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Physical modelling of a high energy coastal lake outflow, Canterbury, New Zealand

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ABSTRACT

A 1:50 scale laboratory physical model was constructed to simulate canal outflows from Wairewa/Lake Forsyth, Canterbury, New Zealand, in order to assess the propensity for canal blockage due to beach sediment transport. A terrestrial survey, depth soundings and side scan sonar surveys were carried out to establish baseline topographic data. These data were used to derive a high-resolution digital elevation model (DEM) of the area. Profiles derived from the DEM were used to cut metal guides to represent beach topography. These were placed in the model tank and a beach was shaped of fine, silica sand to represent the area of the canal opening. Canal outflows were simulated using flow through a polystyrene channel with a rectangular cross-section. A thin-plate wave generator was built for simulating waves. The model was initially designed to simulate sediment transport by longshore drift from south-westerly swells but was later adapted to also simulate south-south-easterly swells. Testing was carried out simulating the base conditions with and without the existing groyne configuration. The model simulated sediment movement well under these conditions. The effectiveness of five groyne scenarios in maintaining a permanent canal opening was tested. Swells from both the SW and the SSE were simulated.

1. Introduction

Since the end of the Holocene marine transgression, longshore drift has been transporting sediment eroded from New Zealand's Southern Alps and carried to the coast by braided rivers over a 30 km length of the Canterbury region's coast, forming a gravel barrier (known locally as Kaitorete Spit) and creating two coastal lakes, Lake Ellesmere (Te Waihora) and Lake Forsyth (Wairewa) (Kirk, 1994). Both lakes provide important wildlife habitat in Canterbury as well as being culturally significant to New Zealand's indigenous people, the Māori. Since being cut off from the sea approximately 150 years ago (Soons, 1998), Lake Forsyth has experienced high sedimentation rates and heightened nutrient levels (phosphorous in particular) derived from the surrounding land, and frequently has algal blooms of cyanobacteria. In addition, the lack of a permanent outlet leads to flooding of land adjacent to the lake in high rainfall events, requiring mechanical excavation of a drainage canal to the sea to reduce lake levels.

In an effort to improve water quality in the lake, the local Māori governing body and the Christchurch City Council excavated a one km long outlet canal leading from the seaward end of the lake to the eastern end of the Kaitorete Spit where it meets the volcanic cliffs of Banks Peninsula, with the aim of providing a permanent opening to the sea. A permanent opening proved difficult to maintain, so a rock groyne composed of locally sourced volcanic boulders was constructed to intercept gravel, under the assumption that longshore drift was the primary mode of sediment transport. This too has proven unreliable and openings of the lake for flood control are carried out with mechanical excavators when necessary. Caretakers of the lake required some indication of the likely success of continued efforts to establish a permanent canal outlet. This paper outlines the development and testing of a 1:50 scale physical model with a range of groyne geometry scenarios to assess options for maintaining a permanent opening for the lake.

There are numerous examples of similar lakes and lagoons in similar geomorphic settings around the world, though few examples of physical models have been identified. For example, Ranasinghe and Pattiaratchi (1999, 2003) have examined the seasonal closure of Wilson Inlet in Western Australia with both field measurements and a numerical model. At the same site, Ranasinghe et al. (1999) identified several mechanisms that lead to inlet closure, suggesting two primary mechanisms: sediment transport from longshore drift, or onshore transport under persistent swell wave conditions. Dodet et al. (2013) carried out a similar study of the Albufeira Lagoon in Portugal while Bertin et al. (2009) highlighted the impact of tidal asymmetry in wave-dominated

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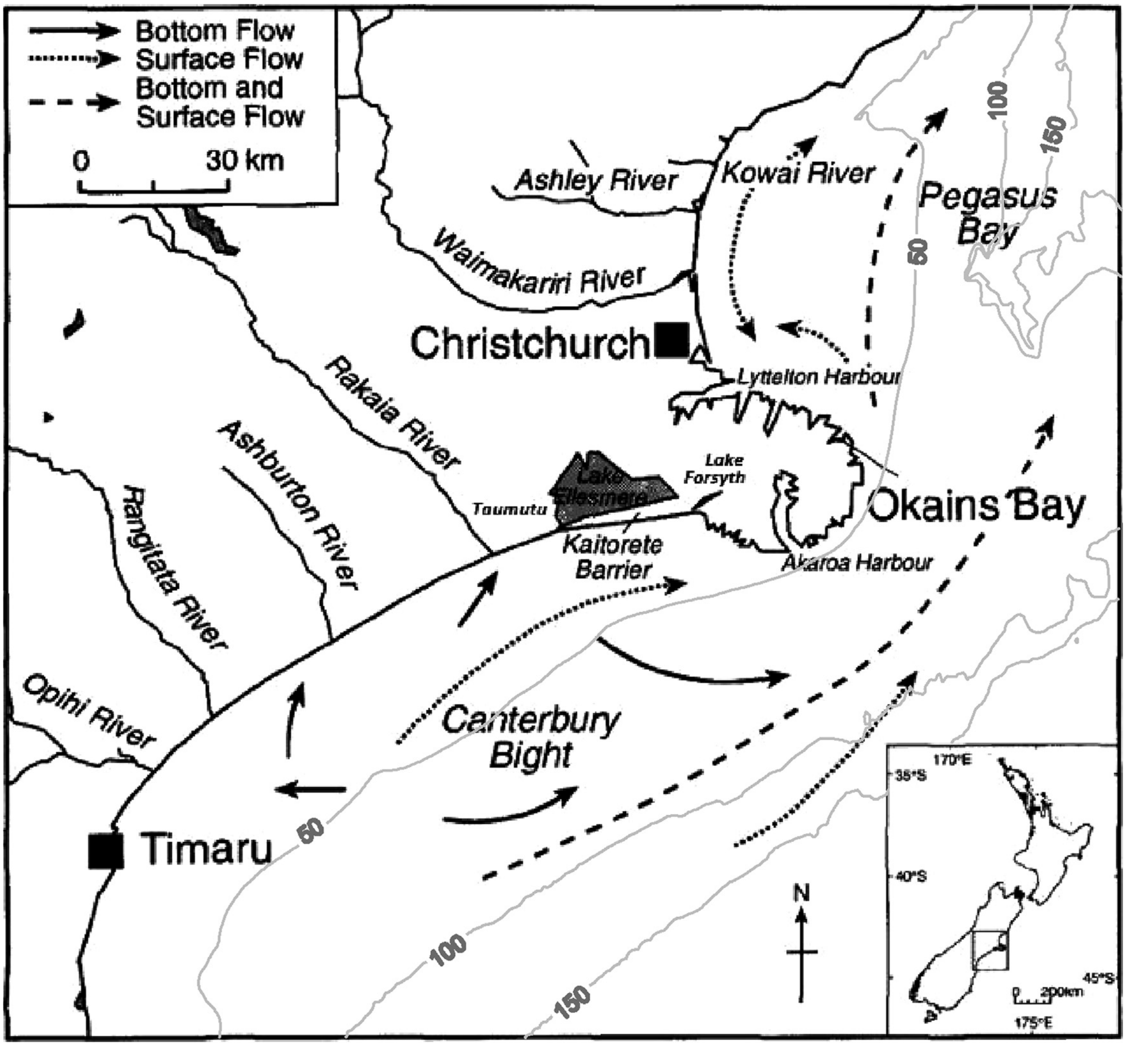

Fig. 1. The Canterbury Bight and offshore ocean currents (Adapted from Stephenson and Shulmeister, 1999). The 50, 100 and 150 m bathymetric contours provide an indication of water depths.

inlets. These papers highlight several factors that explain inlet closure, including an onshore component of wave radiation stress (the "bulldozer" effect), the acceleration and convergence of longshore transport at an inlet due to wave refraction, and increases in mean sea level. Cooper (1994) explored the processes at the Mvoti estuary, South Africa, a river-dominated inlet.

While Lake Forsyth has some similar characteristics to these examples, it differs in several significant ways. According to Kjerfve (1994), the lake could be classified as a coastal lagoon with respect to depth and the existence of a barrier, though it may be better classified as a "waituna" as defined by Kirk and Lauder (2000) which emphasises their occurrence on microtidal, mixed sand and gravel coasts, long residence times, absence of an offshore bar, and rare, natural openings to the sea.

2. Site description

The lake is at the northern extremity of the Canterbury Bight which extends from Timaru in the south, arcing to the northeast and ending at the cliffs of Banks Peninsula (see Fig. 1). Rivers discharging from the Southern Alps (e.g. the Rangitata and Rakaia Rivers) deliver large volumes of sediment eroded from the mountains into the coastal system. Sediment sources are also to be found in the unconsolidated alluvial cliffs along the beaches south of Taumutu (Hemmingsen, 2004). Particle sizes transported in the nearshore zone range from fine sands and mud through to gravel. Gibb and Adams (1982) point out the influence of the Southland Current in the outer nearshore transport zone (NTZ) in transporting sediment in a net north-easterly direction. Fig. 1 shows the larger physical context while highlighting the presence of offshore currents. Hemmingsen, 2004 reports that previous estimates of sediment transport along the Canterbury Bight by longshore drift range from 30,000 m^3/yr up to 206,000 m^3/yr.

Stephenson and Shulmeister (1999) suggested that sand-sized particles are transported offshore and around Banks Peninsula and are then deposited in a banner bank off the northeastern end of the peninsula. Gravels remain within the inner NTZ where their transport is influenced by nearshore currents and wind-induced swells (Carter and Herzer, 1979). Over the past 6000 years, gravels have been transported northwards along the coast and have built up the Kaitorete Barrier, extending from Taumutu at its southern end, to the cliffs at Birdlings Flat at its northern end (Soons et al., 1997), in the process impounding and creating Te Waihora/Lake Ellesmere and Wairewa/Lake Forsyth. As the barrier formed, gravel deposition at the distal end forced the prograding shore south, closing off and creating Lake Forsyth in the process. Evidence for the progradation of the gravel beach at Birdlings Flat is outlined in Soons (1998), although at present the beach appears to be in equilibrium with a large and active beach envelope (Hemmingsen,