CONFIGURATION DREDGING FOR BEACH STABILISATION

Alexander (Lex) Nielsen[1] and **Benjamin Williams[1]**
[1]Advisian WorleyParsons, Sydney, NSW

Introduction

Dredging can change nearshore wave characteristics through the process of wave refraction, which is caused by variations in seabed level and, hence, water depth. The amount of change to nearshore wave height and direction depends on the size of the dredged configuration relative to the wavelength, the relative water depths and the angle of wave incidence. The shape of a dredged configuration can be designed such as to promote beach stability (Riedel and Byrne, 1982; Riedel et al., 2003). In so doing, the dredged spoil, if suitable, may be used to nourish an eroded beach.

Case Studies

Botany Bay, New South Wales

While configuration dredging has not been used commonly to engender beach stability, there are many examples where dredged trenches, in the form of navigation channels, have caused beach and foreshore erosion. In Botany Bay, New South Wales, unforeseen erosion and inundation resulted from the provision of an access channel dredged to win sand fill for runway extensions to Sydney's airport. In 1970. When dredging commenced over the southern portion of the dredging area shown in Figure 1, the contractor cut an access channel 2 600 m long, 60 m wide and 9 m deep along the alignment indicated. This channel was so oriented, relative to the direction of swell waves coming through the heads that, over most of its length, the critical angle of wave incidence was exceeded and wave energy reflection occurred (Hydraulics Research, 1972). As a consequence, waves were directed towards the southern half of Lady Robinsons Beach and local areas of erosion and accretion developed. The adverse drift patterns were remedied in September 1971, when the access channel was backfilled to its original depth (Hydraulics Research, 1972).

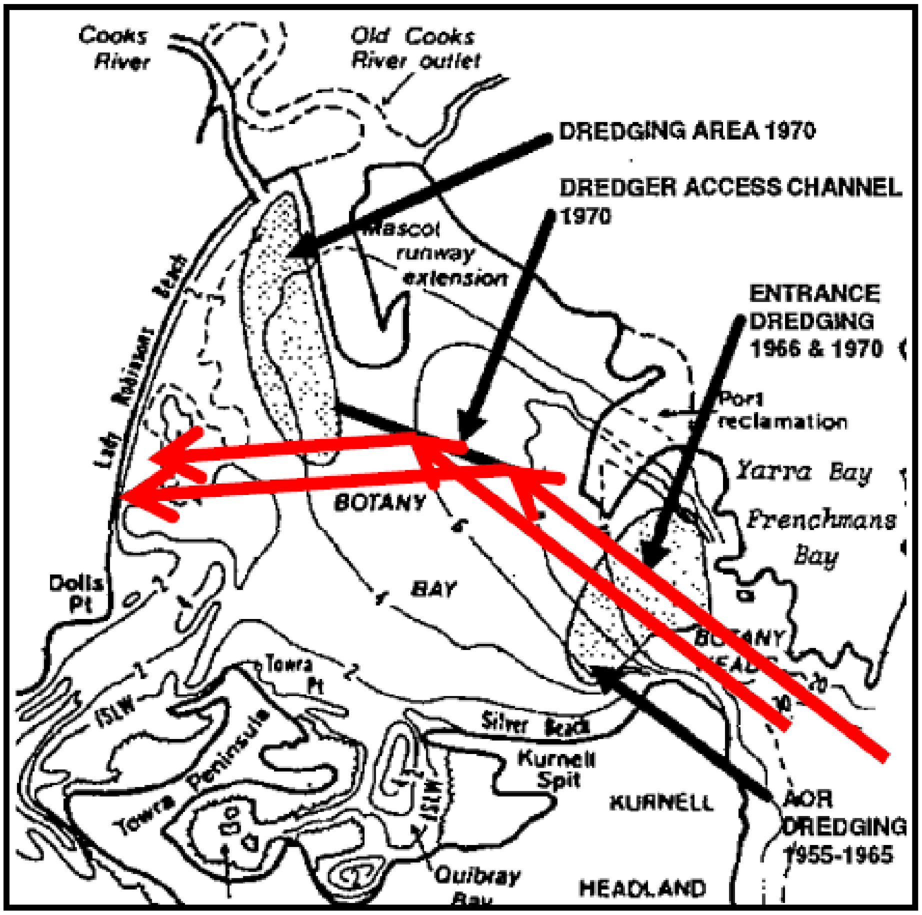

Figure 1. Botany Bay Dredged Areas 1970 and schematic diagram of swell wave reflection off a dredged channel

Port of Townsville, Queensland

The port of Townsville is located on the western shores of Cleveland Bay, North Queensland, and is connected to deep water by the Platypus Channel. Waves approach Cleveland Bay from a narrow range of easterly offshore directions and the Platypus Channel and the dredged pocket for Berth 11 are of such an orientation and of such dimensions that they cause wave reflection.

The difference in the transformed wave heights behind Berth 11 and on the adjacent revetment were demonstrated dramatically during a storm in January 2009. As shown in Figure 2, while there is virtually no difference in the bathymetry immediately fronting the breakwater and the revetment, except for the dredged berth further offshore, there was a significant difference in the incident wave heights. This is attributed to wave reflection off the dredged areas, as indicated schematically in Figure 3.

Figure 2. Wave conditions behind berth 11 in front of the breakwater (top) and those in front of the reclamation revetment (bottom)

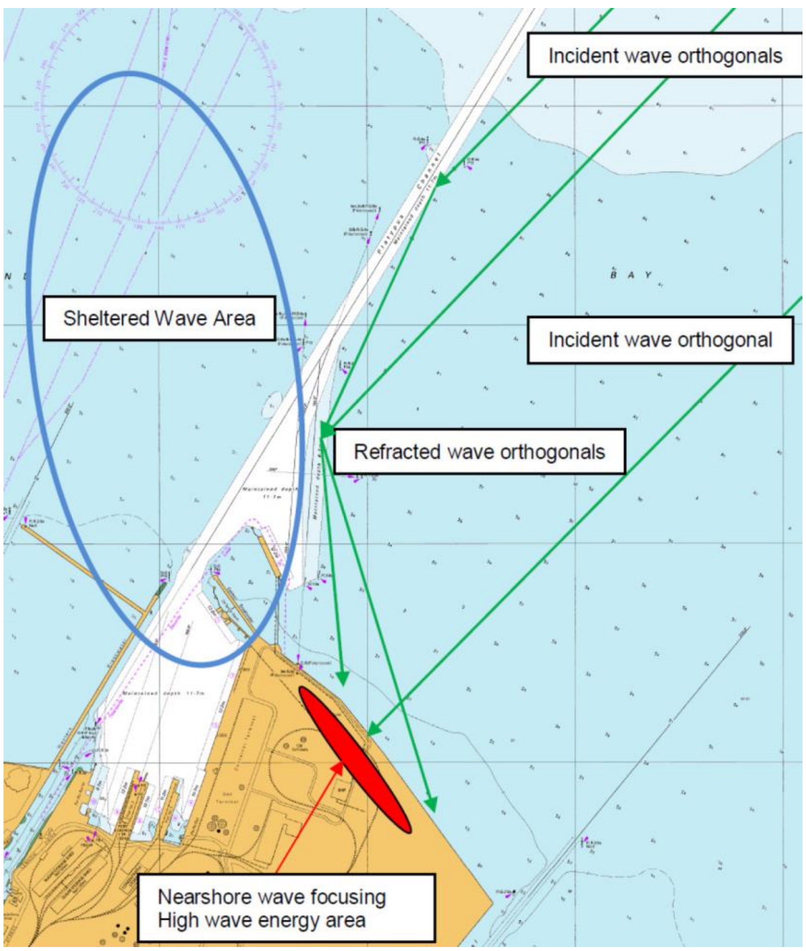

Figure 3. Schematic diagram depicting wave transformation processes causing conditions shown in Figure 2

Analytical Assessment

Theory for Wave Refraction and Reflection

As waves propagate from deep water towards the shoreline, their speed, height, steepness and direction is influenced by the local bathymetry. Based on linear low amplitude wave theory in shallow water and Snell's law of wave refraction, the change of direction of a wave orthogonal as it passes over a channel of semi-infinite width (Figure 4) is given by:

$$sin\alpha_{ch} = \left[\frac{C_{ch}}{C_i}\right] sin\alpha_i = \left[\frac{h_{ch}}{h_i}\right]^{0.5} sin\alpha_i$$

where: α is the angle of the wave crest relative to the centerline of the channel (Figure 4)
h is the water depth
subscripts *i* and ch denote the incident and channel locations.

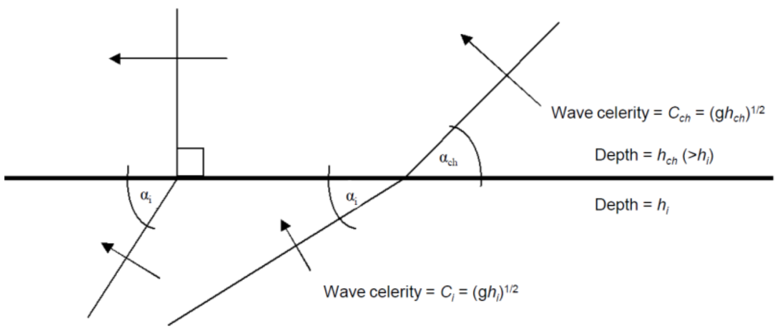

Figure 4. Wave refraction schema

At a channel wave orthogonal angle (α_{ch}) of 90º the wave propagates directly down the channel. For a channel of semi-infinite width, all of the wave energy will then be refracted out of the channel and back along the same channel side as the incident wave.

Method of Analysis

Nielsen et al. (2011) undertook a parametric study using the BOUSS2D wave transformation program to define the conditions for wave reflection off a dredged channel. The model had a flat bed with a deeper channel cut through it (Figure 5). Incident wave spectra of various wave periods, wave angles, channel depths and widths were tested. The length parameters that were varied were normalised to the shallow water wavelength.

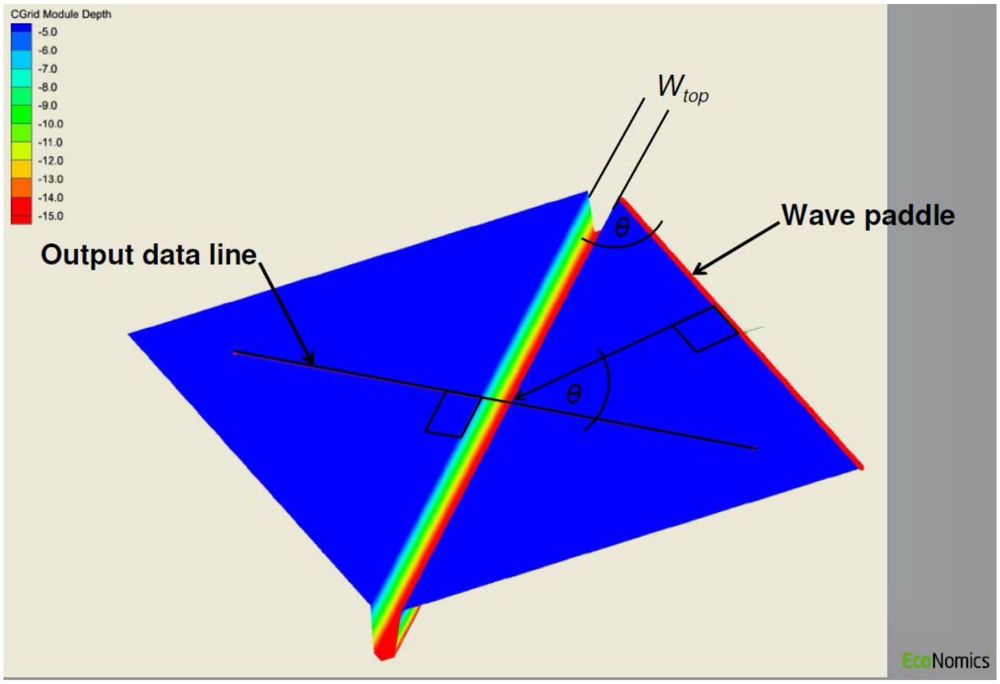

Figure 5. Parametric model layout

The following symbols defined the parameters and their values as used in the modelling:

- d1: general water depth (5 m, 10 m)
- d2: water depth in the channel (7 m, 10 m, 15 m, 25 m)
- W_{top}: top width of channel (40 m, 50 m, 60 m, 80 m, 120 m); side slopes were 2H:1V.
- θ: direction of wave advance with respect to the channel orthogonal (15°, 30°, 45°, 60°, 75°)
- Tp: spectral peak wave period (7 s, 10 s, 20 s)
- L1: wavelength in the general water depth (46 m, 60 m, 68 m, 139 m)
- Δθ: wave directional spread (±10°)

Wave heights were determined as averages derived over lengths of ~100 m along a line normal and adjacent to the channel (Figure 5). Figure 6 presents a typical output from the modelling that shows, for the conditions presented, a reflected wave height coefficient of around 1.30, indicating some 70% of the wave energy was reflected off the channel, with a transmitted wave height coefficient of around 0.55, indicating some 30% of the incident wave energy was transmitted across the channel.

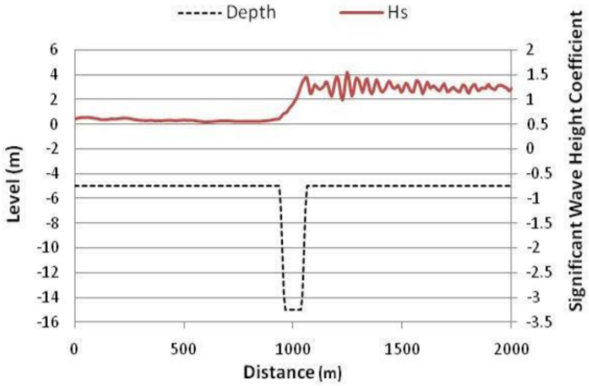

Figure 6. Typical BOUSS2D model result for Tp = 10 s, incident Hs = 1.0 m, incident wave direction 45° (waves travel from right to left), directional spread ±10°, water level = 0 m

Wave Reflection/Transmission versus Wave Angle

The modelling results for the angle of wave incidence are presented in Figure 7. For the conditions modelled, the results showed that significant wave energy reflection (70%) occurred when the angle of wave incidence exceeded 45° with some 30% of the wave energy being transmitted across the channel.

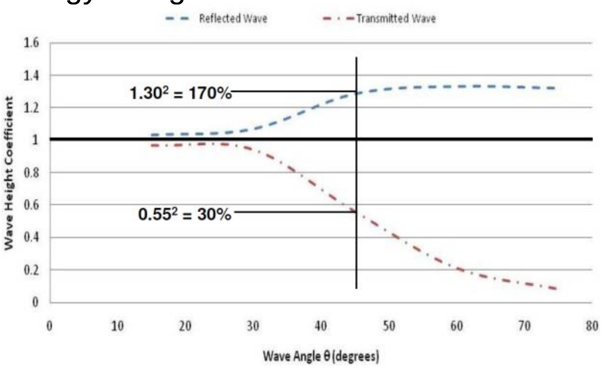

Figure 7. Reflected and transmitted wave height coefficients versus angle of wave incidence (d1/L1 = 0.074; d2/d1 = 3.0; Wtop/L1 = 1.3)

Wave Reflection/Transmission versus Channel Width

The modelling results for varying channel widths are presented in Figure 8. The results showed that significant wave energy reflection began to occur once the channel width exceeded some 60% of the wavelength. At a channel width of around one wavelength some 80% of wave energy was reflected whereas only some 10% of the wave energy was transmitted across the channel.

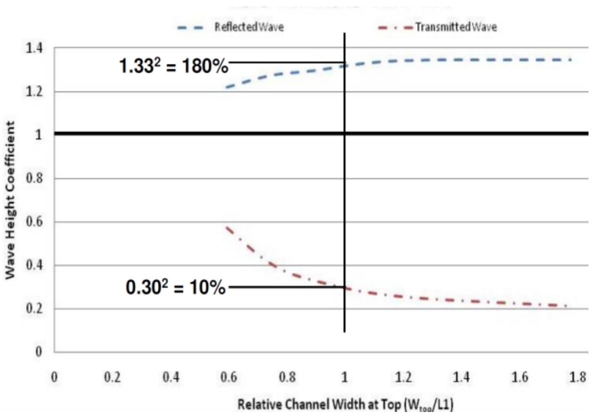

Figure 8. Reflected and transmitted wave height coefficients versus channel width (d1/L1 = 0.074; d2/d1 = 3.0; θ = 60°)

Wave Reflection/Transmission versus Channel Depth

The modelling results for varying channel depths are presented in Figure 9. For the conditions modelled, the results showed that some 70% of the wave energy was reflected when the channel depth was twice the depth of the surrounding seabed with only some 10% of the wave energy being transmitted across the channel.

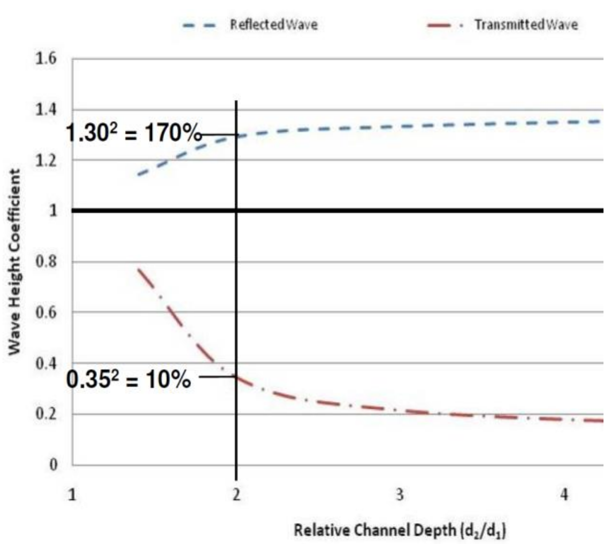

Figure 9. Reflected and transmitted wave height coefficients versus relative channel depth (d1/L1 = 0.074; Wtop/L1 = 1.3; θ = 60°)

Wave Reflection/Transmission versus Water Depth

The modelling results for varying the water depth at which reflection may occur are presented in Figure 10. For the conditions modelled, the results showed that some 80% of the wave energy was reflected where the relative water depth d1/L1 ≤ 0.1.

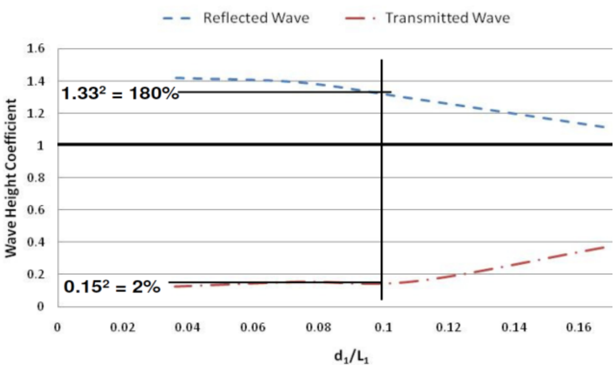

Figure 10. Reflected and transmitted wave height coefficients versus relative water depth (d2/d1 ≥ 3; Wtop/L1 ≥ 1.3; θ = 60°)

Results

The results of the parametric study indicated that almost 100% reflection of wave energy can occur off dredged discontinuities where the following criteria are met:

- the relative water depth, d/L, is less than 0.1 (d/Lo < 0.06)
- the angle of wave incidence (crest to channel alignment) exceeds 45°
- the top width of the channel exceeds the local wavelength
- the depth of the channel exceeds twice that of the adjacent water depth.

Example

Nielsen and Williams (2016a, b) investigated the coastal processes causing severe erosion at Portsea Front Beach, Victoria and proffered, inter alia, configuration dredging as an option to ameliorate and manage the situation.

The erosion was found to be caused by the focusing of some swell wave energy off shallow offshore sand banks (Figure 11). The nomograms in Figure 7 to Figure 10 were used to develop a concept design for a dredged configuration that would reflect the refracted swell wave energy train away from the beach. Several configurations were modelled and the final concept design comprised a 700 m × 160 m × 10 m deep pyramidal parallelogram located at an angle across the higher energy wave train. The volume of dredging was estimated at 650,000 m3 with 350,000 m3 of sand to be used for beach nourishment and 300,000 m3 of calcareous sandstone side-casted over an area 700 m × 150 m on the seaward side of the trench, raising the seabed there by around 4 m.

Wave transformation modelling of the concept is presented in Figure 12 and consequential modelling of littoral drift rates is presented in Figure 13. The modelling showed that the dredged configuration would cause swell wave energy to be reflected away from Portsea Front Beach to be dissipated on sandbanks to the east. The significant reduction in the potential rate of littoral drift transport would result in the elimination of any differential in the transport rates along the foreshore, which, along with a significant reduction in the degree of cross-shore sand transport, would eliminate the cause of beach erosion at Portsea Front Beach.

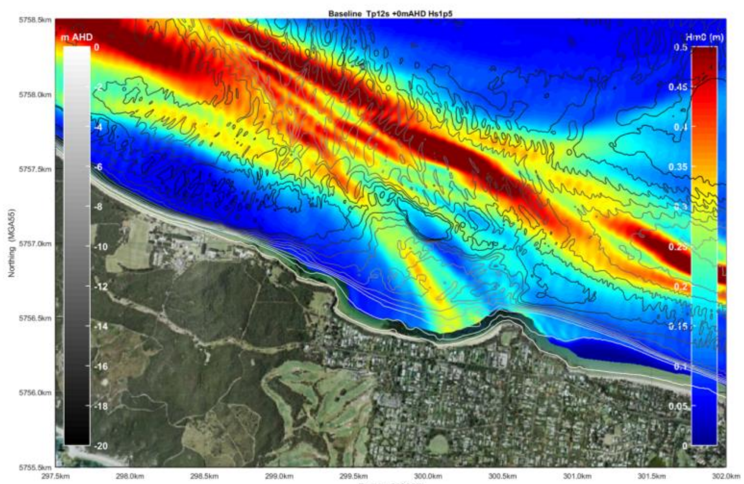

Figure 11. Wave transformation modelling of the existing baseline conditions showing focusing of wave energy onto Portsea Front Beach

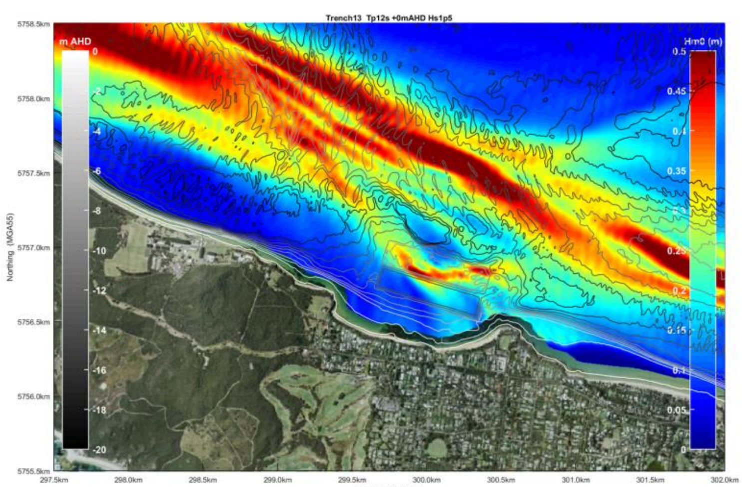

Figure 12. Plan of a configuration dredging depression and its modification to the wave transformation processes, engendering swell wave reflection away from the beach

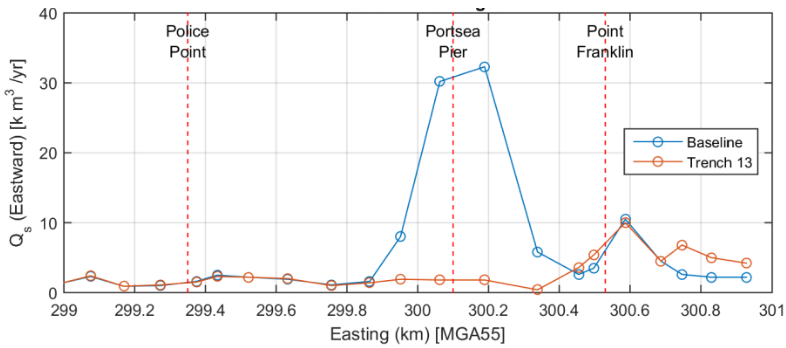

Figure 13. Calculated annual rates of littoral drift transport for the nearshore configuration dredging option compared with the existing baseline conditions

Discussion and Conclusions

Nearshore configuration dredging can be designed to divert destructive incident swell wave energy from an eroding foreshore. Such a project could result in winning sand that could be used to restore an eroded foreshore. In so doing the impact on other areas would need to be considered.

The visual amenity and safety of a beach could be enhanced considerably with this method. A wide stable beach could be restored with a benign wave climate. However, there would be still wind waves and some swell wave energies incident at the shore, which would help to maintain a clean sand quality. There would be no adverse impacts on the subaerial (terrestrial) domain.

Near the shoreline, some considerable areas of nearshore seabed could be smothered with sand. This could result in a temporary loss of some seagrass and benthic infauna in the area. However, the bare sand areas could re-colonise in time.

Offshore where the dredging would be undertaken some seabed areas would be disturbed. Some areas would be lowered and other areas could be raised to shape the desired configuration. This could introduce new habitats, which may enhance local biodiversity.

While there is confidence in the numerical modelling methods as presented, which are based on sound and well-understood physics, designs can been tested also with a physical scale model in a wave basin.

Consideration would need to be given to the probabilities that the dredged depression may be likely to fill in. Sand transport rates near the trench would need to be determined and the requirement for maintenance dredging would need to be assessed.

A configuration dredging option would continue to perform effectively under moderate levels of sea level rise and changes in wave climate. The refraction process is controlled by wavelength (that is, wave period) and the range of swell wave periods is not expected to change with climate change. Nevertheless, should they increase then such an option is likely to remain effective. The trench would remain effective with any relatively large changes to the incident wave conditions.

There may be uncertainties in respect of the amount of suitable sand that could be won for nourishment. Uncertainties could be addressed with a geotechnical investigation. Vibrocoring could be undertaken over the project footprint to assess the depth and quality of the sediment to be dredged.

References

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