South Otago Coast Sediment Transport: Summary and Recommendations

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DUNEDIN CITY COUNCIL kaunihera a-rohe o Ōtepoti

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1 Introduction

This document summarises the sediment transport investigations of the southern Otago coast, which was commissioned by the Dunedin City Council (DCC) to provide technical support for the development of the Coastal Plan for the St Clair to St Kilda coast. A broader understanding of the larger coastal sediment transport system is imperative not only to inform decision making in the development of the St Clair to St Kilda Coastal Plan, but also to support public consultation. This document summarises the findings of a literature review and modelling assessment of the coastal sediment transport along the southern Otago Coast from Tokatā (Nugget) Point to Kaimata (Cape Saunders)[1,2]; and considers these findings within the context of potential management for the St Clair to St Kilda coast (Figure 1).

While these studies are directed at coastal sediment transport and fluxes, and the St Clair to St Kilda coast, a broad acceptance that the natural systems that maintain the beach environment on the south Otago coast are not restricted to the subject of the SPM. Sediment pathways extend along the Southland coast and up to the mountain lakes of Wakatipu, Wanaka and Hawea, and offshore islands and reefs, such as Okaihe (Green Island) and Ponuiahine (White Island), are important control points in the overall sediment transport regime. The coastal landscape, especially the dune areas, have fundamentally changed in the last 70-80 years, with coastal squeeze coming from infrastructure, dune stabilisation with a mix of native and invasive plant species, variations in land use, and resource extraction in the form of sand mining.

The **Clutha River** is by far the largest source of sand and gravel for the Otago coastline. Damming of the Clutha River at Roxburgh in 1956 and Clyde in 1992 has reduced the amount of material reaching the coast by as much as 95% (Hicks *et al*., 2000), with pre-damming contributions estimated at 594,444 -854,300 m^3/yr. Associated with the largest input is the largest sand "**store**" of the Otago sediment transport system, the **modern sand wedge**. This is a large body of sand that extends from Tokatā Point, where the sand is ~35 m thick, to the north where the width and thickness of the sand store diminish (Figure 1).

[1] Atkin., E.A., O'Neill, S. and Mead, S.T., 2020. South Otago Coast Sediment Transport: Literature Summary. eCoast technical report prepared for the Dunedin City Council, June 2020.
[2] Atkin., E.A., Mead, S.T. and O'Neill, S., 2020. South Otago Coast Sediment Transport: Numerical Modelling. eCoast technical report prepared for the Dunedin City Council, June 2020.

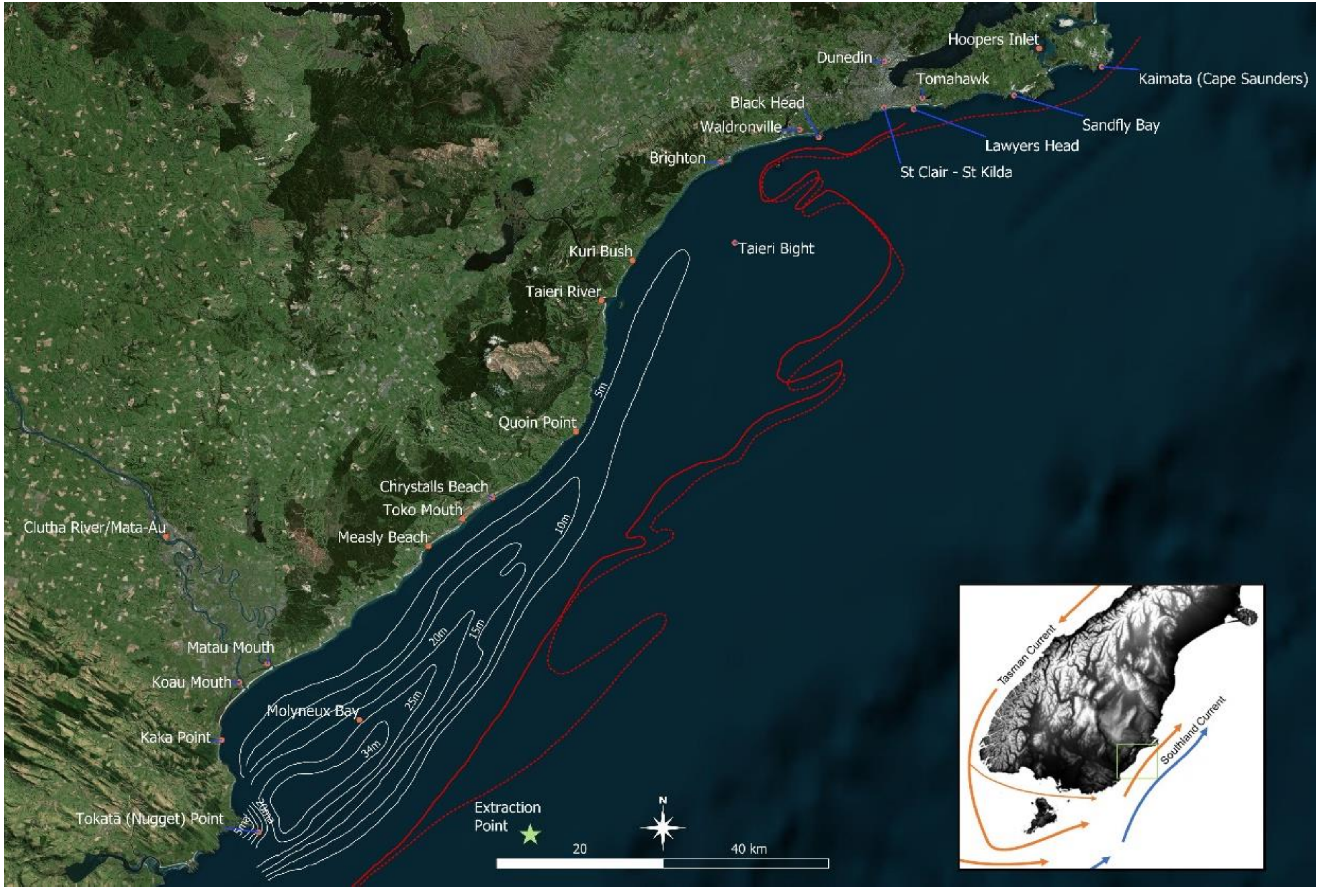

Figure 1: Annotated aerial photo showing: the depth of material in the modern sand wedge of Carter and Carter (1986 - white lines); the seaward limit of the modern sand facies (Carter *et al*., 1985 (dashed red line); Carter and Carter, 1986 (solid redline)); offshore wave climate time series extraction point (white dot); and prominent locations within the study site. Insert: illustration of the Tasman and Southland Currents around the southern tip of the South Island of New Zealand, and approximate study site (green box).

Sediment transport on the south Otago coast is predominantly south to north, with temporary reversals (north to south) associated with metocean conditions (more northly events) and more localised reversals around prominent coastal features. The capacity for waves and currents to transport sediment changes along the coast from Tokatā Point to Kaimata. Generally, there is an increase in depth at which material is being mobilised, and the rate at which it is undergoing **Longshore Sediment Transport (LST)**. Whilst there is a large amount of material in the sand wedge, which likely feeds material to the coastline, the bulk of the sand wedge is located well outside the area where sediment transport takes place.

The increase of LST rates from Tokatā Point to Kaimata leads to demand outstripping supply. As these beaches are largely sustained along the coast, an intuitive assumption is that LST accounts for only a portion of the sediment transport system. At a more local level, it is estimated that the LST flux is reduced through the Waldronville Beach, compared to Brighton area (updrift) and St Clair – St Kilda (downdrift). If we consider that Waldronville is the source for St Clair – St Kilda, then it is in net deficit. However, LST only accounts for a portion of the total sediment transport and it is likely that the cross-shore sediment transport is contributing equivalent amounts, with circulation of beach sediments within the St Clair – St Kilda embayment[2,3,4].

Numerical modelling indicates that area of beach at the seaward end of Moana Rua Road is likely a hinge-point in the St Clair to St Kilda embayment, with sediment transported away from this area balanced in both directions (Figure 2). This physical setting means that the Moana Rua Road area is likely the most vulnerable part of the beach with respect to the effects of a sediment deficit and will likely be the first area to show the impact. Erosion is very apparent in this part of the beach, which is also only ~600 m from the hard engineering at the St Clair end of the beach that also exacerbates erosive processes (Figure 2).

The following summarises the current scenario for the St Clair – St Kilda, noting that many of these factors are compounding:

- Damming of the Clutha River has drastically reduced sediment input.
- The St Clair – St Kilda embayment is at the far end of a 'supply chain' where the net LST demand outstrips the supply.
- The character of coastal dunes has changed dramatically since humans have occupied the area. Extensive colonisation of the dune field at Waldronville may have

[3] Johnson, D., McComb, P., Beamsley, B., Weppe, S. and Zyngfogel. R., 2010. Ocean Beach Dunedin - A numerical study of the coastal dynamics. Technical report prepared for Dunedin City Council.
[4] Davenport, C., 2020. Effects of bathymetry, wave environment and sea level on rip current dynamics in a wave resolving model. Unpublished MSc thesis, University of Otago.

reduced the amount of material in storage and available for transport around the headlands and reefs to the St Clair – St Kilda embayment.

- Net and gross transport of material in the St Clair – St Kilda embayment is greater than in the Waldronville embayment – with reversals in net LST associated with Okaihe.
- There is likely to be periodic reductions in sediment supply due to the intermittent nature of headland bypassing[5] and the ~5.0 km of headlands and reefs between Waldronville and St Clair.
- The St Clair – St Kilda embayment is heavily modified:
  - An inflexible seawall protecting infrastructure and businesses, which was advanced seaward and extend alongshore in 2004.
  - Extension of the seawall with geotextile containers in response to the erosional “end effect” the seawall imposed, which has translated the end effect eastward along the beach.
  - Removal of an active (flexible/robust) dune field in favour of public facilities through clay-capping and roading.
  - Introduction of salt-intolerant, non-native, dune plant species that build tall, steep dunes susceptible to failure and erosion.
- All within the large-scale setting of:
  - Climatic cycles which may result in a reduction of sediment supply along the coast, and/or a rotating of the St Clair – St Kilda embayment[6].
  - Effects of sea level rise which will likely lead to chronic retreat/erosion on a system that has been highly modified and lacks the capacity (space to respond through the natural processes of beach recovery.

[5] Klein, A. H.F. G. Vieira da Silva, R. Taborda, A. P. da Silva, A. D. Short, 2020. Headland bypassing and overpassing: form, processes and applications. Chapter 23, In: Sandy Beach Morphodynamics, Eds. Jackson, D. W. T., and A. D. Short. Elsevier ISBN: 978-0-08-102927-5

[6] Ranasinghe, R., McLoughin, R., Short, A.D., Symonds, G., 2004. The Southern Oscillation Index, wave climate, and beach rotation. Mar. Geol. 204, 273–287.

Figure 2: Schematic of process and environmental setting within the St Clair to St Kilda embayment. The Moana Rua Road area is a hinge-point with sediment being transported away from this point in both directions. The Moana Rua Road area is likely the most vulnerable part of the beach and will likely be the first area affected by a sediment deficit. Erosion is very apparent in this part of the beach and it is only ~600 m from the hard engineering at the St Clair end of the beach.

A Synopsis of Understanding[7] identified the knowledge gap regarding the larger south Otago sediment transport system. The Synopsis of Understanding also provided a catalogue of potential coastal adaptation options. The following presents and discusses those options that a have a direct relationship with the sediment transport regime.

Dune rehabilitation/reshaping

This option is combined with "Salt resistant planting" as the 2 options are essentially synonymous when considering rehabilitation and the introduction of native halophyte plant species. The overall system is in a net deficit, and St Clair-St Kilda may receive less material through LST from Waldronville than is passes downdrift. Retaining material, or prolonging residence time, through increased trapping of aeolian transported sand by halophytes, in the St Clair to St Kilda embayment would be of benefit. Progradation of the shoreline by sand trapping halophytes is a function of supply; where material is fed into the system the plants will extend seaward.

Do the minimum

Holding the line is not a sustainable option at the St Clair end of the beach and holding the line efforts associated with the use of geotextile containers are translating the problem eastwards – noting the Moana Rua Rd erosion hotspot and historic landfill site are only ~600 m to the east. Material tends to move away from this area and the current management option does not act to retain material, exacerbates mobilization with an end effect (during storms) and SLR is expected to worsen the current situation.

Beach recharge/nourishment

This option has been combined "Sand bypass/backpass". Direct input to alleviate the demand on the current system would likely be effective and appropriate given that the system is in deficit. The time over which the nourishment would be effective, the placement area, volume and timing will all require further investigation. At present, the episodic erosion is aggressive, and so this approach would benefit greatly if combined with a management option focussed on retaining the material at nourished sites (control structure and/or planting). Finding source material is a limiting factor in nourishment schemes. However, there are several options in this

[7] Serrano, A., 2019. Long Term Coastal Plan for St Clair to St Kilda: Synopsis of Technical Understanding & Data Gap Analysis. Opus technical report prepared for Dunedin City Council

case, although budgetary limitations may exist. Sand backpass from the more rural, sediment rich downdrift sites such as Sandfly Bay is plausible - although would require a detailed study.

The study site in this work was terminated at Kaimata but the sediment transport system of the South Island, at least for the southeast coast, is continuous. Maintenance dredging, to allow access for container ships, is an ongoing operation for Port of Otago. The Port is consented to deposit 450,000m^3 of dredged material (both maintenance and capital) each year. The bulk of this sand is deposited at 3 consented sites that currently require specific management due to their proximity to two Surf Breaks of National Significance[8]; this represents a potential source for renourishment of St Clair – St Kilda's beaches. It is estimated that 45 M m^3 of material accumulated behind the Roxburgh dam over 30 years[9]. Given that this was historically the major input of sand into the southern Otago coastal system, management options to rectify this deficit should be considered for the medium to long-term, since this has the potential to impact on the whole coast.

Groyne(s)

The transport system is not solely driven by LST, and cross shore transport may be as, or even more, consequential in the total sediment flux through this embayment[2, 3, 4]. This means a traditional groyne or groyne field option would likely be ineffective at retaining material, at least for significant amounts of time. Groynes function in the same way that natural headlands block the sediment transport pathway and create beaches[10]. However, natural headlands represent the boundaries between littoral cells, when groynes are placed within a littoral cell, the usual outcome is to 'shift the problem down the coast'. Groynes form an artificial headland that in isolation results in erosion on the downdrift side of the structure. This effect is well known (the 'groyne-effect') and has been documented world-wide[11]. Groyne-fields are used to counter the effect of the previous, up-drift groyne; a traditional groyne in isolation is likely to result in additional issues.

Variations on the traditional groyne include the low-profile groyne and the permeable groyne. The low-profile groyne acts like a longshore "backstop", that while beach volume is high sediment transport remains uninhibited; when beach volumes reduce to a predetermined

[8] Mead, S.T. and Atkin, E.A., 2019. Managing issues at Aotearoa New Zealand's surf breaks. In: Bryan, K.R. and Atkin, E.A. (eds.), Surf Break Management in Aotearoa New Zealand. Journal of Coastal Research, Special Issue No. 87, pp. 13–22. Coconut Creek (Florida), ISSN 0749-0208.
[9] Smith, A.M, 2007. Marine Sedimentation and Coastal Processes on the Otago Coast. University of Otago, Report to Otago Regional Council.
[10] Grigg. B., 2004. Headlands and Groins: Replicating Natural Systems. Special Issue 33, Journal of Coastal Research, 280-293.
[11] Kraus and Rankin 2004. Functioning and Design of Coastal Groins: The Interaction of Groins and the Beach – Process and Planning. Special Issue 33, Journal of Coastal Research.

height, the low-profile acts to retain longshore transported material. With the permeable groyne longshore transport is reduced but not completely inhibited; the inhibition is a function of the size and spacing of cross shore gaps in the structure. Neither of these variations address cross shore sediment transport; and when included in the surf zone under storm conditions they will likely acerbate erosion, like most hard, land-based structures.

Nearshore Breakwaters

Nearshore, or attached, breakwaters which form tombolos were also included in the potential coastal adaptation options. These types of features are, like groynes, very unlikely to retain material in this setting. Indeed, it is difficult to find any examples in the world were breakwaters are symbiotic with a natural dune and beach setting.

Offshore breakwater(s)

There are examples of how effective natural offshore breakwaters, or detached breakwaters, are on the south Otago coastline. For example, the widening of the beach (known as a salient) on Smails Beach due to the presence of Bird Rock (Figure 3), and from the modelling work, at Waldronville where a reversal in net sediment direction occurs in the lee of Okaihe[2]. The effects of offshore features are relatively well understood and have been simulated for many years in coastal engineering practice. While detached breakwaters do not physically trap material themselves, when designed correctly they are effective at locally interrupting LST and reducing (redirecting) cross-shore exchange. This kind of intervention option would need to be considered carefully, especially at the St Clair end of the beach, due to the presence of Surf Breaks of Regional Significance. While offshore breakwaters can be highly effective at reducing wave energy, this does not always lead to accretion of the coast directly inshore (e.g. if too close and semi-emergent). In addition, poorly designed breakwaters can result in the long-term retention of material that was destined for other parts of the coast which subsequently erode due to the reduced sediment input.

Revetment - Rock or concrete units

Given the current environmental and management setting (revetments, rock armour, geotextile containers, no high tide beach, aggressive erosion etc.) and considering a net deficit system, it is very likely that the response to this type of option will be negative. Although potentially effective at protecting the land behind such structures, erosion of the beach in front of them would be exacerbated, which is not part of the vision for St Clair to St Kilda coast, where the beach itself is a highly valued asset and amenity.

However, the St Clair foreshore has little to no buffer or flexibility, with extensive existing infrastructure and no natural beach setting to speak of. This area is heavily modified and a diligently designed revetment style structure will likely be considered as an option at this end of the beach. The design scope for revetments is large, when compared to a seawall for example. There is also broader scope for incorporation of revetments into a holistic management plan, especially when considered as a last line of defence, but also designed to work with other management objectives (retain material) and suit the natural environmental setting (e.g. mirror natural beach slopes). The design of a revetment can also be balanced against the requirement for ongoing maintenance, which in a heavily modified area will be a likely requirement to meet the aspirations of the community.

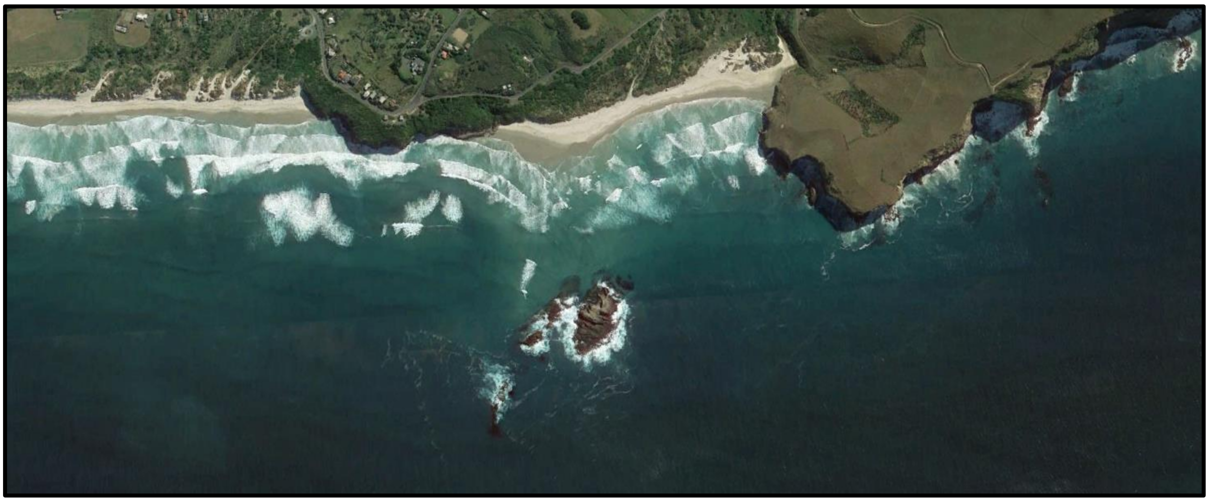

Figure 3: A substantial salient, that is a widening of the beach, is present at Smails Beach due to Bird Rock just offshore, which reduces wave energy at the beach and rotates waves to reduce LST.

Secondary/set-back raised defence

Hard structures at St Clair in the current sediment transport setting are ineffective at providing infrastructure security (e.g. structural failure of the promenade, undermining of the seawall, perceived requirement for geotextile container extension etc.) and have led to a reduction in coastal amenity through exacerbation of erosion. However, if set-back so that they do not interact with waves during storm events, this type of management option could be part of a buying time approach, by allowing the beach to continue to function normally (e.g. continue to erode at Moana Rua Road and the surrounding area). However, issues with applying this kind of intervention include lack of space to set-back into and/or contaminated fill that could be released into the marine environment.

Primary Recommendations

High resolution numerical modelling supported by field data collection is the best way to develop a long-term solution. In the absence of these data, most interventions are likely to be full-scale experiments, which is not recommended. Different approaches will be required for the sustainable management of the different parts of the St Clair to St Kilda embayment. Consideration of the potential impacts of sea level rise will need to be incorporated into any strategies. To this end, the following summarises the recommendations:

- A field campaign to validate the sediment transport quantities between Waldronville, St Clair and Tomahawk.
- Bathymetric data collection. A comprehensive study will require data that justly represents the seafloor adjacent to St Clair to St Kilda. At a bare minimum this should include verification of charted data and high-resolution depiction of the reefs and rocky platforms around the St Clair Headland.
- Expansion of the existing model to accommodate for high resolution hydrodynamics capable of accounting for the distinct infrastructure and geomorphological differences between St Clair, St Kilda and the Lawyers Head end of the embayment.
- Monitoring, both now and going forward, is a critical aspect of any successful long-term management plan. Monitoring provides a quantified understanding of how the beach is changing in response to various drivers, and allows for adaptive management such as the initiation of a new intervention and/or planning pathway change in response to triggers.