Christchurch City Council:
Review of NIWA reports *Coastal sand budget for Southern Pegasus Bay Stage A and Stage B*

Martin Single

Prepared for
Christchurch City Council

June 2019

Shore Processes and Management Ltd
Contact Details: 1/15a Lothian St Christchurch, New Zealand
Phone: (03) 351 4041 or (021) 790797
E-mail: beachdr@slingshot.co.nz or martin.single@canterbury.ac.nz

1.0 Introduction

This report presents a review of two reports prepared for Christchurch City Council (CCC) by NIWA. The reports are:

Coastal sand budget for South Pegasus Bay Stage A (April 2018) (Stage A report)

Prepared by D M Hicks, R Gorman, R Measures, J Walsh and C Bosserelle

Coastal sand budget for South Pegasus Bay Stage B: Future sand budget (June 2018) (Stage B report)

Prepared by D M Hicks, R Measures, R Gorman

The reports are part of a wider study by CCC, covering multi-hazard analysis for preparation of floodplain management plans. The reviewed NIWA reports provide information on the contemporary coastal sediment budget for the city coast between the Waimakariri River mouth and Taylors Mistake, and assess how that sediment budget may change in the future with regard to climate change, projected possible sea level rise scenarios and the effects of possible landslides resulting from a major earthquake affecting the upper Waimakariri River catchment.

This external review has been prepared at the request of CCC to provide comment on the technical aspects, readability and clarity of the reports. The technical assessment is from an expertise in coastal science and a general background in geomorphology, so no technical comment is offered here on the analysis of river sediment transport or landslip incidence in the Waimakariri catchment. However the train of logic of the findings presented in the reports has been followed. Although there are a couple of minor typographical or grammatical glitches in the reports, it is assumed that these will be picked up by NIWA internal reviews, so have not been detailed to any length in this review.

The following sections provide general comments for each of the reports, along with specific comments linked to sections or pages in the pdf copies of the reports provided for review.

2.0 *Coastal sand budget for South Pegasus Bay Stage A*

General comments

The report provides a list of the study tasks that are carried out as follows:

> The study tasks reported here include:
>
> - Providing an updated estimate of the Waimakariri River's supply of beach-grade sand to the coast, including measuring the sand load of the river during a small flood.
>
> - Estimating the wave-driven longshore transport potential along the study shore by undertaking a wave-refraction model study.
>
> - Assessing changes in beach sand volume using the extensive beach-

profile survey dataset compiled by Environment Canterbury.

- Assessing potential net sand exchanges with the Avon-Heathcote Estuary associated with the Christchurch Earthquake Sequence.

- Assembling the above components into a coastal sediment budget.

These tasks appear to be well researched and result in a compilation of worthwhile science on the sediment load of the Waimakariri River and wave processes along the southern Pegasus Bay coast. The analysis of Environment Canterbury beach profile data also provides an updated appreciation of changes to coastal dunes and beach.

The findings presented in the conclusions of each section and the concluding remarks in Section 4 of the report (and the Executive Summary) are well founded, and consistent with the data and analysis.

However, the strength of the report in providing a defendable coastal sediment budget of the southern Pegasus Bay for use by CCC is lessened by the lack of interpretation of the technical science, and presentation of the sediment budget in a way that is readily understood by non-experts. This is made more significant in that the introduction to the Stage B report provides a diagrammatic summary of the current sand budget, as derived from the Stage A report, that is in keeping with general sediment budgets of the coastal literature as shown here in Figure 1.

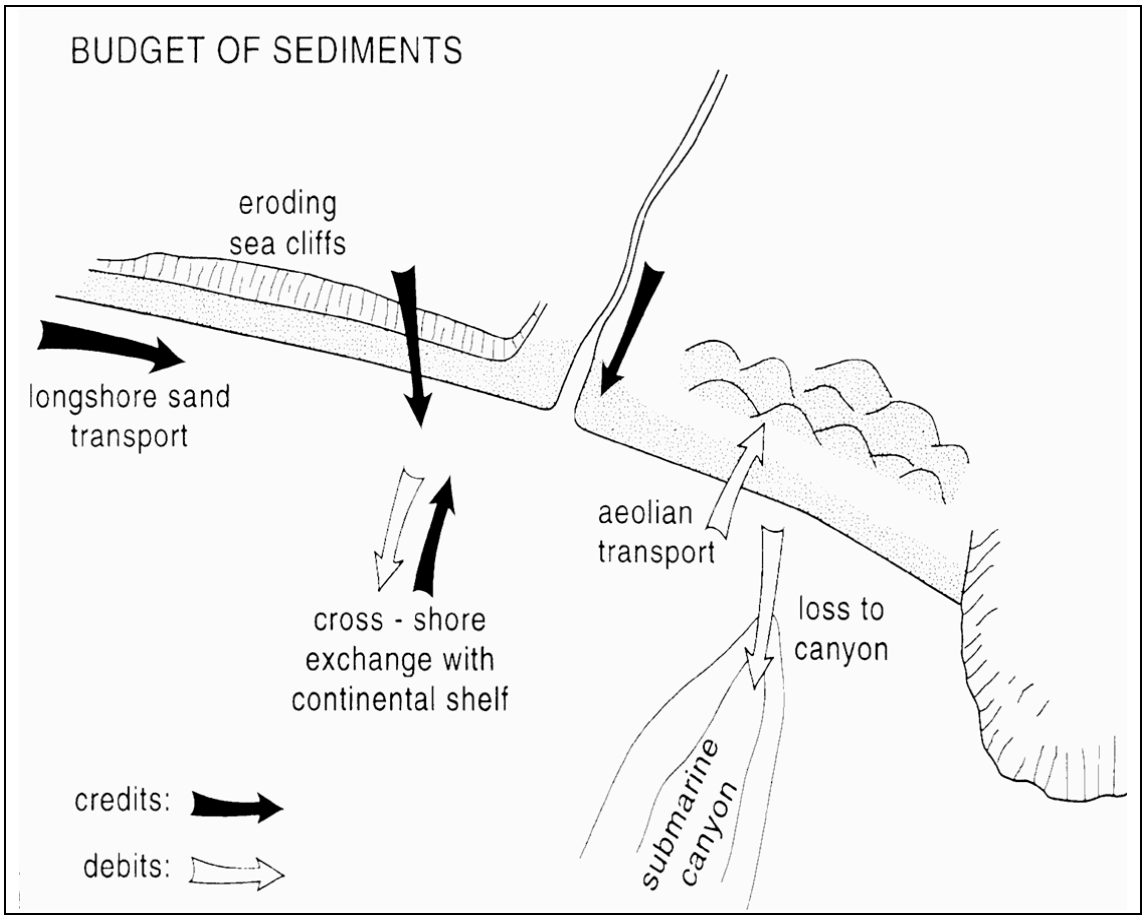

Figure 1 Schematic illustration of the components that are involved in the coastal sediment budget (after Komar 1998, p67).

A coastal sediment budget is generally used to describe or determine the state of coastal stability with regard to sediment supply or inputs, and loss or outputs from a coastal system. A budgeting or accounting style of approach is adopted, where the budget is considered from summing the inputs and subtracting the outputs to determine the state of the "budget". The boundaries of the coastal system need to be considered spatially, while the inputs and outputs, and the processes of sediment transport within or through the coastal system also need to be considered temporally. If the budget is equal, then the state of the coastal stability is considered to be in balance, or stable. If the budget is positive, then the coastal state is considered to be in surplus, as there is more material entering the system than leaving. In this situation the coast may move seaward, prograding, or more volume of sediment may be added to the landward part of the coastal system, accreting. If the budget is negative, then there is more sediment leaving the system than arriving, and the coastal state is in deficit. For any coastal system with mobile sediments forming the shore, then a deficit budget state will result in erosion of the land, or retreat of the shoreline.

Most often the state of the budget will be known, if only in identifying an erosion, stable or accretional state. The details of the inputs and outputs of sediment to the system are most likely not completely, or quantitatively known. For the southern Pegasus Bay coast, the state of the coastal system is well represented from the analysis of the Environment Canterbury survey data (Sections 2.3 and 3.3 of the Stage A report). This shows the state of the budget to be in surplus, with accretion of the sand volume in the beaches and progradation of the shoreline at most sites along the coast.

The Stage A report notes that "there are knowledge gaps, or at least significant uncertainties, in components of the contemporary budget" of the southern Pegasus Bay coastal system. The objective of Stage A is stated "to update the contemporary coastal sediment budget for the Christchurch beaches, including updating the supply of beach sand from the Waimakariri River, the longshore transport potential of waves incident on the Christchurch shore, and the sand volume stored in the beaches." In addition to the Waimakariri River source, alongshore transport of sediment, and sand stored in the beaches, the Stage A report investigates the potential sand storage in the Avon-Heathcote ebb tidal delta and inlet throat. However there is no discussion of whether these are all of the components of the coastal sediment budget for the area.

For example, is there a source of sand from offshore of Pegasus Bay, or a loss of sand to infilling of the Avon-Heathcote Estuary, or to landward of the coastal dunes? Should Taylors Mistake be considered as a separate coastal system, as the sediments on the beach are dissimilar to those on the rest of the shore south of the Waimakariri River? Even if, as suspected, these unknown components to the coastal sediment budget are small or not relevant to the greater budget assessment, they should be identified and discussed in the report.

Identification of the wider components of the coastal sediment budget, the known and unknown variables, then provides a clear context for the studies and analysis of the report, and a strong basis for the approach taken. Filling in the gaps clearly presents the findings of the studies, and sets up the context of examining potential changes in the future in the Stage B report.

Specific comments

Section 2 Methods

The scientific method approach does not come across as a clear presentation of the study or the findings for a lay reader. Although setting out the methods and approach to assessing the data in a structured format, there is too much disconnection between the method and the results for the range and number of study tasks. It would be clearer to follow through each study task to completion within independent sections and then bring the results together to a final section (prior to conclusions) on what this means to the sediment budget.

2.1.5 Proportion of the river load retained on shore

The meaning of this topic is not clear. However, trap efficiency is clearly defined in the Stage B report, page 58:

> The trap efficiency refers to the likelihood that a river sediment grain of given size will be retained on the beach profile above the closure depth, rather than being dispersed offshore while suspended in currents or by diffusion processes. Mud grains, for example, are not found on the Pegasus Bay beaches because they are too easily suspended by waves and currents, thus they have a trap efficiency of zero.

It would be useful to insert this description into the Stage A report 2.1.5.

Were the data for the CCC outfall investigations examined for this study? Those investigations were referred to in the Stage B report, but should also be noted in the Stage A report.

2.2 Longshore transport rates

Work by Cox for Christchurch outfall may provide more data for calibration of the SWAN modelling of wave data.

Cox, D R et al (2003) *Christchurch ocean outfall: numerical modeling. 25 June to 28 May 2003.* Water Research Laboratory, University of NSW, Manley Vale, Technical Report 2003/42. For Christchurch City Council.

2.3 Sand volume changes on Christchurch City beaches

This section would benefit from use of more diagrams to link the terminology in Section 2.3.1 of the geomorphology to the schematic illustration of the shore with closure point in Fig 2-6.

2.3.2 First paragraph has confusing wording, especially when looked at with Fig 2-6. The closure point on the figure does not appear to close the profile translation, as in the depth at which there is no change to the profile.

Is the closure depth different for this study with other studies such as the Tonkin and Taylor 2017 report? Is this significant, or is any difference accommodated in assessing the like-for-like sediment sizes of the river sand source with what is found on the nearshore bed?

How does the closure depth fit with the measured nearshore profiles over time as shown in Allan et al. 1999 and subsequent work for the CCC outfall?

Equations and terms

It would be useful to have all equations and a glossary of terms after the contents pages.

2.4 Sand exchange with the Avon-Heathcote Estuary

First sentence would be a good addition to description of the sediment budget variables.

Good to see the flood tidal delta mentioned here, but this consideration is not clear in subsequent tasks where the inlet throat is named as the internal estuary consideration of sand losses from the budget.

3 Results

See comments above regarding *2 Methods*. Would be clearer to have the results and methods together for each of the tasks.

3.1

Average sand proportion 33.5% in Fig 3-1, and load weighted average sand proportion. Explanation of the difference between this and the total sand load 39.4% needs to be expanded, and noted that it is used in the calculation of long-term average sand load (3.03 x 0.394 = 1.19 million t/yr).

3.1.2 through 3.1.5 appears all clear, but would also benefit from a figure at the end that illustrates where the sand is lost in the travels down the river, and proportions of gravel/sand/mud to show what gets to the coast. So the mud portion doesn't just disappear, but it doesn't stay on the beach or nearshore as it goes further offshore to mantle the seabed.

3.1.6

What is the sensitivity of the sand trap efficiency for the overall retention of sand on the beach? If the values from Allan et al. are used, does the total sand supply become too high for what is retained on the beach as determined from the ECan profile analysis? If so, then how is the difference accounted for in the overall state of the budget? Does it mean that the depth of closure is too shallow, or is more sand lost to landward by wind processes and dune building?

3.2 Longshore transport rates

Shows longshore transport potential, and shouldn't be confused with an actual quantitative volume transported. The relative changes in potential transport are still relevant.

Similar qualification of potential should be included in paragraphs 1 and 2 on page 38, so that a potential for erosion/deposition is suggested rather than actual erosion/deposition. Any actual erosion/deposition would depend on the availability of sediment supply. This distinction is made in Section 3.2.2 and in the Stage B report.

On page 38, last paragraph: would the submarine topography around the Waimakariri River mouth also affect wave shoaling and result in changes to the transport potential of the waves? The bathymetry shown does not show enough detail to tell if this is factored into the SWAN model, but adds to the potential of work done by any outflow jet of the Waimakariri River.

Is the bathymetry shown in Fig 3-11 the bathymetry used in the model?

3.2.3

Need to explain why other potential sources of sand were discounted. For example sand from offshore to the south, or from erosion of the dunes. Discussion of sensitivity of *k* would help to show that your selected *k* is appropriate.

3.2.5

Page 40, last paragraph. Is semi-qualitatively correct? Should it just be qualitatively, or quantitatively but with a degree of caution, and how does this change the final transport potential when reconciling with actual sediment supply as determined in section 3.3?

3.3.1 Upper beach volume analysis

Would be useful to include a dune/beach cross-section diagram showing the location of the features mentioned in the text.

Page 42 reference to (Figure A) is reference to Fig 3-15? It would also be useful to put the figure above the first two bullet points so that it is more easily referred.

Fig 3-15 could also have the axes swapped to appear more relatable to the real world (Sumner to Waimakariri bottom to top on y axis; time on x axis). Onshore energy flux could then plot below the main figure.

Is the unit volume of change between surveys normalised over time, or is the difference from the mean profile volume plotted?

It is a very informative picture, but needs to be explained more in the text to save the reader from misinterpreting what is there.

Fig 3-17 needs to be shown in a wider context with the profile locations, maybe on the Appendices maps, or on Fig 2-5 and Table 2-1. It would also help clarity if the backshore and foreshore were shown as separate columns and then combined.

Fig 3-19, for clarity should have labels consistent between legend and axis labels.

3.3.3 Closure depth and lower beach volume changes

This section requires an explanation be included as to the difference between the closure depth (as calculated in the SWAN model) and the envelope of change for the offshore profiles as shown in Fig 3-21. The Do and Di used are located in an area of large changes in vertical position of the seabed, so indicate movement of sediment beyond this depth. If this is indicative of sediment finer than the sand component of the sediment budget, then that should be shown. Otherwise, it could or should be indicated as the depth limit of the coastal compartment, with unknown inputs and outputs of sediment across this boundary within the sediment budget calculation.

A diagram showing the spatial limits of the profile for the calculations, and the translation of the accreting profile to illustrate the accreted volume for the whole profile (upper plus lower) would also clarify the derivation of the inferred total sand accumulation rate.

3.4 Sand exchanges with the Avon-Heathcote tidal deltas and estuary

The 2011 to 2017 time period of estuary delta, estuary bed level and inlet change should be shown as an anomalous part of the 1990 to 2017 data set. Is there any data on delta and inlet change for 1990 to 2011? Is this thought to be zero change, so that

the earthquake effects are an added aspect of dynamics over the temporal sediment budget, rather than part of the overall long-term average budget?

3.5 Coastal sediment budget

This section needs to be framed in terms of the sediment budget components, inputs, outputs, sources and sinks (losses) of sediment. There is no "demand" for beach sand. Sand is either there or not there. The volume of sand will increase, decrease or stay the same. The sediment budget state is the result of the additions, transfers and losses of sand rather than a state that is to be achieved based on the process environment. The "demand" is effectively the sum of the sources of sediment. Considering things in this way allows for the unknown sources to be investigated and identified. This is what this study does, and appears to do well, but does not clearly present as the study results.

Fig 3-22 is a step away from the cells discussed in earlier sections, and is not intuitively clear. For example, it would be more in keeping with earlier figures of cell and profile locations to have Sumner at the right hand side of the graph. It would also be useful to see this information relative to the cells, or surveyed profile positions.

If demand was re-termed as the budget state or resultant, then the Waimakariri supply is the known input to the budget. The difference between the resultant and the known supply is therefore sourced from other potential inputs. Based on the 182,000 m^3/yr supplied to the southern Pegasus Bay shore from the Waimakariri River (3.5.3) and the budget state for the coastal compartment at +174,000 m^3/yr, the unknown sources and losses in the overall budget appear to be relatively minor, and within the uncertainty due to standard error.

This is a significant finding, and important for investigating the effects of changes to the process environment (sea level and climate change) and potential changes to the river supply of sediment.

The inclusion of a component of the budget that is estimated as accommodating potential losses that would arise from sea level rise (due to landward translation of the beach profile per the Bruun rule approach) is also significant, and carries through to one of the objectives of the Stage B report.

The report should include a clear statement of the reflecting on what the findings mean in determining and describing the sediment budget for the southern Pegasus Bay beaches. This should also recognise the level of confidence in the findings.

For example, "the city shore is accreting" (bullet 6 of *Section 4 Conclusions*) is a good statement to start the conclusions. The sediment budget is in surplus, and this is shown in the geomorphology by progradation of the shoreline and increase in the upper and lower beach volume.

The rest of the conclusions should outline where the sediment comes from, how it gets to the beach (and nearshore) and where does it go (into dunes, building the shoreline seaward and raising the level of the nearshore seabed relative to a datum, but in keeping with sea level rise). Emphasis is put on the sediment delivery from the Waimakariri River, and the few remaining unknowns are identified and noted if they are significant or not.

3.0 *Coastal sand budget for South Pegasus Bay Stage B: Future sand budget*

General comments

The Stage B report presents the results from the Stage B study, "focussing on potential changes in the future coastal sediment budget and their consequences". The objectives of the Stage B study are stated as "to assess potential changes in the coastal sediment budget due to climate change effects (including changes in the Waimakariri River flow, the wave climate, and sea-level rise) and a large earthquake affecting the Waimakariri catchment, and to assess the impact that any current or projected future changes in the coastal sediment budget would have on future shorelines, river mouth stability, and inundation hazards."

As with the Stage A report, the scientific studies carried out and reported in the Stage B report appear well structured and robust. The work is relevant to the objectives and the findings are appropriate to the data and theoretical bases of the study.

However, as with the Stage A report, the communication of the science and resulting conclusions lacks clarity for the lay reader. In particular, the scientific method structure to the report does not present a clear explanation of the potential changes to the future coastal sediment budget due to climate changes and a large earthquake affecting the Waimakariri catchment.

It is acknowledged that the topic of climate change and future projections is complex and includes numerous uncertainties, assumptions and different combinations of effects. Therefore extracting a clear line of effect on the coastal sediment budget will also be subject to many different scenarios and assumptions, giving a range of resulting effect. A useful addition to the report would be an assessment of the likelihood of different scenarios occurring, and a view on the range of likely outcomes to the southern Pegasus Bay coast in plain language.

For example, the key conclusion (in the *Executive Summary*) repeats the information from an earlier paragraph (two above the key conclusions), stating that the shore sand budget should remain in surplus and should not begin to erode except under the worst case RCP8.5 climate change scenario. The earlier paragraph notes what the RCP8.5 scenario includes, but it would be useful to put this in comparison to the BAU or present condition (sea level rise of 2 mm per year) or the recommended Ministry for the Environment Guidelines climate change scenario. The reader should not have to hunt through the report to find this information.

A list of equations and a glossary of terms should also be included.

Specific comments

Executive summary

This summary is generally clear but too long, so detracts from the concluding findings of the study. A clear statement about the present coastal sediment budget state is lacking, as is a statement about how the potential climate change and earthquake effects will alter the budget from the present.

A table of the scenarios examined would put the range of situations and results into a more readily discernable context. For example showing the information in the top part of Table 3-9 combined with information from Tables 2-1, 2-2 and 3-1.

1.1 Background

A note regarding paragraph 2: The coastal sediment budget is not necessarily a "control" on coastal erosion and inundation, but the state of the budget is an indicator of the likelihood of, or actual measure of erosion and then the potential for inundation.

The knowledge gaps and uncertainties (as detailed in LDR113) should be stated to give context to how they were addressed by the Stage A report. This then leads into the following section.

1.2 Summary of sand budget

Fig 1-1 is a great attempt at summarising the findings of the Stage A report, and should (or a variant of it – see comments above and below) be included in the earlier report.

The progradation number (0.46m/yr) should also be in m3/yr to be consistent with the budget numbers (in white). Although it is a per year budget, it is an average over a longer timeframe. This should be indicated in the text, and include the variable factors such as sea level rise and the earthquake effects.

The long period used to derive the budget is good because it includes variability in environmental processes such as flooding events and storm wave events from many directions, so encompasses the broad base state of the sediment budget that is comparable to the long time period addressed in the rest of the report. Acknowledge this feature of the study up front.

The bullet points should use more common sediment budget terms such as "surplus' and "deficit". The use of the term "misclose" really is indicative of both the uncertainties from standard errors and also reveals there are still some unknown aspects to the budget. However these unknowns are small in relation to the overall budget.

2.1

Waimakariri River sand load doesn't need the possessive "'s" as that tends to anthropomorphise the river.

Should the Kidson weather types also be shown for the historical period over which the sediment budget has been calculated?

2.2.2 Future sea level

Does the baseline sea level take into account the sea level change over 1990 to 2017, or is it a static state sea level? It should be clear that existing sea level rise (accounted for in the budget) is not double counted in determining the effects of future sea level rise scenarios.

2.2.3 Changes to the wave climate

The discussion of potential change in storminess, clusters of storms etc. (last paragraph on page 19) should be expanded to show acknowledgement of movement of sediment from the upper to lower beach profile and that there are possible adverse geomorphological effects and subsequent coastal management implications. These are

important for on-going coastal management for CCC and ECan, so don't detract from the long-term sediment budget investigation. However this should be noted in the consideration of limitations of the study.

2.2.6

The last sentence of the section should define the source of the residual sand supply less specifically, as there could be a range of sources of the sediment, including the estuary (flood delta and tidal flats), adjacent seabed deeper than Di etc.

2.4.1 Model development

This section makes sense and tells the method used, but is very complicated for a report to the client. Is it possible to use the Figs 2-5 and 2-6 earlier, and add a further schematic (including the alongshore aspect for example) to show the parameters considered, and to list the equations and variables more clearly? Consider the target reader of the report.

2.4.2 paragraph 3

Reference to "northward increasing grain size" should be changed to southward decreasing grain size to reflect the source area effect and the direction of sediment transport along the shore.

3 Results

3.2.2 Changes in closure depth

It should be made clear that Do is a depth, rather than an elevation relative to a land datum.

The last sentence of the summary is a good explanation of the complexities of the determination of Di and Do, and should come earlier in the section.

Table 3-4

The meaning of the last sentence of the caption to Table 3-4 is unclear. If this is important then it should be explained in the text, otherwise what does it mean?

3.2.3

Has potential infilling of the estuary to match sea level rise been considered? Is there a need for future investigation of the flood tide delta and estuary bed changes with regard to sea level change (and earthquake effects), and of the relative work done by the flood and ebb tidal flows?

3.4 Effects of future sand budget changes on sand volumes and shoreline position

This section should be Section 4 as it directly addresses the objective and the finding of the study.

Footnote 11 should just be stated in the text rather than as a footnote.

Under the first bullet, the last dashed note should note the total sea level rise scenario as well as the per year rate.

An interesting side question as to the result of a large input of sediment from the river over a short time period, is whether the additional sediment volume in the budget would result in progradation of the shoreline or increased dune building? There is evidence across the Christchurch topography of periods of dune building and periods of rapid shoreline progradation.

The description of "trap efficiency" given in this section is very clear, and would fit well in describing this process in the Stage A report.

The bullet on the proportion of sand transported south should include the present rate so that a comparison to the changes is readily apparent.

Tables and diagrams (such as a comparative figure to Fig 1-1) showing the changes of the different variables would help to clarify the overall effects in relation to the sediment budget derived for the present day process environment.

3.4.2 page 61, bullet point 3

Why is Hicks (1993) introduced at this point of the report? If the findings of that study are an important aspect of the study, then it should be introduced in full earlier in the report and discussed in full. Otherwise, this does not seem relevant to this report.

A discussion of the function of the dunes and dune topography and form along the coast is warranted to identify the potential alongshore variability of effect, and the influence of the backshore on shoreline progradation. This should include reference to the figure identifying how dune height changes in relation to changes in sea level. This is also important with regard to the effects on inundation (*Section 3.6*), and the variability due to local topography and backshore features.

Table 3-9

Baseline sea level rise should be given as a number rather than "baseline", so that it can be directly compared to the scenario sea level rise figures.

Can the reason be stated for why the sea level rise by 2120 is about 90 years times the SLR rate at 2120? It is likely because the rate is not linear over the period 2018 to 2120, and that the variable rate does not significantly affect the calculations of effect on the sediment budget. However, this should be made clear in the text.

4 Conclusions

Clarity of the conclusions, and findings of the study would be enhanced by reference back to the objectives of the study with headings and an overall conclusion and statement regarding the sediment budget changes, that is at present in conclusion point 7, out of 10. Revisiting Fig 1-1, and giving comparative figures for the main, or most likely scenarios would also promote the findings of the report with regard to the objectives.

4.0 Overall

The reports in general show a high level of scientific research and investigation of the sediment budget of the southern Pegasus Bay shore. However the presentation of the work and findings are suited more to an internal research report rather than a report for a client that is not an expert in the fields studied. This can be readily rectified with minor changes in the style of commentary and discussion of the investigations and clear presentation of the findings in relation to the study tasks and objectives.