army Corps of Engineers (EM 1110-2-1618, 1995).

Kieslich (1981) presents a useful summary of experience with single mole installations and outlines some of the common problems experienced. For instance, over time, the main channel tends to migrate towards the mole and periodic dredging is often required to improve navigation conditions. There is also continued exposure to wave effects, particularly from waves coming from the unprotected side of the entrance or from directly offshore. Wave exposure on the unprotected side of the channel is likely to complicate both navigation and maintenance dredging.

4.5.3 Practicality to implement

Single moles have been widely used and constructed for entrance improvements.

4.5.4 Operational availability

It may be possible to maintain reasonable operational availability with a single mole, provided that depths are monitored and maintenance dredging is conducted as required. However, the channel will shoal and move over time. Wave action on the unprotected side of the entrance will also complicate navigability, particularly on an ebbing tide or during significant river flows. Waves in excess of 2.0 m are likely to break in the channel and use of the entrance will be difficult under such conditions.

4.5.5 Sustainability of entrance improvements

A single training wall is likely to require periodic maintenance dredging to counter channel shoaling and/or movement. Moreover, overseas experience is that the disadvantages of single mole installations usually lead to the construction of a second mole (CETN-IV-3, 1981). Therefore, at best, a single mole is only likely to provide an interim solution to navigability problems at Opotiki.

Maintenance dredging requirements may be high, due to the elongated bar that will develop on the unprotected side of the channel, the active recirculation of sediment between the channel and this bar, and the transport of sediments stirred by wave action into the channel by wave and flood tide currents (Figure 8). The channel will probably move around in the first few years until a relatively stable location near the mole is achieved. It is extremely difficult to make a reliable estimate of likely maintenance dredging without more detailed field data and investigation. However, a figure of 30,000 m^3/yr is not unrealistic and higher rates may be experienced. As the jetty will reduce sediment supply to downdrift beaches, a portion of the maintenance dredging will need to be disposed to these beaches to prevent or mitigate shoreline erosion.

Therefore, while a well-designed and located mole would probably produce useful improvements in entrance navigability, it is unlikely to be a sustainable long-term solution. However, a single mole may be a useful interim measure until economic circumstances permit the construction of a second mole – though the benefits would need to be carefully assessed by detailed design.

4.5.6 Effects on coastal processes and wider environment

Investigations of single mole installations indicate that they impact on the magnitude and direction of tidal currents, riverine and littoral sediment depositional patterns, and wave and littoral current patterns (CETN-IV-3, 1981). Consequently, a single mole is likely to have a significant effect on coastal processes and morphology at the Opotiki Entrance.

The general pattern of entrance response to single moles is shown in Figure 8a and 8b.

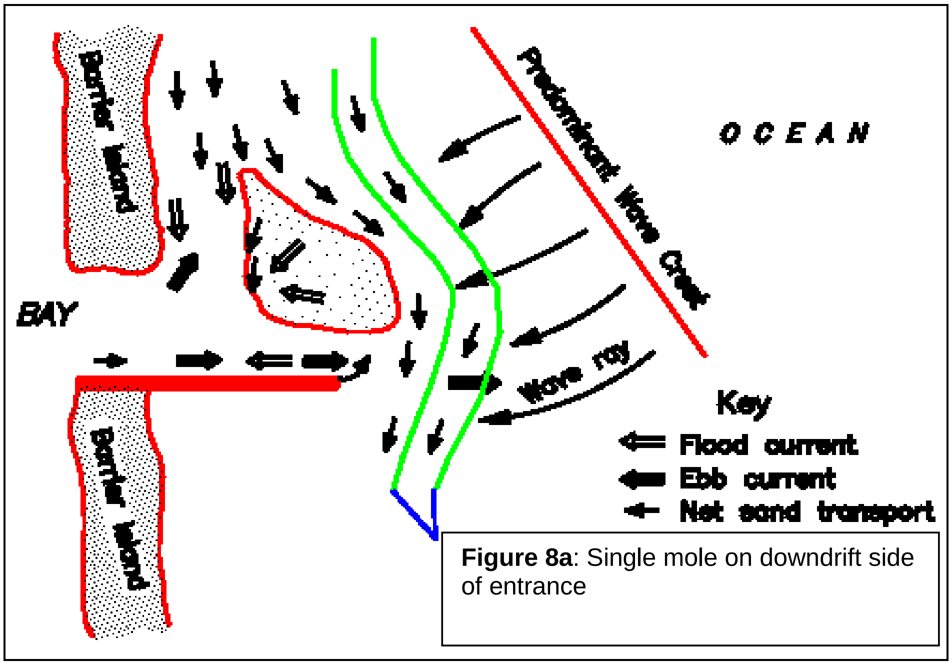

Figure 8a: Single mole on downdrift side of entrance

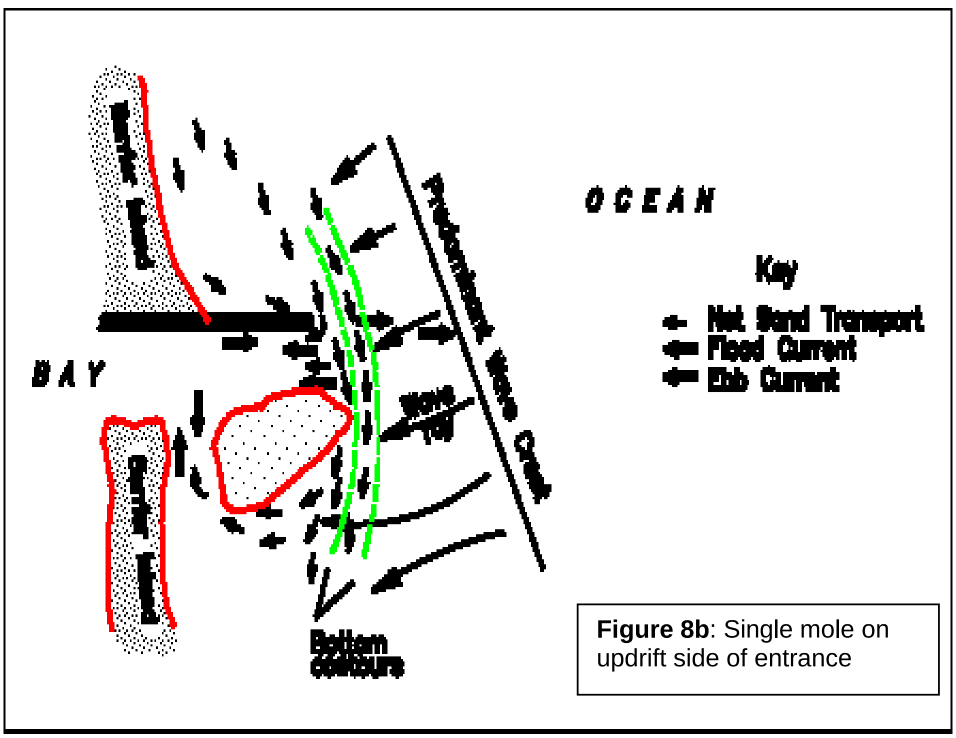

Figure 8b: Single mole on updrift side of entrance

Figure 8. Typical morphologic response to installation of single jetties at river and tidal entrances. Major features are channel tending to move close to mole, development of elongated bar on unprotected side of channel and strong entrance-ward transport adjacent to beach on unprotected side. Any net littoral drift is also intercepted. (Source. USACE, 1995).

A review of the response of 13 tidal inlets in the United States found that the construction of single moles resulted in the main channel migrating towards the mole – regardless of whether the mole was located on the updrift or downdrift side of the entrance (Kieslich, 1981). It was found that the moles did not prevent shoaling in the entrance channel until the deepest part of the channel (thalweg) was up against the jetty. Therefore, over time, the deepest part of the channel will move adjacent to the mole. At Opotiki, this is also likely to result in deep scour along the channel edge of the mole during major floods, necessitating careful attention to scour protection during design and construction.

The movement of the channel towards the mole probably reflects the influence of wave action on the unprotected side of the mole and the tendency for a large and relatively unstable bar to develop on the unprotected side of the training wall (Figure 8). Kieslich (1981) noted that this bar tended to extend seaward as the mole was extended seaward. A similar effect is likely to be observed with a single mole at Opotiki, with a large bar likely to form on the unprotected side of the entrance channel, this bar extending as far seaward as the mole. In contrast, with double moles, the offshore bar tends to become smaller and more compact (NSW, 1990).

Single moles located on the updrift side of the entrance intercept littoral drift, resulting in a general trend for the updrift beach to accrete and the downdrift beach to erode (Kieslich, 1981). A similar effect is likely to be observed with the construction of a mole on the downdrift (western) side of the Opotiki Entrance with accretion of beaches on the eastern side of the entrance and erosion on the west. In this case, the effect may be further accentuated by the tendency of the mole to also trap sand from the river on the eastern side of the channel. The increased volume of sediment trapped on the eastern side of the channel might also result in more frequent and severe channel shoaling problems. This is one of the key reasons that a single mole is probably best constructed on the eastern side of the entrance rather than the western.

In addition to the effects on coastal processes, the construction of a mole at the entrance would introduce a very notable human-built structure into what is otherwise an area with a very high level of natural character. Therefore, the structure would be likely to diminish the natural character of the entrance area. This is a significant matter in terms of the Resource Management Act 1991 and subsidiary policy documents.

However, on the positive side, improvements in harbour navigability would have major gains in terms of both recreational amenity and economic benefits to the local district. Moreover, where pedestrian access is provided along the top of moles, the structures have been found to be extremely popular areas and extensively used for fishing, walking and boat watching (Nordstrom, 1987). Rubble mound moles can also function as artificial reefs and be colonised by a diversity of marine organisms (Hurem, 1979).

4.5.7 Effect on Flooding

The effect of a single mole on flood release is difficult to predict with certainty, though there is unlikely to be any adverse effect on flood release since a single mole would not constrain channel enlargement. Any improvement in channel depth would probably assist flood release.

4.5.8 Capital and Maintenance Costs

Estimated costs are shown in the table below. As per the requirements of the brief, lower and upper limit estimates are provided for maintenance costs, with present best estimates shown in brackets. Costs assume that a limited volume of channel dredging will accompany the construction of the mole. The aim of this dredging will be to locate the channel relatively close to the mole, though the exact location will need to be determined based on experience at other sites and appropriate modelling of the Opotiki Entrance. This dredging will hopefully reduce subsequent channel movements and associated maintenance dredging costs and increase operational availability.

Expenditure Item	Estimated Capital Costs ($2002)	Estimated Annual Maintenance Costs ($/yr: 2002)
Design and consenting	$0.3-0.5 million	$5-25000 ($15000)
Entrance mole (600m)	$2.5-3 million	$0.02-0.5 million ($0.1 million)
Scour protection apron along channel margin of mole (600m)	$1.5-2 million	$0.02-1.5 million ($50,000)
Protection works at landward end of mole (300ml)	$0.5 million	$5-50,000 ($15,000)
Capital dredging to form initial channel	$1-1.5 million	
Maintenance dredging and monitoring of depths		$0.2-1.6 million/yr ($0.6 million)
Bypassing costs		$0.1-0.5 million/year ($0.3 million)
Total Estimated Costs	**$5.8-7.5 million**	**$0.4-$4.2 million ($1.1 million)**

4.5.9 Consent requirements

The mole and the associated dredging are Restricted Coastal Activities under the NZCPS. Therefore, the works would require a publicly notified consent application, with the Minister of Conservation as the final approving authority. The consent application will require a detailed and extensive assessment of environmental effects and the consent process may be lengthy and have an uncertain outcome.

4.5.10 Risks and risk mitigation

This option involves considerable uncertainties in respect of navigational improvements and maintenance dredging requirements, particularly as overseas experience has been that single structures are generally unsatisfactory.

Available modelling techniques will enable improved assessment of navigational benefits and maintenance dredging requirements. However, these results are likely to be indicative rather than definitive, due to the extreme complexity of the processes and the limitations of existing modelling tools.

There is also potential for a lengthy consent process because of the effects on natural character likely to accompany the mole.

4.5.11 Summary

This option may effect adequate improvements to the entrance channel to facilitate increased commercial use of the harbour and significantly enhance recreational amenity.

However, uncertainties are high and ongoing maintenance requirements may be considerable. It will also have significant effects on coastal processes and natural character. Relevant consents could be difficult to obtain if there is widespread opposition.

This option probably should not be given serious consideration unless there is widespread support and an ability and willingness to later proceed with dual walls if the single mole proves unsatisfactory. It is probably best viewed as an interim or trial option that may avoid or delay the need for dual moles.

4.6 Dual Entrance Moles

4.6.1 Description

This option involves twin moles extending seaward from the harbour entrance. Twin moles are normally aligned parallel with the entrance channel alignment. However, at Opotiki the natural alignment of the entrance channel can vary from shore normal to an angle of approximately 45 degrees to the coast in a NW direction (e.g. see survey conducted by Martin McCauley Morton Ltd, Plan No. 121045/P Sheet 1). Advice from ODC staff suggests that the near perpendicular orientation is the more common. This orientation would also minimise length and capital costs and therefore is probably the most appropriate alignment for moles at the Opotiki Entrance. However, the most appropriate configuration for entrance moles will need to be determined by more detailed investigation and design.

Parallel moles are normally adopted as experience has found that converging alignments are generally not satisfactory, being more costly to construct due to greater length, acting to trap more sediment and often allowing channel meandering (EM-1110-2-1618, 1995).

In terms of length, it is important that the moles extend sufficiently seaward to maintain desired design depths over the full length of the channel (Figure 9) and to extend beyond the breaker zone. Preliminary assessment suggests the moles will need to be about 600 metres long if perpendicular with the coast and approximately 800 metres long if oriented obliquely to the coast.

The optimum width for moles at Opotiki involves complex consideration, as it requires a compromise between the requirements for navigation and flood release. Croad et al (1993) proposed widths varying from 80-100 metres. However, preliminary assessments of channel scour using the procedure outlined by Hughes (2002) suggest these widths may lead to excessive scour during severe floods (Figure 10). For instance, with floods of sufficiently long duration, there is theoretical potential for the channel to be scoured to depths of 8-10m during 5-10% AEP flood events and up to 15-20m during rare and extreme (i.e. 1% AEP) events (Figure 10). In localised areas, where channel thalweg impinges against the moles, potential scour may be higher. In practice, the more extreme scour depths may not be achieved due to the limited duration of the flood events.

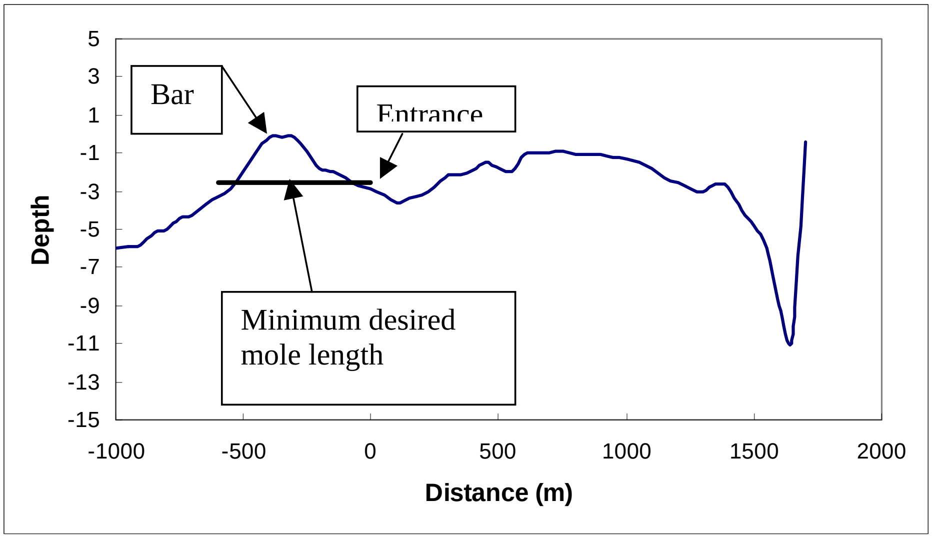

Figure 9: Long section from confluence to seaward edge of river bar. Note that any moles will need to extend from the entrance to beyond seaward edge of outer bar.

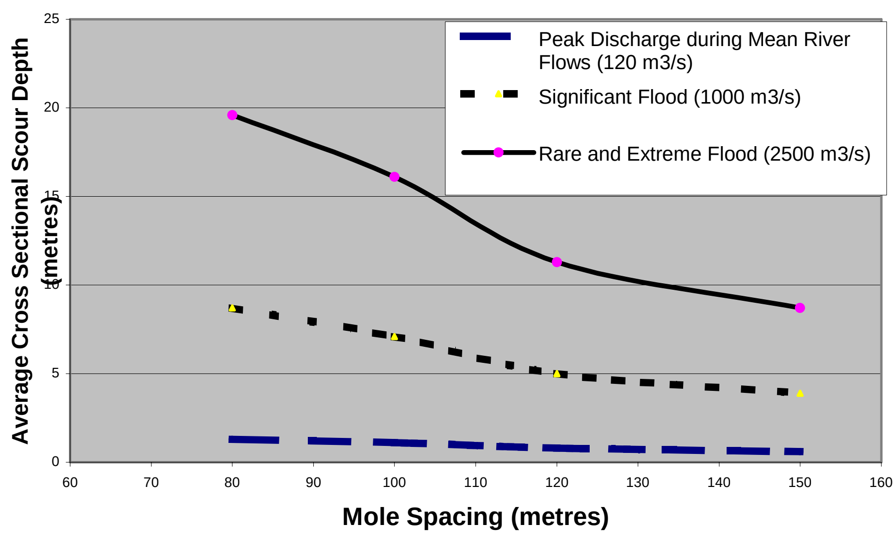

Figure 10:Estimates of average cross-sectional scour between dual moles for various different peak flow rates. Calculations conducted using method developed by US Army Corps of Engineers for tidal and river entrances (see Hughes, 2002).

There is also a risk with narrower mole spacings that flood release could be slowed, with potential to aggravate flood levels upstream.

Therefore, a wider spacing may well be required to avoid problems during major floods. Further detailed work will be required to determine the optimum spacing, but preliminary calculations suggest mole spacing may have to exceed 120-150 metres to avoid problems during major floods. With such mole spacing, calculations suggest that peak discharges of around 400-700 m^3/s will be required to achieve average scour depths of about 2.5-3 metres across the channel. Therefore, moderate flow events, probably occurring at least 2-3 times a year on average, will be capable of scouring to the desired navigation depth, even if mole spacings of 150-200 metres ultimately prove to be required. In addition, the ebb-dominated nature of the entrance channel may result in the design discharge being able to be achieved with lesser peak discharges, particularly as the moles will prevent significant volumes of littoral drift from entering the entrance channel.

The ebb-dominated nature of the channel is also likely to reduce sedimentation problems that will occur during periods of lower peak discharge and consequent maintenance dredging requirements that might otherwise be experienced with wider channels. It is possible that the channel will even slowly scour and enlarge over time. However, these matters will need to be considered and confirmed by more detailed investigations.

Some maintenance dredging is inevitable, particularly after sustained low flows.

4.6.2 Improvement of entrance depths and navigability

Twin moles are likely to significantly improve navigability through the entrance by:

- Concentrating discharging flows to optimise scouring action.
- Preventing deposition of littoral drift in the entrance channel.
- Stabilising the position of the harbour entrance.
- Minimising the effect of wave action and cross-currents on vessels crossing the bar.

4.6.3 Practicality to implement

Dual entrance moles (or jetties as they are generally referred to in US literature) are widely used to improve and maintain navigability at river and tidal entrances and detailed design information and procedures are available.

4.6.4 Operational availability

It should be possible to maintain good operational availability on most occasions with a dual mole system though navigability may be difficult at the seaward entrance under high wave conditions and an ebbing tide.

4.6.5 Sustainability of entrance improvements

Maintenance dredging is likely to be required to maintain desired navigable depths, particularly with the wider spacing likely to be necessary for flood release. The volume of maintenance dredging will ultimately depend on the mole spacing adopted, increasing with mole spacing. Most sedimentation is likely to be associated with sands coming down the river channel, these volumes estimated at 15,000 m^3/yr by Croad et al. (1993). However, during periods of low river flows, flood tide currents and wave action may also transport sediment into the seaward end of the channel. Overseas experience indicates that some sand will also infiltrate through the rubble moles unless these are specifically designed to be sand tight.

The maintenance dredging requirements will need to be assessed by field and model studies during detailed design. However, over time, they will probably average out at less than 15,000-20,000 m^3/yr (i.e. the estimated annual rate of river sand delivery to the entrance).

However, the improvements will not be sustained indefinitely. In the longer term, a new ebb tide delta will eventually establish seaward of the entrance moles, resulting in total or significant loss of navigational improvements.

McLean and Burgess (1975) provide a well-documented example of this trend at the Wanganui river mouth and the effect has also been widely observed elsewhere.

They noted that original bar depths at Wanganui were of the order of 1.5-2.5m. These depths improved after training of the entrance with a dual mole system – reaching a maximum of about 4.6m some 30-40 years after initial mole construction. However, the depth improvements steadily declined as the ebb tide delta re-established and had returned to depths of 2-2.5m by the mid 1960's. At this site, the first significant deterioration in bar depths appeared to commence about 40-45 years after the moles were installed.

The time taken for this process at Opotiki will depend on the rate of net sand accumulation over the area of the new ebb tide delta. Given the limited net sand supply to the entrance (estimated in chapter 3 to range from 10-50,000 m^3/yr), the process seems likely to require several decades, probably 50-100 years and possibly longer. Therefore, useful depth improvements may be obtained for a period of some decades but will eventually be lost – unless preventive action is taken. If dual moles are installed, the rate of re-establishment of the ebb tide delta should be carefully monitored by periodic surveys of the entire entrance area. Periodic dredging of this offshore area can be used to slow the re-establishment of the ebb tide delta. Such dredging will also mitigate the effect of the modified entrance to act as a sediment sink.

4.6.6 Effects on coastal processes and wider environment

Dual mole systems have a very marked effect on river and coastal processes and usually result in significant changes to the dynamics and morphology of river and tidal entrances. The moles essentially disrupt existing dynamics and introduce a new set of conditions to which the entrance must readjust (McLean and Burgess, 1975).

The effects of twin moles at Opotiki will need to be assessed by field and model investigations during detailed design, but are likely to include:

- **Interception of littoral drift along the coast, preventing sediment from bypassing the entrance**. This is likely to result in beach advance on one side of the entrance and erosion on the other. Typically, beaches prograde on the updrift side of entrance moles and erode on the downstream, though variations to this pattern have been observed. Therefore, at Opotiki, the most likely result is sediment accumulation and beach advance on the eastern side of the entrance and erosion on the western. As the rate of net littoral drift at Opotiki is relatively low (see Section 3), this process may be relatively slow. These effects will need to be mitigated by periodic dredging and bypassing of the sediment that accumulates on the eastern side of the entrance.

- **Changes to the morphology and dynamics of the ebb tide delta.** In the short term, sediment discharging from the channel will tend to accumulate in deeper water offshore from the moles, interrupting the pattern of sediment circulation responsible for maintaining this feature. Therefore, those portions of the ebb tide delta to the east and west of the moles are likely to "collapse" and slowly migrate onshore. The accumulation of sediment offshore from the moles will also tend to act as a sediment sink for sand supply from the river, decreasing sand supply to adjacent beaches, particularly west of the entrance. This process will accentuate any erosion of downdrift beaches.

- **Re-establishment of a new ebb tide delta.** In the longer term (decades) sediment accumulating around and seaward of the moles will re-establish both a new ebb tide delta and sediment bypassing. At this point in time, the navigational benefits of the moles will largely be lost.

- **Other effects.** These may include influences on flood release (discussed further below) and a slight increase in tidal range and tidal prism within Opotiki Harbour. The channel between the moles may also scour over time as a consequence of the ebb-dominated nature of the channel and the moles preventing littoral drift from entering the entrance.

4.6.7 Effect on flooding

The installation of moles has the potential to significantly influence flood release. The increased hydraulic efficiency and deepening arising from the moles will probably improve the release of small and moderate flood events. However, if the moles are placed too close together, there is potential to slow the release of major floods, because of the increased length of the channel and the large volume of sediment that has to be scoured from the 600 metre length channel to allow cross-sectional adjustment to the higher flows. These problems can be overcome but will require detailed field investigations and modelling during the design stage.

4.6.8 Other environmental effects

In addition to effects on coastal processes, the construction of dual moles will introduce a notable human-built structure into what is otherwise an area with a high level of natural character. Therefore, the structure is likely to diminish the natural character of the entrance area. This is a significant matter in terms of the Resource Management Act 1991 and subsidiary policy documents.

However, the improvements in harbour navigability arsing from the moles will also have environmental benefits in terms of the Resource Management Act. These include significant gains in recreational amenity, most notably through increased boating and surface water use. Furthermore, if an access path is provided along one or both moles, overseas experience suggests that the features will prove extremely popular for fishing, walking and boat watching (Nordstrom, 1987).

Rubble mound moles can also function as artificial reefs and be colonised by a diversity of marine organisms (Hurem, 1979).

4.6.9 Capital and maintenance costs

Estimated costs are shown in the table below, with lower and upper limit estimates provided for maintenance costs, with present best estimates shown in brackets.

Expenditure Item	Estimated Capital Costs ($2002)	Estimated Annual Maintenance Costs ($/yr: 2002)
Design and consenting	$0.3-0.5 million	$5-25000 ($15000)
2 Entrance moles (600m each)	$5-6million	$0.02-0.5 million ($0.1 million)
Scour protection apron along channel margin of both moles (1200m in total)	$3.5-4 million	$0.02-0.3 million ($0.1 million)
Protection works at landward end (probably 500-600m in total)	$1 million	$0.005-0.1 million ($30,000)
Capital dredging to form initial channel	$1.5 million **May not be required**	
Maintenance dredging and monitoring of depths		$0.05-1 million/yr ($0.1 million)
Bypassing costs		$0.1-0.5 million/year ($0.3 million)
Total Estimated Costs	**$9.8-11.5 million**	**$65000-$2.4 million (645,000)**

Dredging costs assume equipment will have to be brought in from further afield and that establishment/disestablishment costs will be required. The unit rate may decrease if suitable dredging equipment is ultimately purchased, though obviously other costs will be incurred. It is assumed that all dredging will involve pumping to downdrift beaches or (less likely) bottom disposal from hopper or barges on western side of the western mole. The relatively quiet environment within the moles should mean that dredging in this is relatively uninterrupted and will therefore involve a lesser unit rate than the dredging and bypassing of sands trapped on the updrift side of the moles. Bypassing is likely to have to be done by dredging as land-based bypassing systems are very expensive. However, bypassing costs may be able to be reduced by adopting a weir jetty system at the landward end of the eastern mole, whereby littoral drift is allowed to enter a settling basin within the moles where it can then be dredged and pumped from a more sheltered environment. We have not considered a weir jetty in any detail during this preliminary study because we suspect it may be difficult to design a feature that can adequately handle flood release. However, weir jetties are now widely used overseas and this option should be evaluated during detailed design.

There is also a high level of uncertainty in regard to maintenance dredging and bypassing costs associated with the poor understanding of net sediment supply to the entrance area. This uncertainty is reflected in the range of these costs.

The moles will require periodic maintenance to repair wave damage. The scour protection and upstream armouring will also need periodic repair and/or extension after major river flow events. These costs are very difficult to estimate with any certainty and will depend on the design standards adopted for the initial works.

Our costing has assumed that the emphasis will be on the design of rigorous works (emphasizing capital costs over maintenance) and the adoption of a programme of regular inspection and repair. These costs could change markedly if Council decides to adopt a higher level of risk in the design of the works to reduce capital costs, or if regular inspection and maintenance is not undertaken.

Repair costs are likely to be very irregularly distributed in time.

4.6.10 Consent requirements

The structures would be a Restricted Coastal Activity in terms of the NZCPS and would require a publicly notified consent application, with the Minister of Conservation as the final approving authority. The consent application will require a detailed and extensive assessment of environmental effects and the consent process may be lengthy and have an uncertain outcome.

4.6.11 Risks and risk mitigation

A significant risk with this option relates to the potential impact of moles on major floods. It will be important to ensure that the design improves navigation without aggravating flooding.

An additional risk is the potential for the spit on the eastern side of the entrance to be breached by waves and major river flows, thereby forming a new entrance and abandoning the training walls. This risk could be accentuated if the moles are sufficiently closely spaced that they constrain the release of major floods. Once the moles are in place, it is probable that sediment accumulation on the eastern side of the moles will gradually widen the spit and reduce the risk of breaching. Nonetheless, this matter will require careful consideration during detailed design.

There is also risk that the moles will be damaged or outflanked by erosion of unprotected channel banks at the upstream end of the structures. Therefore, extensive lengths of armouring will almost certainly be required at the upstream end of both moles to ensure they are not outflanked by erosion.

The issue of river scour will also require careful assessment during detailed design. Channel scour is the major cause of severe damage to entrance training walls and, as highlighted in Section 3, it is probable there will be significant channel scour at Opotiki during major floods. If moles are constructed at Opotiki, it will be critical that adequate scour protection is placed along the channel margin of both moles.

From an environmental perspective, there is also the risk that the moles will give rise to severe erosion of downdrift beaches. This effect can be mitigated by a regular bypassing programme but will need careful design and monitoring.

There is also the risk of a lengthy and controversial consent process because of the effects of the moles on coastal processes and natural character. The effects on coastal processes cannot be avoided, though they can be mitigated by activities such as bypassing of sediment. The effects on natural character can be reduced by using natural materials (e.g. rock) for construction of the moles - as opposed to concrete or other materials. The beneficial effects on recreational amenity will also help to offset adverse effects on natural character. The provision of pedestrian access along one or both moles will further enhance recreational benefits.

If the moles are constructed, they may be blamed or implicated in any future erosion or flooding problems. In our review of overseas experience, we encountered examples where the construction of moles has resulted in litigation, including at least one example where the features were being blamed for erosion some considerable distance alongshore. At Opotiki, the most likely source of litigation is with respect to flooding problems upstream.

4.6.12 Summary

Overall, well-designed moles are likely to provide significant navigational improvements for several decades with a high level of operational availability, though ongoing maintenance dredging and bypassing will be required. In the longer term, probably 50-100 years, the navigational benefits will gradually be lost as a new ebb tide delta re-establishes seaward of the moles, though this effect can be mitigated/delayed by various actions.

The structures will have adverse effects on natural character and coastal processes, though these effects can be partially mitigated. The structures will also have significant beneficial impacts on recreational amenity.

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