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Port redesign and planned beach renourishment in a high wave energy sandy-muddy coastal environment, Port Gisborne, New Zealand

Terry Healy [a,*], Scott Stephens [a], Kerry Black [a], Richard Gorman [b], Russell Cole [b], Brett Beamsley [a]

[a] Coastal Marine Group, Department of Earth Sciences, The University of Waikato, Hamilton, New Zealand
[b] National Institute of Water and Atmospheric Research Ltd, Private Bag 3105, Hamilton, New Zealand

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Abstract

Redesign of Port Gisborne for the 21st century has encompassed a broad interdisciplinary approach. This procedure has taken into account the operational requirements of the port, effects of dredging and construction upon the benthic fauna, and wave activity within the port confines after the proposed development. Added amenity value of the development to the local community is an important ancillary redesign consideration. Initially, a major research project into the environmental impacts of the developments has been undertaken.The project, which commenced in 1996 and is still continuing, involves an iterative approach integrating the initial design and development options with the operational feasibility, construction constraints, environmental constraints, social acceptability, and economic practicality of the port; all of these require in-depth assessment to obtain the necessary planning and development approvals. This requires close liaison between the professional environmental research scientists, port management, port operation staff (pilots), construction engineers, planners, and the community interest groups.Numerical modelling of the hydrodynamics of Poverty Bay, simulating waves and current effects on the various initial designs options, and calibrated against data from a substantial field program, has been a fundamental tool. It was applied experimentally to determine the best option for the port layout, as well as to assess sedimentation impacts. Modelling results indicated a significant increase in maintenance dredging expected as a result of deepening the navigation approach channel. Because this may have an impact on the nearby sandy beach by inducing erosion, the best option for disposal of the sandy dredged material was determined to be disposal in the surf zone for subtidal beach profile renourishment. Textural analysis of the sediments trapped in the navigation channel demonstrated that they were suitable for this purpose.

Keywords: Port redesign; Environmental impact; Subtidal beach profile renourishment

1. Introduction

Port Gisborne is enclosed within a harbour and breakwater system in the north of Poverty Bay, New Zealand (Figs. 1 and 2). Since historical development in the 1880s, it has experienced ongoing coastal

* Corresponding author. Fax: +64-7-838-4061.
E-mail address: t.healy@waikato.ac.nz (T. Healy).

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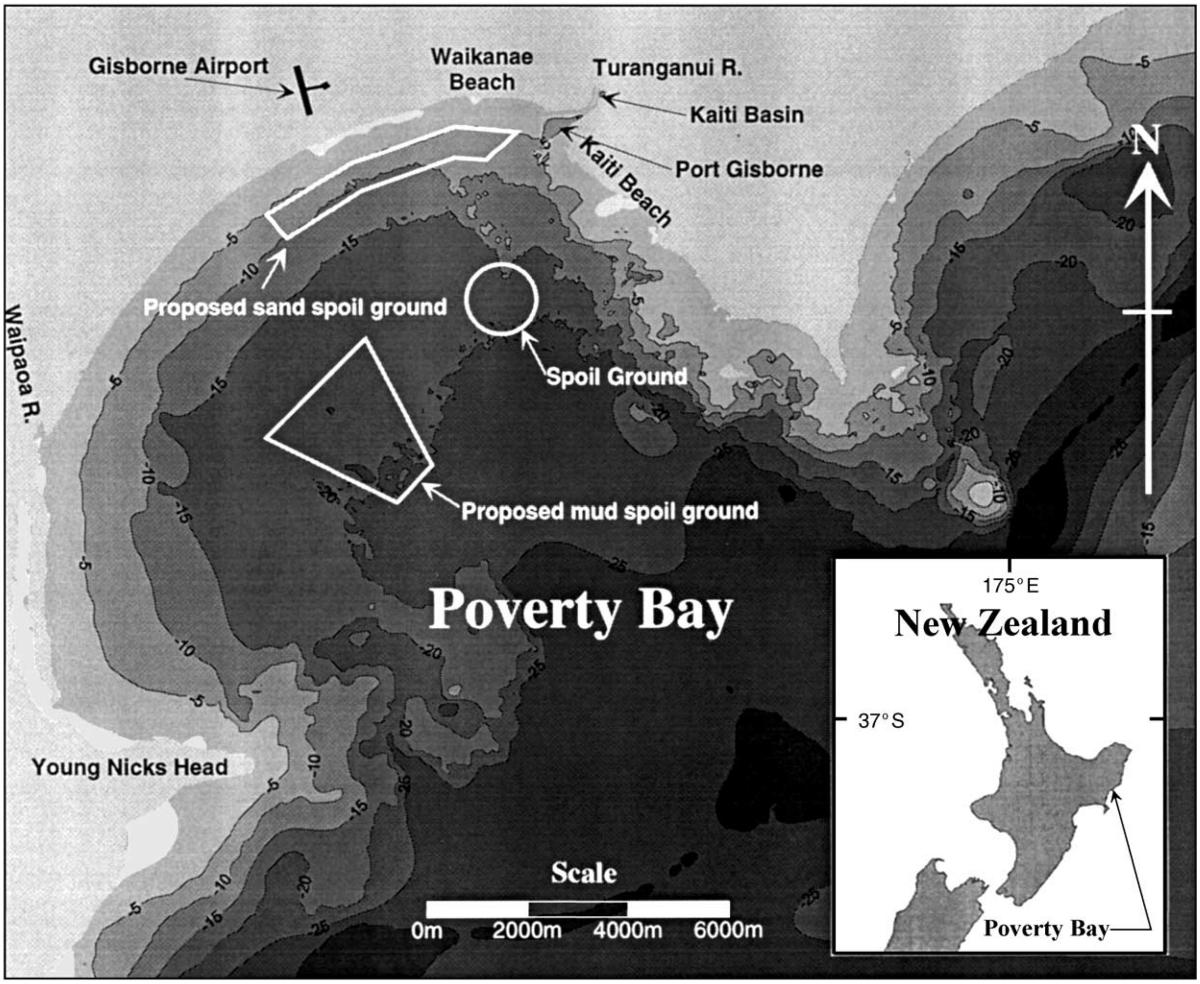

Fig. 1. Poverty Bay, New Zealand, showing location of Port Gisborne, the historical spoil ground, and proposed future disposal sites for predominantly sandy sediments off Waikanae Beach, and muddy sediments in the centre of Poverty Bay (Stephens et al., 1997b).

engineering problems relating to wave exposure, siltation within the port, extensive dredging requirements, as well as seiching within the confines of the present harbour (Whyte, 1984).

Following port reform in New Zealand (1989–1990), Port Gisborne has seen a growth in trade, especially for export of forestry products. Economic projections for Port Gisborne (Port Gisborne, 1998) indicate a sustained growth in the export of wood product well into the 21st century. This required reassessment of the existing port facilities and infrastructure, which are becoming inadequate to support an expanded efficient forestry product export operation. Objectives of the port redesign include: development of three overseas shipping berths to accommodate large vessels; reclamation of approximately 40 ha for log storage and port operations; design configuration to mitigate seiching within the port; minimisation of future maintenance dredging; and consideration of developing public amenities (Selsky and Memon, 1997), such as fishing and small boat loading ramps, opportunities for aquaculture, and an artificial surfing reef for use by the general public. An important consideration is to mitigate potential adjacent beach erosion arising from the development. This is accomplished by using the maintenance-dredged

Fig. 2. Aerial view of Port Gisborne navigation approach channel, log handling area and existing breakwaters. Additional reclamations are envisaged along the shore platform to the east (left of photo).

material to re-nourish the nearshore subtidal beach profile.

As a first step toward obtaining territorial local authority approval, a field and numerical modelling environmental study was undertaken in 1996–1997 (Stephens et al., 1997a; Healy et al., 1998) to provide information for the Assessment of Environmental Effects (AEE). In addition, a pilot study was conducted to determine the effect on ship handling of deepening the navigation approach channel and a new port configuration. The modelling included simulation of waves, fresh water input from rivers, current circulation patterns, and sediment transport within Poverty Bay and around the port (Black et al., 1997,1999).

This paper outlines the broad scope of the AEE study and initial design considerations for the potential developments and port layout redesign at Port Gisborne. It provides an example of AEE requirements for port redevelopment in high wave energy, active multi-input sedimentation environment. The main sedimentation effects expected to arise from phase one of the project—the deepening of the shipping approach channel—are assessed, and proposed mitigation measures presented. The paper further serves as a modern example of Integrated Coastal Zone Management (French, 1997; Kay and Alder, 1999).

2. Historical development and problems of the port

The port was initially sited close to the landing spot of Lt. James Cook—the first European to set foot on New Zealand in 1769—at the mouth of the Turanganui River. In the 19th century, and indeed until the 1960s, the small port of Gisborne was serviced by lighters to ships anchored offshore. By the 1880s, construction commenced on an extended groin/breakwater to provide shelter for vessels from south-easterly waves, and during the 1950–1960s, deeper draught wharves, a vessel turning basin, and protective vertical sea walls were constructed in an attempt to minimise swell wave activity. The need to dredge the port entrance has been a problem since the first breakwater was constructed, and in the 1910s the port invested in a steam powered bucket dredge. During the 1930s, a boat harbour and shipping channel was excavated from the soft "papa" siltstone bedrock that comprises the shore platform. By the 1960s, the port and channel had been deepened to 9 m and required constant maintenance dredging (Whyte, 1984). More-over, the port structures likely caused some erosion on the adjacent northern Waikanae beach, as the beach readjusted its equilibrium planform.

The construction of an enclosed harbour with the shipping channel facing toward the southeast allows wave energy to be "pumped" into the port, while the vertical walls within the harbour allow wave energy reflections to set up a resonating long wave condition (seiching) within the port. This undesirable feature is common to a number of ports (Abecasis, 1964; Muir Wood, 1969; Le Mehaute and San-Hwang, 1970; Okihiro and Guza, 1997). For Port Gisborne, this is especially noticeable on occasions of long period waves of $T \geq 14$ s and may be very damaging to vessels and the quayside. Thus, one aim of the redesign of port layout is to attempt to avoid such a resonating condition.

3. The physical background

Port Gisborne is situated in a difficult environment from a number of physical perspectives. Firstly, it is located in an open embayment subject to large episodic storm waves from the east and southeast. On occasion, storm waves of significant height, H_s>5−6 m can pound the port entrance. The port itself is located in one of the more sheltered sectors of the bay (Fig. 2), except for waves approaching directly from the southeast. This location enhances potential for sediment deposition because it is a meeting point for littoral drift from both the east and the southwest (Miller, 1981). In addition, the adjacent Turanganui River system, which drains a catchment of soft erodible Tertiary "papa" siltstones, delivers high concentrations of fine suspended load to the sea adjacent to the port during high flow events or "freshes" (Healy and Nelson, 1981). Thus, there is potential for high rates of sediment deposition near the port from several sources: wave generated littoral drift along the adjacent Waikanae Beach from the southwest; alongshore drift from Kaiti Beach to the east; diabathic (cross shore) sediment transport in storms; and high suspended load muddy input from the adjacent Turanganui River (Healy et al., 1980).

4. Preliminary scoping for redesign

Over the past decades, large areas of the unstable catchments surrounding Poverty Bay have been con-

Fig. 3. Port outlay and present area of log storage. For redesign the reclamation is planned to extend along the shore platform, and the right breakwater will need to be removed.

verted from pastoral farming into plantation forestry. During this time, Port Gisborne has experienced a rapidly growing export trade of bulk logs and timber products, including wood chips. The length-over-all (LOA) of modern logging and wood chip carrying vessels is on the order of 230 m with draughts approaching 10 m. Efficient (cost-effective) export of logs requires about 10 ha of adjacent flat land to service each berth. Flat land is severely restricted in the present port service area (Figs. 2 and 3), and a redesign of port layout and facilities to obtain the required extra berths and service area is necessary. The only real option to obtain such an area is to undertake reclamation along the adjacent shore platform (Fig. 3).

While in earlier decades port development was focussed primarily upon economic and national strategic issues (Quinn, 1961), in modern times environmental and social issues are an integral part of the planning and development procedures (Butlin, 1976; Bruun, 1989; Harlow, 1989; Svendsen, 1989). Clearly, the development of a port is a multidisciplinary problem requiring consideration of economic and social planning issues, port operations, as well as the environmental, scientific, and coastal engineering problems. Early in the project, a multidisciplinary "brainstorming" scoping meeting was held to review the issues and identify initial potential solutions. These considerations then influenced the direction of the research investigations and subsequent outcomes of the study. Subsequent review meetings were guided by the constraints indicated by the research investigations, and so on. This is an ongoing process.

5. AEE study objectives

In preparation for the potential future redevelopment of the port, a major environmental impact study was initiated in 1996. This comprised a number of components, including:

- options for approach channel alignment;
- selection of a new dredged material disposal ground;
- effects of the dredging on the marine flora and fauna;
- geotechnical properties of the material to be dredged;
- field data measurements;
- modelling of wave actions;
- modelling of currents, density stratification and sediment transport;
- port redesign considerations.

5.1. Options for approach channel alignment

Consideration was given to dredging a new shorter, curved approach channel, which would significantly reduce the initial capital dredging required. However, the curved approach channel is considered impractical from a piloting perspective (Herbich, 1992). Thus, Stage 1 of the development, completed in 2000, encompassed deepening the existing approach channel to 10 m to take deeper draught vessels.

5.2. Selection of a new disposal site for capital dredged sediment

Capital dredging involved removal of some 300,000 m^3 of relatively soft "papa" siltstone rock and silty sand from the existing approach channel. The Department of Conservation (DoC) had expressed continued concern over the proximity of the historical dredge spoil dump ground to an area of the Temoana reef rocks of potentially high ecological value (Fig. 1; see also Fig. 7), Therefore, it was decided to investigate an alternative site for the disposal of muddy and rock dredged material. Options included disposal on land, in reclamation adjoining existing port land, and at two new marine dumpsites.

A perusal of the sea floor sediment patterns presented in Miller (1981) and Kensington (1990), and several side scan sonar surveys conducted over the past two decades (Healy et al., 1997) suggested that an area seaward from the Waipaoa River in the southwestern sector of the bay was a likely disposal site (Fig. 1). This site is located away from any known reefs, avoids the navigation leads, and possesses a muddy sea floor which is frequently subjected to inundation of muddy water outflows from the Waipaoa River. It has the disadvantage of being located at a greater distance from the dredging site, and would therefore increase dredging costs for the port.

5.3. Effects of the dredging on marine flora and fauna

Assessments of the impacts of a capital dredging project on the ecology adjacent to the channel, and of subsequent maintenance dredging and disposal programs were undertaken (Cole et al., 1997). The rocky reefs adjacent to the shipping approach channel possess a limited fauna of encrusting organisms, and they are adjusted to episodic high turbidity events which occur when the muddy sediments are stirred up by large waves and when storm discharges from the Waipaoa River eject large amounts of suspended sediment (mud) into Poverty Bay. Ecological data on recolonisation rates of the dredged channels and dumping ground were available from Wood (1994) and Merrett (1997). A description of the generalized benthic infauna around the existing disposal site was also presented in Wood (1994). Because phase one of the redevelopment initially involves capital dredging of the shipping channel, chemical contamination of the dredged material is not an issue (Saunder, 1993). Ecological surveys were undertaken on the rocky reefs adjacent to the port where an abundant ecology of molluscs and algae occur, and which that would be destroyed should reclamation of the shore platform proceed.

The site selected for deposition of muddy maintenance dredged material on the southern side of the bay was found to be covered in soft sediments comprising mainly (>80%) muds (>4ϕ). More detailed infaunal surveys over this area found a moderately diverse infauna comprising polychaets, bivalves, crustaceans, and other taxa (Cole et al., 1997). Most of the taxa were found in abundances similar to those reported in surveys of the existing dumpground and elsewhere in Poverty Bay. The area was, therefore, assessed as suitable from an ecological perspective for the dumping of muddy dredge spoil (Cole et al., 1997).

5.4. Effects of breakwater realignment on wave dissipation

Plans for reclamation and construction of new berths for larger ships involved consideration of a

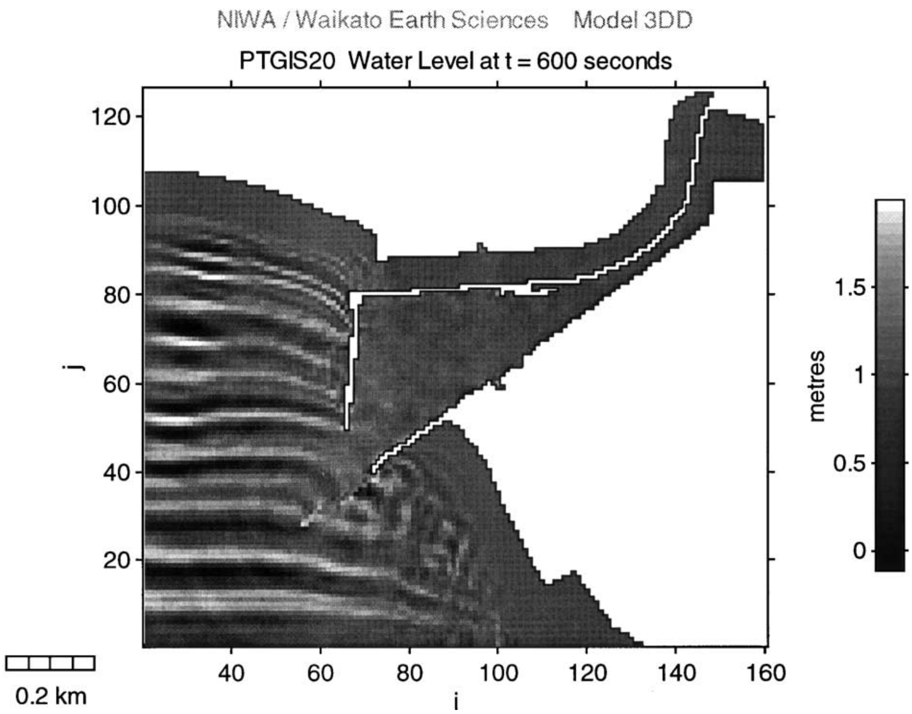

Fig. 4. Numerical model output of wave refraction from WBEND for the current port configuration. Light shading indicates wave crests (Black et al., 1997).

new port layout. Such a scheme (not officially approved at time of writing) envisages replacement and realignment of breakwaters (Black et al., 1997). The effect of the breakwater and reclamation realignment on wave processes both within and adjacent to the port itself, and its impact upon the wave environment at the adjacent beach, are issues needing careful assessment (Gorman and Black, 1997).

Several options for a new port layout, as well as the existing port structure, were subjected to numerical waves modelling to assess their interaction with the local environment. Modelling of wave processes around the port was performed over a nested 10 m grid using a wave refraction model, WBEND (Black, 1997). Example model outputs are shown in Figs. 4 and 5 for the existing of port design and a proposed option. The needs of the port in terms of berth and log storage space are met far better in the second design, and the modelling indicates that long wave energy, and therefore the likelihood of seiching, within the port is reduced.

5.5. *Effects of the deepened channel on sediment movement*

The port and dredged navigation channels are located at the confluence of several sedimentary pathways. These include littoral drift northwards along Waikanae Beach, westwards along Kaiti Beach; wave induced onshore (diabathic) drift, and fluvial sedimentary input from the adjacent Turanganui river system. Thus, the extent to which the deepened channel acts as a sediment trap is a major issue. It is evident that the deeper dredged channel will enhance sediment trapping and will necessitate increased maintenance dredging. This initial assessment is derived from information provided in the theses on sediments and currents by Miller (1981) and Kensington (1990), and experience elsewhere (Healy et al., 1996; Mathew et al., 1997). To address this problem, the AEE investigations included additional deployment of wave and current meter instrumentation (Gorman et al., 1997), and side-scan sonar surveys to map the

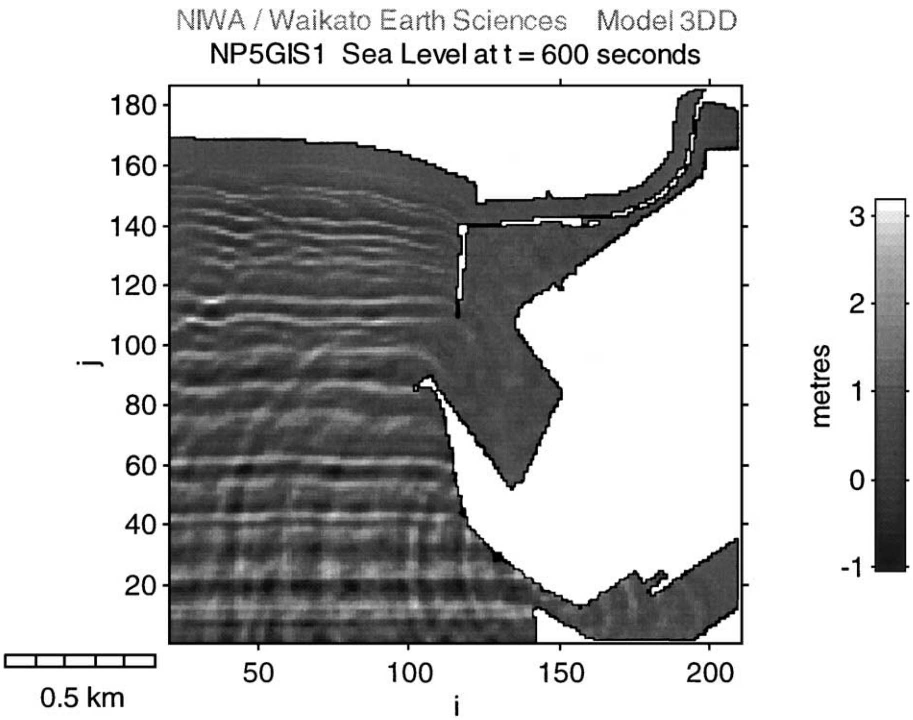

Fig. 5. Numerical model output of wave refraction from WBEND for a potential redesign of the port, which minimises long wave energy in the harbour (Black et al., 1997).

sediments either side of the channel (Healy et al., 1997).

An assessment of the extent to which the deepened channel acts as a sediment trap requires both wave and sediment transport numerical modelling. Such tools are becoming standard applications for designing ports (e.g., Sawaragi, 1995). The model applied in this study was a coupled three-dimensional hydrodynamic and advection/diffusion numerical model POL3DD (Black, 1983, 1995; Black et al., 1999). POL3DD contains five coupled models in a single computer code, i.e. two- and three-dimensional circulation, advection/dispersion of salinity and/or temperature, surface gravity waves in shallow water and ocean/atmosphere heat transfers.

A substantial field program to obtain calibration data across a wide set of physical processes is required to obtain good confidence in the modelling output for a project such as this (Healy et al., 1987; McComb et al., 2000). We aimed to obtain concurrent field data measurements (Gorman et al., 1997) of water levels (tide gauges), vector-averaging wave and current meters (S4DWs), sediment transport monitoring devices, and detailed side-scan sonar survey. Temperature and salinity data were collected using a combination of fixed sensors and periodic conductivity, temperature, and depth (CTD) surveys, while meteorological and river discharge data were available from Gisborne Airport weather station and Gisborne District Council, respectively. Detailed analysis of sediment samples collected adjacent to the channel were performed through settling and resuspension calculations to obtain friction factors applied in the numerical model, and as a modern baseline against which to monitor future change.

The modelling results have shed new light on the oceanography of Poverty Bay including the complexity of circulation patterns. Although not the focus of this paper, circulation in the shallow bay has been found to depend on freshwater intrusion, density gradients, and temperature variation in the presence of slow local tidal currents (Stephens et al., 1997a,1999,in press). With high fresh water inputs, temperatures in the surface layers are often cooler than at the bed which is contrary to initial expectations, while solar inputs cause differential heating as a function of depth and drive an associated up/down-welling circulation. Thermohaline mixing is dominated by water-body overturning associated with the baroclinic pressure gradients, and by waves.

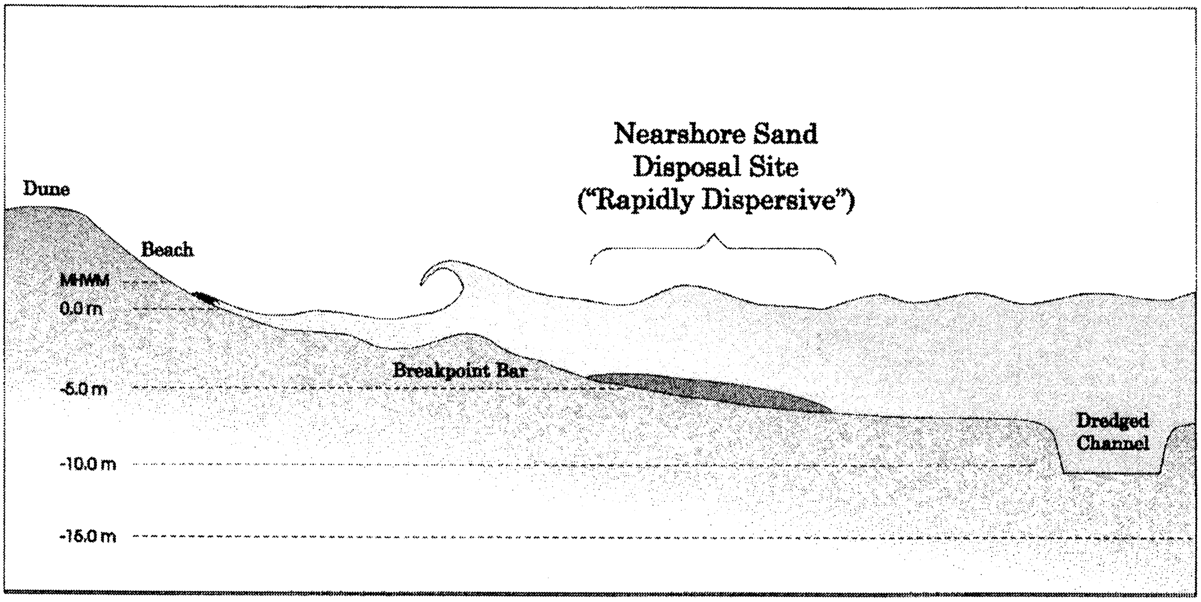

Fig. 6. Schematic concept of nearshore disposal of maintenance dredged sandy sediment within closure depth to re-nourish the beach (Port Gisborne, 1998).

Prior to the recent capital dredging, maintenance dredging of the navigation approach channel had been about 50,000 m^3/year. Sediment transport modelling (Black et al., 1997) shows that, in the future, the maintenance dredging requirements of the deepened navigation channel are expected to be about 100,000 m^3/year under average conditions and 250,000 m^3/year under stormy conditions. However, under extreme episodic cyclone conditions dredging requirements could reach about 730,000 m^3/year, and the channel could fill quickly under these conditions. This wide range and uncertainty of the dredging estimates for future maintenance dredging capacity requirements is a perplexing problem for the port.

5.6. Disposal of future muddy-sand maintenance dredging

The most appropriate site for the future dumping of muddy dredge spoil is at the disposal site towards the southern end of the bay, exposed to the dominant waves from the southeast (Fig. 1). Under the present current regime at this site, mud resuspended by wave action in this area migrates offshore with time (Stephens et al., 1997b). A side-scan sonar survey of the proposed spoil ground in the center of Poverty Bay shows the area to be devoid of any rocky reefs, while a geotechnical investigation (Beamsley et al., 1998) showed sediment from this site to comprise >80% mud, higher than surrounding areas of the Poverty Bay sea floor. As noted, ecologically this area is considered to be a suitable site for future muddy dredge spoil disposal.

6. The potential need and suitability of maintenance dredging for beach renourishment

The sediment transport modelling results (Black et al., 1997) suggested that the planned capital dredging

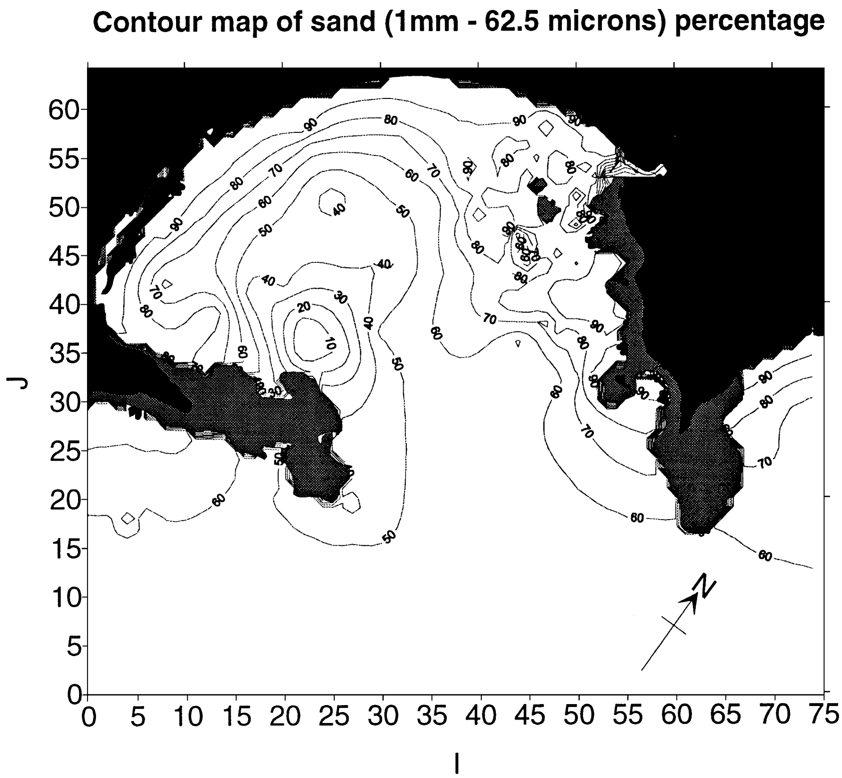

Fig. 7. Contour map of sand percentages for Poverty Bay surficial sediments. Sand percentages in the shipping approach channel area are greater than 80% (Black et al., 1997).

and deepening of the shipping channel may induce significant erosion on the adjacent Waikanae Beach. This would likely be as a result of storm-induced diabathic offshore sediment transport of beach sediments. These sediments would become trapped in the deepened channel. The neat solution appears to be: recycle the sands trapped in the shipping channel back to the active subtidal beach, ensuring that the sediments are returned to the beach profile well inside the diabathic "closure depth" (Bruun, 1988; McLellan, 1990; Hands and Allison, 1991; Komar, 1998) (Fig. 6). This technique was successfully undertaken and monitored off Mt. Maunganui Beach, New Zealand, using dredged medium to coarse sandy sediment which was laid in a berm at ~8-m water depth (Foster et al., 1994;1996). Hoekstra et al. (1996) report a similarly successful large-scale beach profile renourishment where sand was deposited between 5 and 7 m offshore of the Dutch barrier island, Terschelling.

For the situation at Poverty Bay, we selected a nearshore site for disposal of the sandy material maintenance dredged from outside the port in the shipping approach channel (Fig. 1). The proposal allows for sandy dredged material to be deposited in a shallow berm at about 5 m water depth located just seaward of the daily breaking wave zone, but within the storm wave breaking zone, so that the nourishment sand remains part of the active beach profile surface sediment agitation layer (Fig. 6; Smith and Jackson, 1990; Hands and Allison, 1991). This design is very analogous to both the Dutch barrier island (Terschelling) large-scale sand emplacement at 5–7 m water depth (Hoekstra et al., 1996), and the dispersive disposal mound emplaced between 5 and 8 m water depth off San Diego (Andrassy, 1991). The emplace-

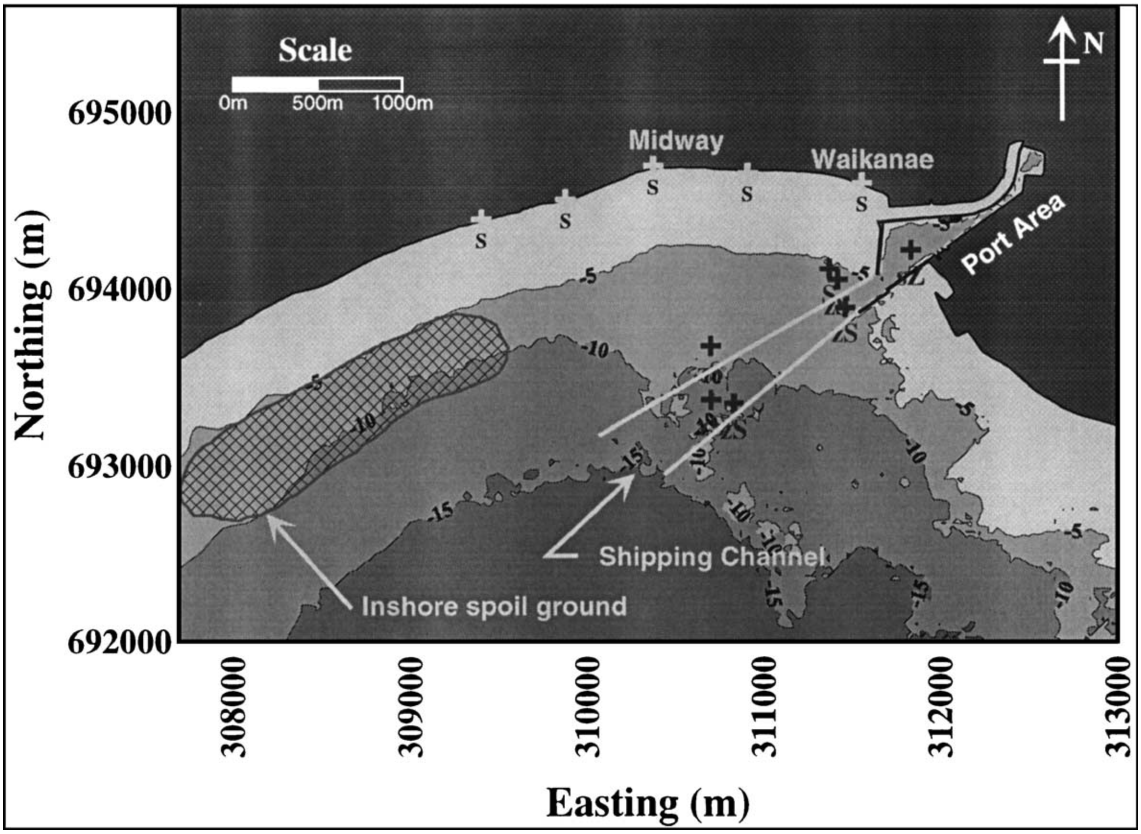

Fig. 8. Sites of surficial sediment samples collected as part of an assessment of maintenance dredged sediment for nearshore disposal (Beamsley et al., 1998).

ment of sand with a significant mud content, as we get at Poverty Bay, is also gaining acceptance in the USA (McNair and Hales, 2000). The aim of the nearshore beach profile is not specifically to renourish and widen the subaerial beach (Bruun, 1988), but rather to provide an erosional buffer against sand lost from the littoral system.

Prior to obtaining approval by local authorities for sandy sediment disposal in the nearshore zone, it was necessary to ensure compatibility of the dumped sediment with the beach sediment. Beach renourishment is most effective when the renourishing sediment is coarser than the naturally occurring sediment on the beach (Dean, 1992; National Research Council, 1995). Sediment textural assessment was based upon the extensive data collected by Miller (1981) and Kensington (1990), as well as on additional samples collected in this study (Beamsley et al., 1998). Grain size analysis of the beach sediment was undertaken from five sample sites collected at the low-tide swash zone (Figs. 7 and 8). These data were compared with surficial sediments collected in and adjacent to the shipping channel. The comparison of the grain size distributions of sediments collected at the shipping channel, the beach and between 5- and 10-m depth contour (Fig. 9) confirms the suitability of shipping channel sediment for achieving the aims of nearshore disposal. The proportion of sediment in the very fine sand (3–4ϕ) range size is very similar in the shipping channel and at the 5–10 m depth contour. This indicates that there should be no deleterious effects from renourishment sediment dispersal in the littoral zone. The dredged material is likely to contain about 15% silt, so that one might expect some plumes to be visible during the disposal activity. Natural water discoloration is not expected to be unduly increased

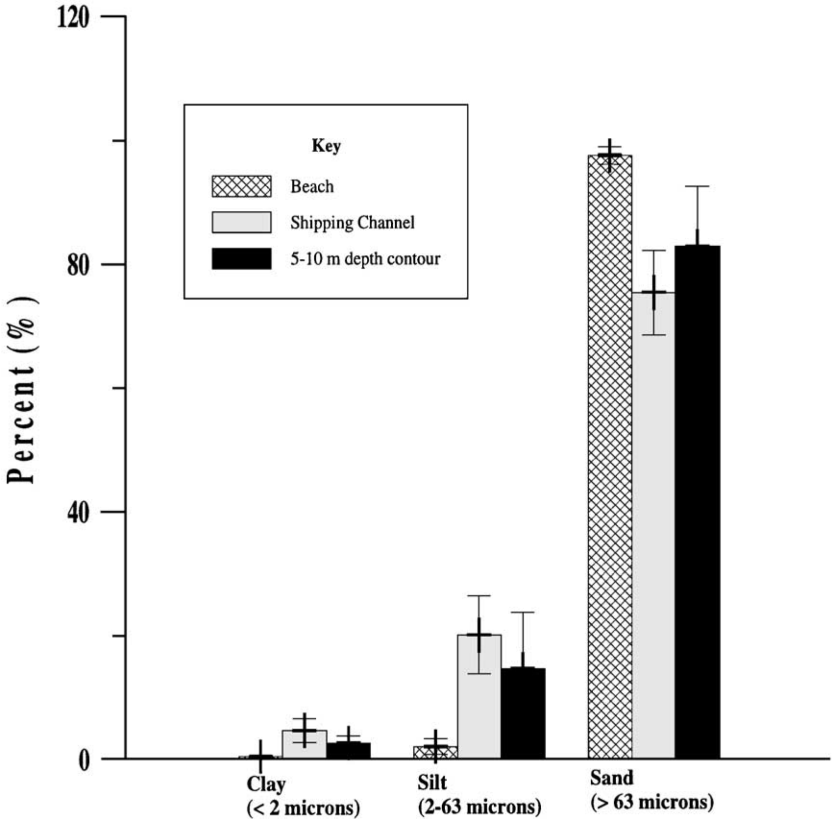

Fig. 9. Grain size distribution histograms for sediment on Waikanae Beach, the shipping channel, and between 5- and 10-m depths, from Beamsley et al. (1998). Error bars are 95% confidence intervals.

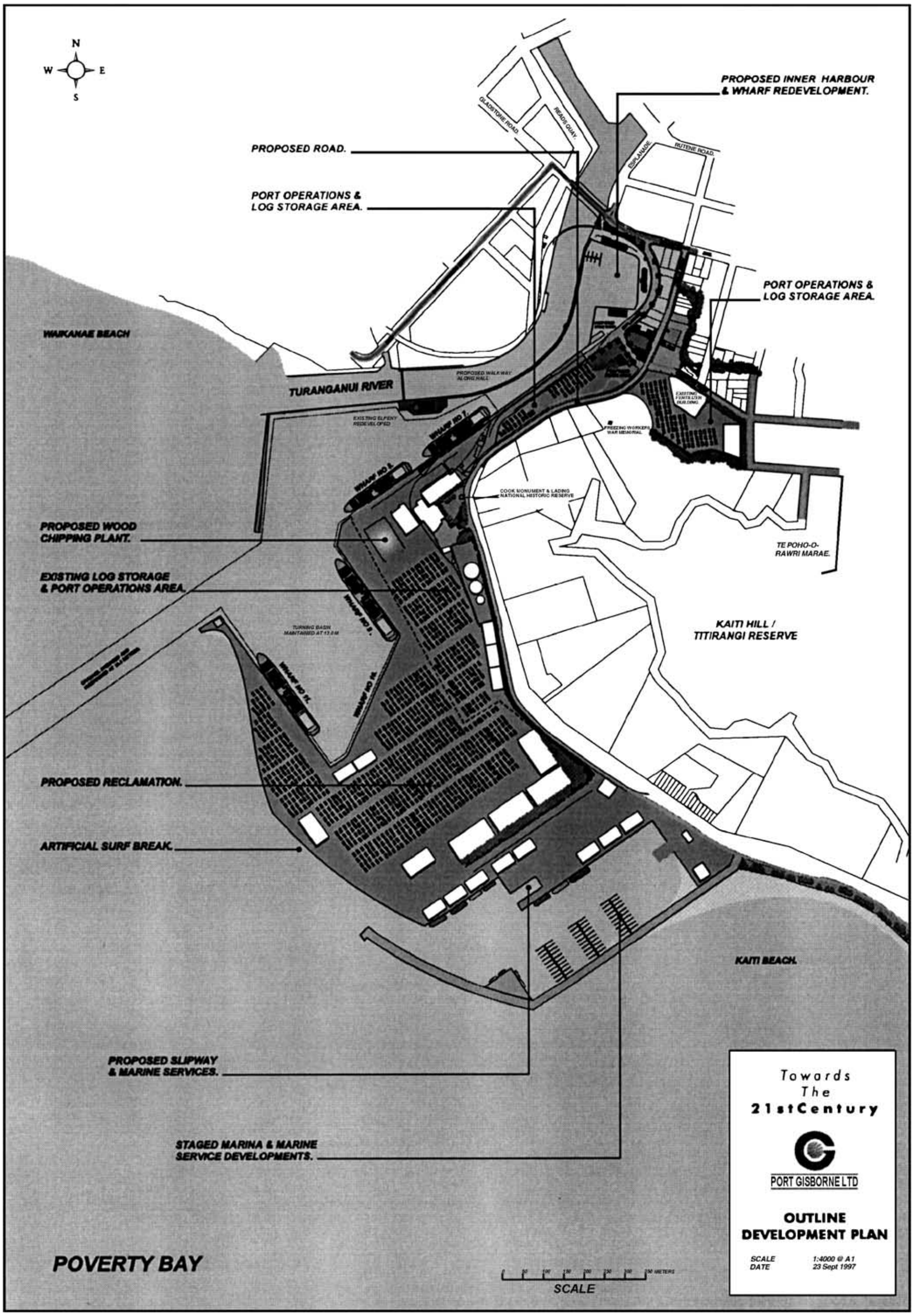

Fig. 10. A potential design proposal for Port Gisborne, incorporating a proposed marina and an artificial surfing reef planned along the outer breakwater curve (Port Gisborne, 1998).

by the disposal operation because, except during abnormally calm weather, the nearshore Poverty Bay waters typically possess low visual clarity due to wave-induced fine sediment suspension of river inputs. An ecological survey by Cole et al. (1997) concluded that dumping of sandy sediment in the nearshore zone would have little impact on the fauna of that area, providing the texture is similar. Disposal of the sandy material just off the beaches will allow the coarser component of the sands (2–3ϕ) to move back onto the beach through natural diabathic onshore sediment transport, as has been reported elsewhere (Andrassy, 1991; Foster et al., 1994,1996; National Research Council, 1995; Hoekstra, 1998). This landward migration of sediment will help to maintain the nearby sandy beach and dune shoreline.

7. Amenity value to the community

Amenities and facilities that might be incorporated into the design to enhance public accessibility, utilisation, and enjoyment of the coastal marine environment were evaluated along with port operational requirements and environmental considerations (French, 1997; Kay and Alder, 1999). An artificial surfing reef (Black, 1999) is one such amenity. For this to be effective, the alignment and shape of the breakwater needs to be at an angle to the incident waves which allows creation of the ideal wave breaking form for surfing (Hutt et al., 1999; Mead and Black, 1999; Sayce et al., 1999). To achieve the desired condition, sand filled geotextile bags will be used to shape the breakwater (Black, 1999). A marina has also been incorporated into the design (Fig. 10) along with increased access for the public using the breakwater for recreational purposes such as fishing, exercise, or nature study.

8. Conclusions

Redesign of Port Gisborne for the 21st century has encompassed a careful Integrated Coastal Zone Management process, which involves a major research program into the environmental impacts of the development. An integral philosophy of modern redesign procedures is the iterative process of professional interdisciplinary interaction and collaboration leading to consideration of initial options. These then require research assessments, followed by interdisciplinary reassessment, followed by refinement of the options, and so on. This process takes into account constraints imposed by the economic and operational requirements of the port, the environmental effects upon the benthic fauna, sedimentation and dredging impacts, post-construction long wave seiching within the port, engineering design and construction cost constraints, and added amenity values for, and impacts on, the local community. An important aspect of the process is community consultation and feedback to the design team.

Research into sediment transport patterns has been an essential component of the study because the siltation history of the area suggests that the problem will be magnified due to the substantial capital dredging planned for the future and to the increased maintenance dredging that can be expected. Numerical modelling of waves and the general hydrodynamics of Poverty Bay have been completed while research into sediment transport processes linked with the hydrodynamics is ongoing. Assessment of the nearshore sediment textures indicates that material trapped in the shipping channel is suitable for nourishment of the subtidal profile of the adjacent beaches, which are expected to suffer sediment depletion due to the port redevelopment. This sediment, to be disposed as a shore-parallel berm at about 5 m water depth, is expected to migrate onshore and help maintain the subaerial beaches in a healthy condition.

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