Urban Planning that Sustains Waterbodies: Southern RUB Case Study

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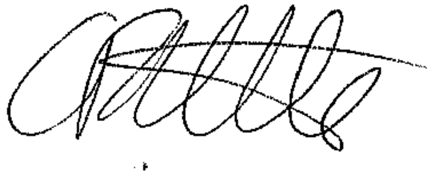
Approved for Auckland Council internal publication by:  Name: Greg Holland Position: Manager – Research, Investigations and Monitoring Unit
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Urban planning that sustains waterbodies: southern RUB case study

Jonathan Moores[1], Marcus Cameron[2], Sharleen Harper[1] and Christopher Batstone[3]

[1]NIWA

[2]Auckland Council

[3]Cawthron Institute

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Executive Summary

Background

The Urban Planning that Sustains Waterbodies (UPSW) research project has developed a pilot decision support system (DSS) for assessing the impacts of urban development on the values of receiving water bodies. As part of the development of its draft Unitary Plan (UP), Auckland Council (AC) is considering options for future urban development outside of the current Rural Urban Boundary (RUB). This report describes the application of the UPSW pilot DSS to assess the potential effects of a range of future urban development scenarios in the Southern RUB area on parts of the Southeastern Manukau Harbour and adjoining tidal creeks.

The study focused on assessing changes to estuarine sediment quality and the health of estuarine benthic invertebrate communities. The pilot DSS makes its predictions of these environmental indicators based on models (or versions of models) that have been previously developed and applied outside of the UPSW research project.

The study involved assessing eleven development scenarios:

- Scenario 1, the baseline scenario;
- Scenarios 2A – 2D, development of the Core development areas, with varying levels of stormwater treatment;
- Scenario 2E, development of the Core development areas with ‘best’ levels of earthworks controls;
- Scenarios 3, 5 and 6, involving development of the Core and additional areas in the centre-south of the study area, including the Pukekohe Focus (Scenario 5) and Corridor Focus (Scenario 6) scenarios; and
- Scenarios 4 and 7, involving development of the Core and additional areas in the north of the study area, including the West-East Focus scenario (Scenario 7).

The baseline scenario for this assessment was a set of predictions made in a previous study, the Southeastern Manukau (SEM) Harbour contaminant study, in which all future urban development was assumed to occur inside the existing urban footprint as defined by the current Rural Urban Boundary.

Key Findings – Environmental Indicators

Based on predicted changes in indicators of estuarine sediment quality and benthic health, the results of the study include the following key findings.

The SEM study area has already been impacted to some degree, predominantly as a result of elevated metal levels from existing urban land use (in the north and east) and elevated sediment levels from existing rural land use (in the south and west). As a result, the overall benthic ecological health of the area is currently predicted to be ‘moderate’, meaning that some impact has already occurred but that reasonable ecological function is still being maintained, particularly in Drury Creek Estuary.

Comparing results for the three major scenarios being considered for the Southern RUB: Scenario 5 (Pukekohe focus), Scenario 6 (Corridor focus) and Scenario 7 (West-East focus):

- Scenarios 5 (Pukekohe focus) and 6 (Corridor focus) are predicted to have a more acute effect on eastern subestuaries than Scenario 7 (West-East focus) as most of the development in scenarios 5 and 6 is concentrated in catchments draining to eastern subestuaries.
- Scenario 7 (West-East focus) is predicted to have a greater effect on western subestuaries (and a greater overall footprint of effect) than Scenarios 5 and 6 as some of the development in Scenario 7 also occurs in catchments draining to western subestuaries.
- Scenario 6 (Corridor focus) is predicted to have a greater overall effect than Scenario 5 (Pukekohe focus) as it covers a greater land area and includes a greater number of dwellings

Based on the results of scenarios 2A to 2E (Core with varying earthworks and stormwater treatment options) any new development utilizing current or reduced earthworks and stormwater treatment controls is predicted to have substantial additional effects on the receiving environment over and above predicted baseline effects. However, if the best available earthworks and stormwater treatment controls are applied *and* achieved then it is predicted that the effects of any new development could be maintained at similar levels to (or even slightly improve on) those predicted under the baseline scenario.

Effects on the receiving environment in the study area are predicted to increase substantially over time regardless of whether any new development goes ahead (i.e. under ‘baseline’ Scenario 1). These underlying (or ‘sliding’ baseline) effects are predicted to primarily occur as a result of inputs of sediment from ongoing rural land use in southern and western catchments and ongoing inputs of metals from existing urban land use in northern and eastern catchments of the SEM Harbour.

Social and Economic Indicators

The UPSW pilot DSS also predicts a set of social and economic indicators which assess the costs and benefits of stormwater treatment and associated effects on how communities relate to receiving water bodies. These methods remain under development and a number of limitations apply to their application for the Southern RUB case study. Accordingly, it is recommended that caution be applied in the use of the results for these indicators, with any interpretation focusing on their relative values.

Under all scenarios the levels of the five social indicators (extraction, contact recreation, partial contact recreation, non-contact recreation and sense-of-place) are predicted to either deteriorate or stay the same over the study timeframe. Lower indicator levels are predicted in some subestuaries using ‘worst case’ and ‘business as usual’ levels of stormwater treatment and under scenarios involving additional development to the Core.

There is a general lack of discrimination in the predictions of the scores for the economic indicators. However, lifecycle costs of stormwater treatment are predicted to be markedly higher under the ‘best case’ stormwater treatment scenario than under any other scenario. The economic benefits indicator is predicted to be negative in all or most subestuaries under all scenarios, reflecting the fact that the environmental attributes from which the benefits indicator is calculated are predicted to decline from their current state. However, there are differences between the scores predicted in relation to variations in stormwater treatment, with greater environmental losses predicted in relation to lower levels of stormwater treatment.

Recommendations

There are several caveats that should be taken into account when considering the recommendations that follow:

- This study should not be considered a comprehensive assessment of the potential effects of the proposed Southern RUB development options. It has been deliberately limited in its scope, focusing on effects on estuarine muddiness and metal level-related indicators.
- The current study presents results from a broad scale modeling assessment which, while based on the best available information and understanding of the systems modelled, does not provide estimates of uncertainty associated with the results. Therefore, interpretation of the results should focus on the relative differences (or similarities) between scenarios rather than on the absolute values.
- The current study has made predictions about receiving environment health over a 50 year timeframe and differences in the results predicted for different scenarios may become more or less accentuated, or stay the same, over a longer period.

Bearing in mind the caveats outlined above the following recommendations are made:

- A full assessment of all the uses and values of the estuaries and freshwater water bodies in the study area is recommended, to allow consideration of matters beyond the scope of the current study.

- If such an assessment suggests that eastern subestuaries have greater overall value than western subestuaries this would support locating some of the development (and thus risk) in western catchments as per Scenario 7 (West-East focus). Alternatively, if western subestuaries are found to have greater overall value than eastern subestuaries this would support concentrating the bulk of the development (and thus risk) in eastern catchments as per Scenarios 5 (Pukekohe focus) and 6 (Corridor focus).

- In order to maintain receiving environment health at least at predicted baseline levels (or possibly slightly better) the ‘best available’ controls for both earthworks (90% Total Suspended Solids (TSS) removal) and stormwater (90% TSS removal, high metals removal) would need to be applied *and* achieved for any new development, particularly given the large scale and extended timeframe of the proposed development.

- Currently available earthworks and stormwater treatment systems, as well as Low Impact Design (LID) principles, should be investigated in more detail to assess the feasibility of achieving the ‘best available’ earthworks and stormwater treatment standards proposed in the current study.

- Management action (such as riparian planting and fencing in rural areas and additional stormwater treatment in urban areas) is currently required on the scale of the whole SEM Harbour catchment area in order to address the substantial underlying (or ‘sliding baseline’) effects from existing and ongoing land use in this area and prevent critical ecological thresholds being breached (especially in the Drury Creek Estuary) regardless of whether any additional development goes ahead.

- An analysis of the relative costs and benefits of enhanced earthworks sediment controls vs. riparian management in rural parts of the catchment is recommended to provide guidance on where the greatest sediment load reductions could be achieved and what the associated costs and benefits of the two different approaches might be.

- It is recommended that the following thresholds are adopted as targets to be met in the study area so that the basic functionality and resilience required to sustain the receiving environment is maintained:
    - Benthic Health Model (BHM) metals and mud scores should not drop below group 3.
    - Muddiness should not exceed 60% and ideally not exceed 25%.
    - Sediment deposition during storms should not exceed 3 mm in any one event or occur more frequently than once every few years.
    - Sediment Accumulation Rates (SARs) should be kept to 1-2 mm/yr and ideally below 1mm/yr.

- The findings from the current study are likely to be applicable to many low energy estuarine receiving environments in the Auckland region. As such the best available earthworks and stormwater treatment controls and additional catchment management outside the area to be developed are also likely to be required in the north and west RUB investigation areas, given that these areas also drain to low energy estuarine receiving environments.

Glossary

AC	Auckland Council
BBN	Bayesian Belief Network
BHMmetals	Benthic Health Model (metals)
BHMmud	Benthic Health Model (mud)
CLM	(Auckland Council's) Contaminant Load Model
C-CALM	Catchment Contaminant Annual Loads Model
DSS	Decision support system
Economic benefits indicators	Indicators which reflect an assessment of the monetised environmental benefits (or losses) associated with the influence of a given development scenario on the attributes of receiving water bodies
Economic costs indicators	Indicators which reflect an assessment of the lifecycle costs of stormwater and riparian management
ERC	Environmental Response Criteria (sediment metal concentration thresholds)
ERL	Effects Range Low (a sediment metal concentration threshold)
ERM	Effects Range Median (a sediment metal concentration threshold)
ERU	Estuary Reporting Unit (spatial units for which indicators are reported by the UPSW pilot DSS)
GLEAMS	Groundwater Loading Effects of Agricultural Management Systems, a sediment load model
Implementation	Setting up a model to represent a given study area
ISQG-Low / High	Interim Sediment Quality Guideline – Low / High (sediment metal concentration thresholds)
LID	Low Impact Design
MBIE	Ministry for Business, Innovation and Employment
Mud content	The proportion of estuary bed-sediments in the clay and silt Wentworth particle size classes (<63 µm diameter)
NIWA	National Institute of Water and Atmospheric Research Ltd
PEL	Probable Effects Level (a sediment metal concentration threshold)
PLU	Planning Unit (spatial units for which input data is entered into the UPSW pilot DSS)
RUF	Resilient Urban Futures research programme
SAR	Sediment accumulation rate

Scenario	A unique configuration of future land use and stormwater management representing one possible option for future urban development in the Southern RUB study area
Sediment metal concentrations	Concentrations of metals (in this study copper, lead and zinc) in the surface mixing layer of estuarine bed sediments
SEM study	Southeastern Manukau Harbour contaminant study
Social indicators	Indicators which reflect an assessment of the relationships between communities and a set of use and non-use values of receiving water bodies
Southern RUB	Southern Rural Urban Boundary
SRU	Stream Reporting Unit (spatial units for which indicators are reported by the UPSW pilot DSS)
SQG	Sediment quality guideline
Study area	The area for which the UPSW pilot DSS is implemented, comprised of PLUs, ERUs and SRUs.
Study timeframe	The period of time for which the UPSW pilot DSS provides and assessment of the effects of development (50 years in this study)
TEL	Threshold Effects Level (a sediment metal concentration threshold)
TSS	Total suspended solids
UDO	Urban Development Option (the input data entered in a given PLU for a future development scenario)
UP	Unitary Plan
UPSW	Urban Planning that Sustains Waterbodies research project
USC, USC-3	Urban Stormwater Contaminants model (USC-3 refers to a sophisticated version of the model used in the SEM study)

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1.0 Introduction

1.1 Background

NIWA and Cawthron Institute are developing a spatial decision support system (DSS) to help assess the impacts of urban development on attributes such as water and sediment quality; ecosystem health; and cultural, amenity and recreation values. The project, Urban Planning that Sustains Waterbodies (UPSW), is part of the Resilient Urban Futures (RUF) research programme funded by the Ministry for Business, Innovation and Employment (MBIE). Progress to date has resulted in the development of a pilot version of the DSS which is currently being tested and refined through its application in case studies. The results of this testing will guide the further development of the system culminating in its delivery as an operational tool for use in local government planning processes.

Auckland Council (AC) is currently involved in the development of its Unitary Plan (UP). The UP will supersede the operative district plans and several regional plans of the eight legacy councils to provide the principal resource management rule book for the Auckland region. AC is currently involved in public consultation on a draft version of the UP. This includes options for future urban development outside of the current Rural Urban Boundary (RUB) to the south, west and north of the city. The development of the options under consideration is most advanced for the Southern RUB investigation area, extending west from Drury to Karaka and south to Pukekohe.

Urban development in the Southern RUB area has the potential to affect the values and services of receiving water bodies and, in particular, south eastern parts of the Manukau Harbour and adjoining tidal creeks. This potential arises from the likely change in stormwater quality discharged to the harbour as stream catchments in the Southern RUB area undergo urbanisation. In particular, urban development is known to result in elevated levels of sediments and metals in stormwater that can accumulate in depositional zones of receiving water bodies. A decline in water and sediment quality can result in ecological degradation and a reduction in levels of ecosystem services available to the community, reflected in the suitability of a water body for recreation. An assessment of the potential for such effects is therefore an important part of the consideration of the Southern RUB development options.

AC’s need for such an assessment arose concurrently with the need of NIWA and Cawthron Institute to take opportunities to test and refine the UPSW pilot DSS by its application in case studies. Recognising the potential benefits for all parties, AC, NIWA and Cawthron Institute therefore agreed to apply the system in a Southern RUB case study which would assess a number of urban development scenarios under consideration as part of the UP planning process. The objectives of each party are outlined below.

The case study was undertaken as an integral part of the testing and development of the UPSW pilot DSS and, accordingly, was largely resourced from RUF research programme funding. AC provided additional funding to report the results of the study (i.e. the writing of this report), including to cover researchers' time in running the system for three of the development scenarios not included in the original assessment.

1.2 Objectives

The objectives of the study were as follows.

For AC:

- To provide an assessment of the potential effects of a range of Southern RUB urban development scenarios on the sediment quality and benthic ecology of receiving estuarine water bodies relative to the effects arising with no additional urban development in the area[1].

For NIWA and Cawthron Institute:

- To apply the UPSW pilot DSS in an operational setting in order to test its capacity for providing guidance for 'real world' planning processes and to inform the further development of the system.

Reflecting the first of these objectives, the study focused on assessing changes to indicators of estuarine sediment quality and the health of estuarine benthic invertebrate communities. The pilot DSS makes its predictions of these environmental indicators based on models (or versions of models) that have been previously developed and applied outside of the UPSW research project. The development of these models has involved a significant level of scientific effort to characterise and understand the physical processes and ecology of Auckland's estuarine environments. As such, these indicators are both well-founded and well-suited for the purpose of informing the Southern RUB investigations.

The pilot DSS also predicts a set of social and economic indicators which assess the costs and benefits of stormwater treatment and associated effects on how communities relate to receiving water bodies. The development of the methods by which these indicators are predicted has been and continues to be a significant task for the UPSW project. While the development process has been subject to review through engagement with peer researchers and we consider the methods soundly based and able to play a highly informative role in the use of the DSS, we emphasise that these methods remain under development. Accordingly,

[1] The UPSW pilot DSS can make predictions of indicators for streams as well as estuaries (see Section 2.2). However, reflecting the need for timely information and the relative progress in developing the estuarine and stream components of the DSS, this case study focused solely on estuarine indicators. Further work is planned to apply the stream models in this, and other, case study areas.

we recommend that any use of the social and economic indicators for the purposes of informing the Southern RUB investigation proceeds with caution and only considers the relative values of these indicators.

1.3 Contents of this report

This report has been co-authored by members of the UPSW research team employed by NIWA, Cawthron Institute and AC's Research, Investigations and Monitoring Unit (RIMU). The respective roles of the co-authors have been:

- NIWA and Cawthron Institute – describing the background to, methods and results of the study, including providing commentary on matters of relevance for the further development of the UPSW DSS; and
- RIMU – discussing the results of the study and, in the context of other relevant information, making recommendations on matters that should be taken into consideration in the Southern RUB planning process.

Chapter 2.0 of this report provides an overview of the two projects which have supported this investigation of Southern RUB development scenarios. Firstly, it describes progress made under the UPSW research project, giving a summary of the design of the DSS along with a description of the steps involved in running the system. Secondly, Chapter 2.0 provides a summary of the Southeastern Manukau (SEM) Harbour study. The SEM study modelled the accumulation of sediment, copper and zinc in the harbour under a number of scenarios, all of which assumed that future urban development would be constrained to lie within the present-day RUB[2]. The results of that study provide the baseline for the assessment of the Southern RUB development scenarios.

Chapter 3.0 describes, firstly, the implementation of the UPSW pilot DSS for the Southern RUB case study, including how the study area was represented in the system and the information sources used to define baseline environmental characteristics. Secondly, it describes how inputs to the DSS were configured to represent each of the eleven Southern RUB urban development scenarios evaluated.

Chapter 4.0 describes the predictions of environmental indicators made by the pilot DSS. These indicators are:

- concentrations of copper and zinc in estuary bed-sediments;
- a benthic health score, based on sediment metal concentrations;
- the mud content of estuary bed-sediments;
- a second benthic health score, based on the mud content of estuary bed-sediments and
- the sediment accumulation rate.

[2] Or Metropolitan Urban Limit (MUL) as it was termed at the time.

Chapter 5.0 describes and discusses the predictions of socio-economic indicators made by the pilot DSS. These indicators are:

- five social indicators: extraction, contact recreation, partial contact recreation, non-contact recreation and sense of place; and
- two economic indicators: costs and benefits.

In recognition of the continuing research and development effort associated with the prediction of these indicators, this chapter also describes a number of caveats to be taken into consideration in relation to these results and discusses considerations for the further development of the methods by which the social and economic indicators are predicted.

Chapter 6.0 provides a discussion of the implications of the results of the study for planning and managing existing use and future development in the Southern RUB area while Chapter 7.0 provides a set of recommendations in this regard.

Chapter 8.0 provides a summary of the study, its key findings and recommendations. A series of Appendices describes the inputs to and outputs of the pilot DSS.

2.0 Background

2.1 Introduction

This chapter provides an overview of the two projects which have supported this investigation of the Southern RUB urban development scenarios. Firstly, it describes progress made under the Urban Planning that Sustains Waterbodies (UPSW) research project to develop a decision support system (DSS) for evaluating the effects of urban development on receiving waterbodies. A summary of the design of the DSS is given, along with a description of the steps involved in running the system.

Secondly, this chapter provides a summary of the Southeastern Manukau (SEM) Harbour study which predicted the accumulation of sediment, copper and zinc in the harbour over the period 2001 to 2100. The SEM study area included the catchments and receiving waterbodies which are the focus of the Southern RUB investigations. A description is given of the methods employed in the SEM study, the scenarios evaluated and key findings.

2.2 The UPSW research project

2.2.1 Overview

The Urban Planning that Sustains Waterbodies (UPSW) research project aims to help local government to plan the sustainable development of New Zealand's cities and settlements in a way which protects and enhances the values and services associated with urban waterbodies. It involves the development of a spatial decision-support system (DSS) that allows the impacts of urban development scenarios on attributes such as water and sediment quality; ecosystem health; and cultural, amenity and recreation values to be investigated and compared. The DSS incorporates a sustainability indexing system which integrates indicators of environmental, social, economic and cultural wellbeing and allows planners to consider these impacts holistically.

The project initially received three years of funding from the Ministry of Business, Innovation and Employment (MBIE), resulting in the development of a pilot version of the DSS. Since October 2012, the project has been part of the wider Resilient Urban Futures (RUF) research programme, also funded by MBIE. The following sections provide a summary of the design and use of the pilot DSS. A more detailed description is provided in Moores et al. (2012a) and a series of supporting documents cited in that report.

2.2.2 Design of the pilot DSS

There are three novel aspects to the design of the pilot DSS. Firstly, it incorporates indicators of environmental, economic and social wellbeing. An aim of its further development is to also incorporate indicators of cultural wellbeing. Secondly, it links a number of distinct methods in order to make predictions of outcomes under alternative urban development and stormwater management scenarios. These methods include: deterministic models; a probabilistic model; non-market valuation; look-up tables populated through expert elicitation techniques; and index construction. Thirdly, while a number of the methods have been appropriated from existing stand-alone applications, others have been developed specifically for incorporation in the pilot DSS. These include a model for estimating the costs of catchment-scale stormwater management, a stream ecosystem health model and a method for predicting social wellbeing indicators from precursor environmental attributes.

The pilot DSS operates as a single entity executed from an MS Excel platform, calling on each of several constituent methods in a logical sequence (Figure 2-1). The inputs to the system are the characteristics of 'urban development options' (UDOs), specified for each of several 'planning units' (PLUs) within a study area. The outputs from the system are summary indicators of environmental, economic and social wellbeing, provided for each 'reporting unit' within the study area. Typically, each planning unit corresponds to a stream catchment and contains a single stream reporting unit (SRU). The estuarine environment to which these streams discharge is divided up into a number of estuary reporting units (ERUs), each of which is representative of relatively homogeneous bed-sediment characteristics and sediment dynamics.

Alternative urban development options are represented in terms of their land use, land development controls, transport characteristics, stormwater management and riparian (stream bank) management characteristics. These attributes drive a suite of environmental models which predict changes in water and sediment quality and indicators of ecosystem health in rivers and estuaries, and are also used to estimate the costs of stormwater and stream management. The environmental models are:

- A modified version of the Catchment Contaminant Annual Loads Model (C-CALM), which makes predictions of the level of imperviousness and annual loads of sediments, copper, lead and zinc for each year of the study timeframe (Moores and Semadeni-Davies, 2011);
- A Bayesian Belief Network (BBN), which makes predictions of seven indicators of stream ecosystem health based on inputs relating to: riparian and stormwater management characteristics, level of imperviousness and contaminant loads predicted by C-CALM, and various stream characteristics established as part of implementing the system (Gadd and Storey, 2012);
- A modified version of the Urban Stormwater Contaminants (USC) model (see also Section 2.3.2), which makes annual predictions over the study timeframe of estuary bed-sediment concentrations of copper, lead and zinc, sediment accumulation rates and sediment grain size distribution based on inputs of the contaminant loads predicted by C-CALM and various estuary characteristics established as part of implementing the system; and

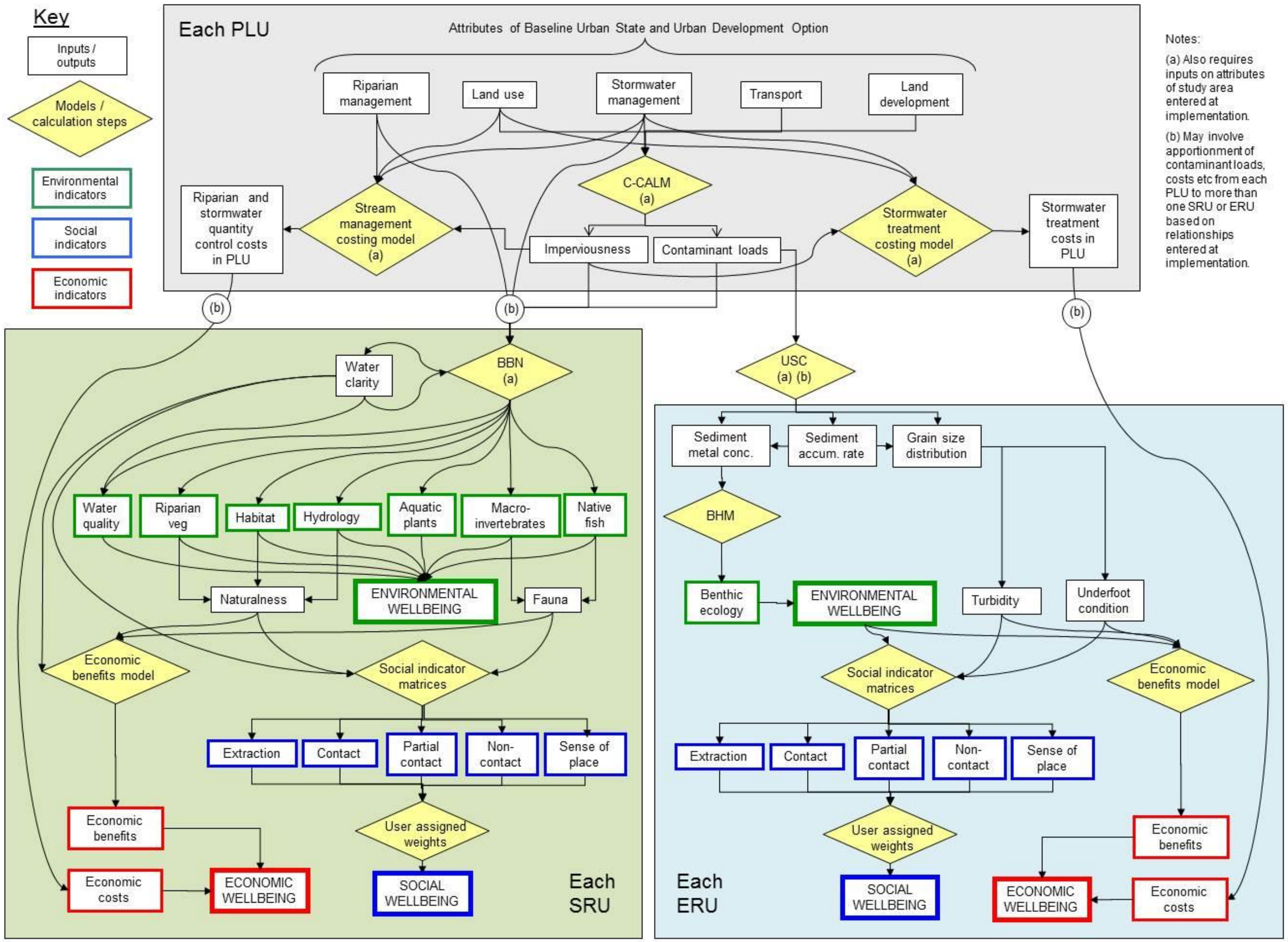

Figure 2-1 Structure of the pilot DSS

- The Benthic Health Model (BHM; Anderson et al., 2006), which is used here to predict a benthic health indicator score from inputs of the estuary bed-sediment concentrations of copper, lead and zinc predicted by the USC model[3].

The economic costing models are:

- A catchment-scale stormwater treatment costing model, which makes predictions of the life-cycle costs of stormwater treatment over the study timeframe based on inputs relating to the extent and desired level of performance of treatment, land use and the level of imperviousness (Ira et al., 2012); and
- A catchment-scale stream management costing model, which makes predictions of the life-cycle costs of riparian management and stormwater quantity control over the study timeframe based on inputs relating to the extent and quality of riparian planting and maintenance, land use and level of imperviousness.

Outputs from the environmental models are used to derive the scores for the economic benefit indicators. The economic benefits models were developed through a technique referred to as 'benefit transfer' in which the results of prior research described in Kerr and Sharp (2003) and Batstone et al. (2008) are applied to the pilot DSS. Benefit transfer takes information gained through primary data collection at study sites and applies it, with adjustment where necessary, to policy sites. A key requirement of the process is that there are consistencies in the biophysical characteristics between the policy and study sites, and the human populations at the respective sites. In this case both the study sites and populations were located in the Auckland region. Both prior studies were applications of choice experiments which derived estimates of household willingness to pay or accept compensation for changes in environmental conditions. There are two models:

- One for streams, which makes predictions of the monetised environmental benefits of an urban development scenario based on the change over the study timeframe in water clarity (as predicted by the BBN) and 'naturalness' and 'fauna' (based on combinations of indicators predicted by the BBN); and
- One for estuaries, which makes predictions of the monetised environmental benefits of an urban development scenario based on the change over the study timeframe in environmental wellbeing, turbidity, underfoot condition (the latter two being derived from sediment grain size distribution predicted by the USC model) and the number of households affected by changes to these attributes.

[3] An alternative method for scoring benthic health based on the mud content of estuary sediment has also been developed more recently (Hewitt et al. 2012). While this method is not currently incorporated in the pilot DSS, the predictions of mud content made by the system for this investigation of Southern RUB development scenarios are reported here with reference to the mud content classes adopted in the benthic health (mud) method (see Section 4.4).

Outputs from the environmental models are also used to derive scores of the social indicators, which are also predicted separately for streams and estuaries. These scores are generated by a set of social indicator matrices, which act as look-up tables for the prediction of four classes of relationship (extraction activities and contact, partial contact and non-contact recreation) and one non-use value (‘sense of place’). The look-up tables are populated with scores ascribed by workshop participants to combinations of the same environmental attributes used by the economic benefits models.

2.2.3 Running the pilot DSS

The first step in using the pilot DSS is to implement it for a given study area. This involves defining:

- the number and size of planning units and reporting units that make up the study area;
- the baseline year and the year for which indicators are to be reported;
- baseline land use, stormwater management and other characteristics of the catchment;
- baseline characteristics of streams in the study area, such as slope, length and substrate;
- baseline characteristics of estuaries in the study area, such as size, bed-sediment particle size distribution and bed-sediment metal concentrations; and
- relationships between planning units and reporting units, for instance specifying how the contaminant load generated in a particular planning unit is distributed among several receiving estuaries.

Once implemented, the system is ready for use. Before entering an urban development scenario, the user can choose to set indicator targets to provide a benchmark against which the results of any scenario can be compared. The user also has the option of assigning weights to social indicators. These weights are used in the calculation of the summary social wellbeing indicator from the scores of the five individual social indicators and provide an opportunity for more importance to be placed on some social indicators than others. For example, it might be the case that a particular estuary is seldom used for swimming but walking tracks along its margins are in frequent use. In that case, a higher weight could be assigned to 'non-contact recreation' than to 'contact recreation' in calculating the social wellbeing score. The weights for each indicator are assigned by the user of the pilot DSS using a method known as an ‘analytical hierarchy process’ (Saaty, 1987). The method involves comparing pairs of indicators at a time and making a judgement as to their relative importance. An overall weight for each indicator is calculated once all pairs have been compared.

- The user runs the system by entering an urban development option for each planning unit in the study area. This involves specifying the time to the start and end of the development phase;

- the development phasing;
- the proportion of the PLU in each land-use category;
- stormwater treatment characteristics;
- characteristics of earthworks controls associated with land development;
- the rate of change in vehicle numbers; and
- the characteristics of riparian management.

Table 2-1 Characteristics of Urban Development Options

	Characteristic	**Specified as:**
Development period characteristics	Time to start of development (T_s)	Time in years in the range 0 to (T_r - 1) where T_r is the reporting time set at implementation
	Time to end of development (T_d)	Time in years in the range (T_s + 1) to T_r
	Development phasing option	Continuous, phased or stepwise (rate of change in land use over the development period)
Land use	Land use sub-category	0-100% of PLU in each of the following sub-categories: Rural: pasture, exotic forest, native forest, horticulture , custom Residential: low density, medium density, high density, CBD, residential LID, custom Commercial: suburban, commercial CBD, commercial LID, custom Industrial: traditional industrial, industrial LID, custom Major roads: three categories based on traffic numbers, custom
	Roof runoff source control	Yes or no (where “yes” results in selection of low zinc-yielding roof types)
Methods of land development	Bulk earthworks target TSS removal	0, 25, 75 or 90% (removal of earthworks-generated sediment associated with greenfield land development)
	Other earthworks target TSS removal	0, 25, 75 or 90% (removal of earthworks-generated sediment associated with infill land development)
Transport characteristics	Target change in vehicles per day	% change over period of development
	Direction of change	Increase or decrease
Stormwater management	Target TSS removal	0, 25, 50, 75 or 90% (removal of total sediment)
	Effectiveness on other contaminants	Low, medium or high (removal of copper, lead and zinc)

	Characteristic	Specified as:
Stream management	Extent of managed riparian vegetation	0-100% of stream length
	Width	Wide or narrow
	Extent of unmanaged riparian vegetation	0-100% of stream length

Once the urban development options for all planning units in the study area have been entered, the pilot DSS runs by calling on the constituent models in sequence. While the pilot DSS reports numeric values (scores) of all indicators, it also assigns an indicator 'level,' in order to allow communication of predictions to technical and non-technical audiences, respectively. There are five levels, each of which corresponds with a quintile (20%) of the range of indicator scores. The system adopts a traffic light approach to representing the indicator levels, with the highest level coloured green and the lowest level coloured red (see Figure 2-2). The reporting of results also includes comparison of pre- and post-development indicator scores.

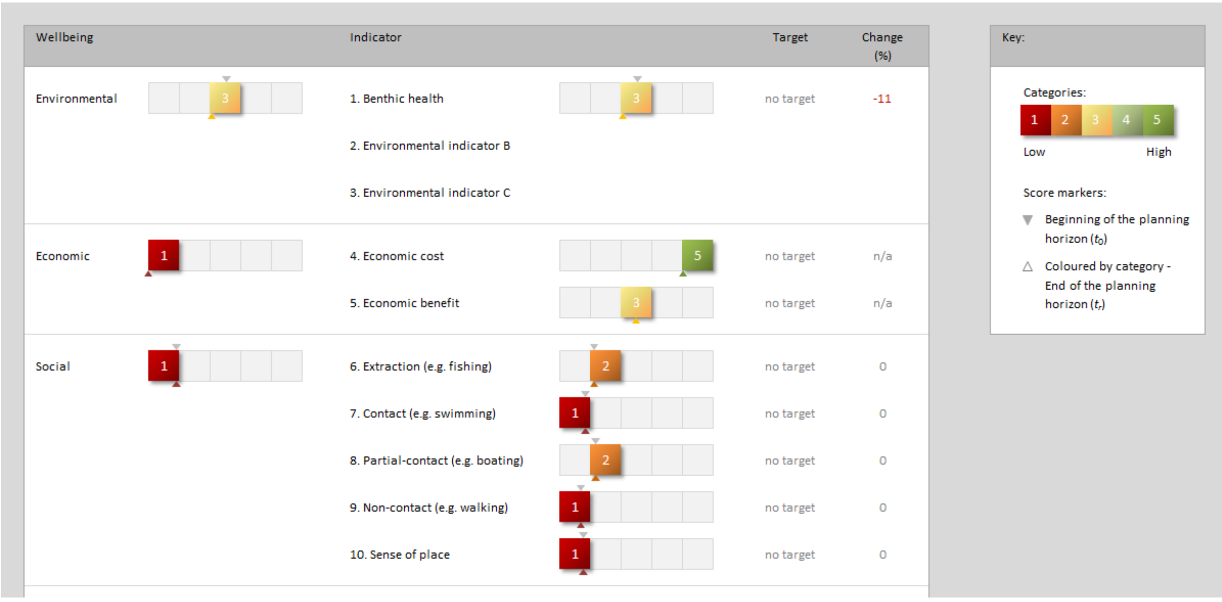

Figure 2-2 Example of predicted indicator levels for an estuary reporting unit

2.3 The Southeastern Manukau Harbour Contaminant Study

2.3.1 Overview

The focus of the Southeastern Manukau (SEM) Harbour Contaminant Study was the prediction of the accumulation of the contaminants sediment, copper and zinc in the SEM Harbour over the period 2001 to 2100. The study was commissioned by the former Auckland Regional Council (ARC) in recognition of the cross-TLA boundary distribution of contaminant sources discharging to the SEM Harbour and the hydrodynamically complex nature of the environment. The aims of the project were to:

- predict trends over the period 2001 to 2100 of sediment deposition and copper and zinc concentrations in harbour bed-sediments for probable future population growth and urban development consistent with the Auckland Regional Growth Strategy (ARGF, 1999), with existing stormwater treatment;
- predict trends in the accumulation of these contaminants with various combinations of industrial roof source control and stormwater treatment; and
- predict the year(s) when sediment-quality guidelines would be exceeded.

The study involved the application of a suite of linked models: a sediment generation model (GLEAMS), Auckland Council's stormwater Contaminant Load Model (CLM) and a harbour sediment/contaminant accumulation model (USC-3). The implementation of the USC-3 model was supported by other models simulating the dispersal of sediments by physical processes such as tidal currents and waves (a suite of DHI models). Model development was also supported by the collection of data describing physical and chemical properties of the harbour, its sediments and freshwater inputs and by the analysis of spatial information describing catchment characteristics such as land use, topography and soil type.

The methods employed and results of the study are described in full in a suite of ARC technical reports[4].

2.3.2 Methods

The cornerstone of the approach adopted was the use of the Urban Stormwater Contaminant-3 (USC-3) model (Green, 2008a, b and c). The USC-3 is a physically-based model that makes predictions of sedimentation and the accumulation of zinc and copper in the bed-sediments of estuaries on the "planning timescale", which is decades and greater.

There are three stages to the application of the USC-3 model: (1) implementation; (2) calibration; and (3) prediction. Model implementation consists of specifying the sediment grain sizes to be addressed in the model, defining subestuaries and subcatchments, specifying the weather time series used to drive the model, defining the way land-derived sediments and associated heavy metals are to be fed into the harbour at the subcatchment outlets, evaluating various terms that control sediment and associated heavy-metal transport and deposition inside the harbour, and defining the way heavy-metal concentration in the estuarine bed-sediment surface mixed layer is to be evaluated. Model implementation partly relies on field-derived input data and partly on the output of other models, in particular harbour sediment transport processes derived from the suite of DHI models.

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[4] http://www.aucklandcouncil.govt.nz/EN/planspoliciesprojects/reports/technicalpublications/Pages/technicalreports2008.aspx#south

Model calibration in the SEM study was achieved by running the model for the historical period 1940 to 2001, with inputs of the estimated sediment, copper and zinc loads hindcast by GLEAMS and CLM for that period. The aim of the calibration process was to adjust various terms in the USC-3 model so that its hindcasts of the historical period matched observations from that same period. Adjustments in these terms were made until realistic sediment dispersal patterns, sedimentation rates and metal accumulation rates were simultaneously obtained. Sedimentation and metal concentrations were compared with those derived from field data.

The model was then run in predictive mode in order to project the accumulation of sediment, copper and zinc over the period 2001 to 2100. Again, this relied on input data from other models, including:

- the delivery of flows and sediment to the harbour from the rural part of the catchment (GLEAMS); and
- loads of the stormwater contaminants sediment, copper and zinc associated with different urban development and stormwater management scenarios (CLM)[5].

The USC-3 model was used to predict future rates of contaminant accumulation in each of several harbour subestuaries given variations in subcatchment input loads reflecting alternative stormwater management scenarios. The predictions identify those parts of the harbour most at risk and those subcatchments where stormwater management interventions may be of greatest benefit.

Figure 2-3 and Figure 2-4 show the division of the SEM into subcatchments and subestuaries, respectively. The model tracks the transport of contaminants so that sinks can be linked to sources. By way of an example, the model predicted that the four main sources of sediment accumulating in Glassons Creek subestuary (GCK) were Drury Creek (106), Karaka (103), Papakura Stream (110) and Whangapouri Creek (104) subcatchments.

2.3.3 Stormwater management scenarios

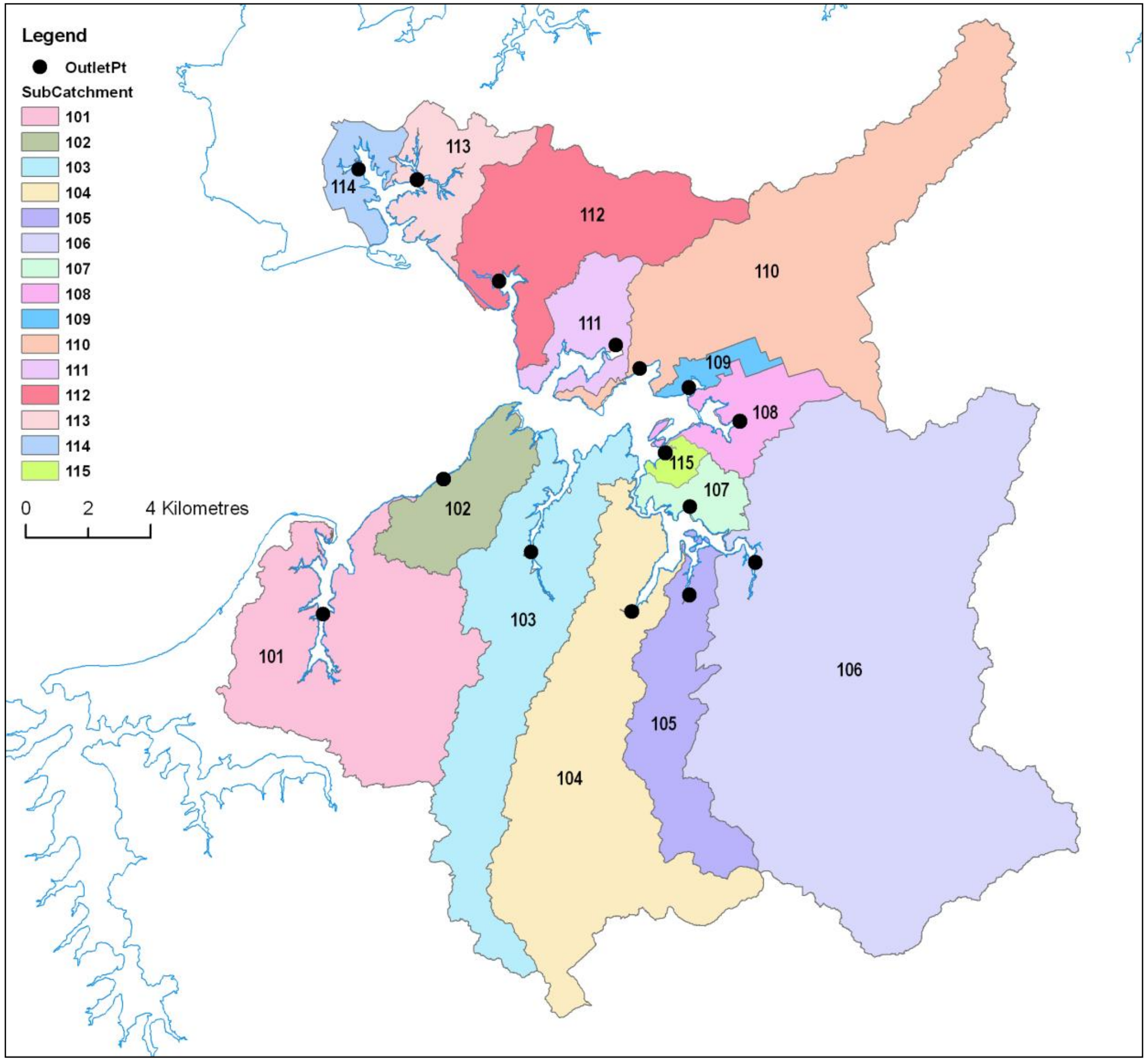
Four scenarios were modelled: a baseline scenario and three general stormwater management intervention scenarios. The baseline scenario (Scenario 1) assumed current projections (at the time of the study) of:

- future population growth,
- future land use changes,
- expected changes in building roof materials, and
- projected vehicle use.

It also assumed that stormwater treatment would remain at the existing levels. The three general stormwater management intervention scenarios evaluated were:

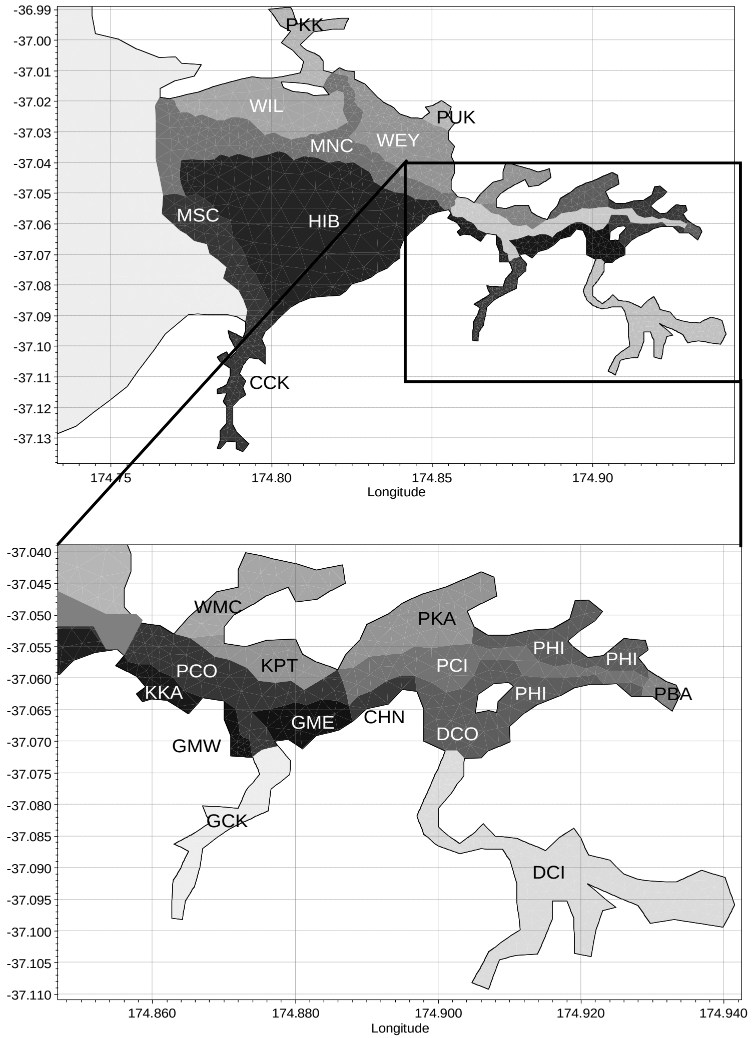
[5] Note that natural or ‘background’ loads of copper and zinc delivered in catchment sediments, as distinct from urban (anthropogenic sources), were also treated as an input to the USC model.

- Scenario 2 - source control of zinc from industrial areas by painting existing unpainted and poorly painted galvanised steel industrial building roofs;
- Scenario 3 - additional ‘realistic’ stormwater treatment, including:
    - rain gardens on roads carrying more than 20,000 vehicles per day and on paved industrial sites;
    - silt fences and hay bales for residential infill building sites; and
    - pond / wetland trains treating twenty per cent of the catchment area.
- Scenario 4 - combination of the two previous scenarios.



101 - KST	Kingseat
102 - EBH	Elletts Beach
103 - KKA	Karaka
104 - WHC	Whangapouri Creek
105 - OIC	Oira Creek
106 - DRY	Drury
107 - HGA	Hingaia
108 - PKA	Papakura
109 - TKI	Takanini
110 - PAS	Papakura Stream
111 - MAW	Manurewa / Weymouth
112 - PAU	Papatoetoe / Puhinui
113 - MEP	Mangere East / Papatoetoe
114 - MGE	Mangere
115 - BTB	Bottle Top Bay

Figure 2-3 Division of the Southeastern Manukau Harbour study area into subcatchments (source: Green, 2008a).



1 – HIB Hikihiki Bank
2 – KKA Karaka
3 – GMW Glassons Mouth West
4 – GME Glassons Mouth East
5 – CHN Cape Horn
6 – DCO Drury Creek Outer
7 – PHI Pahurehure Inner
8 – PBA Pahurehure Basin
9 – PKA Papakura
10 – KPT Kauri Point
11 – WMC Waimahia Creek
12 – WEY Weymouth
13 – WIL Wiroa Island
14 – PUK Puhinui Creek
15 – PKK Pukaki Creek
16 – DCI Drury Creek Inner
17 – GCK Glassons Creek Inner
18 – CCK Clarks Creek
19 – MHB Manukau Harbour
20 – PCI Pahurehure Channel Inner
21 – PCO Pahurehure Channel Inner
22 – MNC Manukau Channel North
23 – MSC Manukau Channel South

Figure 2-4 Division of the Southeastern Manukau Harbour study area into subestuaries (source: Green, 2008a).

The stormwater loads of sediment, copper and zinc under each scenario were estimated using Auckland Council's CLM. The version of the CLM used in the SEM study was developed specifically for the SEM and Central Waitemata Harbour (CWH) studies and differs from the standard version in its ability to predict time series of annual contaminant loads on the basis of projected trends in population growth, building roof materials and vehicle use. The development, functionality and application of this version of the CLM, including the projected trends and assumptions adopted in the SEM study, are described in Timperley and Reed (2008) and Moores and Timperley (2008).

2.3.4 Results

2.3.4.1 Scenario 1 (baseline)

Contaminant sources

The SEM study predicted that, for the future period 2001–2100 under Scenario 1, Drury subcatchment would be the principal source of sediment to the harbour, and Papakura Stream subcatchment would be the next largest source. Sediment runoff from subcatchments that lie to the south of Pahurehure Inlet was predicted to derive typically mainly from rural sources. With one exception, sediment runoff from subcatchments that lie to the north of Pahurehure Inlet was predicted to derive mainly from urban sources. The exception was Papakura Stream subcatchment. For most subcatchments there was no obvious trend – decrease or increase – in the amount of sediment runoff over the future period.

Papatoetoe / Puhinui subcatchment was predicted to be the largest source of zinc, followed by Papakura Stream subcatchment, which drains parts of Manurewa, Drury subcatchment, which contains part of the town of Papakura and the town of Drury, and Papakura subcatchment, which contains most of the town of Papakura. Zinc was predicted to derive mainly from urban sources, even in subcatchments where sediment was predicted to derive mainly from rural sources. Urban zinc loads were predicted to decrease rapidly in the first 10–15 years in the future period in most subcatchments, then level off, or slightly increase, after that time. The initial drop in zinc loads reflected projected trends in the replacement of high zinc-yielding roofing materials (Timperley and Reed, 2008).

Papatoetoe / Puhinui subcatchment was also predicted to be the largest source of copper. Like zinc, copper was also predicted to derive mainly from urban sources. However, in contrast to zinc, urban copper loads were predicted to increase in most subcatchments over the future period. This reflected the projected increase in the numbers of vehicles, with roads being the principal source of copper in the CLM (Timperley and Reed, 2008).

Sediment accumulation

The study predicted the annual-average sedimentation rate in each subestuary for the future period and compared this with annual-average sedimentation rate hindcast for the historical period (Table 2-2).

Table 2-2 Sedimentation rate. "Predicted" is the predicted average over the future period and over 50 model runs. "Hindcast" is the hindcast average over the historical period and over 50 model runs. (source: Green, 2008b)

Subestuary	Hindcast, mm/year	Predicted, mm/year	Predicted / hindcast
1 – HIB	0.02	0.03	1.07
2 – KKA	0.58	0.62	1.06
3 – GMW	5.14	5.57	1.08
4 – GME	1.70	1.82	1.07
5 – CHN	1.18	1.27	1.08
6 – DCO	3.03	3.30	1.09
7 – PHI	2.28	2.45	1.07
8 – PBA	4.86	4.34	0.89
9 – PKA	2.37	2.56	1.08
10 – KPT	0.14	0.15	1.08
11 – WMC	1.49	1.44	0.96
12 – WEY	0.04	0.04	1.15
13 – WIL	0.01	0.01	1.10
14 – PUK	2.86	3.61	1.26
15 – PKK	1.73	1.67	0.96
16 – DCI	1.52	1.66	1.09
17 – GCK	1.55	1.69	1.09
18 – CCK	1.07	1.17	1.08
19 – MHB	-	-	-

The predicted sedimentation rates for the future are not greatly different to the hindcast rates, which reflects the fact that sediment runoff for the future period was not predicted to be that much different to hindcast sediment runoff for the historical period. The greatest differences in sedimentation rate were predicted for Puhinui Creek tidal creek (14–PUK) and Pahurehure Basin (8–PBA), both of which were explained by changes in sediment runoff in the subcatchments from which these subestuaries derive most of their sediment load.

The most obvious spatial pattern evident in the predictions is the distinction between sedimentation outside Pahurehure Inlet (close to zero) and inside Pahurehure Inlet (non-zero). Other aspects of the model results also revealed differences between subestuaries within Pahurehure Inlet. Predictions of changes in bed-sediment level showed that more sediment tends to accumulate in the inner reaches of Pahurehure Inlet (subestuaries 6, 7, 8 and 9) than in the outer reaches of Pahurehure Inlet (subestuaries 2, 3, 4, 5, 10 and 11). Furthermore, the tidal creeks that drain to Pahurehure Inlet (16 and 17) accumulate sediment at very much the same rate (as each other).

Metal accumulation

The study predicted changes in metal (zinc and copper) concentrations in the surface mixed layer of the estuarine bed-sediments for the future period, together with the times at which sediment-quality guideline threshold values (Threshold Effects Level - TEL, Effects Range Low - ERL and Probable Effects Level – PEL) would be first exceeded (for further explanation of these guidelines see Section 6.4.1). Table 2-3 presents the dates at which sediment quality guideline concentrations were predicted to be exceeded, while Figure 2-5 and Figure 2-6 summarise the predictions.

Table 2-3 Times (years from 2001) at which zinc and copper sediment-quality guideline threshold values are predicted to be first exceeded in the future period under SEM Scenario 1. "–" denotes the threshold is not exceeded by the end of the future period. "TEL" denotes Threshold Effects level. "ERL" denotes Effects Range Low. "PEL" denotes Probable Effects Level (source: Green, 2008b).

	Zinc			Copper		
Subestuary	**TEL**	**ERL**	**PEL**	**TEL**	**ERL**	**PEL**
1-HIB	-	-	-	-	-	-
2-KKA	-	-	-	93	-	-
3-GMW	90	-	-	72	-	-
4-GME	80	-	-	76	-	-
5-CHN	94	-	-	85	-	-
6-DCO	72	-	-	67	-	-
7-PHI	37	68	-	51	-	-
8-PBA	18	62	-	53	-	-
9-PKA	25	51	-	37	-	-
10-KPT	-	-	-	-	-	-
11-WMC	27	51	-	34	93	-
12-WEY	-	-	-	-	-	-
13-WIL	-	-	-	-	-	-
14-PUK	35	57	-	42	-	-
15-PKK	79	-	-	83	-	-
16-DCI	90	-	-	66	-	-
17-GCK	-	-	-	-	-	-
18-CCK	-	-	-	-	-	-

The study predictions for risk of exceeding effects thresholds included that:

- There would be no threat within the forecasting period for subestuaries designated "TEL not exceeded". These subestuaries are the intertidal flats of Southeastern Manukau Harbour (Hikihiki Bank, Weymouth and Wiroa Island); Glassons Creek tidal creek and Clarks Creek tidal creek, which drain predominantly rural subcatchments; and Kauri Point, in an exposed location in the middle of Pahurehure Inlet.
- The threat would be low for subestuaries designated "TEL exceeded late in future period". These subestuaries are those clustered around the mouth of Glassons Creek on the southern side of the Inlet (Karaka, Glassons Mouth West, Glassons Mouth East, Cape Horn and Drury Creek Outer); Drury Creek Inner tidal creek, which drains the semi-rural Drury subcatchment; and Pukaki Creek tidal creek.
- The threat would be heightened in the remaining subestuaries, in which the zinc TEL was predicted to be exceeded early in the future period, and the zinc ERL was predicted to be exceeded in the middle of the future period. Exceedance of copper sediment-quality guideline thresholds was predicted to be somewhat delayed relative to zinc. These results indicated that management may be needed "now or soon" to safeguard ecological values in these areas. These subestuaries are Puhinui Creek tidal creek, subestuaries in the inner, sheltered reaches of Pahurehure Inlet (Pahurehure Inner and Pahurehure Basin), and the

sheltered embayments along the northern shoreline of Pahurehure Inlet (Papakura and Waimahia Creek), all of which drain major urban centres.

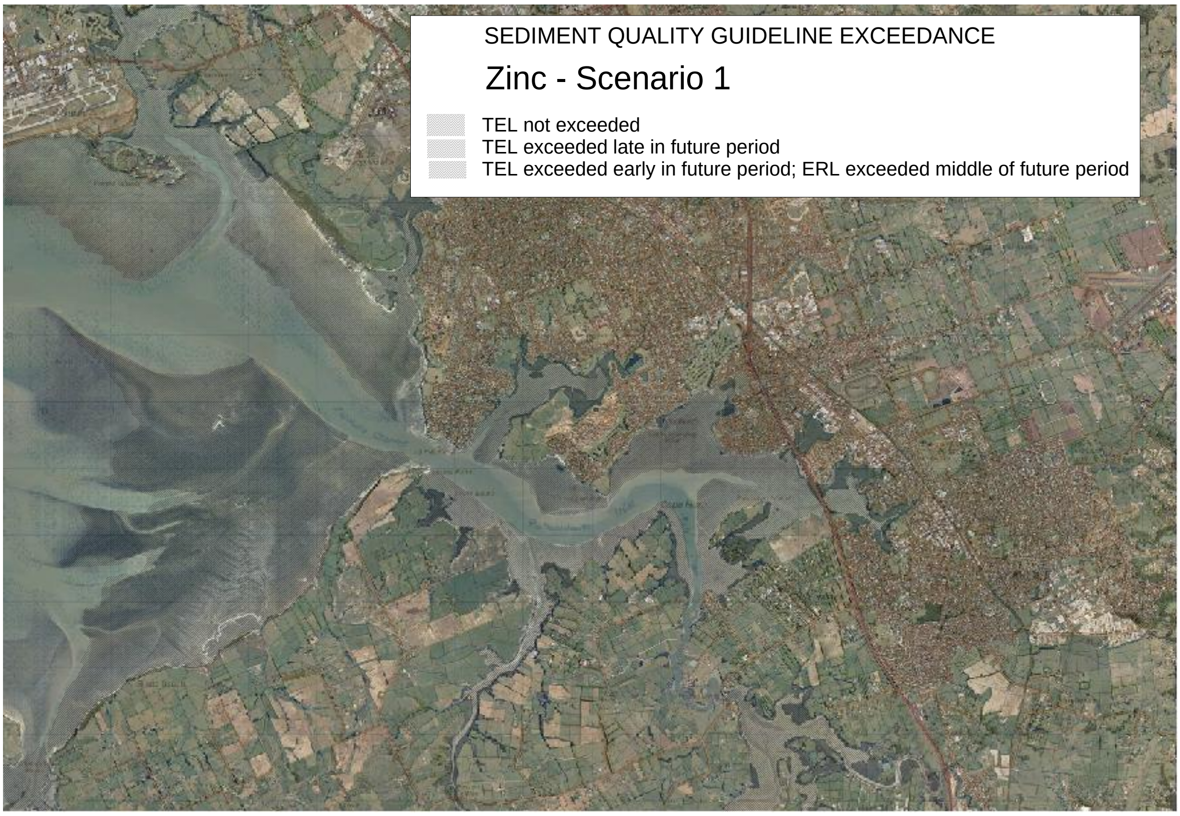


Figure 2-5 Summary of predictions for SEM Scenario 1, zinc (source: Green, 2008b).

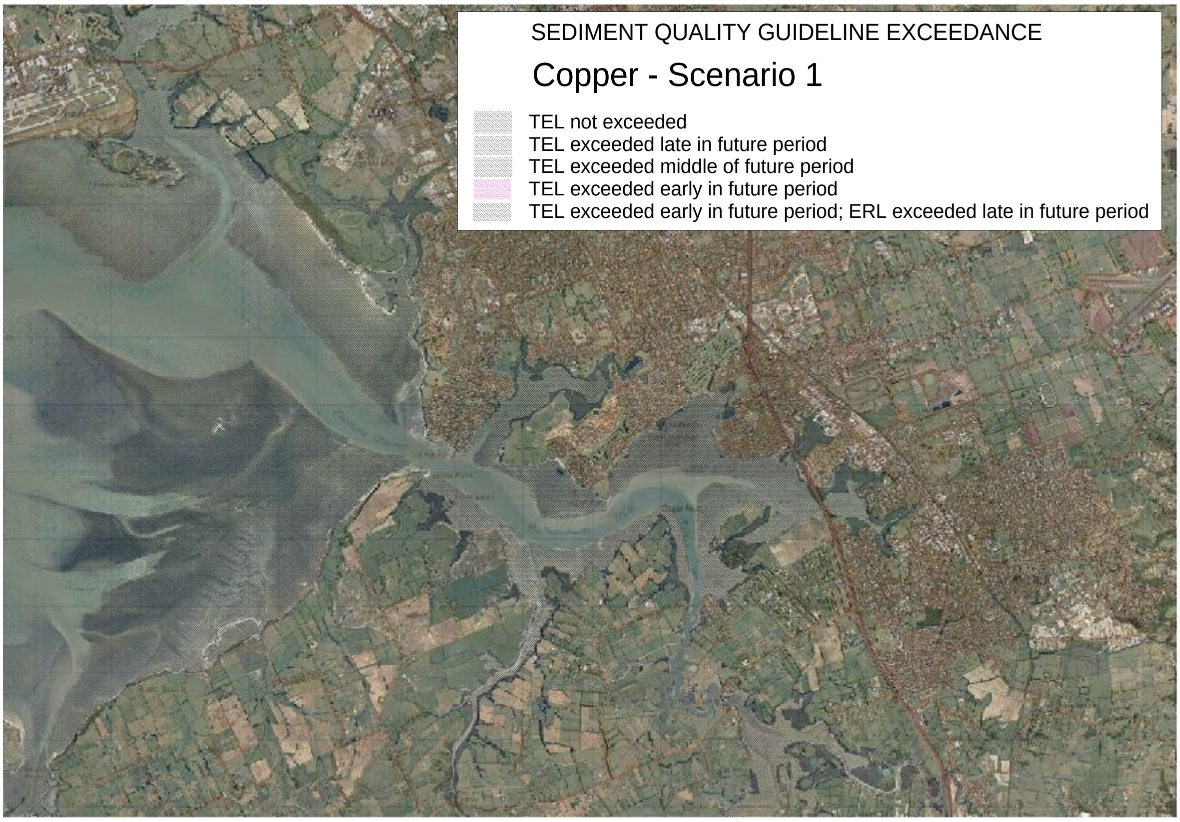


Figure 2-6 Summary of predictions for SEM Scenario 1, copper (source: Green, 2008b).

2.3.4.2 Scenarios 2, 3 and 4

The study predicted that the zinc source control in Scenarios 2 and 4 would have little effect on metal concentrations in the harbour bed-sediments. The study made the following predictions of how the additional realistic stormwater treatment depicted in Scenarios 3 and 4 would improve on the 'no additional stormwater treatment' depicted in Scenario 1. These predictions are summarised in Figure 2-7 and Figure 2-8 .

- There would be no gains to be achieved in subestuaries which either have a small sedimentation rate or that deposit sediment and metal mainly from rural subcatchments. This includes the intertidal flats of Southeastern Manukau Harbour (Hikihiki Bank, Weymouth and Wiroa Island), Glassons Creek tidal creek, Clarks Creek tidal creek, and Kauri Point. However, it was also predicted that there was no threat within the study forecasting period for these subestuaries (see above).
- The greatest gains would be achieved in subestuaries that deposit sediment and metal from mixed rural−urban subcatchments, where metal concentration in freshwater runoff would be most reduced by improved stormwater treatment. This includes the subestuaries that are clustered around the mouth of Glassons Creek on the southern side of the Inlet (Karaka, Glassons Mouth West, Glassons Mouth East, Cape Horn and Drury Creek Outer); Drury Creek Inner tidal creek, which drains the semi-rural Drury subcatchment; and Pukaki Creek tidal creek. However, the threat for these subestuaries was already predicted to be low (see above).
- Intermediate gains were predicted for the inner, sheltered reaches of Pahurehure Inlet (Pahurehure Inner and Pahurehure Basin) and for Puhinui Creek. The threat was predicted to be heightened in these subestuaries (see above).
- The smallest gains were predicted for Papakura and Waimahia Creek, where the threat was also predicted to be heightened. The reason is that these subestuaries deposit sediment and metal that derives mainly from highly urbanised subcatchments, for which improved stormwater treatment increases the metal concentration in the freshwater runoff.

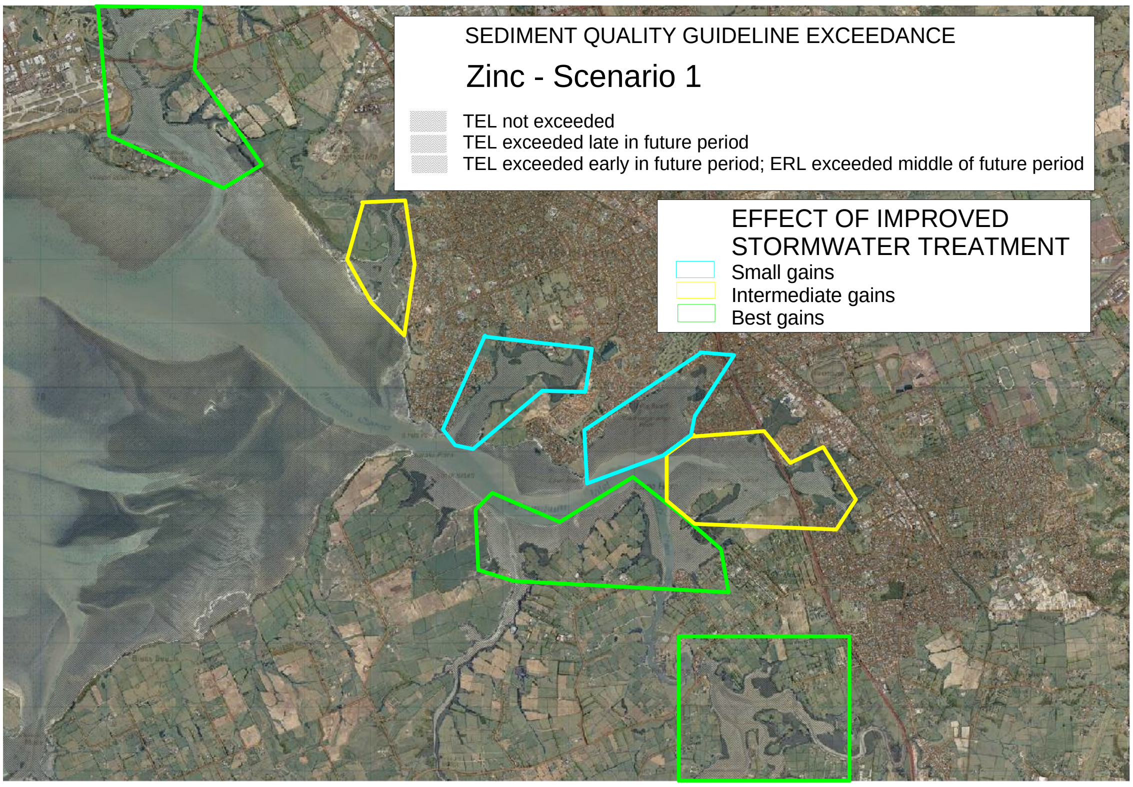


Figure 2-7 Summary of how the additional realistic stormwater treatment depicted in SEM Scenarios 3 and 4 is predicted to improve on the no additional stormwater treatment depicted in Scenario 1, zinc (source: Green, 2008c).

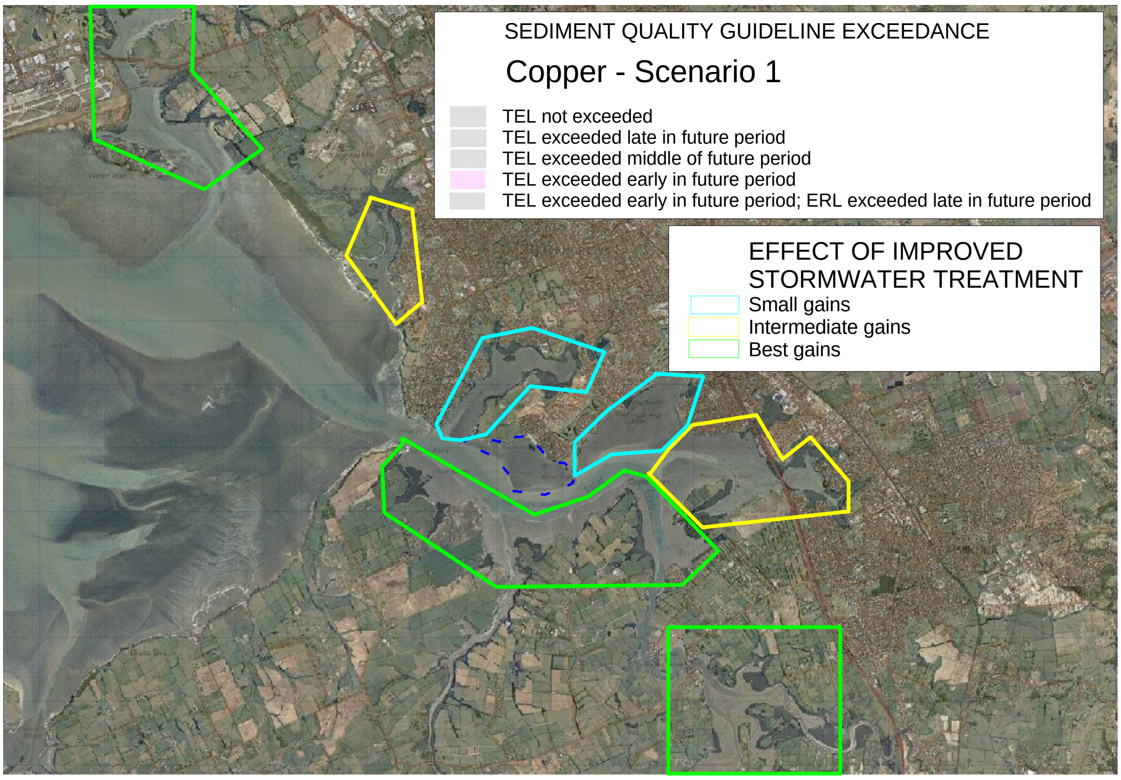


Figure 2-8 Summary of how the additional realistic stormwater treatment depicted in SEM Scenarios 3 and 4 is predicted to improve on the no additional stormwater treatment depicted in Scenario 1, copper (source: Green, 2008c).

3.0 Methods

3.1 Introduction

This chapter describes, firstly, the implementation of the UPSW pilot DSS for the Southern RUB case study, including how the study area was represented in the system and the information sources used to define baseline environmental characteristics. Secondly, this chapter describes the urban development scenarios evaluated. It includes a summary of how predictions made in the SEM study were replicated in order to establish a baseline for evaluation of the Southern RUB scenarios. It also describes how inputs to the system were configured to represent each of the Southern RUB development scenarios under investigation.

3.2 Implementation of the pilot DSS

3.2.1 Overview

As noted in Section 1.2, the principal objective of this exercise was to use the pilot DSS to make predictions that could be compared with those of the SEM study. Accordingly, the implementation of the pilot DSS was undertaken in such a way that the system could be used to closely match the baseline predictions of the SEM study and make predictions under a set of new scenarios that could easily be compared with those for the SEM baseline.

The implementation therefore involved referring to information from the SEM study area in order to:

- define the boundaries of PLUs in a way that allowed incorporation of subcatchment input data used in the SEM study;
- define the boundaries of ERUs in a way that allowed comparison of predictions from the pilot DSS with those for the subestuaries defined in the SEM study;
- specify the proportion of the contaminant load generated in each PLU to be delivered to each ERU; and
- specify baseline environmental characteristics in ERUs, including present-day sediment metal concentrations and percentage mud in bed-sediments.

As with the SEM study, the focus of the exercise was the effects of urban development on the harbour and, to date, no attempt has been made to make predictions of indicators relating to streams in the study area. Accordingly, it was not necessary to define SRUs.

The system was implemented for the fifty-year period commencing in 2012, in order to cover the time period within which the proposed Southern RUB development options would be completed (2022-2041, see Section 3.4) and allowing for an assessment of effects on estuarine environmental indicators during the post-development phase.

Each of the key steps involved in implementing the pilot DSS is described further below.

3.2.2 Definition of PLUs and ERUs

The SEM study area comprised 15 subcatchments and 23 subestuaries (see Section 2.3.2). For the present exercise, attention was focused on those parts of the SEM study area which would be likely to be most affected by the Southern RUB scenarios under consideration. Information available from the SEM study was used to establish which subestuaries received the majority of their contaminant runoff from the subcatchments within which the Southern RUB scenarios are located. Based on that assessment, the study area for this exercise was defined as including six of the SEM subcatchments and seven of the SEM subestuaries. In the SEM study it was predicted that these seven subestuaries receive 82-96% of their long-term average sediment loads from these six subcatchments (Green, 2008a). The contaminant delivery relationships between subcatchments and subestuaries are further described below (Section 3.2.3).

Four of the six SEM subcatchments were each divided into an upper and lower catchment, with boundaries defined on the basis of the Southern RUB scenarios. The resulting divisions gave nine PLUs for the specification of input data to the pilot DSS (Figure 3-1). In addition, sediment and metal loads estimated by the SEM study for the Papakura Stream were read in to the pilot DSS, because this subcatchment generates a significant part of the total load delivered to the subestuaries included in the present study[6].

Seven ERUs were defined as part of implementation (Figure 3-2). These match the seven SEM study subestuaries which receive the main part of their contaminant runoff from the Southern RUB PLUs.

3.2.3 Relationships between PLUs and ERUs

An important part of implementing the pilot DSS was defining how much of the contaminant load generated in a given PLU ends up in a given ERU. There were two aspects to specifying these relationships.

Firstly, it was necessary to specify the proportion of the contaminant load generated in each PLU which is delivered to the harbour. It was assumed that, as a result of in-stream deposition, some storage of contaminants occurs between catchment sources and the harbour. Estimates of the proportion of sediments delivered to the harbour made as part of the SEM study were for used this purpose (see Table 3-1). Secondly, it was necessary to apportion the contaminant loads delivered to the harbour from each PLU among the seven receiving ERUs. Again, estimates derived from modelling undertaken as part of the SEM study provided a basis for specifying these relationships (see Table 3-2).

[6] In this implementation Papakura Stream catchment differs from the nine PLUs in that it is located outside the area affected by the Southern RUB scenarios. Future development, and consequently contaminant loads were assumed to be unchanged from the baseline SEM scenario.

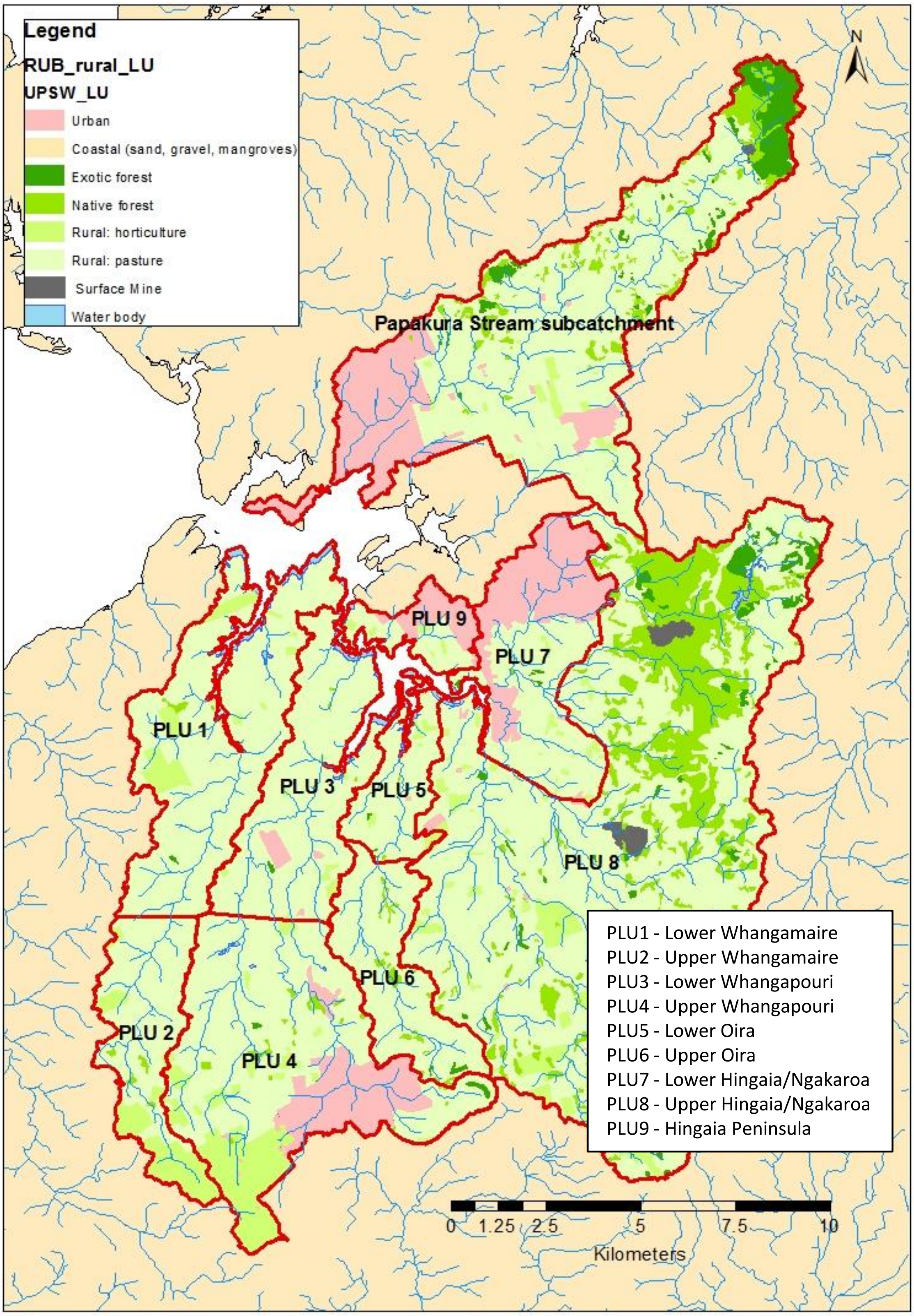


Figure 3-1 Definition of PLUs, Southern RUB study area. Although not defined as a PLU, contaminant loads from the Papakura Stream subcatchment estimated previously in the SEM study were also used in the present exercise.

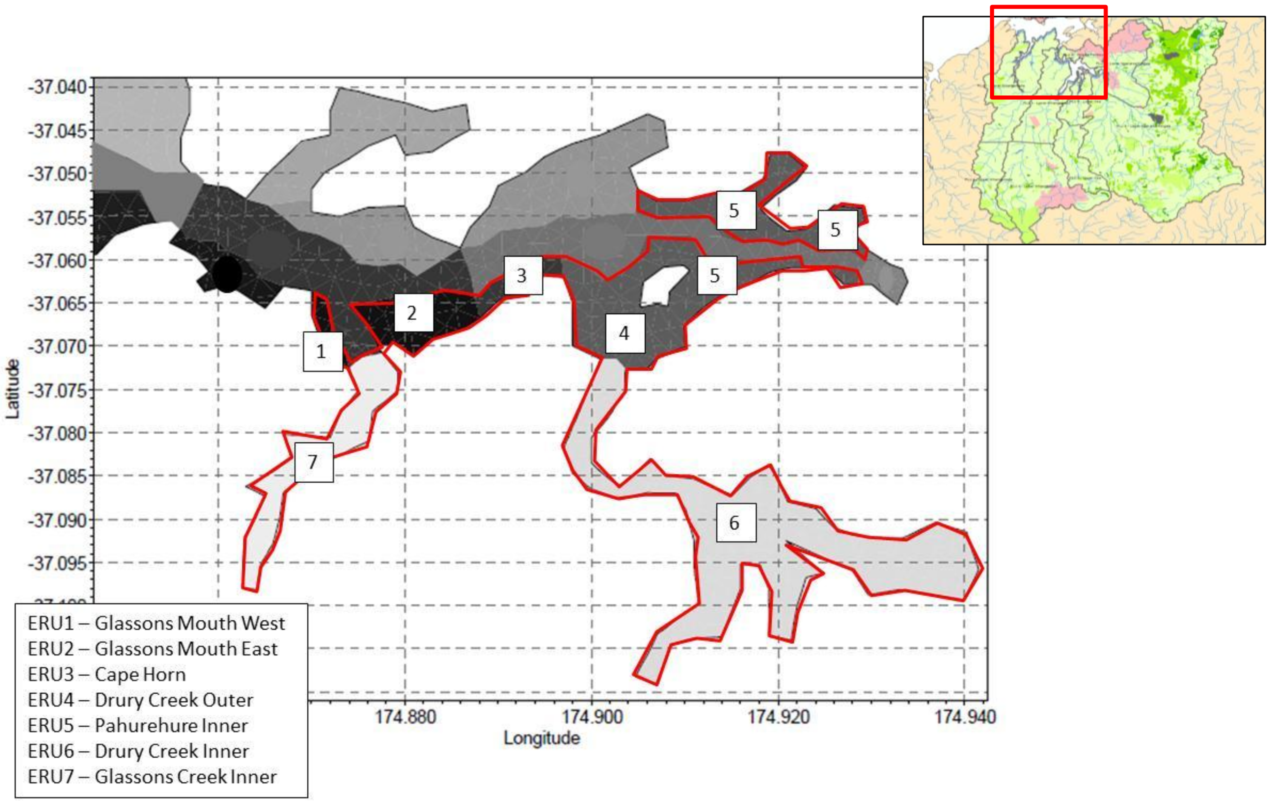


Figure 3-2 Definition of ERUs, Southern RUB study area. The Southern RUB ERUs are outlined in red while the remaining areas are subestuaries of the SEM study which were excluded from the present exercise.

Table 3-1 Estimated sediment delivery ratios (proportion of sediment discharged to streams which is delivered to the stream outlet) by PLU (source: Parshotam, 2008)

PLU	Sediment delivery ratio (%)
PLU1 - Lower Whangamaire	39.8
PLU2 - Upper Whangamaire	39.8
PLU3 - Lower Whangapouri	13.1
PLU4 - Upper Whangapouri	13.1
PLU5 - Lower Oira	15.2
PLU6 - Upper Oira	15.2
PLU7 - Lower Hingaia/Ngakaroa	9.2
PLU8 - Upper Hingaia/Ngakaroa	9.2
PLU9 - Hingaia Peninsula	60.2

Table 3-2 Proportion of sediment load delivered from each PLU to each ERU (source: Green, 2008a)

ERU	1	2	3	4	5	6	7	TOTAL	Other SEM[1]
PLU									
1	15%	9%	3%	6%	9%	8%	19%	69%	31%
2	15%	9%	3%	6%	9%	8%	19%	69%	31%
3	3%	3%	1%	15%	16%	26%	5%	69%	31%
4	3%	3%	1%	15%	16%	26%	5%	69%	31%
5	3%	3%	1%	15%	16%	25%	5%	68%	32%
6	3%	3%	1%	15%	16%	25%	5%	68%	32%
7	3%	3%	1%	15%	16%	25%	5%	68%	32%
8	3%	3%	1%	15%	16%	25%	5%	68%	32%
9	3%	3%	1%	22%	19%	21%	5%	74%	26%
Papakura Stream	1%	2%	1%	6%	13%	17%	3%	43%	57%

[1] Portion of the load generated in the Southern RUB PLUs which is predicted to be delivered to parts of the SEM Harbour outside of the Southern RUB study area.

3.2.4 Baseline environmental characteristics

The final step in implementing the system was the definition of certain baseline (present day) environmental characteristics for each ERU. With one exception, data for this part of the implementation were also taken from the SEM study (

Table 3-3).

Table 3-3 Implementation data on baseline environmental characteristics of each ERU (source: Green, 2008a, except where indicated otherwise)

ERU	1	2	3	4	5	6	7
Area (ha)	16.8	63.5	25.4	103.8	177.8	375.9	98.2
Depth of mixing layer (m)	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Proportion of bed-sediments < 63 µm (%)	0.79	0.79	0.33	0.2	0.6	0.23	0.87
Zn bed-sediment concentration (mg/kg)	77	77	76	74	91	83	98
Cu bed-sediment concentration (mg/kg)	10	10	9	9	10	11	12
Pb bed-sediment concentration[1] (mg/kg)	14	14	14	13	17	15	18

[1] not measured in SEM study, estimated from Auckland Council long term sediment chemistry monitoring data.

3.3 Baseline scenario (SEM scenario 1)

Once implemented, the pilot DSS was run to replicate the predictions of the SEM study in order to establish a baseline from which predictions for the new Southern RUB scenarios could be evaluated. This involved entering input data to the system which corresponded with inputs entered for SEM Scenario 1. However, because the contaminant load models used by the pilot DSS and in the SEM study differ, some modifications were required in order to make the data from the SEM study ready for input to the run the pilot DSS. In the SEM study, rural sediment loads were estimated using the GLEAMS model while urban sediment and metal loads were estimated using a version of AC's CLM (see Section 2.3.2). In contrast, in the pilot DSS sediment and metal loads for the whole study area are estimated using a version of C-CALM (see Section 2.2.2). It was therefore necessary to take input data on, for instance, areas in each PLU under a given GLEAMS or CLM land use class and assign that to the closest C-CALM land use class.

As well as trying to match the inputs at the start of the study timeframe, it was also necessary to represent future trends in contaminant sources that were adopted in the SEM study. A key assumption in the SEM study was that there would be replacement of high-yielding zinc roofing materials from 2001 onwards and that this would be well advanced by 2012. Since the baseline year for the Southern RUB study is 2012, the assumption was adopted that low-zinc yielding roofing materials were in place when attempting to replicate the predictions of the SEM study. Running the system without this assumption led to the marked over-prediction of zinc loads from urban PLUs.

The SEM study also adopted trends in the growth of motorway traffic based on projections for Auckland City. An increase in vehicle kilometres travelled (VKT) of approximately 100% was projected between about 2010 and 2060 (Timperley and Reed, 2008). This was adopted as the increase in vehicle numbers for the 50-year timeframe of the Southern RUB study. Appendix A lists input data to the pilot DSS under SEM Scenario 1.

It should be noted that the predictions made by the pilot DSS for SEM Scenario 1 do not exactly match those of the original study. These differences reflect the fact that the two studies have used different models with different input data. An example of the way in which results differ is in the predicted date at which sediment quality guidelines will be exceeded (discussed in Section 4.2). The predictions of the pilot DSS range from being a few years earlier to a few years later than those made in the SEM study, depending on location. However, in the context of a multi-decadal timeframe and with particular interest in the relative differences between scenarios, the predictions made by the pilot DSS were considered close enough to the originals to provide a baseline from which to evaluate the predictions for the Southern RUB scenarios.

3.4 Southern RUB scenarios

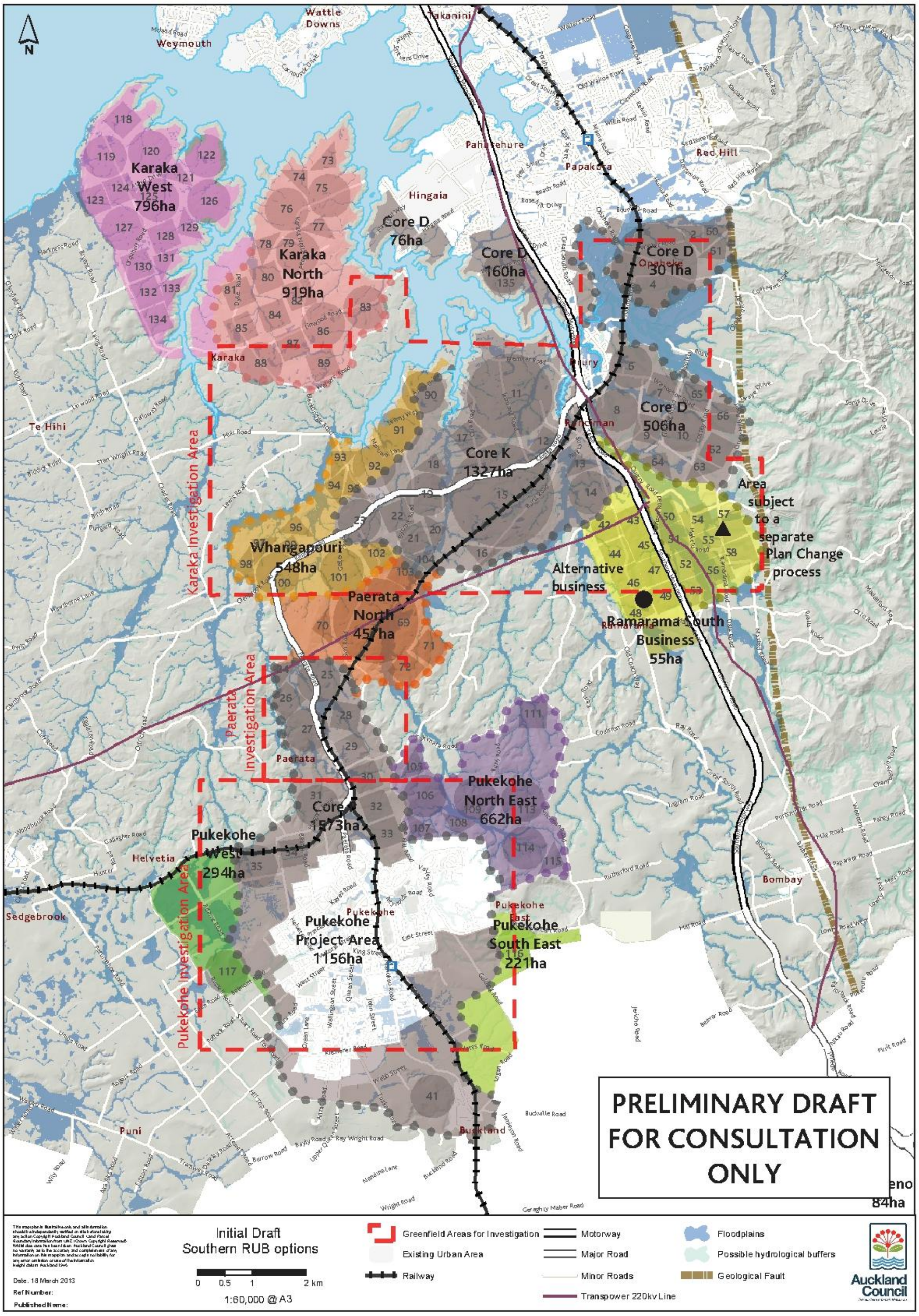


Figure 3-3 Indicative location and extent of Southern RUB scenarios as at March 2013. The Drury South plan change area is shown in yellow and labelled “Area subject to separate Plan Change process”. An “alternative business” area is also shown in yellow and located immediately to the west of the Drury South area.

Figure 3-3 shows the indicative location and extent of a number of scenarios developed by AC for consideration as part of the Southern RUB investigations as at March 2013. This map also includes the Drury South plan change area which is a proposed business development subject to a separate plan change application. This development (or an adjacent alternative business area, also shown on the map) may proceed irrespective of the outcome of the Southern RUB process. The Drury South development was therefore included in all of the Southern RUB scenarios described below.

The following scenarios were run (for completeness, the baseline SEM study scenario described above is included in this list):

- Scenario 1 – SEM study: this corresponds with SEM 'baseline' scenario (also called "scenario 1" in the SEM study), and involves:
    - land use change restricted to limited further urban development within the existing Metropolitan Urban Limit (MUL); and
    - stormwater treatment restricted to the level that existed in 2001.

- Scenario 2A – Core: this involves:
    - land use change within the MUL as per Scenario 1 along with additional urban development in the core areas of Core D, Core K, Core P and the Drury South separate plan change area; and
    - stormwater treatment consistent with current AC guidelines (75% removal of TSS, with 'medium' metals removal[7]).

- Scenario 2B – Core (best case stormwater treatment): this involves:
    - land use change as per Scenario 2A; and
    - stormwater treatment of 90% TSS removal and 'high' metals removal.

- Scenario 2C – Core (business as usual stormwater treatment): this involves:
    - land use change as per Scenario 2A; and
    - stormwater treatment of 50% TSS removal and 'low' metals removal.

- Scenario 2D – Core (worst case stormwater treatment): this involves:
    - land use change as per Scenario 2A; and
    - stormwater treatment of 25% TSS removal and no metals removal.

- Scenario 2E – Core (best earthworks controls): this involves:
    - land use change as per Scenario 2A;
    - stormwater treatment as per scenario 2A; and

[7] The level of metals removal (none, low, medium, high) corresponds with separately specified percentage removal rates for dissolved, fine particulate and coarse particulate copper, lead and zinc, respectively.

    - removal of 90% of earthworks-generated sediment[8].

- Scenario 3 – Core + Pukekohe North East: this involves:
    - land use change as per Scenario 2A plus development of the Pukekohe North East area; and
    - stormwater treatment as per Scenario 2A.

- Scenario 4 – Core + Karaka North: this involves:
    - land use change as per Scenario 2A plus development of the Karaka North area; and
    - stormwater treatment as per Scenario 2A.

- Scenario 5 – Core with Pukekohe Focus: this involves:
    - land use change as per Scenario 3 plus development of the Pukekohe West and Pukekohe South East areas; and
    - stormwater treatment as per scenario 2A.

- Scenario 6 – Core with Corridor Focus: this involves:
    - land use change as per Scenario 3 plus development of the Whangapouri, Paerata North and Pukekohe South East areas; and
    - stormwater treatment as per scenario 2A.

- Scenario 7 – Core with West-East Focus: this involves:
    - land use change as per Scenario 4 plus development of part of the Karaka West area (see below); and
    - stormwater treatment as per scenario 2A.

In summary:

- the variants of Scenario 2 involve the development of the Core area only;
- Scenarios 3, 5 and 6 involve the development of areas in the centre-south of the study area in addition to the Core; and
- Scenarios 4 and 7 involve the development of areas in the north of the study area in addition to the Core.

Table 3-4 gives the projected areas to be developed and dwelling numbers under each of the scenarios. Note that Auckland Council revised the extent of certain of the development areas during the period over which this case study was conducted. While the most recent data (provided

[8] Observations indicate that this is achievable with well-managed chemically treated sediment ponds (Moores and Pattinson, 2008). Note all other scenarios adopt the current AC guideline of 75% sediment removal.

in March 2013) were used for the later scenarios assessed, this was not the case for the earlier scenarios. The versions of the data used were:

- For scenarios 2, 3 and 4; data dated 5 November 2012.
- For scenarios 5, 6 and 7, data dated 5 November 2012 for all areas common with scenarios 2, 3 and 4; and data dated 19 March 2013 for all additional areas.

However, as Table 3-4 shows, the differences between the development areas used in this assessment and those currently proposed by the Council are negligible (0.3%) at the scale of the study area. This slight difference in areas is unlikely to make a material difference to the predictions described in this report.

Table 3-4 Projected development areas and dwelling numbers by scenario. Figures in brackets indicate the area of development as a proportion of the total study area.

Scenario	**Area of development (ha)**		**New dwellings (as per 19 March 2013)**
	Used in this assessment	Most recent (19 March 2013)	
2	4020 (15.1%)	3943 (14.8%)	40822
3	4683 (17.6%)	4605 (17.3%)	47086
4	4938 (18.6%)	4862 (18.3%)	48386
5	5198 (19.6%)	5120 (19.6%)	51172
6	5909 (22.3%)	5831 (22.0%)	59561
7	5734 (21.6%)	5658 (21.3%)	57365

In all scenarios development was assumed to commence in 2022 and be completed in 2041. The phasing of development over this period was assumed to be continuous and occur at a constant rate.

Land use input data to the pilot DSS for each of the scenarios were defined as follows. Appendix A lists the input data under each of the Southern RUB scenarios.

- Residential land use: AC provided data on the indicative extent (area in hectares) and intensity of residential land use in each of the scenario areas. While housing densities vary between areas, they were readily grouped into high (61-104 dwellings per ha); medium (20-

28 dwellings per ha); and low (4-15 dwellings per ha) densities, which correspond with residential land use classes for which the pilot DSS is configured.

- Industrial land use: The data provided by AC also included the extent of business land. This was assumed to correspond with the industrial land use class in the pilot DSS.
- Commercial land use: The data provided by AC distribute development in each scenario among sub-areas which can include any of the following: ‘major centre’, ‘town centre’, ‘local centre, ‘business’ or ‘rest of area’. The ‘centres’ are further divided into ‘core’ and ‘outer’ zones. The total area of a ‘core’ zone is generally greater than the sum of the different density residential land use classes specified for that zone. The balance was therefore assumed to be commercial land, representing shopping and service areas required to support the various centres comprising each scenario area.
- Rural land use: The increase in urban land use in any of the scenarios was assumed to occur at the expense of pastoral land, with horticultural land and forests remaining unchanged.

In Scenario 7 (Core with West-East Focus), approximately half (around 400 ha) of the Karaka West development area lies outside of the study area. Therefore, the potential effects of this part of the development under Scenario 7 were not modelled by the pilot DSS. Instead, these potential effects were assessed with reference to relevant predictions made in the SEM study (see Section 4.7).

4.0 Results - Environmental Indicators

4.1 Introduction

This chapter describes and discusses the predictions of environmental indicators made by the pilot DSS. These indicators are, for each ERU under each scenario:

- concentrations of copper and zinc in the surface mixed layer of estuary bed-sediments[9];
- a benthic health score, based on sediment metal concentrations (BHMmetals);
- the mud[10] content of estuary bed-sediments;
- a second benthic health score, based on the mud content of estuary bed-sediments (BHMmud), and,
- the sediment accumulation rate.

The pilot DSS makes its predictions of these environmental indicators based on models (or versions of models) that have been previously developed and applied outside of the UPSW research project (see Section 2.2.2). The development of these models has involved a significant level of scientific effort to characterise and understand the physical processes and ecology of Auckland's estuarine environments. As such, these indicators are both well-founded and well-suited for the purpose of informing the Southern RUB investigations.

As noted in Section 3.4, the pilot DSS was not used to make predictions for part of the Karaka West development area. A separate assessment of the potential effects of that development is provided, based on relevant predictions made in the SEM study (see Section 4.7).

Note that the results presented here for Scenario 1 (SEM study baseline) are those produced by running the pilot DSS to match as closely as possible those reported in the original SEM study. They are <u>not</u> the results reported in the original study itself, unless stated otherwise.

4.2 Sediment metal concentrations

4.2.1 Scenario 2A - core

Table 4-1 compares the results of Scenario 2A with the baseline scenario in terms of the date at which the 'Threshold Effects Level (TEL)' metal concentrations are predicted to be exceeded (if at all). As noted in Section 2.3 (and described in further detail in Section 6.4.1), The TEL provides a benchmark above which metal concentrations have the potential to result in adverse ecological effects. Under the Core (2A) scenario:

- In three ERUs (2, 3 and 7) copper and zinc concentrations are predicted to remain below the TEL, as per the SEM study;

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[9] The pilot DSS also predicts sediment concentrations of lead, but there is no baseline against which to compare these since they were not modelled in the SEM study.

[10] The mud content is defined as the proportion of the estuary bed-sediments in the clay and silt Wentworth particle size classes (<63 µm diameter).

- In two ERUs (4 and 5) copper and zinc concentrations are predicted to cross the TEL at a similar time to the SEM study;
- In two ERUs (1 and 6) zinc concentrations are predicted to exceed the TEL in the late 2050s (compared to the 2080s / 2090s in the original SEM study) but copper concentrations are predicted to remain below the TEL as per the SEM study.

Figure 4-1, Figure 4-2 and Figure 4-3 show examples of the change in copper and zinc concentrations over time for each of these three groupings of ERUs. Similar plots for all ERUs are contained in Appendix B.1.

Table 4-1 Predictions of whether or not zinc and copper TELs will be exceeded by 2062 and, if so, in which year, Scenarios 1 and 2A.

	Zinc		Copper	
	Scenario 1 (SEM)	Scenario 2A (Core)	Scenario 1 (SEM)	Scenario 2A (Core)
ERU1	< TEL	> TEL, 2057	> TEL, 2038	> TEL, 2042
ERU2	< TEL	< TEL	< TEL	< TEL
ERU3	< TEL	< TEL	< TEL	< TEL
ERU4	> TEL, 2053	> TEL, 2049	> TEL, 2037	> TEL, 2039
ERU5	> TEL, 2049	> TEL, 2047	> TEL, 2041	> TEL, 2043
ERU6	< TEL	> TEL, 2059	> TEL, 2048	> TEL, 2048
ERU7	< TEL	< TEL	< TEL	< TEL

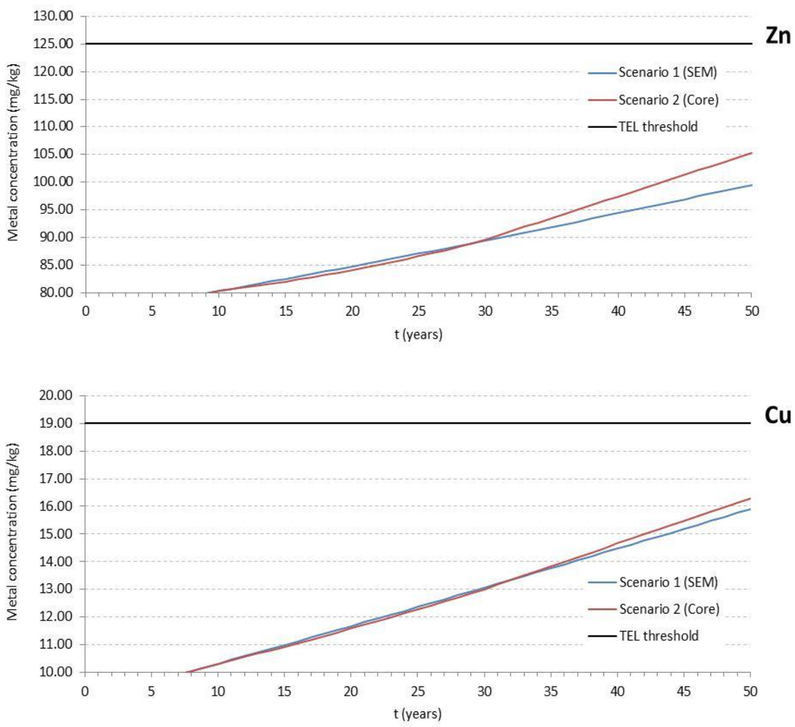


Figure 4-1 Predicted change in zinc and copper concentrations in estuary bed-sediments under Scenarios 1 and 2A, ERU 3 (Cape Horn)

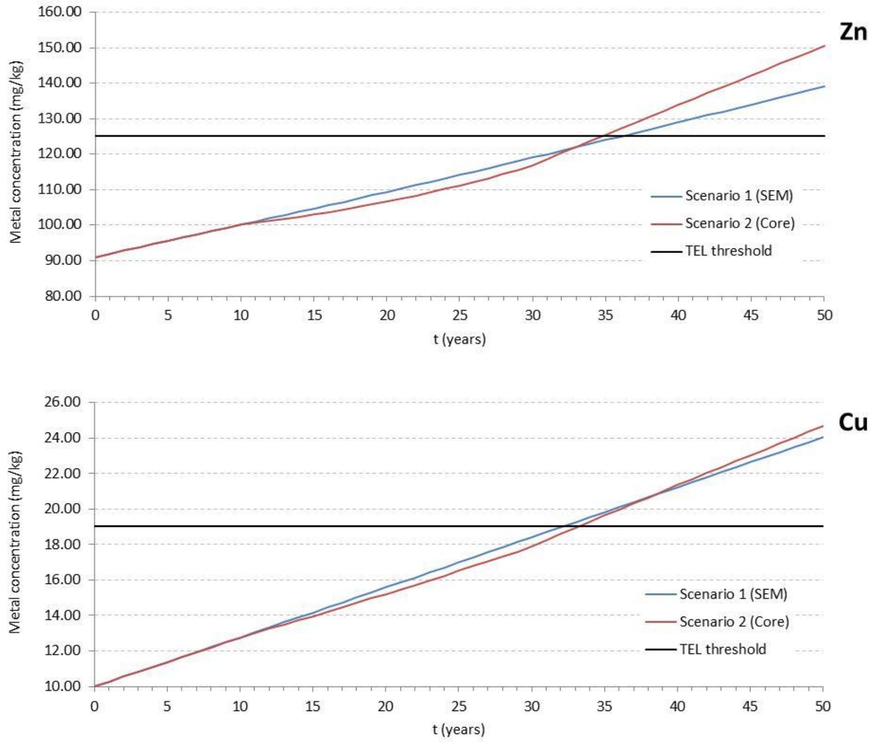


Figure 4-2 Predicted change in zinc and copper concentrations in estuary bed-sediments under Scenarios 1 and 2A, ERU 5 (Pahurehure Inner)

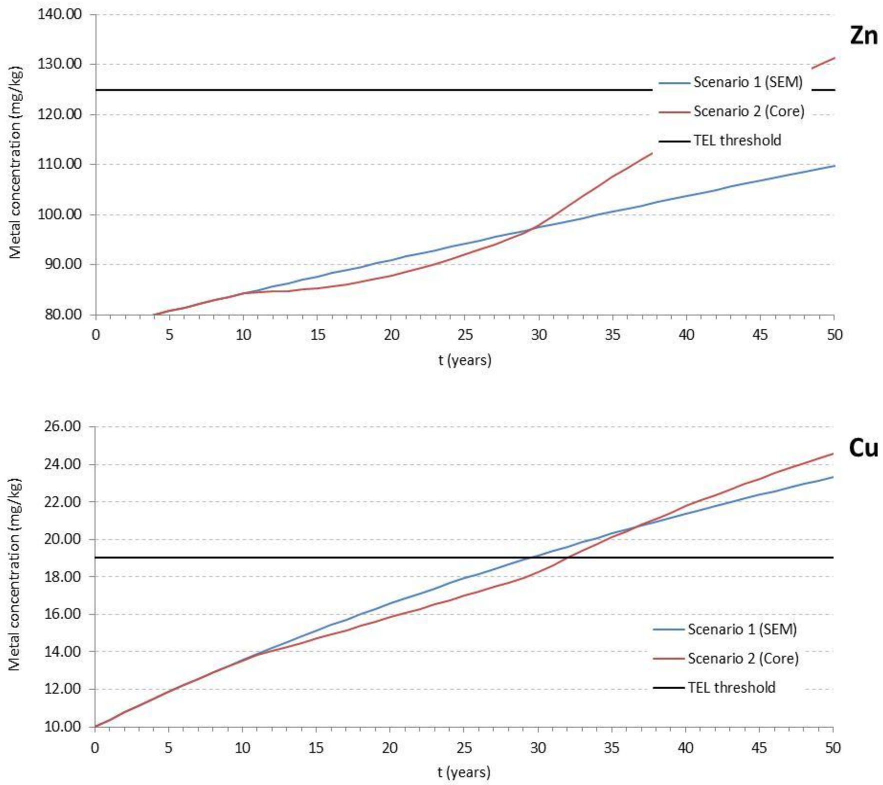


Figure 4-3 Predicted change in zinc and copper concentrations in estuary bed-sediments under Scenarios 1 and 2A, ERU 1 (Glassons Mouth West)

4.2.2 Scenarios 2A to 2D – variations in stormwater treatment

Figure 4-4 compares the results of scenarios 1 and 2A to 2D for ERU6 (Drury Creek Inner) as an example of the influence of varying the level of stormwater treatment on predicted sediment metal concentrations. The results for the various scenarios begin to diverge once the development phase has commenced (2022). The rate of increase in sediment metal concentrations is highest under scenario 2D (worst case stormwater treatment) and least under scenario 2B (best case stormwater treatment). The latter scenario is the only scenario under which sediment metal concentrations are predicted to increase at a lower rate than the baseline SEM study predictions. This is because, under this Scenario, the higher levels of contaminant removal apply to all urban parts of the study area, including existing areas which were modelled as receiving only limited treatment in the SEM study. A similar pattern of divergence between the scenarios is predicted for all ERUs (see Appendix B.2).

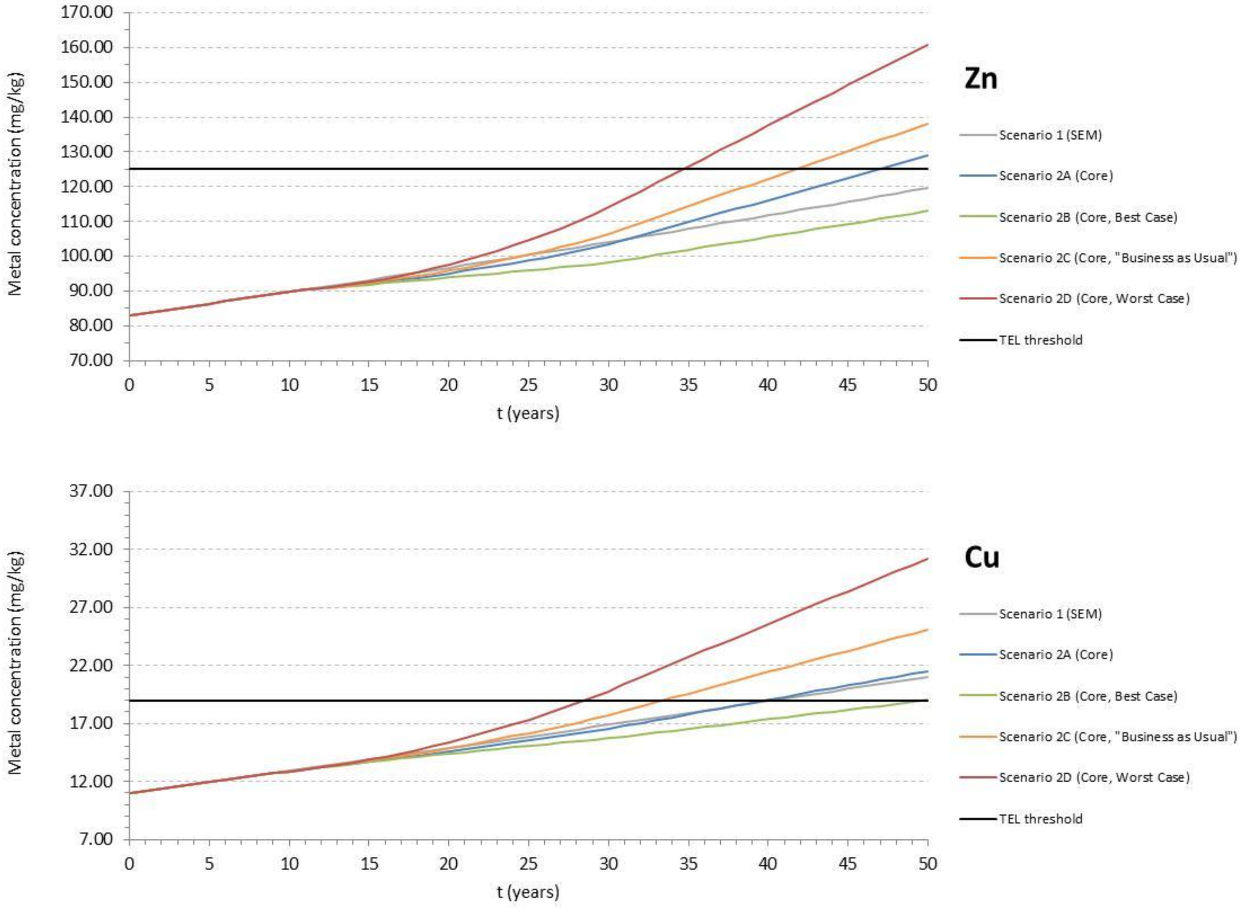


Figure 4-4 Predicted change in zinc and copper concentrations in estuary bed-sediments under Scenarios 1 and 2A to 2D, ERU 6 (Drury Creek Inner)

4.2.3 Scenario 2E – best earthworks controls

Figure 4-5 compares the results of scenarios 1, 2A and 2E for ERU6 (Drury Creek Inner) as an example of the influence of varying the level of earthworks sediment removal on predictions of estuary sediment metal concentrations. This shows a steeper increase in sediment metal concentrations over the construction period (2022-41) under Scenario 2E (best earthworks controls, 90% sediment removal) than under Scenario 2A (guideline level of earthworks controls, 75% sediment removal). The inputs to the pilot DSS under these two scenarios are identical in all other respects. The difference between the two scenarios reflects the fact that a lower sediment load is predicted to be delivered to the estuary during the construction phase under the 90% removal scenario. Under these circumstances, there is less sediment available to 'dilute' the increasing metal loads associated with the expansion of urban land uses over this period.

A similar pattern of divergence between scenarios 2A and 2E is predicted for all ERUs (see Appendix B.3).

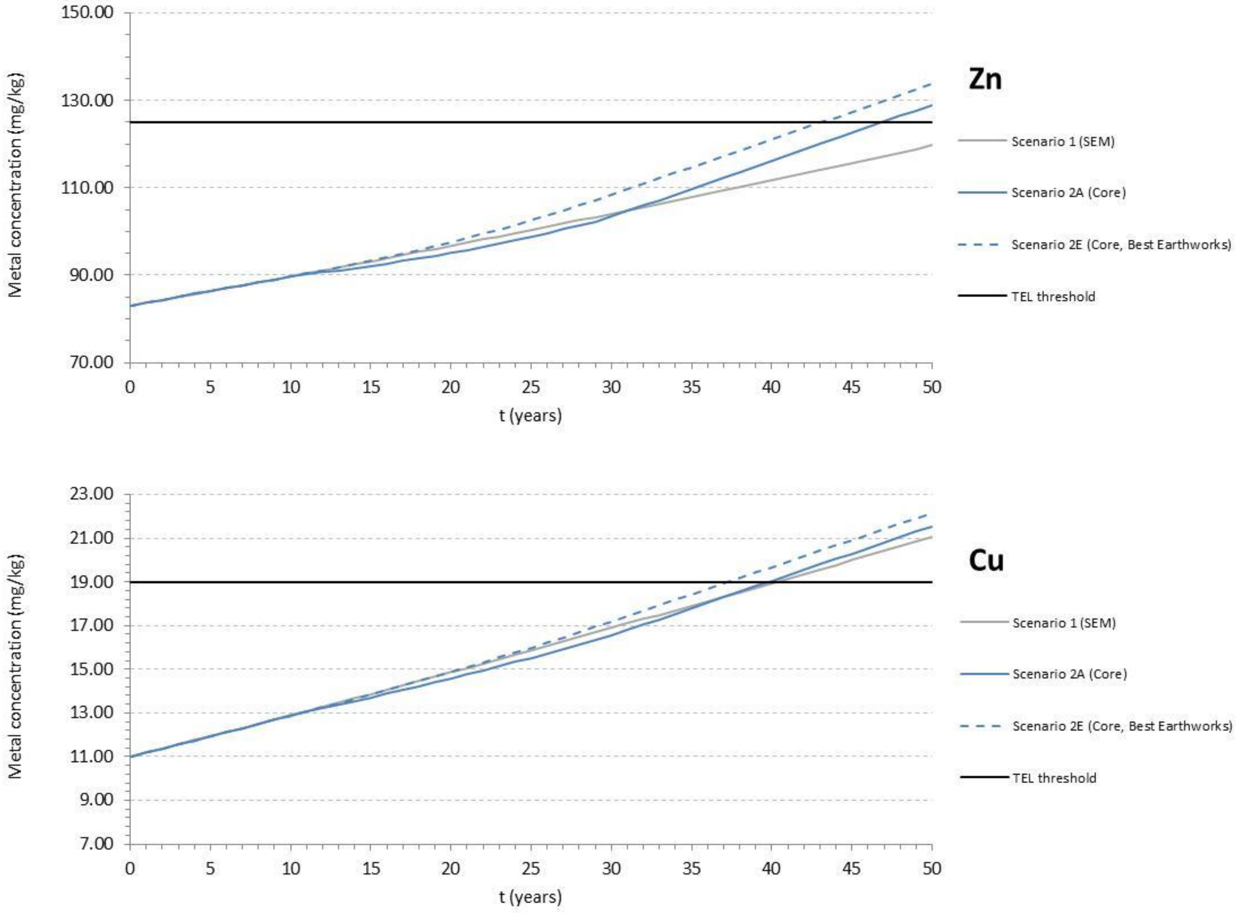


Figure 4-5 Predicted change in zinc and copper concentrations in estuary bed-sediments under Scenarios 1, 2A and 2E, ERU 6 (Drury Creek Inner)

4.2.4 Scenarios 3 to 7 – additions to the core

Centre-south additions compared with northern additions

Figure 4-6 and Figure 4-7 compare the results of Scenarios 1, 2A, 3 and 4 for ERU6 (Drury Creek Inner) and ERU7 (Glassons Creek Inner) as an example of spatial differences in sediment metal concentrations predicted under additional development in the centre-south (Scenario 3 - Core + Pukekohe North East) and in the north (Scenario 4 – Core + Karaka North) of the study area.

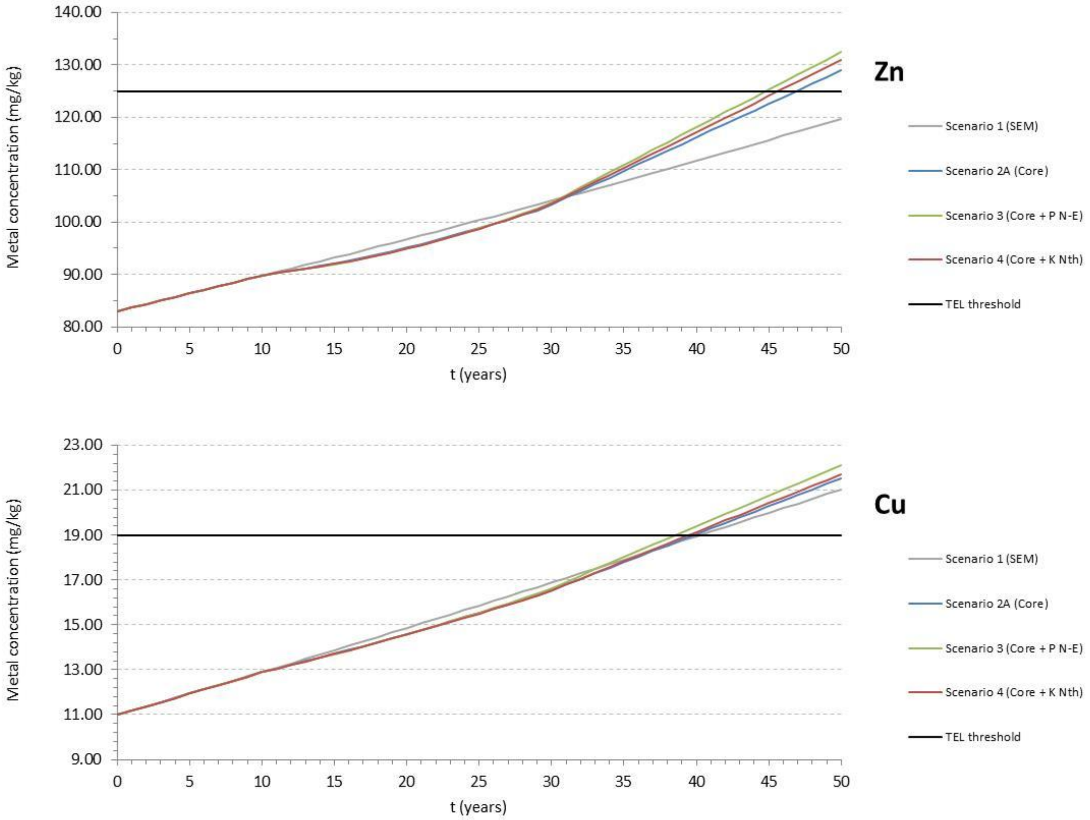
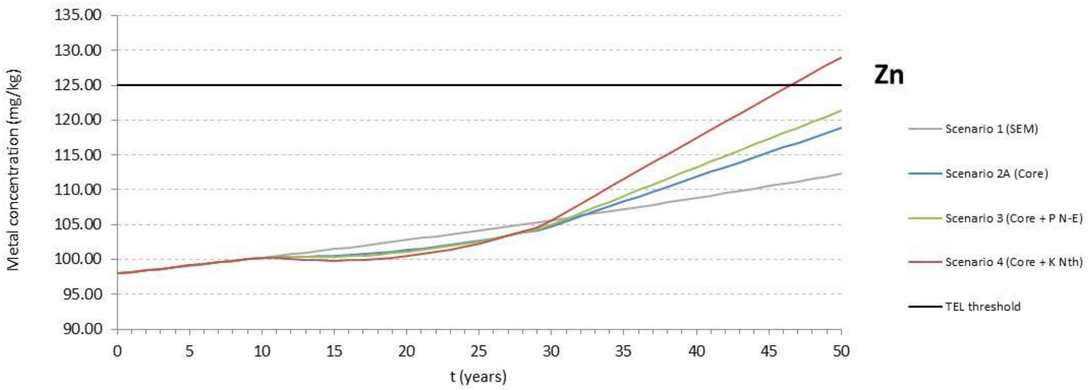


Figure 4-6 Predicted change in zinc and copper concentrations in estuary bed-sediments under Scenarios 1, 2A, 3 and 4, ERU6 (Drury Creek Inner).



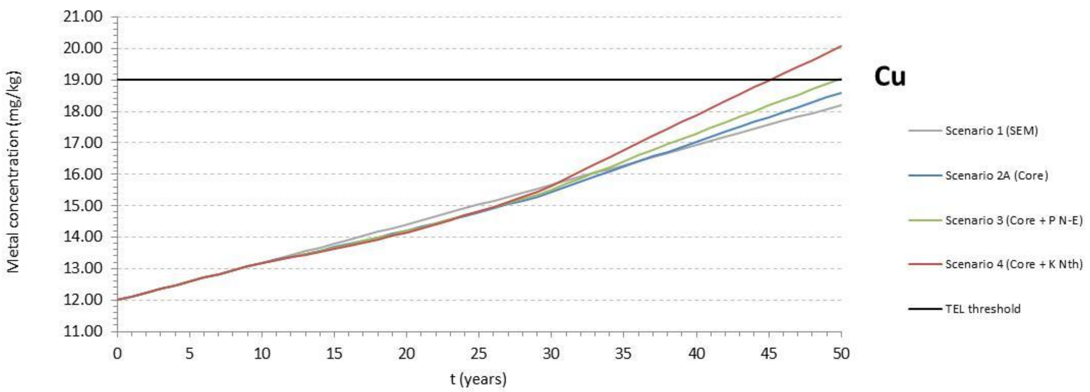


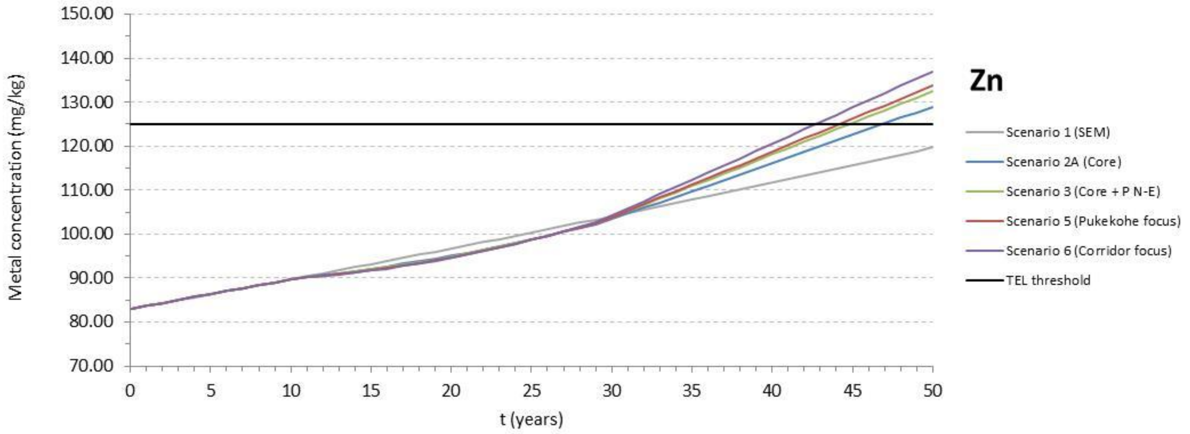
Figure 4-7 Predicted change in zinc and copper concentrations in estuary bed-sediments under Scenarios 1, 2A, 3 and 4, ERU7 (Glassons Creek Inner).

In ERU6 (Drury Creek Inner), sediment metal concentrations are predicted to increase more steeply under Scenario 3 than under Scenario 4, reflecting the fact that Scenario 3 involves additional development in part of the catchment draining to Drury Creek. The predicted rates of sediment metal accumulation under both Scenarios 3 and 4 are only marginally greater than under Scenario 2A. The results are similar for other ERUs in the eastern part of the study area (ERUs 4 and 5, see Appendix B.4).

In ERU7 (Glassons Creek Inner), sediment metal concentrations are predicted to increase more steeply under Scenario 4 than under Scenario 3, reflecting the fact that Scenario 4 involves additional development in part of the catchment draining to Glassons Creek. In this case, the predicted rates of sediment metal accumulation under Scenario 3 are markedly greater than under either Scenario 2A or Scenario 4. The results are similar for other ERUs in the western part of the study area (ERUs 1, 2 and 3, see Appendix B.4).

Alternative centre-south additions

Figure 4-8 compares the results of Scenarios 1, 2A, 3, 5 and 6 for ERU 6 (Drury Creek Inner) as an example of differences in sediment metal concentrations predicted for eastern estuaries under the alternative centre-south additions to the Core.



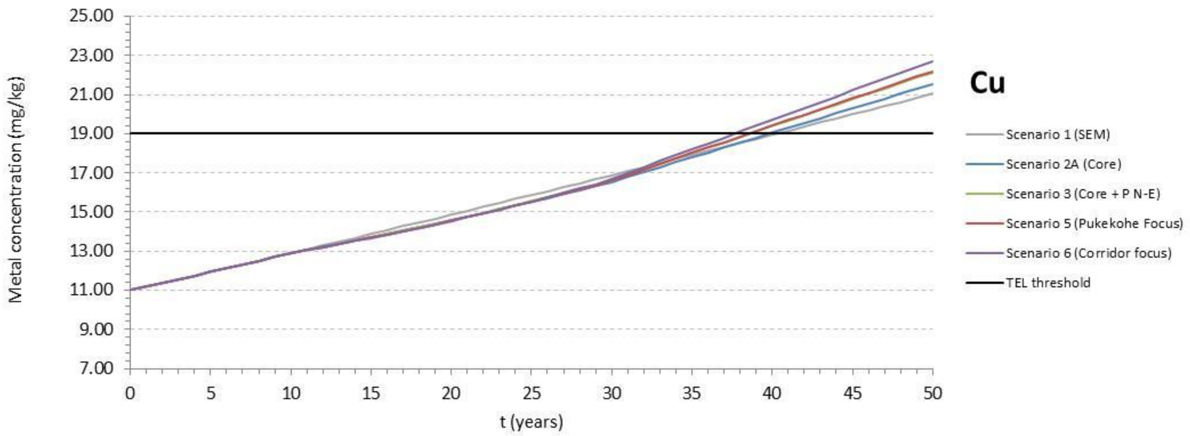


Figure 4-8 Predicted change in zinc and copper concentrations in estuary bed-sediments under Scenarios 1, 2A, 3, 5 and 6, ERU6 (Drury Creek Inner).

The predicted rates of increase in sediment metal concentrations are greatest under Scenario 6 (Corridor Focus), with little difference between the results predicted for Scenario 3 (Core + Pukekohe North East) and Scenario 5 (Core with Pukekohe Focus). The results are similar for all other ERUs (see Appendix B.5).

Alternative northern additions

Figure 4-9 compares the results of Scenarios 1, 2A, 4 and 7 for ERU 7 (Glassons Creek Inner) as an example of differences in sediment metal concentrations predicted for western estuaries under the alternative northern additions to the Core. The predicted rates of increase in sediment metal concentrations are greater under Scenario 7 (West East Focus) than under Scenario 4 (Core + Karaka North). The results are similar for all other western ERUs (ERUs 1, 2 and 3), while in eastern ERUs there is little difference between the results predicted for the two scenarios (see Appendix B.6).

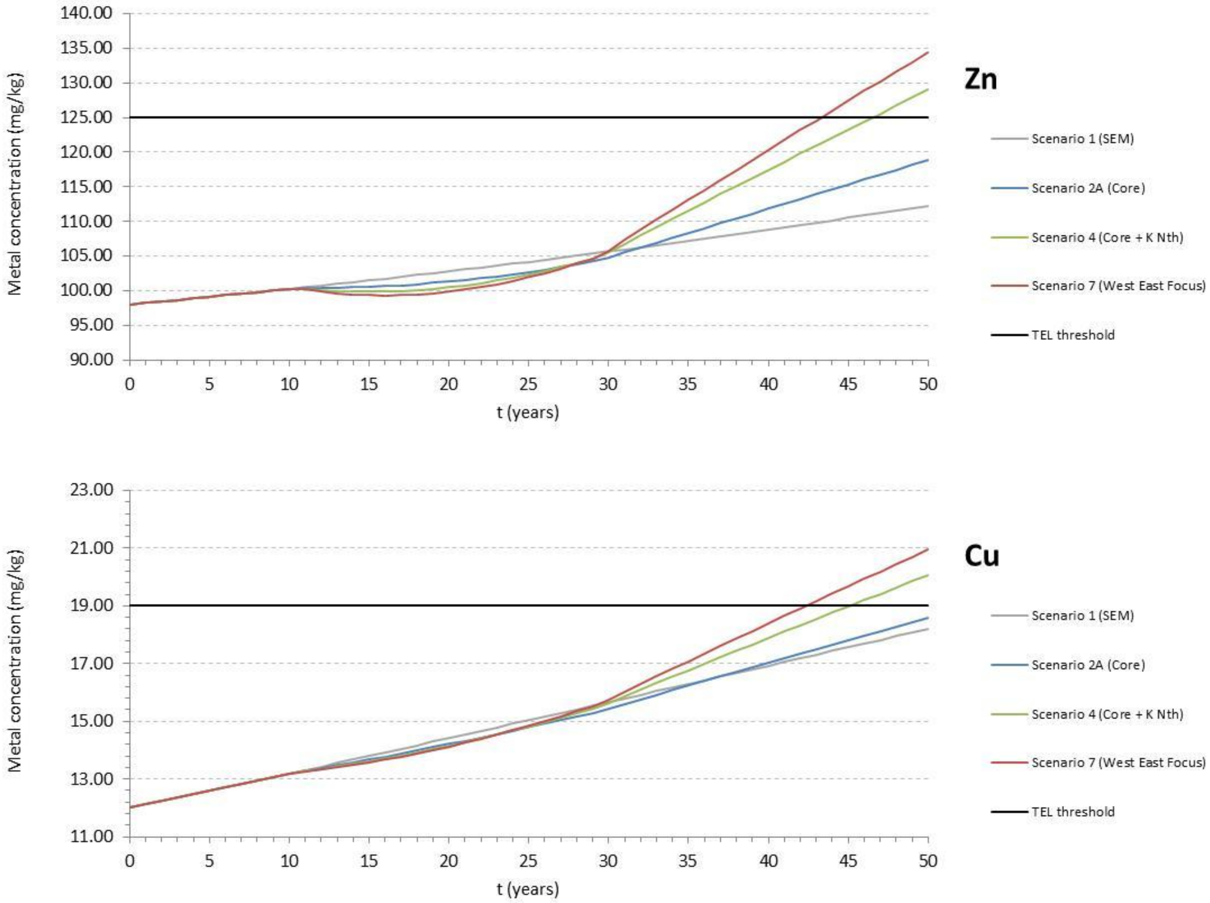


Figure 4-9 Predicted change in zinc and copper concentrations in estuary bed-sediments under Scenarios 1, 2A, 4 and 7, ERU7 (Glassons Creek Inner).

4.3 Benthic health metals score (BHMmetals)

4.3.1 Scenarios 2A to 2D – variations in stormwater treatment

Figure 4-10 compares the results of Scenarios 1 and 2A to 2D for ERU6 (Drury Creek Inner) as an example of the influence of varying the level of stormwater treatment on predicted BHMmetals scores. Each coloured line shown in the figure represents the change in the ‘raw’ BHMmetals score under a given scenario. An increase in this raw score represents deterioration in the health of benthic macroinvertebrate communities. The solid horizontal black lines shown in Figure 4-10 mark the boundaries between five benthic health score classes, from 1 (healthy) to 5 (polluted).

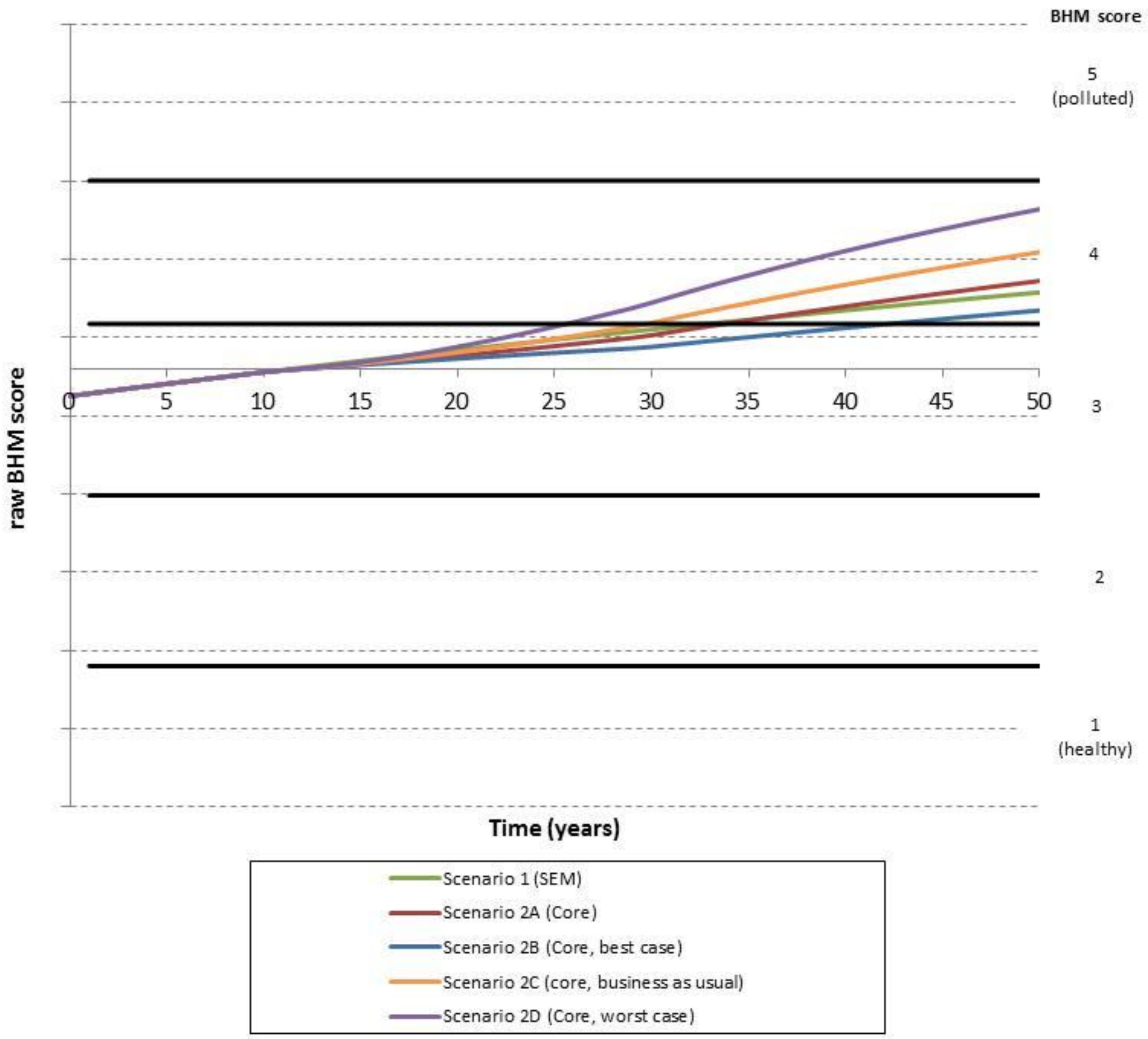


Figure 4-10 Predicted change in BHMmetals scores under Scenarios 1 and 2A to 2D, ERU 6 (Drury Creek Inner)

As with sediment metal concentrations, the results for the various scenarios begin to diverge once the development phase has commenced (2022). The rate of deterioration in the predicted BHMmetals scores is highest under scenario 2D (worst case stormwater treatment) and least under scenario 2B (best case stormwater treatment). The latter scenario is the only scenario under which predicted BHMmetals scores are predicted to deteriorate more slowly than the baseline SEM study predictions.

In this example, all BHMmetals scores at the end of the study timeframe are predicted to fall in the same score class (4). However, at the end of the study timeframe Scenario 2B (best case) just breaches the score class 4 threshold while Scenario 2D (worst case) is close to breaching the score class 5 threshold. This highlights the fact that, while scores for different scenarios may fall into the same score class at the end of the study timeframe, there may still be relatively large differences in the predicted raw scores and in the percentage change in raw scores over the study timeframe (see Table 4-2 and Appendix B.7 to B.11). In the following cases, the differences between BHMmetals scores predicted at the end of the study timeframe under Scenarios 2A to 2D are large enough to be reflected as differences in the score class (see Table 4-2 and Appendix B.7):

- Scores predicted under the best case stormwater treatment (Scenario 2B) are in a higher class than those predicted under the current standard stormwater treatment (Scenario 2A) in two ERUs.
- Scores predicted under the current standard stormwater treatment (Scenario 2A) are in a higher class than those predicted under the business as usual stormwater treatment (Scenario 2C) in two ERUs.
- Scores predicted under the business as usual stormwater treatment (Scenario 2C) are in a higher class than those predicted under the worst case stormwater treatment (Scenario 2D) in three ERUs.

Table 4-2 BHMmetals scores at the start (2012) and end (2062) of the study timeframe (and % change in raw scores) predicted under all scenarios. Scores are assigned to one of five classes ranging from 1 (healthy) to 5 (polluted).

		End of Study Timeframe (2062), by Scenario										
	Start (2012)	1	2A	2B	2C	2D	2E	3	4	5	6	7
ERU1	3	4	4	3	4	5	4	4	4	4	4	4
	-	(-25.6%)	(-34.1%)	(-18.6%)	(-47.5%)	(-65.3%)	(-37.3%)	(-37.7%)	(-50.7%)	(-38.4%)	(-42.4%)	(-58.3%)
ERU2	3	3	3	3	4	4	3	3	4	3	4	4
	-	(-18.6%)	(-21.4%)	(-15.0%)	(-27.7%)	(-37.4%)	(-23.1%)	(-22.8%)	(-25.8%)	(-23.1%)	(-24.5%)	(-27.6%)
ERU3	3	3	3	3	4	4	3	3	3	3	3	4
	-	(-19.9%)	(-22.2%)	(-16.9%)	(-27.6%)	(-36.0%)	(-23.6%)	(-23.5%)	(-26.0%)	(-23.7%)	(-24.9%)	(-27.6%)
ERU4	3	4	4	4	4	5	4	4	4	4	4	4
	-	(-43.7%)	(-50.3%)	(-37.0%)	(-60.1%)	(-75.0%)	(-52.9%)	(-51.8%)	(-51.0%)	(-52.0%)	(-54.2%)	(-50.2%)
ERU5	3	4	4	4	4	5	4	4	4	4	4	4
	-	(-35.6%)	-(39.0%)	(-29.8%)	(-47.9%)	(-60.8%)	(-42.4%)	(-41.0%)	(-40.7%)	(-41.1%)	(-42.9%)	-(40.3%)
ERU6	3	4	4	4	4	4	4	4	4	4	4	4
	-	(-28.0%)	(-31.0%)	(-23.1%)	(-38.8%)	(-50.4%)	(-33.7%)	(-32.8%)	(-32.1%)	(-33.1%)	(-34.6%)	(-31.7%)
ERU7	3	4	4	3	4	4	4	4	4	4	4	4
	-	(-13.6%)	(-16.2%)	(-9.1%)	(-23.3%)	(-34.3%)	(-18.7%)	(-17.7%)	(-22.0%)	(-18.0%)	(-19.6%)	(-24.6%)

4.3.2 Scenario 2E – best earthworks controls

Figure 4-11 compares the results of scenarios 1, 2A and 2E for ERU6 (Drury Creek Inner) as an example of the influence of varying the level of earthworks sediment removal on predictions of the BHMmetals score. This shows a slightly greater deterioration in predicted BHMmetals scores over the construction period (2022-41) under Scenario 2E (best earthworks controls, 90% sediment removal) than under Scenario 2A (guideline level of earthworks controls, 75% sediment removal). This reflects the differences in the trajectories of sediment metal concentrations under the two scenarios (see Section 4.2.3).

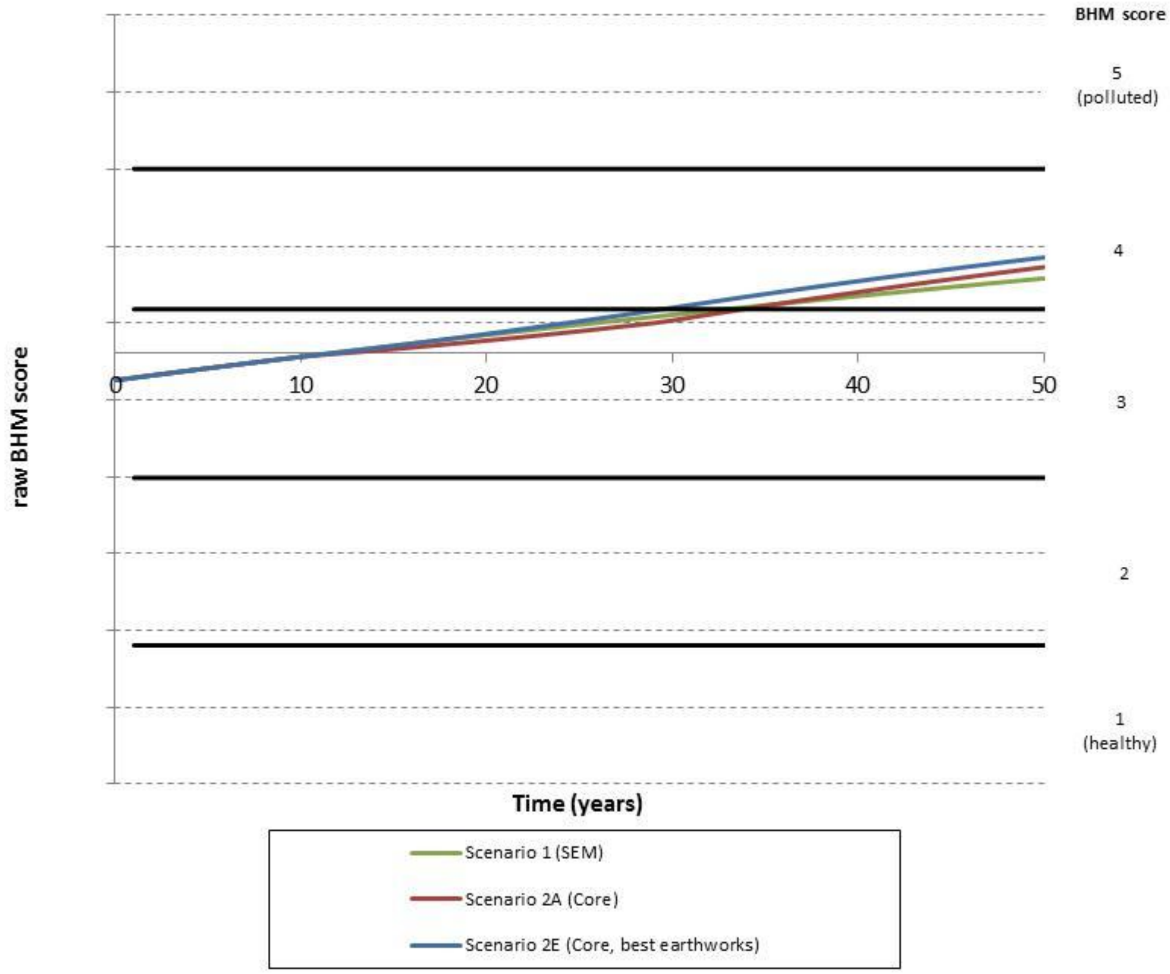


Figure 4-11 Predicted change in BHMmetals scores under Scenarios 1, 2A and 2E, ERU 6 (Drury Creek Inner)

However, the BHMmetals scores at the end of the study timeframe under Scenario 2E are predicted to fall in the same score class as for Scenario 2A. This holds true for all ERUs (see Table 4-2 and Appendix B.8).

4.3.3 Scenarios 3 to 7 – additions to the core

Centre-south additions compared with northern additions

Figure 4-12 and Figure 4-13 compare the results of Scenarios 1, 2A, 3 and 4 for ERU6 (Drury Creek Inner) and ERU7 (Glassons Creek Inner) as examples of spatial differences in BHMmetals scores predicted under additional development in the centre-south (Scenario 3 - Core + Pukekohe North East) and in the north (Scenario 4 – Core + Karaka North) of the study area.

In ERU6 (Drury Creek Inner), the BHMmetals score is predicted to deteriorate slightly more under Scenario 3 than under Scenario 4, reflecting the fact that Scenario 3 involves additional development in part of the catchment draining to Drury Creek. However, the predicted deterioration in the BHMmetals score under both Scenarios 3 and 4 is only marginally greater than under Scenario 2A. The results are similar for other ERUs in the eastern part of the study area (ERUs 4 and 5, see Appendix B.9).

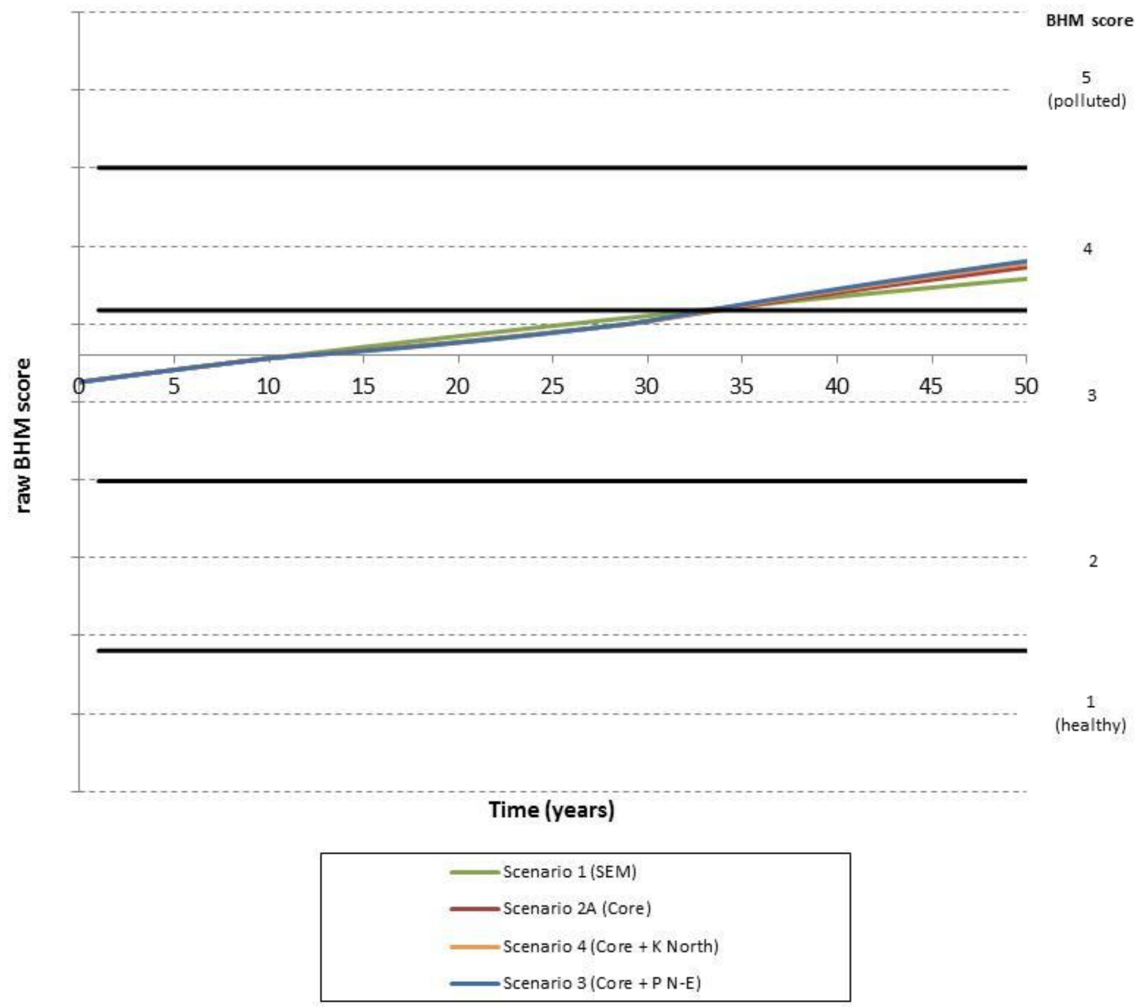


Figure 4-12 Predicted change in BHMmetals scores under Scenarios 1, 2A, 3 and 4, ERU6 (Drury Creek Inner)

In ERU7 (Glassons Creek Inner), the BHMmetals score is predicted to deteriorate more under Scenario 4 than under Scenario 3, reflecting the fact that Scenario 4 involves additional development in part of the catchment draining to Glassons Creek. The results are similar for other ERUs in the western part of the study area (ERUs 1, 2 and 3, see Appendix B.9).

The BHMmetals scores at the end of the study timeframe under Scenarios 3 and 4 are predicted to fall in the same score class as for Scenario 2A. This is the case for all ERUs, with one exception: ERU2 under Scenario 4 (see Table 4-2 and Appendix B.9).

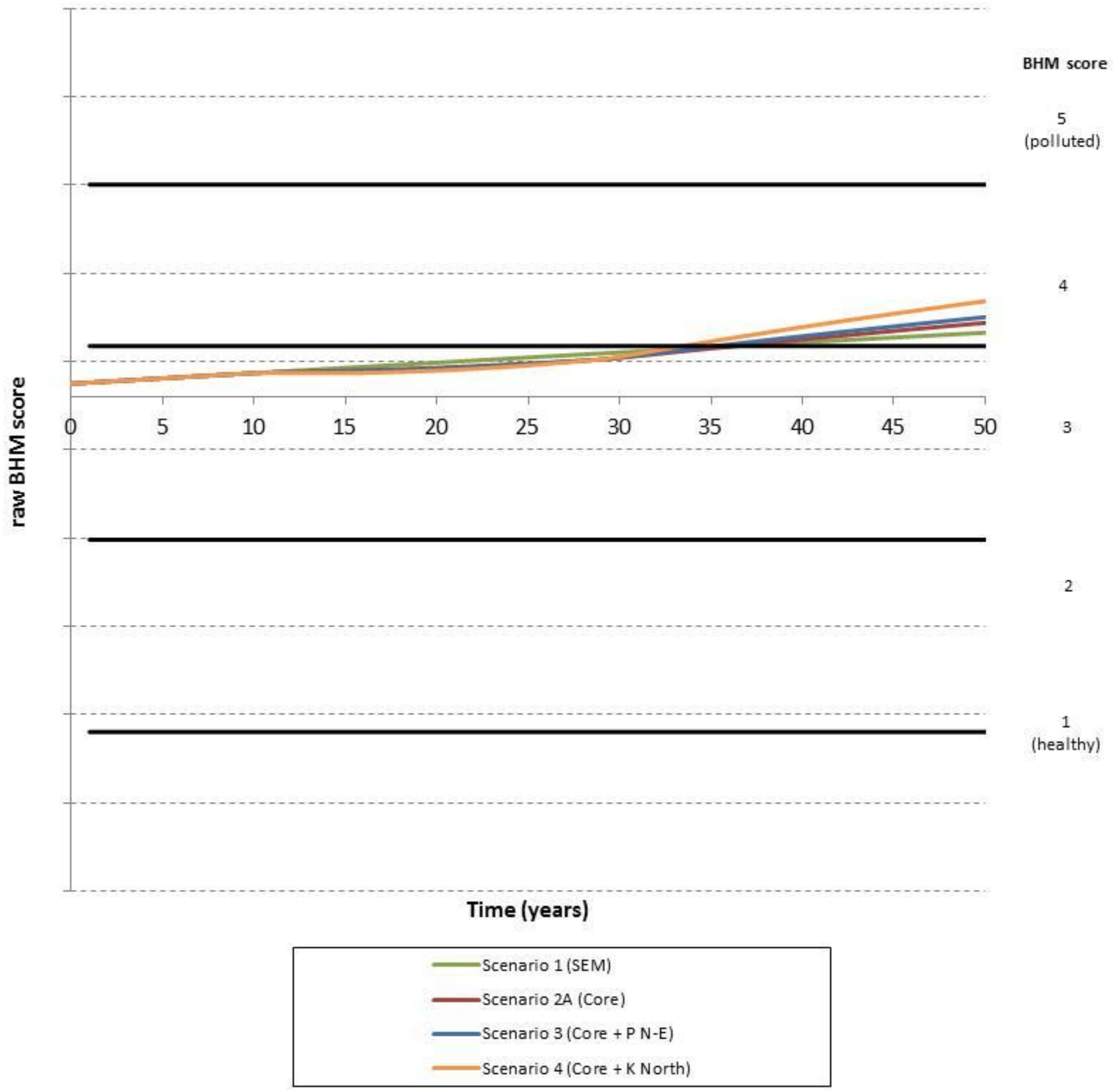


Figure 4-13 Predicted change in BHMmetals scores under Scenarios 1, 2A, 3 and 4, ERU7 (Glassons Creek Inner)

Alternative centre-south additions

Figure 4-14 compares the results of Scenarios 1, 2A, 3, 5 and 6 for ERU 6 (Drury Creek Inner) as an example of differences in the BHMmetals scores predicted for eastern estuaries under the alternative centre-south additions to the core. The predicted rates of increase in the BHMmetals score are greatest under Scenario 6 (Corridor Focus), although there is little difference between the results predicted for any of the centre-south scenarios. The results are similar for all other ERUs (see Appendix B.10), although in one case (ERU2), the slightly greater deterioration in BHMmetals score predicted under Scenario 6 translates into a difference in the score class at the end of the study timeframe (a four compared with a three under Scenarios 3 and 5, see Table 4-2).

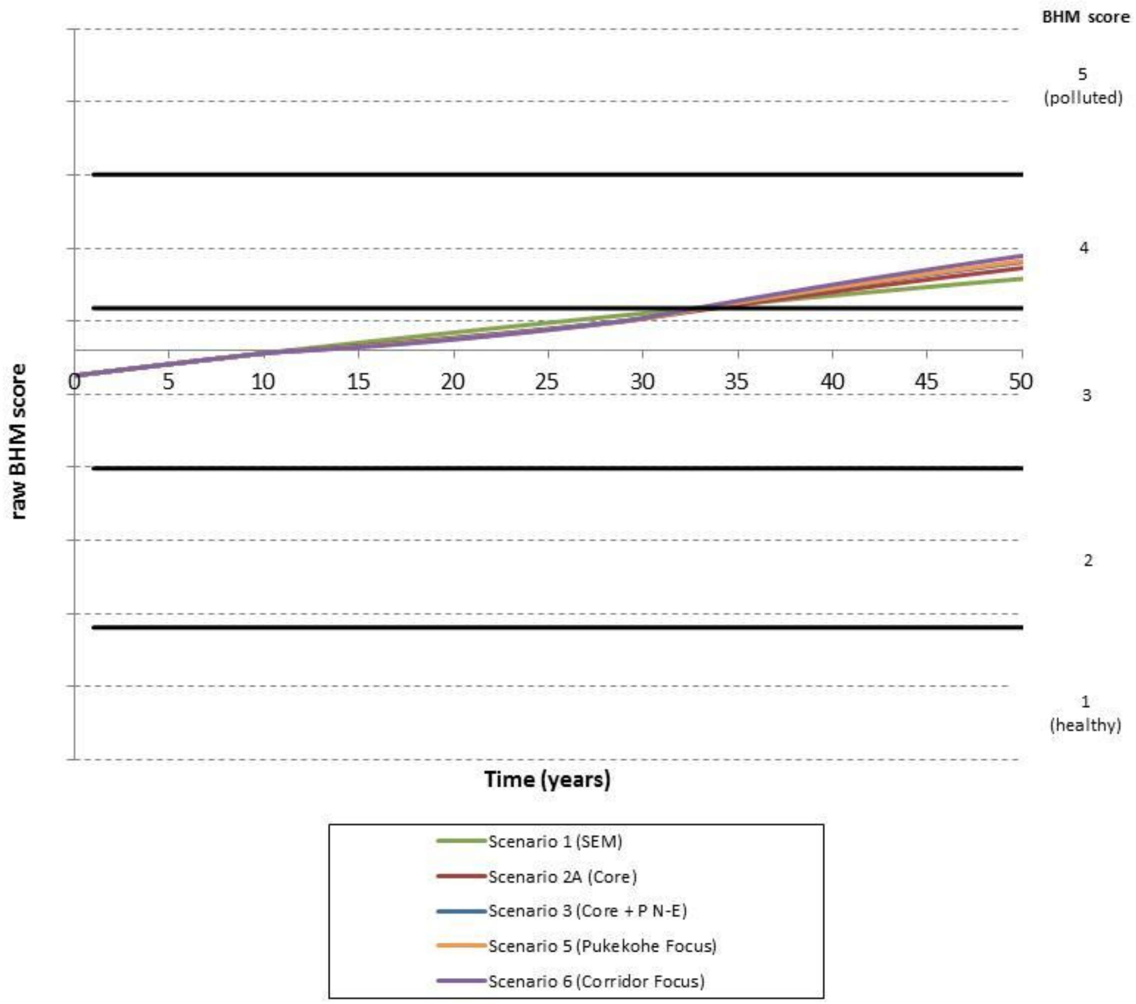


Figure 4-14 Predicted change in BHMmetals scores under Scenarios 1, 2A, 3, 5 and 6, ERU6 (Drury Creek Inner).

Alternative northern additions

Figure 4-15 compares the results of Scenarios 1, 2A, 4 and 7 for ERU 7 (Glassons Creek Inner) as an example of differences in the BHMmetals scores predicted for western estuaries under the alternative northern additions to the Core. The predicted rate of increase in the BHMmetals score is greater under Scenario 7 (West East Focus) than under Scenario 4 (Core + Karaka North). The results are similar for all other western ERUs (ERUs 1, 2 and 3), while in eastern ERUs there is little difference between the results predicted for the two scenarios (see Appendix B.11). In ERU3 the slightly greater deterioration in BHMmetals score predicted under Scenario 7 translates into a difference in the score class at the end of the study timeframe (a four compared with a three under Scenario 4, see Table 4-2). In all other ERUs, the score classes predicted at the end of the study timeframe are the same under both scenarios.

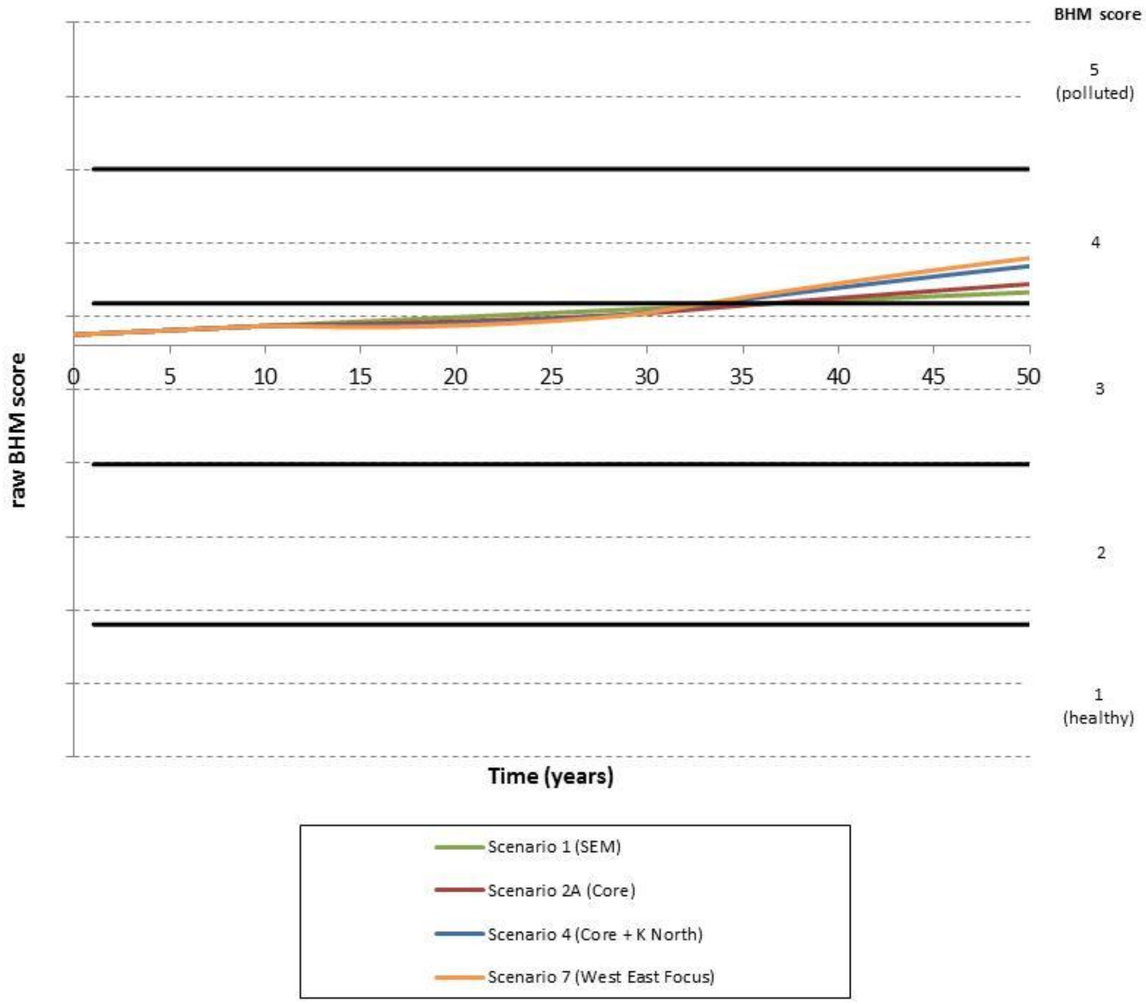


Figure 4-15 Predicted change in BHMmetals scores under Scenarios 1, 2A, 4 and 7, ERU7 (Glassons Creek Inner).

4.4 Mud content of bed-sediments

Scenarios 2A to 2E – Variations in Stormwater Treatment and Earthworks Controls

Table 4-3 shows the mud content of the estuary bed-sediments in each ERU at the start of the study timeframe and predicted at the end of the study timeframe under each scenario. Figure 4-16 compares the results of scenarios 1 and 2A to 2E for ERU4 (Drury Creek Outer) as an example of the influence of varying levels of stormwater treatment and earthworks sediment removal on predictions of mud content. Under Scenarios 2A to 2D, 75% of earthworks-generated sediment is retained while under Scenario 2E this increases to 90%.

Table 4-3 Mud content (%) of estuary bed-sediments in 2012 and predicted at the end of the study timeframe.

	Start (2012)	End of Study Timeframe (2062), by Scenario										
		1	2A	2B	2C	2D	2E	3	4	5	6	7
ERU1	79.0	94.9	95.8	95.7	95.9	96.2	94.7	96.0	96.7	96.1	96.1	97.1
ERU2	79.0	84.3	85.1	85.1	85.3	85.5	84.2	85.3	85.7	85.4	85.5	86.0
ERU3	33.0	48.1	50.4	50.2	50.7	51.4	47.9	50.9	51.8	51.1	51.3	52.7
ERU4	20.0	53.0	60.0	59.4	61.0	63.0	52.1	61.6	61.0	62.2	63.3	61.4
ERU5	60.0	72.4	75.0	74.8	75.4	76.2	72.0	75.6	75.5	75.9	76.3	75.7
ERU6	23.0	39.8	44.1	43.7	44.8	46.1	39.2	45.1	44.7	45.6	46.3	44.9
ERU7	87.0	90.9	91.4	91.3	91.4	91.6	90.8	91.5	91.8	91.5	91.5	92.0

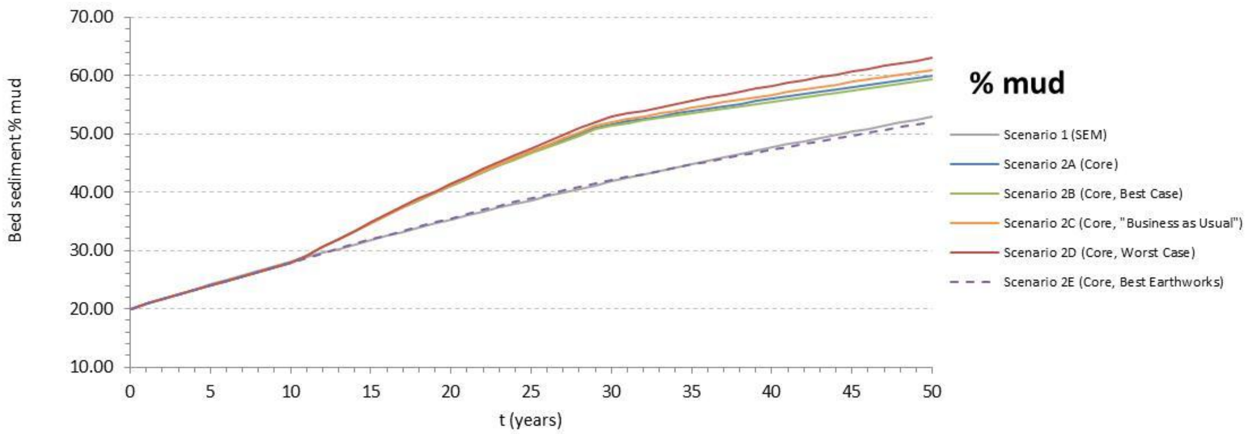


Figure 4-16 Predicted change in the mud content of estuary bed-sediments under Scenarios 1 and 2A to 2E, ERU4 (Drury Creek Outer).

In all ERUs and under all scenarios mud content is predicted to increase between the start (2012) and end (2062) of the study timeframe. While the increases predicted under Scenarios 2 to 7 are larger than under Scenario 1 (SEM study), these differences are relatively small. In other words, the majority of any increase in mud content is predicted to occur under the current land use configuration (which does not change under Scenario 1) with a lesser contribution arising from urban development under any of the Southern RUB development scenarios.

While there is some difference in the results for the various stormwater treatment scenarios, this is relatively minor compared with the divergence between the predictions for those scenarios (2A to 2D) and predictions for Scenario 2E (best earthworks controls). Under all of Scenarios 2A to 2D, the mud content is predicted to increase at a markedly more rapid rate than under the baseline scenario over the period of development (2022-2041), reflecting the exposure of bare earth associated with development of the Core area. Once the development phase is over (post-2041), the rate of increase in mud content under the Scenarios 2A-2D is predicted to be slightly less than under Scenario 1 because the developed areas are assumed to have lower sediment yields than the rural land use that they have replaced.

In contrast, under Scenario 2E (best earthworks controls) the rate of increase in mud content is predicted to remain much the same as under Scenario 1 (SEM study) throughout both the development and post-development phases.

A similar pattern of divergence between the scenarios 2A-2D and 2E is predicted for all ERUs (see Appendix B.12).

4.4.1 Scenarios 3 to 7 – additions to the core

Centre-south additions compared with northern additions

Figure 4-17 and Figure 4-18 compare the results of scenarios 1, 2A, 3 and 4 for ERU6 (Drury Creek Inner) and ERU7 (Glassons Creek Inner) as an example of spatial differences in increases in mud content predicted under additional development in the centre-south (Scenario 3 - Core + Pukekohe North East) and in the north (Scenario 4 – Core + Karaka North) of the study area.

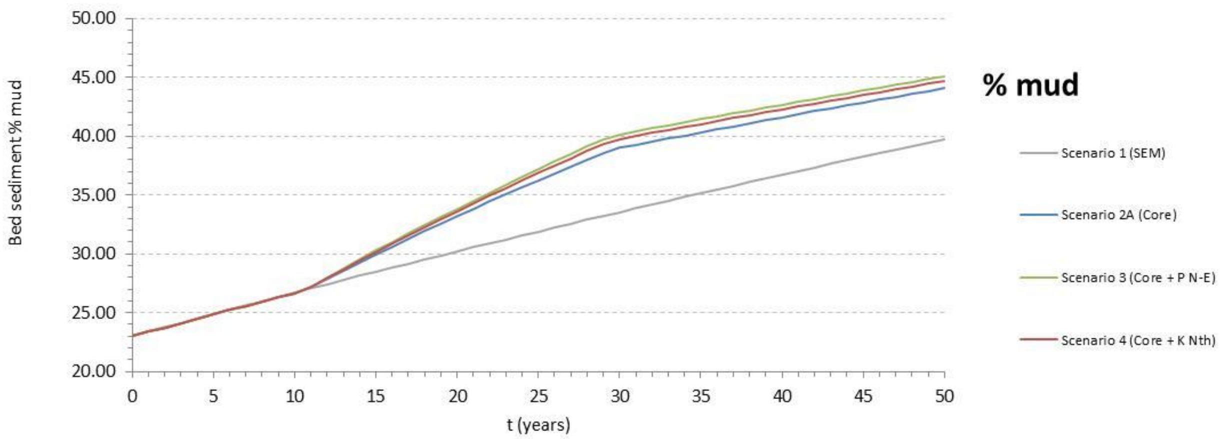


Figure 4-17 Predicted change in the mud content of estuary bed-sediments under Scenarios 1, 2A, 3 and 4, ERU6 (Drury Creek Inner)

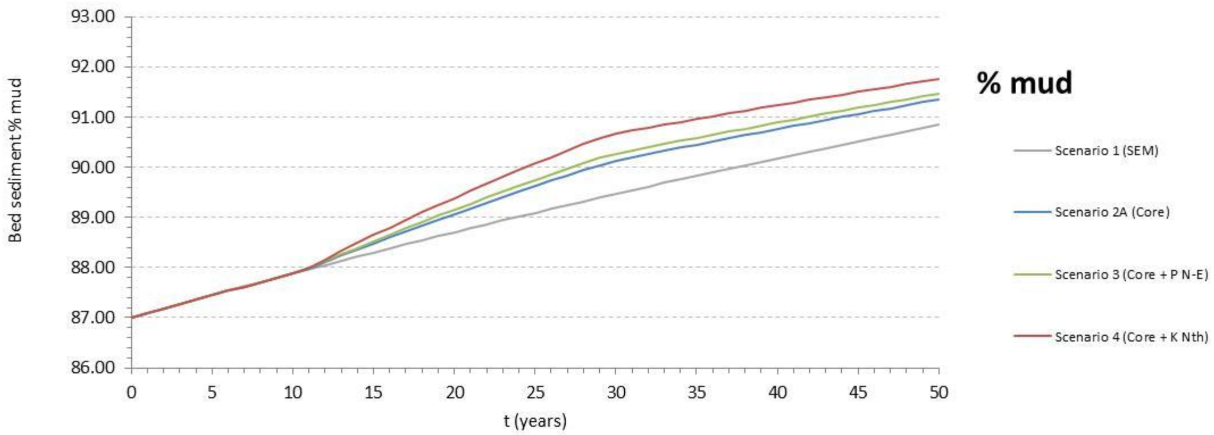


Figure 4-18 Predicted change in the mud content of estuary bed-sediments under Scenarios 1, 2A, 3 and 4, ERU7 (Glassons Creek Inner)

In ERU6 (Drury Creek Inner), there is very little difference between Scenarios 2A, 3 and 4 in the rate at which the mud content is predicted to increase. The predicted rate of increase in mud content during the development phase is marginally higher under Scenario 3 than under the other two scenarios, reflecting the fact that Scenario 3 involves additional development in part of the catchment draining to Drury Creek. The results are similar for other ERUs in the eastern part of the study area (ERUs 4 and 5, see Appendix B.13).

In ERU7 (Glassons Creek Inner), the mud content is predicted to increase more steeply during the development phase under Scenario 4 than under Scenario 3 and 2A, reflecting the fact that Scenario 4 involves additional development in part of the catchment draining to Glassons Creek. The results are similar for other ERUs in the western part of the study area (ERUs 1, 2 and 3, see Appendix B.13).

Alternative centre-south additions

Figure 4-19 compares the results of Scenarios 1, 2A, 3, 5 and 6 for ERU 6 (Drury Creek Inner) as an example of differences in the mud content predicted for eastern estuaries under the alternative centre-south additions to the Core. The predicted rate of increase in mud content is greatest under Scenario 6 (Corridor Focus), followed by Scenario 5 (Pukekohe Focus). The results are similar for all other eastern ERUs (ERUs 4 and 5) while in western estuaries there is little difference in the results predicted under the three scenarios (see Appendix B.14).

Alternative northern additions

Figure 4-20 compares the results of Scenarios 1, 2A, 4 and 7 for ERU 7 (Glassons Creek Inner) as an example of differences in the mud content predicted for western estuaries under the alternative northern additions to the Core.

The predicted rate of increase in mud content is greater under Scenario 7 (West East Focus) than under Scenario 4 (Core + Karaka North). The results are similar for all other western ERUs (ERUs 1, 2 and 3) while in eastern estuaries there is little difference in the results predicted under the two scenarios (see Appendix B.15).

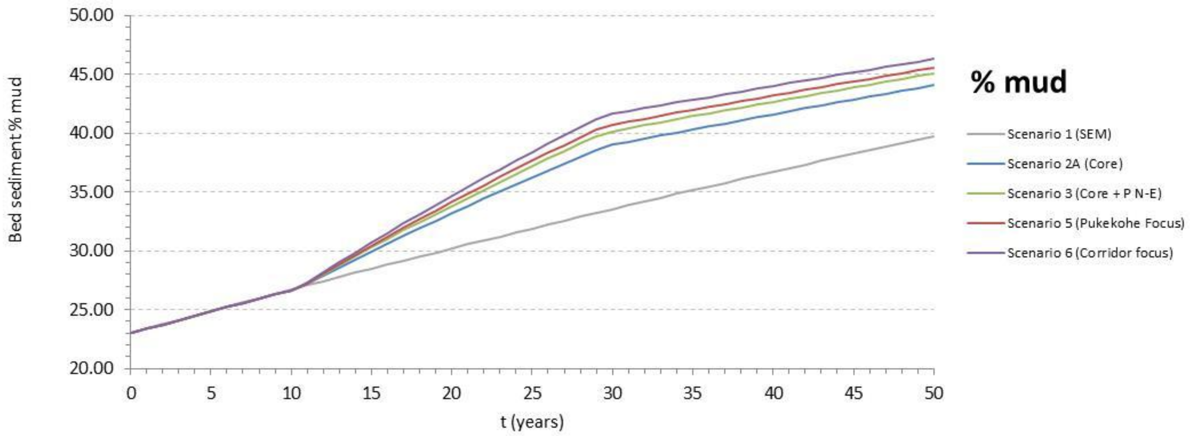


Figure 4-19 Predicted change in the mud content of estuary bed-sediments under Scenarios 1, 2A, 3, 5 and 6, ERU6 (Drury Creek Inner).

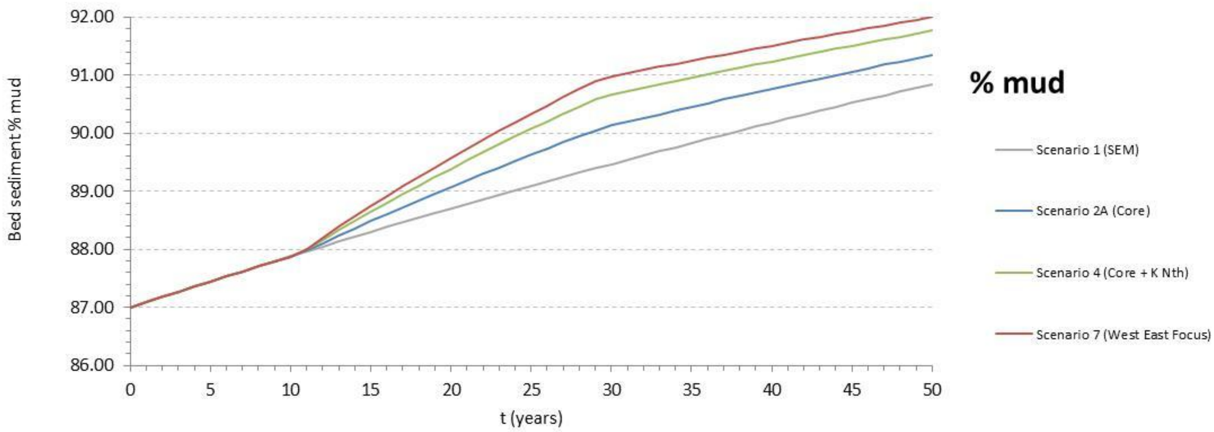


Figure 4-20 Predicted change in the mud content of estuary bed-sediments under Scenarios 1, 2A, 4 and 7, ERU7 (Glassons Creek Inner).

4.5 Benthic health mud score (BHMmud)

4.5.1 Scenarios 2A to 2E –variations in stormwater treatment and earthworks controls

Figure 4-21 and Figure 4-22 show the implications of predicted changes in mud content for benthic health in ERU 1 (Glassons Mouth West) and ERU 6 (Drury Creek Inner), respectively. The solid horizontal black lines shown in these figures mark the boundaries between five BHMmud classes, from 1 (most healthy) to 5 (least healthy).

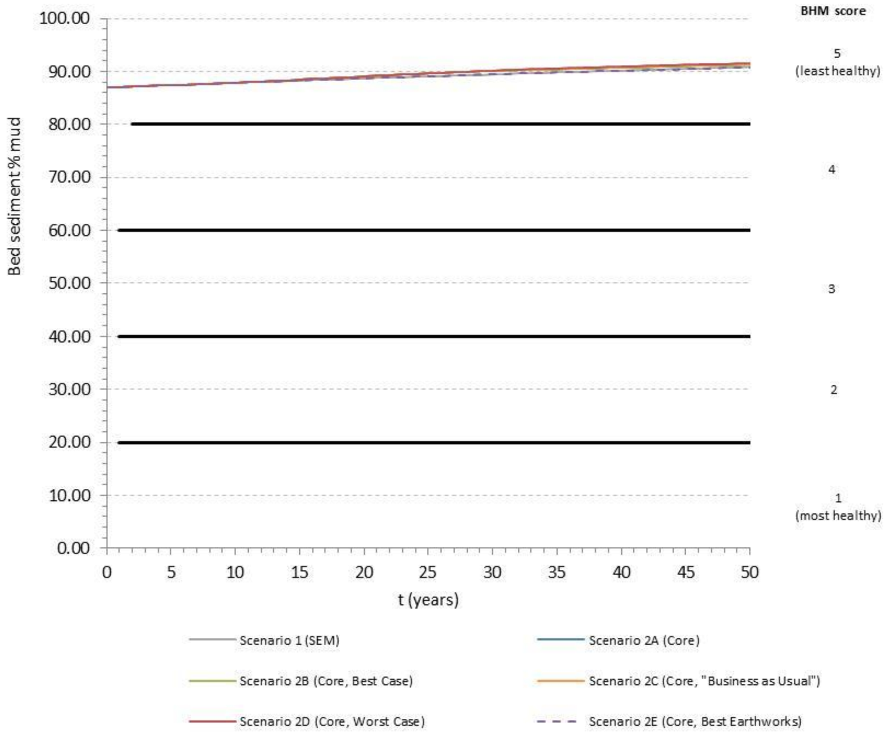


Figure 4-21 Predicted change in the mud content of estuary bed-sediments, with reference to BHMmud classes, under Scenarios 1 and 2A to 2E, ERU1 (Glassons Mouth West).

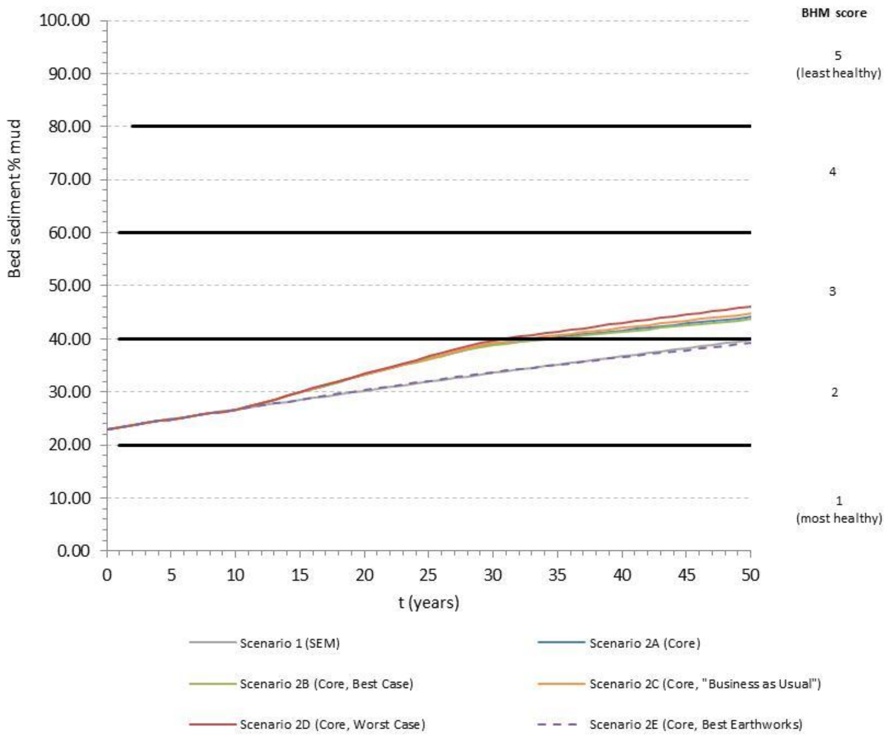


Figure 4-22 Predicted change in the mud content of estuary bed-sediments, with reference to BHMmud classes, under Scenarios 1 and 2A to 2E, ERU6 (Drury Creek Inner).

In ERU 1, a BHMmud score of 5 (least healthy) is predicted for the entire study timeframe, reflecting the fact that the mud content is already above 80% at the start of the period. Similar results are predicted for ERUs 2, 5 and 7 (see Appendix B.16).

In contrast, the BHMmud score predicted for ERU 6 deteriorates from a 2 to 3 over the study timeframe in Scenarios 2A to 2D, and only just avoids becoming a 3 under Scenario 2E.This reflects an increase in the predicted mud content from 23% to 40% or more over the study timeframe. Similar results are predicted for ERU 3, while in ERU 4, the BHMmud score is predicted to deteriorate by two classes under some scenarios (see Appendix B.16).

4.5.2 Scenarios 3 to 7 – additions to the core

Differences in the mud content predicted under Scenarios 3, 4, 5, 6 and 7 do not result in a difference in the BHMmud class between the scenarios. The BHMmud scores predicted at the end of the study timeframe under all five scenarios are the same as under Scenario 2A (Core) in all ERUs (see Appendix B.17, B.18 and B.19). The predicted scores are also the same as those predicted under Scenario 1 (SEM study), except for ERUs 4 and 6, where the predicted BHMmud scores ends up being less healthy (by one class) than under Scenario 1 (see Figure 4-23, for example).

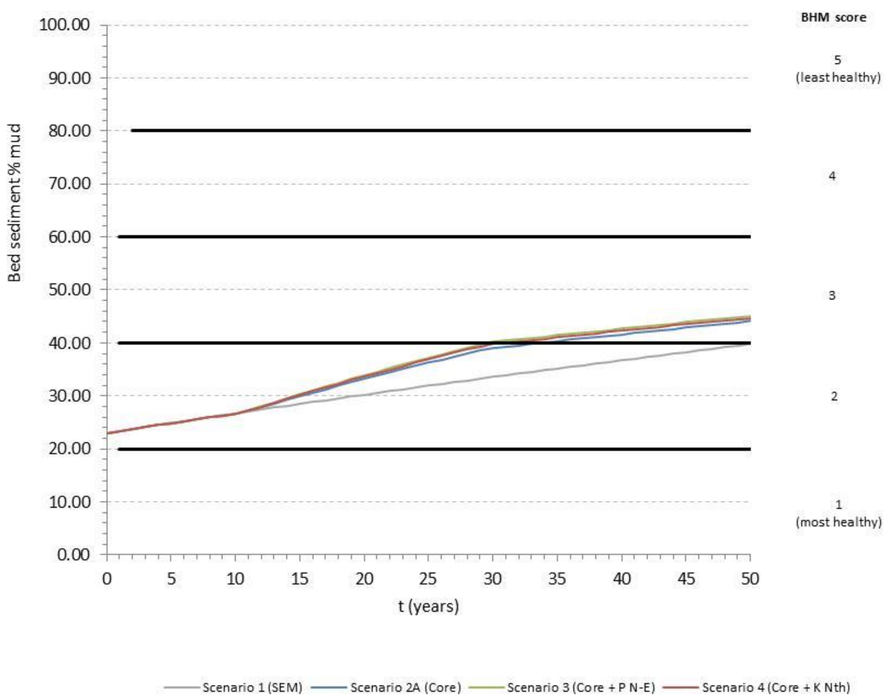


Figure 4-23 Predicted change in the mud content of estuary bed-sediments, with reference to BHMmud classes, under Scenarios 1, 2A, 3 and 4, ERU6 (Drury Creek Inner).

4.6 Sediment accumulation rate

Table 4-4 presents the average sediment accumulation rate (SAR) over the 50 year study timeframe predicted for each ERU under each scenario. Note that the increases in SAR predicted for the Southern RUB scenarios are additional to a 7-9% increase under Scenario 1 on historic rates of sediment accumulation predicted in the SEM study (see Table 2-2).

In summary:

- Predicted SARs are at least twice as much in ERU1 (Glasson Mouth West; 5.54 to 7.73 mm/year) as in any other ERU. Predicted SARs in all other ERUs are in the range 0.98 to 3.09 mm/year.
- Comparing the results for Scenarios 2A to 2D (Core with variations in stormwater treatment) with the baseline (Scenario 1):
    - under the best case stormwater treatment (Scenario 2B), predicted SARs are 12.8-27.6% higher than under Scenario 1; and
    - under the worst case stormwater treatment (Scenario 2D), predicted SARs are 21.1-45.0% higher than under Scenario 1.
- Under the best earthworks scenario (Scenario 2E), SARs are predicted to be slightly lower than under Scenario 1.

Table 4-4 Average sediment accumulation rates over the study timeframe (2012-2062) predicted for each ERU under all scenarios (mm/year). The figures in brackets are the percentage difference from Scenario 1.

	Scenario										
	1	2A	2B	2C	2D	2E	3	4	5	6	7
ERU1	5.54	6.33	6.25	6.46	6.71	5.45	6.52	7.21	6.61	6.59	7.73
	-	(14.3%)	(12.8%)	(16.6%)	(21.1%)	(-1.6%)	(17.7%)	(30.1%)	(19.3%)	(19.0%)	(39.5%)
ERU2	1.17	1.38	1.36	1.41	1.48	1.14	1.43	1.52	1.45	1.47	1.61
	-	(17.9%)	(16.2%)	(20.5%)	(26.5%)	(-2.6%)	(22.2%)	(29.9%)	(23.9%)	(25.6%)	(37.6%)
ERU3	1.02	1.2	1.18	1.22	1.28	1	1.24	1.32	1.26	1.27	1.39
	-	(17.6%)	(15.7%)	(19.6%)	(25.5%)	(-2.0%)	(21.6%)	(29.4%)	(23.5%)	(24.5%)	(36.3%)
ERU4	2.11	2.75	2.63	2.86	3.06	2.04	2.91	2.86	2.97	3.09	2.89
	-	(30.3%)	(24.6%)	(35.5%)	(45.0%)	(-3.3%)	(37.9%)	(35.5%)	(40.8%)	(46.4%)	(37.0%)
ERU5	1.47	1.87	1.83	1.94	2.06	1.43	1.97	1.95	2.01	2.08	1.98
	-	(27.2%)	(24.5%)	(32.0%)	(40.1%)	(-2.7%)	(34.0%)	(32.7%)	(36.7%)	(41.5%)	(34.7%)
ERU6	0.98	1.26	1.25	1.33	1.42	0.94	1.35	1.32	1.38	1.44	1.33
	-	(28.6%)	(27.6%)	(35.7%)	(44.9%)	(-4.1%)	(37.8%)	(34.7%)	(40.8%)	(46.9%)	(35.7%)
ERU7	1.4	1.63	1.6	1.66	1.73	1.37	1.68	1.82	1.7	1.71	1.93
	-	(16.4%)	(14.3%)	(18.6%)	(23.6%)	(-2.1%)	(20.0%)	(30.0%)	(21.4%)	(22.1%)	(37.9%)

- Comparing the results for Scenarios 3 and 4 (additions to the Core):
    - In eastern estuaries (ERUs 4, 5 and 6), the predicted increase in the SAR is greater under Scenario 3 than Scenario 4, reflecting the fact that the former scenario involves additional development in part of the catchment draining to these eastern estuaries; and
    - In western estuaries (ERUs 1, 2, 3 and 7), the predicted increase in the SAR is greater under Scenario 4 than Scenario 3, reflecting the fact that the former scenario involves additional development in part of the catchment draining to these western estuaries.
- Comparing the results for Scenarios 3, 5 and 6 (centre-south additions to the Core):
    - In eastern estuaries (ERUs 4, 5 and 6), the predicted increase in the SAR is greatest under Scenario 6, reflecting the fact that this scenario involves the greatest extent of additional development in part of the catchment draining to these eastern estuaries.
- Comparing the results for Scenarios 4 and 7 (northern additions to the Core):
    - In western estuaries (ERUs 1, 2, 3 and 7), the predicted increase in the SAR is greater under Scenario 7, reflecting the fact that this scenario involves the greatest extent of additional development in part of the catchment draining to these western estuaries.

4.7 Effect of development in the Karaka west area

In Scenario 7 (Core with West-East Focus) approximately half of the Karaka West development area lies outside of the study area. Therefore, the potential effects of this part of the development under Scenario 7 are not captured in the results described above. Instead, these potential effects were assessed with reference to previous predictions made in the SEM study.

The part of the Karaka West development area that lies outside of the study area covers an area of 405 ha of the SEM study ‘Elletts Beach’ subcatchment (see Figure 4-24). In the SEM study, much of the contaminant load from Elletts Beach subcatchment was predicted to be discharged to the Hikihiki Bank (HIB, see Figure 4-25) subestuary (for example, 69% of sediment and 47% of zinc; Green, 2008a). Almost the entire remaining load from this subcatchment was predicted to be discharged into the Manukau Harbour Basin (i.e. lost from the SEM study area).

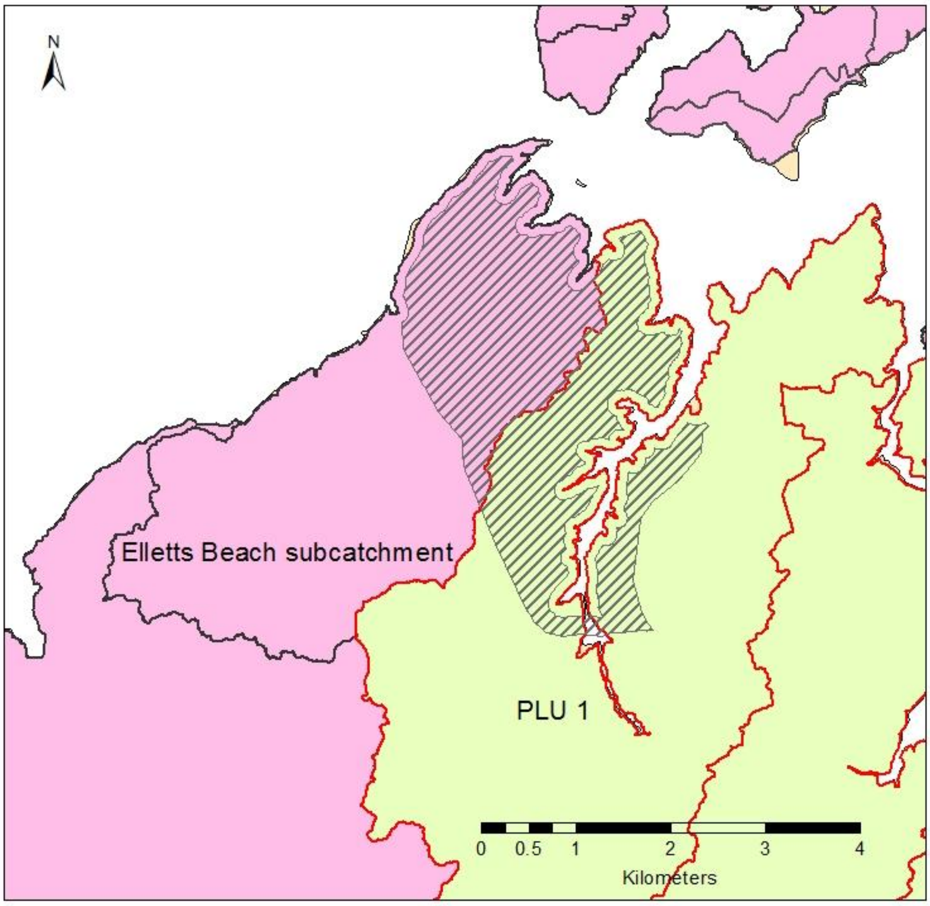


Figure 4-24 Location of the Karaka West development area (hatched) in relation to PLUs defined in this study (green with red borders) and other subcatchments of the SEM study (pink).

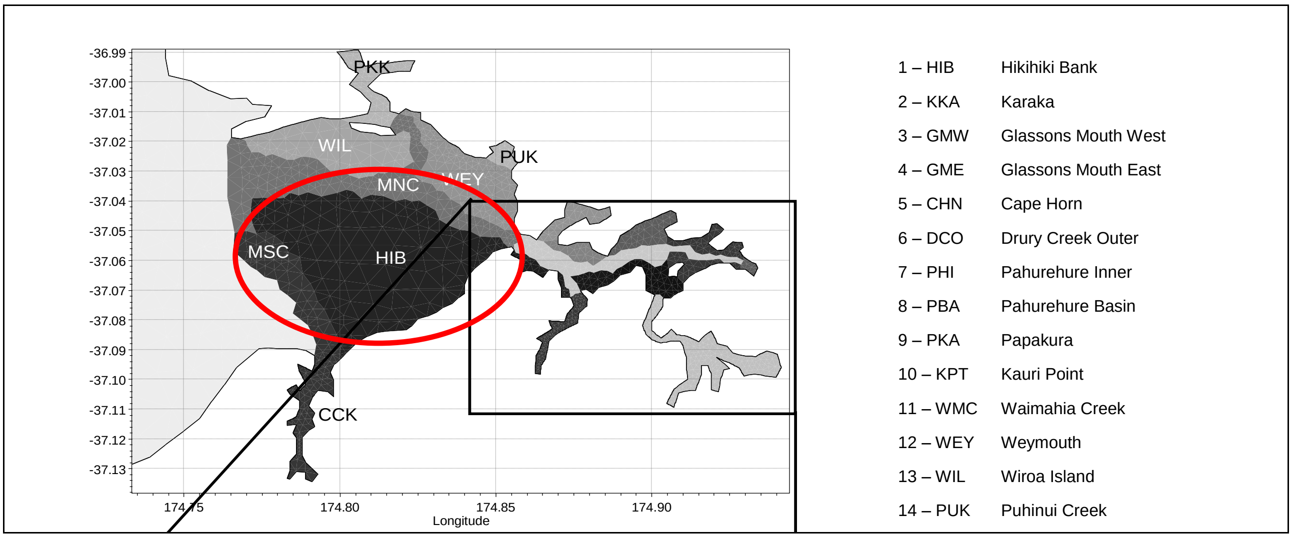


Figure 4-25 Location of the Hikihiki Bank subestuary as defined in the SEM study

The Hikihiki Bank subestuary is an intertidal flat. The SEM study predicted a very low and little-changed SAR (0.03 mm/yr) in this subestuary under all of the future development scenarios considered (Green 2008b and c). Estuary bed-sediment metal concentrations were predicted to remain virtually at present day concentrations (for instance, zinc at around 50 mg/kg).

In the SEM study the Hikihiki Bank subestuary was predicted to receive sediments and metals from almost every subcatchment in the wider study area. While the main sediment source was the Elletts Beach subcatchment, the main metal source was the Papatoetoe/Puhinui subcatchment located in the centre-north of the study area. In order to assess how the Karaka West scenario might influence sediment characteristics of the Hikihiki Bank subestuary it was therefore necessary to estimate the potential change in loads discharged to the subestuary from all contributing SEM study subcatchments.

The mean annual loads discharged to the Hikihiki Bank subestuary from all subcatchments under the Karaka West scenario were estimated to be 19.5% and 16.7% higher for sediment and zinc, respectively, than under the baseline SEM Scenario 1. Based on these load estimates, the delivery concentration of zinc to the Hikihiki Bank subestuary would remain virtually unchanged (242 mg/kg compared to 248 mg/kg under SEM Scenario 1). The slight drop in delivery concentrations reflects the fact that the Elletts Beach subcatchment is proportionally a larger contributor of sediment than zinc to the Hikihiki Bank subestuary. Based on these sediment load estimates, the SAR of the Hikihiki subestuary would also remain virtually unchanged (0.04mm/yr compared to 0.03mm/yr under the SEM1 scenario).

Taken together, although the sediment metal delivery concentration is high (under both the SEM Scenario 1 and Karaka West scenarios) relative to present day bed-sediment concentrations of zinc (50 mg/kg), the SAR is so low relative to the sediment mixing depth (suggested in the SEM study as being >40mm; Green, 2008a) that the prediction of virtually no increase in bed-sediment metal concentrations made in the SEM study can be considered to also be valid for the Karaka West scenario.

5.0 Results – Social and Economic Indicators

5.1 Introduction

This chapter describes and discusses the predictions made by the pilot DSS for two sets of other indicators. These indicators are, for each ERU under each scenario:

- five social indicators: extraction, contact recreation, partial contact recreation, non-contact recreation and sense-of-place; and
- two economic indicators: costs and benefits.

As noted in Section 2.2.2 the pilot DSS makes its predictions of the social indicators based on the levels of three stormwater-related attributes predicted by the suite of environmental models: estuary turbidity, underfoot condition and ecological health. The economic benefits indicator uses the same input data, being calculated as the monetised benefits (or losses) that arise from the changes in these three environmental attributes under each of the scenarios. These benefits are calculated as the present value of a future stream of annual monetised benefits that occur into infinity.

The economic costs indicator is estimated by a catchment-scale stormwater treatment costing model, which makes predictions of the present value of the full life-cycle costs of stormwater treatment based on inputs relating to the extent and desired level of performance of treatment, capital assets employed, land use and the level of imperviousness.

The development of the methods for the prediction of the social and economic indicators has been, and continues to be, a significant task for the UPSW research project. The methods are well founded in the peer-reviewed literature and the development process has itself been subject to review through engagement with fellow researchers in New Zealand and overseas. The methods are considered to be soundly based and able to play a highly informative role in the use of the DSS. They translate the environmental outcomes of urban development into implications for the community in a manner that avoids the requirement for deep scientific understanding. Consequently, they have the potential to be useful in both technical and consultation processes that require communication of the potential effects of urban development on receiving waterbodies.

However, it should be noted that the methods remain under development and that the Southern RUB study is the first real attempt at their application for operational purposes. Further testing and development is planned as we progress the development of the pilot DSS towards an operational tool. We therefore recommend that caution be applied in the interpretation and use of the results described in this section, noting in particular that:

- The need for local data collection in relation to the social indicators is currently under investigation. For the Southern RUB case study all underlying data supporting the prediction of these indicators has been generic (i.e. not place specific) in nature and may be limited in the extent of its application, although it was collected in a previous study in the Auckland region where there are strong similarities, but also differences between the study sites and this policy area under investigation. This is a key issue in making the UPSW tool widely applicable: to what extent is the relationship between levels of the stormwater related attributes and the satisfaction they engender similar between locations, or are they place specific for any given policy area?;

- The economic indicators are explicitly limited to the assessment of the costs of stormwater treatment and the benefits / losses of changes in the environmental characteristics of receiving water bodies: they do not attempt to assess any other development costs or benefits that are associated with the proposed changes under any given urban development scenario;
- The stormwater treatment costing model is based on data extracted from a range of stormwater catchment management plans (most of which are from the Auckland region) which has been manipulated to be generically applicable to assess the relative costs of different stormwater treatment options: again, we have not collected data relevant to the local catchment characteristics in the Southern RUB study area;
- The definition of the economic jurisdiction (the area over which the number of households is calculated) for the estimation of the quantum of the economic benefits indicator is currently under investigation;
- The system takes no account of potential infrastructure development to support the use of and relationships with the study area and adjacent waterbodies (e.g. coastal walkways, restoration, boat launching ramps) that have the potential to influence wiilingness-to-pay values or experienced utility scores.

In view of the stage at which these methods are at in the research and development process, we recommend that no weight be attached to the predicted absolute values of the social and economic indicators for assessing the merits of the various Southern RUB development scenarios. Instead, we recommend that any use of these results for the purposes of informing the Southern RUB investigations only consider the <u>relative</u> values of these indicators, meaning:

- The results predicted for one scenario relative to another, and
- In the case of the social indicators, results predicted at the end of the study timeframe relative to those predicted at the start.

5.2 Social indicators

5.2.1 Overview

For consistency with other international studies relating environmental quality to human use of water bodies, the definitions of the “functional” first four of the social indicators come from a typology of relationships that have their basis in the notion of an ascending hierarchy or “water quality ladder” of uses that reflect increasing environmental quality, in turn enabling expanding levels of ecosystem services. Table 5-1 gives examples of water body use according to this typology.

The final social indicator, sense of place, is a gauge of how changes in environmental quality that arise from the development scenarios impact how the community feel and think about a particular water body. Lower scores for this indicator relative to the baseline score indicate a decline in how community members relate to that water body.

Table 5-1 Examples of water body use relating to the four functional social indicators

Indicator	Example
Non-contact	Walking at water body margins
Partial contact	Boating, sailing, kayaking
Full contact	Swimming, surfing
Extraction	Fishing, shellfish harvesting

Indicator levels can take a value of between 1 and 5 inclusive. Levels of 1 and 5 indicate that the levels of the underlying environmental attributes predicted for a given ERU deliver the 'worst' and 'best' possible experience respectively for the given indicator.

Table 5-2 to Table 5-6 present indicator levels predicted at the start and end of the study timeframe under each scenario for the five social indicators that contribute to overall assessment of social wellbeing: extraction, contact recreation, partial contact recreation, non-contact recreation and sense-of-place. The key to Table 5-2 to Table 5-6 is:

1 (worst)	2	3	4	5 (best)

5.2.2 Social indicator levels

Indicator levels predicted for the start of the study timeframe fall in the range 1 (in ERUs 1, 2 and 7) to 4 (in ERUs 3, 4, 6). These differences reflect variances in baseline environmental characteristics (mud content, turbidity and ecological health), with the former three ERUs already relatively muddy and contaminated. In contrast, the better baseline conditions in the latter three ERUs means that the pilot DSS predicts that these parts of the harbour are currently relatively well suited to all four types of recreation and support a strong sense-of-place.

Under all scenarios indicator levels are predicted to either deteriorate over the study timeframe or stay the same (for instance, where they are already at the lowest level at the start of the study timeframe). The highest post-development indicator levels are a '3', predicted for ERU 6 (all indicators, all scenarios) and ERU 3 (non-contact and sense-of-place, scenarios 1 and 2E only).

Table 5-2 Predicted indicator levels for 'extraction' at the start and end of the study timeframe under all scenarios.

	Start (2012)	End of Study Timeframe (2062), by Scenario										
		1	2A	2B	2C	2D	2E	3	4	5	6	7
ERU1	2	1	1	1	1	1	1	1	1	1	1	1
ERU2	2	2	2	2	1	1	2	2	1	1	1	1
ERU3	4	3	2	2	2	2	3	2	2	2	2	2
ERU4	4	2	2	2	2	1	2	2	2	2	2	2
ERU5	2	1	1	1	1	1	1	1	1	1	1	1
ERU6	4	3	3	3	3	3	3	3	3	3	3	3
ERU7	1	1	1	1	1	1	1	1	1	1	1	1

Table 5-3 Predicted indicator levels for 'contact recreation' at the start and end of the study timeframe under all scenarios.

	Start (2012)	End of Study Timeframe (2062), by Scenario										
		1	2A	2B	2C	2D	2E	3	4	5	6	7
ERU1	1	1	1	1	1	1	1	1	1	1	1	1
ERU2	1	1	1	1	1	1	1	1	1	1	1	1
ERU3	4	3	2	2	2	2	3	2	2	2	2	2
ERU4	4	2	2	2	2	1	2	2	2	2	2	2
ERU5	2	1	1	1	1	1	1	1	1	1	1	1
ERU6	4	3	3	3	3	3	3	3	3	3	3	3
ERU7	1	1	1	1	1	1	1	1	1	1	1	1

Table 5-4 Predicted indicator levels for 'partial contact recreation' at the start and end of the study timeframe under all scenarios.

	Start (2012)	**End of Study Timeframe (2062), by Scenario**										
		1	2A	2B	2C	2D	2E	3	4	5	6	7
ERU1	2	1	1	1	1	1	1	1	1	1	1	1
ERU2	2	2	2	2	1	1	2	2	1	1	1	1
ERU3	4	3	2	2	2	2	3	2	2	2	2	2
ERU4	4	2	2	2	2	2	2	2	2	2	2	2
ERU5	2	1	1	1	1	1	1	1	1	1	1	1
ERU6	4	3	3	3	3	3	3	3	3	3	3	3
ERU7	1	1	1	1	1	1	1	1	1	1	1	1

Table 5-5 Predicted indicator levels for 'non-contact recreation' at the start and end of the study timeframe under all scenarios.

	Start (2012)	**End of Study Timeframe (2062), by Scenario**										
		1	2A	2B	2C	2D	2E	3	4	5	6	7
ERU1	1	1	1	1	1	1	1	1	1	1	1	1
ERU2	1	1	1	1	1	1	1	1	1	1	1	1
ERU3	4	3	2	2	2	2	3	2	2	2	2	2
ERU4	4	2	2	2	2	1	2	2	2	2	2	2
ERU5	2	1	1	1	1	1	1	1	1	1	1	1
ERU6	4	3	3	3	3	3	3	3	3	3	3	3
ERU7	1	1	1	1	1	1	1	1	1	1	1	1

Table 5-6 Predicted indicator levels for ‘sense of place’ at the start and end of the study timeframe under all scenarios.

		End of Study Timeframe (2062), by Scenario										
	Start (2012)	1	2A	2B	2C	2D	2E	3	4	5	6	7
ERU1	1	1	1	1	1	1	1	1	1	1	1	1
ERU2	1	1	1	1	1	1	1	1	1	1	1	1
ERU3	4	3	2	2	2	2	3	2	2	2	2	2
ERU4	4	2	2	2	2	2	2	2	2	2	2	2
ERU5	2	1	1	1	1	1	1	1	1	1	1	1
ERU6	4	3	3	3	3	3	3	3	3	3	3	3
ERU7	1	1	1	1	1	1	1	1	1	1	1	1

The following differences in indicator levels are predicted when comparing specific scenarios:

- Scenarios 2A to 2D (variations in stormwater treatment) – predicted levels are lower for some indicators in ERU 2 (extraction, partial contact) and ERU 4 (extraction, contact and non-contact) under Scenario 2D (worst case) and 2C (business as usual) than under other stormwater treatment scenarios.
- Scenarios 2A and 2E (variations in earthworks controls) – predicted levels for extraction, non-contact and sense-of-place in ERU 3 are higher under Scenario 2E (best earthworks, 90% sediment removal) than under Scenario 2A (75% sediment removal).
- Scenarios 3, 4, 5, 6 and 7 (additions to the Core) – predicted levels for extraction and partial contact in ERU 2 are lower under Scenarios 4, 5, 6 and 7 than under Scenarios 3 and 2A (Core). All other indicator levels predicted under Scenarios 3 to 7 are the same as those predicted under Scenario 2A.

5.2.3 Considerations for further development of the UPSW pilot DSS

When development results in effects on estuaries there are potentially losses and gains in wellbeing for communities. Where models can forecast environmental processes, it is possible in turn to forecast changes in wellbeing that result. The UPSW social indicators attempt to reflect those changes with a view to discriminating between alternate urban development scenarios.

There is much about the UPSW social indicators that is novel, and that in turn motivates caution in application to policy purposes at this stage of its development. Specifically, these novel aspects include: their definition based in terms of relationships with receiving water bodies; the use of the “experienced utility” concept to capture changes in values as the intensity of environmental variables change: and the data collection method based in workshop expert elicitation methods. Application of the UPSW tool to the southern RUB case study has reinforced that to progress from novel to accepted, there is effort required to validate the approach, to establish representativeness in the underlying data, and to test the role of coastal margin effects on relationships such as sense of place. While peer review to date has produced no insurmountable obstacles, it has been limited to international conference presentation and informal academic review. Publication in an international journal is required. Further interaction with AC end-users will provide further review and will help focus the tool in light of current contextual requirements.

Immediate priorities lie in understanding which, if any, of the relationships with the water bodies (e.g. full contact) can be understood in generic terms. Are the effect of changes in the intensity of the environmental attributes on satisfaction scores the same, or close to the same, independent of geographic context? For example, is the effect of increasing water turbidity on swimming quality place dependent? Many of the issues have resonance with issues in the benefit transfer process (see Section 5.3.4). What are the conditions necessary for effective value transfer? Current thinking leans toward a generic approach to the functional relationship indicators – contact, partial contact, non-contact, and extractive use – while the sense of place relationship indicator may be better treated as locale or regionally specific. This has implications for the way the tool is applied in each implementation.

The current phase of the UPSW research project is about making the DSS operational, so that it functions effectively, with data acquisition costs minimized. An action research process will deliver experience of implementation of the expert utility data collection process. For example, as a result of Royal Society resourcing, further investigations are currently testing devolution of the data collection method to a local researcher, with a school as the focus for populating and conducting "expert" workshops[11] from among the parents.

5.3 Economic indicators

5.3.1 Overview

Table 5-7 and Table 5-8 present the predicted scores for the economic costs and benefits indicators, respectively, of each scenario over the study timeframe. The indicator scores (the numeric values shown in each cell of the tables) presented here are normalised: that is they are expressed on a scale of 0 to 1 based on their relativity to maximum and minimum possible costs and benefits, respectively. Each indicator is expressed as a decimal resulting from a mathematical process, the Maxi-min method (Nardo et al., 2005).

In order to aid interpretation of these normalised scores, it is important to note that:

- The costs indicator reflects the estimated lifecycle costs of stormwater treatment for a specified level of treatment relative to the estimated maximum and minimum costs of all

[11] Thanks to Basil Sharp, University of Auckland, and Geoff Kerr, Lincoln University for introducing the technique

possible levels of treatment for the given scenario[12]. The higher the score, the lower the life-cycle cost of stormwater treatment.

- The benefits indicator reflects the estimated change in monetised environmental benefits associated with the scenario relative to the estimated maximum and minimum benefits of all possible scenarios. The monetary values result from benefit transfer of outcomes of a non-market valuation study conducted in the Auckland region in 2008 (Batstone et al., 2010). Benefits can be negative (in which case they are better described as environmental losses), reflecting situations in which the environmental attributes[13] from which the benefits are calculated are predicted to decline from their current state. A normalised score of greater than 0.5 indicates a net benefit (the larger the score, the greater the benefit) while a normalised score of less than 0.5 indicates a net loss (the smaller the score, the greater the loss).

To simplify communication of the outcomes, the normalised indicator scores are also translated into indicator levels defined numerically and visually through a colour identification scheme. As with the social indicators, these indicator levels can take a value of between 1 and 5 inclusive with each level representing a quintile of the range of the normalised scores. A normalised score of 0.35, for instance, falls within the range of the second to lowest indicator level (0.2 – 0.4). Table 5-7 and Table 5-8 represent indicator levels using the same colour-coding as that described above in relation to the social indicators:

1 (worst)	2	3	4	5 (best)

In relation to the costs indicator, levels of 1 (red) and 5 (dark green) indicate that costs are relatively very high and very low, respectively. For the benefits indicator, a level of 3 (yellow) indicates a neutral outcome (no change in benefits over the study timeframe), levels of 4 and 5 indicate a net environmental benefit and levels of 1 and 2 indicate a net environmental loss.

As the results presented in Table 5-7 and Table 5-8 show, this system of indicator levels can mask differences in the underlying scores for the costs and benefits indicators. For example: the economic costs indicator is at level 5 (best outcome) in all ERUs under all scenarios, with the exception of Scenario 2B. This masks the fact that the normalised cost scores vary between 0.801 (at the very bottom of the level 5 range) and 1.0 (at the very top of the level range). The interpretation of these economic indicators is therefore aided by "drilling down" to the normalised

[12] As well as the level of treatment, the calculation of the lifecycle cost is also influenced by the extent of Low Impact Design (LID) development applying in a given scenario. The specification of LID development prompts the lifecycle costing model to calculate costs based on more expensive 'at source' rather than 'end of pipe' treatment devices (Ira, 2012).

[13] Turbidity, underfoot condition (or % mud) and ecological health.

scores to make comparison of both the levels and underlying normalised scores predicted for different scenarios.

Table 5-7 Predicted scores and levels for the economic costs indicator over the study time under all scenarios by ERU.

	Scenario										
	1	2A	2B	2C	2D	2E	3	4	5	6	7
ERU1	0.982	0.807	0.449	0.956	1.000	0.807	0.806	0.803	0.803	0.802	0.801
ERU2	0.982	0.807	0.449	0.956	1.000	0.807	0.806	0.804	0.803	0.802	0.802
ERU3	0.982	0.807	0.449	0.956	1.000	0.807	0.806	0.804	0.803	0.802	0.802
ERU4	0.982	0.808	0.453	0.956	1.000	0.808	0.807	0.807	0.803	0.802	0.803
ERU5	0.982	0.807	0.450	0.956	1.000	0.807	0.806	0.806	0.803	0.802	0.803
ERU6	0.982	0.806	0.447	0.956	1.000	0.806	0.805	0.805	0.803	0.802	0.803
ERU7	0.982	0.807	0.449	0.956	1.000	0.807	0.806	0.804	0.803	0.802	0.801

Table 5-8 Predicted scores and levels for the economic benefits indicator over the study time under all Scenarios by ERU.

	Scenario										
	1	2A	2B	2C	2D	2E	3	4	5	6	7
ERU1	0.391	0.391	0.457	0.391	0.324	0.391	0.391	0.391	0.391	0.391	0.391
ERU2	0.500	0.500	0.500	0.434	0.391	0.500	0.500	0.391	0.457	0.391	0.391
ERU3	0.433	0.379	0.379	0.313	0.313	0.433	0.379	0.379	0.379	0.379	0.313
ERU4	0.313	0.270	0.270	0.270	0.204	0.313	0.270	0.270	0.270	0.270	0.270
ERU5	0.380	0.380	0.380	0.380	0.314	0.380	0.380	0.380	0.380	0.380	0.380
ERU6	0.366	0.366	0.366	0.366	0.366	0.366	0.366	0.366	0.366	0.366	0.366
ERU7	0.434	0.434	0.500	0.434	0.434	0.434	0.434	0.434	0.434	0.434	0.434

5.3.2 Costs

There is a lack of discrimination between the levels predicted for the costs indicator under all but one of the scenarios. For scenarios 2A, 3, 4, 5, 6 and 7 this is because these scenarios all involve an identical level of stormwater treatment (current standard). While the estimated lifecycle costs vary between these scenarios in proportion to the areas to be developed, when normalised in relation to the maximum and minimum costs possible for each scenario, the resulting scores are virtually identical.

Focusing on Scenarios 2A to 2D (where the level of stormwater treatment varies) the normalised indicator scores show that, as might be expected, the predicted costs of stormwater treatment increase from Scenario 2D (worst case) to 2B (best case). The predicted costs of stormwater treatment under Scenario 2B are markedly higher than under any other scenario, such that they result in an indicator level of 3, two levels lower than under any other scenario.

The high score for the costs indicator in all ERUs, other than under scenario 2B, is an artefact of the method by which the costs predicted by the lifecycle costing model are normalised. As noted above, this normalisation is based on the costs of the maximum and minimum possible costs of stormwater treatment under a given scenario. In the lifecycle costing model used by the pilot DSS, the maximum costs are those that would be associated with the highest level of stormwater treatment and LID land use across the full area developed under a given scenario. With an alternative method of normalisation (for instance adopting some other upper cost limit) there is potential for the system to provide greater discrimination between cost indicators predicted for different scenarios.

5.3.3 Benefits

In most ERUs the benefits indicator is at the second to lowest level under all or most scenarios. This indicates that benefits are predicted to be negative, reflecting the fact that the environmental attributes from which the benefits are calculated are predicted to decline from their current state under all scenarios in most ERUs.

In ERU7 and ERU2 (under most scenarios), the benefits indicator is predicted to lie in the level 3 (neutral benefits) range. Mostly, this is because while the predicted benefits are negative (normalised score of less than 0.5), they remain within the 0.4-0.6 range that assigns them to level 3. In ERU2, however, a truly neutral score of 0.5 is predicted under a number of scenarios. This prediction of a neutral benefit results when there is insufficient change in the precursor environmental attributes (underfoot condition, turbidity and ecological health) between the start and end of the study timeframe to trigger a change between the discrete classes of these attributes that were used in the original data collection exercise (see Batstone et al., 2008).

Focusing on Scenarios 2A to 2D (variation in stormwater treatment), the normalised scores are generally consistent with greater environmental losses occurring in relation to lower levels of stormwater treatment. Scores under Scenario 2D (worst case stormwater treatment) are typically the lowest of any scenario. However, it is not the case that scores under Scenario 2B (best case stormwater treatment) are typically the highest under any scenario. In five ERUs, the normalised score for the benefits indicator is identical under Scenarios 2B and 2A (current standard). This indicates that the differences between the precursor environmental attributes predicted in these ERUs are insufficient to translate into difference in the benefits score and provides an interesting contrast with the costs indicator. As noted above, costs under Scenario 2B are predicted to be markedly higher than under any other scenario but these costs do not translate into marked differences in the level of the environmental benefits indicator.

There is only limited discrimination between benefits scores predicted under the centre south and northern additions to the core. As described in Chapter 4.0, the centre-south additions (Scenarios 3, 5 and 6) are generally predicted to have greater impacts on environmental indicators in eastern estuaries while the northern additions (Scenarios 4 and 7) were generally predicted to have greater impacts on environmental indicators in western estuaries. In five of the seven ERUs the predicted benefits score is identical across all of Scenarios 3 to 7. In two of the western estuaries (ERUs 2 and 3), there are differences between the benefits score predicted under some of the centre-south and northern additions to core (and these are consistent with expectations based on differences in environmental indicators). However, the general lack of discrimination in the benefits score indicates that the differences between the precursor environmental attributes predicted in these ERUs are insufficient to translate into difference in the benefits score. There is potential to address this through the further development of the benefits indicator, for instance by reporting the predicted dollar value of the monetised environmental benefits.

5.3.4 Considerations for further development of the UPSW pilot DSS

The economic benefits indicator reflects the changes in values that result from development effects on estuary water bodies. The quantum of benefits and losses generated by stormwater management has been established in a previous study using the benefits transfer process. As the study site(s) and study population are comparable, and the timing of the study relevant, the transferred values are likely to be representative of the southern RUB areas under consideration. The predicted benefit changes are limited to, and reported here as, indicators because (1) the data that informs this part of the study came from a methods investigation, (2) a benefits transfer process has been used, and (3) issues of scope, scale and the specification of economic standing remain to be resolved. The reporting of dollar values for each scenario goes beyond the original scope of the UPSW project, which was conceived as expressing outcomes in terms of sustainability indicators. The indicators are reported to three decimal places: this level of precision may appear unwarranted but it gives an indication as to the potential discriminatory power of the system.

The information basis of the benefits indicator was derived as willingness to pay (WTP) estimates for environmental change expressed in dollars per household. The study area was the greater Auckland region, the study population broadly representative of the region in census terms. The UPSW benefits indicators are a reflection of these per household WTP data. Greater discrimination between scenarios and estimates of potential mitigation expenditure may be achieved through (1) resolution of cross-scale and scope effects, and (2), defining the relevant economic jurisdiction to allow indicators that reflect aggregated benefits and losses. The key to the latter lies in deriving a workable method to define which households have standing in enjoying the benefits or being compensated for the losses that arise from changes to environmental quality and the associated provision of ecosystem services. Addressing the former lies in translating the values transferred from a per household basis to a “per household per unit area of estuary habitat”.

With those limitations in mind, the following is relevant. There is internal consistency evident in the movement of the benefits indicator in response to changes in levels of stormwater treatment and the resulting changes in the environmental precursors that comes about under each scenario. The relative magnitude of the indicators communicates the degree of change from the baseline urban state (i.e. start of the study timeframe), thus allowing a constrained discrimination between the scenarios.

Similar comments, although not as extensive, may also be directed at the current capacity of the costs indicator to discriminate between urban development scenarios. The reported indicator under its current configuration is limited in its utility to differentiate, and further effort should be expended on its shortcomings (see above).

This case study has been very useful in signalling the directions for making the tool operational that are described above. The system works, with the key connection between biophysical and socio-economic domains able to pass information to motivate the economic indicator. Believable, and anticipated changes in the socio-economic domain are generated in each scenario. Directions for future research lie in improving the precision and reliability of input data. Consideration should be given to undertaking a site specific estimation of the monetised benefits and losses for each implementation. Refinements in sample formation, internet data collection, efficient statistical design, and econometric estimation mean the choice experiment approach to non-market valuation is less resource intensive and more believable. This would remove reliance on uncertain benefit transfer information, and reflect changes to Auckland population. Standard assumptions should be adopted around “economic standing”, for example aligning the distribution of benefits with that of costs.

6.0 Discussion

6.1 Introduction

This chapter discusses the implications of the results of this study for planning and managing existing use and future development in the Southern RUB area, focusing on the environmental indicators described in Chapter 4.0.

6.2 Summary of predictions

6.2.1 Effect of the three major development scenarios using the same controls

Three major combined scenarios for the southern RUB have been released for consultation in the March 2013 draft of the Auckland Unitary Plan – a ‘Pukekohe focus’, a ‘Corridor focus’ and a ‘West-East focus’. These scenarios equate to the modeled Scenarios 5, 6 and 7 as outlined below:

1. Pukekohe focus = Scenario 5 (Core plus Pukekohe North-east, West and South-east areas)
2. Corridor focus = Scenario 6 (Core plus Pukekohe North-east, South-east and Whangapouri and Paerata North areas)
3. West-East focus = Scenario 7 (Core plus Karaka North and Karaka West areas)

A summary table of inputs used and contaminant loads estimated by the UPSW pilot DSS for the three major scenarios is provided in Table 6-1.

Table 6-1 Summary of overall inputs used and estimated contaminant loads generated over the 50-year study timeframe for the three major scenarios. Sediment, zinc and copper loads shown are ‘post-treatment’ values using 75% TSS removal for earthworks and 75% TSS removal and medium metals removal for stormwater. Figures in brackets are per cent of total study area (sum of PLUs 1 to 9).

Scenario name	Scenario number	Development area modelled (ha)	New dwellings	Sediment (kT)	Total Zinc (t)	Total Copper (t)
Pukekohe focus	5	5198 (19.6%)	51172	254	47.5	9.35
Corridor focus	6	5909 (22.3%)	59561	262	50.9	9.86
West-East focus	7	5734 (21.6%)	57365	257	48.3	9.46

Based on the modeling results all three major scenarios are predicted to have a significant effect on the estuarine receiving environment over and above the effects from the baseline scenario if current earthworks and stormwater treatment controls (or worse) are applied. However, as detailed in the following section much of the effect from the three major development scenarios could be mitigated if the best available earthworks and stormwater treatment controls are applied. Therefore, adopting the assumption that the same earthworks and stormwater controls would be applied to whichever scenario is adopted, is there an appreciable difference in predicted effects on the estuarine receiving environment between the three scenarios?

The first caveat to note is that the environmental wellbeing section of this study only considers effects on receiving environment muddiness and metal level-related indicators. The full spectrum of uses and values of the different subestuaries assessed in this study (such as habitat provision, natural character and recreational use etc.) would also need to be taken into account before a comprehensive comparison between the different scenarios could be made. Therefore, while some indicators are presented for predicted social and economic outcomes in 5.0, a full assessment of all the uses and values of the subestuaries investigated is beyond the scope of the current study. The second caveat to note here is that the current study presents results from a very broad scale modeling assessment and therefore any results should only be considered as indicative and broadly relative between scenarios rather than highly accurate or absolute. Furthermore, it should be noted that the current study has made predictions about receiving environment health over a 50-year timeframe and that any differences in results for different scenarios may become more accentuated over a longer period. This is most likely to be the case where results follow diverging trajectories at the end of the 50-year study timeframe (i.e. the difference between the results for one scenario and another is increasing). Where results have previously diverged but are following approximately parallel or converging trajectories by the end of the 50-year period (for instance predictions of mud content), then it is reasonable to expect differences between these results to stay approximately the same or become less over a longer timeframe. It should be noted, however, that these statements are based on the assumption of no further development in the study area (i.e. land use and stormwater management remains unchanged beyond the 50-year study time frame).

Bearing in mind the caveats given above a spatial difference in the predicted effects between the scenarios is evident. Essentially Scenarios 5 and 6 are predicted to have a greater effect on eastern subestuaries (ERUs 4, 5 and 6) than Scenario 7, while Scenario 7 is predicted to have a greater effect on western subestuaries (ERUs 1, 2, 3 and 7) than Scenarios 5 and 6. The effects of Scenarios 5 and 6 are also predicted to be more acute in eastern subestuaries, while the effects of Scenario 7 are predicted to be relatively evenly distributed across both eastern and western subestuaries. This is because the bulk of the development in Scenarios 5 and 6 would occur in catchments draining to eastern subestuaries, while the development in Scenario 7 would be spread over a larger number of catchments draining to a larger number of subestuaries. Note here that Scenario 6 is also predicted to have a greater overall affect than Scenario 5, as Scenario 6 covers a greater land area and includes a greater number of dwellings. However, land area and number of dwellings are comparable between Scenario 6 and 7 (Scenario 6 is only slightly greater in both regards).

Given that effects will be distributed differently under the different scenarios are there also differences in the current environmental state of the various subestuaries that the scenarios will affect? While all subestuaries have current BHMmetal scores of 3 there are differences in muddiness between them. Western subestuaries 1, 2 and 7 are currently muddier (80-90% mud content) than eastern subestuaries 4 and 6 (20 and 23% muddiness respectively). This translates into predicted BHMmud scores that are currently worse in western subestuaries than in eastern subestuaries. Therefore Scenarios 5 and 6 are predicted to have more of an impact on subestuaries that are currently relatively healthy compared to the subestuaries which will be more impacted by Scenario 7.

It should also be noted that while Scenario 7 is not predicted to have a significant effect on the Hikihiki bank (which is outside the area modeled in this study), a greater proportion of sediment and associated metals is predicted to be discharged outside the study area under scenario 7, further extending the potential footprint of development effects from Scenario 7 into the wider Manukau Harbour.

6.2.2 Effect of the core scenario vs. the baseline with different earthworks and stormwater controls

Current AC guidelines relating to earthworks and stormwater treatment aim for the removal of 75% total suspended solids (TSS). While best attempts may be being made to meet this target, recent studies have shown that this target is not always met (Moores and Pattinson, 2008; Moores*, et al.* 2009; Moores*, et al.* 2012b). Given this, the results of development Scenarios 2A to 2E (Core with different earthworks and stormwater treatment) reveal that even if current required levels of earthworks and stormwater treatment were achieved this would still be insufficient to prevent substantial additional sediment and metal-related impacts on the receiving environment over and above those predicted from the current baseline scenario. In contrast, it is evident that muddiness, SARs and therefore also BHMmud scores could be maintained at similar levels to the baseline scenario predictions if the best available earthworks controls (90% TSS removal) were achieved. Furthermore, sediment metal levels (and therefore BHMmetal levels) could also be maintained at similar levels to the baseline scenario predictions if the best available stormwater treatment (90% TSS removal, high metals removal) was also achieved.

However, the assessment reported in Chapter 5.0 has not demonstrated whether or not it would be possible to achieve these mud-related and metal-related outcomes simultaneously, because it did not consider a scenario in which both the best available stormwater treatment and best available earthworks controls were applied. Re-running the pilot DSS with one or more further scenarios involving the best available of both of these management measures would therefore be required to investigate the potential for the combination of outcomes described above. It is also of note that the greatest proportion of the increase in muddiness in the receiving environment over the study period is driven by existing land use rather than the developed area. This highlights the need for additional catchment management beyond the area to be developed if the sliding baseline of effects discussed in the section below is also to be addressed. The ecological significance of these outcomes is discussed in sections 6.4 and 6.5.

When comparing results for the different earthworks and stormwater treatment options it is interesting to note that if the best available earthworks controls (90%TSS removal) are used but only standard stormwater controls (75% TSS and ‘medium’ metals removal) are used, then a slight increase in sediment metal levels is predicted over using standard earthworks controls (see results for Scenario 2E). This is because there is essentially less sediment available to 'dilute' the metals in the stormwater. These feedback mechanisms are important to consider when deciding which earthworks or stormwater controls to apply.

6.3 Discussion of the current 'sliding baseline' for this area

Based on the results of both the SEM study (Green 2008b, c; see Section 2.3) and the current study there is predicted to be a substantial underlying increase over the study timeframe in sediment accumulation rates, muddiness, and sediment metal levels (and therefore a decline in associated benthic health rankings) in all subestuaries regardless of whether any extra development goes ahead in this area. This means that this area is subject to a 'sliding baseline' of underlying effects and any new development in the area will have effects in addition to this sliding baseline. Underlying increases in muddiness are primarily predicted to be driven by ongoing rural land use in the southern and western catchments, while underlying increases in sediment metal levels are predicted to be predominantly driven by existing urban land use in the northern and eastern catchments of the SE Manukau Harbour.

6.4 Relevant environmental thresholds

A number of environmental indicator results are produced by the UPSW pilot DSS and are presented in the result section. In order to put these results in a context relevant to the predicted outcomes for the receiving environment, information is provided in the following subsections on environmental thresholds that can be applied to the indicator results.

6.4.1 Metal thresholds

The sediment quality guideline (SQG) utilized in the indicator results section for metals is the 'Threshold Effects Level' or TEL. The justification for using this guideline and its ecological relevance are discussed below and in the following section. Further SQGs relevant to the TEL are also summarised in Table 6-2.

Table 6-2 Environmental Response Criteria (ERC) and associated sediment quality guidelines (SQGs) along with their positions along the PC 1.500 axis from Anderson, *et al.* (2006). Units are mg/kg dry weight for copper, lead, and zinc.

	ERC (ARC 2004a)			MacDonald et al. (1996)		Long et al. (1995)		ANZECC (2000)	
	Green	Amber	Red	TEL	PEL	ERL	ERM	ISQG-Low	ISQG-High
Copper	<19	19–34	>34	18.7	108.2	34	270	65	270
Lead	<30	30–50	>50	30.2	112.2	47	218	50	220
Zinc	<124	124–150	>150	124	271	150	410	200	410
PC 1.500	<0.782	0.782-1.540	>1.540	0.776	3.035	1.500	4.208	2.090	4.213

Each set of SQGs provides:

- a lower range of contaminant concentrations (TEL, ERL, or ISQG-Low), below which adverse effects on benthic ecological health from an individual contaminant are unlikely to occur; and
- a higher range of contaminant concentrations (PEL, ERM, ISQG-High), above which marked adverse effects on a substantial proportion of benthic species are expected from an individual contaminant.

The MacDonald*, et al.* (1996) guidelines are the “Threshold Effects Level” (TEL) and “Probable Effects Level” (PEL). The Long*, et al.* (1995) guidelines are the “Effects Range Low” (ERL) and “Effects Range Median” (ERM). ANZECC (2000) provides “Interim Sediment Quality Guideline – Low” (ISQG-Low) and ISQG-High.

The TEL and PEL guideline values were derived from toxicological studies that included both “effect” and “no-effect” results on test organisms for each individual contaminant. In most cases the ‘effects plus no-effects’ guideline values tend to be more conservative (i.e. protective) than guideline values based on effects data alone (e.g. ERL and ERM values). This is consistent with the use of guidelines as an early warning of environmental degradation, which allows time for investigations into the causes of contamination to be carried out and options for limiting the extent of degradation to be developed. Hence, the green/amber threshold from the former Auckland Regional Council’s Environmental Response Criteria (ERC) ‘traffic light’ system (ARC 2004) is based on the TEL.

The amber/red ERC threshold is also based on the ERL. The ERL is still a relatively sensitive SQG, with contaminant concentrations well below those at which “marked adverse effects” (e.g. PEL or ERM) would be expected to occur from an individual contaminant.

In summary, ERC Green conditions (<TEL) reflect a relatively low level of impact based on an individual contaminant. ERC Amber (>TEL but <ERL) conditions reflect contamination above a level at which adverse effects on benthic ecology may begin to show (the TEL), and ERC Red conditions (>ERL) reflect conditions where significant degradation has already occurred.

While the guidelines outlined above are useful for assessing the effects of individual contaminants they do not take into account the cumulative effects of multiple contaminants present at the same time. Hence the Benthic Health Model metals (BHMmetals) was developed for Auckland marine environments to provide a measure of ecological health in relation to contamination that takes into account the effects of copper, lead and zinc simultaneously (Anderson*, et al.* 2006). Figure 6-1 outlines how the five ecological health groups from the BHMmetals compare to guideline values when copper, lead and zinc values are combined. Benthic health groupings are as follows: 1 = excellent, 2 = good, 3 = moderate, 4 = poor, 5 = unhealthy. Given that ecological effects have been shown to occur below the TEL (Anderson*, et al.* 2006, Hewitt*, et al.* 2009), the TEL is a recommended threshold below which sediment metal levels should be maintained. Hence, the TEL is the guideline presented on graphs in this report. Further information on associated benthic ecology thresholds is given in the following section.

6.4.2 Benthic ecology (metals) thresholds

From Figure 6-1, it is clear that the ISQG-High, ERM and PEL guidelines indicate very high levels of pollution that all surpass significant ecological effect measures from studies within the Auckland Region (Anderson*, et al.* 2006, Hewitt*, et al.* 2009). BHMmetals groups 4 and 5 even occur at slightly lower values along the pollution gradient than the TEL and ERL guidelines (Figure 6-1). The BHMmetals groupings also provide further discrimination at the lower end of the scale, suggesting that benthic health can be affected below the TEL. Therefore, the BHMmetals groupings can provide earlier warning signs of pollution than is possible from sediment quality guidelines alone.

While sites in benthic health metals groups 1 or 2 can be considered healthy, changes in community structure can already be detected within these groups. Furthermore, recent work on the development and implementation of a functional traits based index (the TBI – a measure of the number of different ecological functions carried out by the species present) indicates that the resilience of an ecosystem becomes compromised around benthic health group 4 and that very little if any resilience to further stressors is left in the system once benthic health group 5 is reached (Lohrer and Rodil 2011). Therefore, from the perspective of both health and resilience, BHMmetals scores of 4 and 5 should be avoided, especially group 5. As an ecosystem becomes more degraded it is also likely to become more difficult to restore that environment (a phenomenon termed restoration hysteresis) (Anderson*, et al.* 2006, Hewitt*, et al.* 2009). Therefore, benthic health group 3 can be considered a “critical” group and may warrant the greatest attention with respect to protection and potential remedial management action (Anderson*, et al.* 2006).

Decreases of >25% in raw BHM scores (i.e. equivalent to dropping from the middle of one benthic health group to the middle of the next group) are also considered significant from an ecological perspective. Therefore, areas showing rapid change of this magnitude, even at the healthier end of the scale, should also be of concern (Anderson*, et al.* 2006, Hewitt*, et al.* 2009, Hewitt*, et al.* in prep).

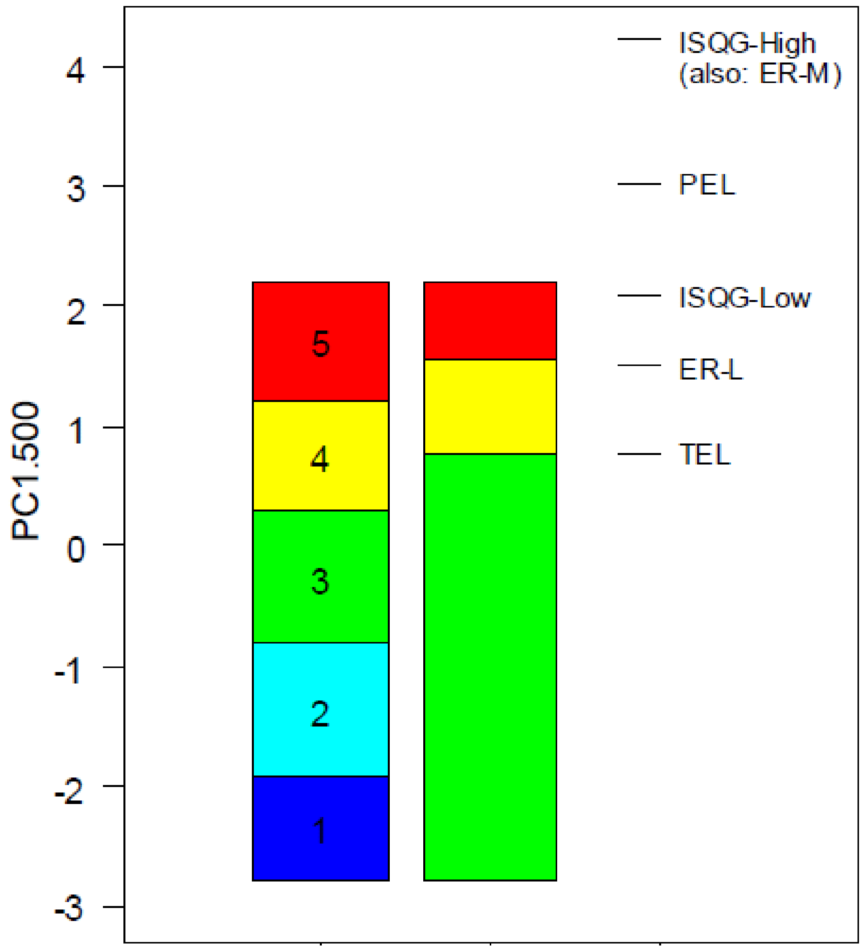


Figure 6-1 Benthic health groupings vs. sediment quality guidelines (given in Table 6-2). The first bar shows the five groups from the benthic health model along the pollution gradient for the combined metals copper, lead and zinc (PC1.500). The second bar shows the environmental response criteria (ERC) as green, amber and red. Other guidelines are shown as single values along the axis.

6.4.3 Muddiness and sediment accumulation rate (SAR) thresholds

Muddiness

Based on findings from the BHMmud and the new TBI, negative shift changes in ecological health and function can occur around 10%, 25% and 60% muddiness (Hewitt*, et al.* in prep, Lohrer and Rodil 2011) (see also Figure 6-2). However, these numbers should just be considered as a guide as different benthic communities can respond to the same level of muddiness in different ways. This is highlighted by the range of health groupings that fall out against different levels of muddiness in Figure 6-2. That said, as with the BHMmetals thresholds, the latter muddiness thresholds of 25% and 60% should be avoided, especially 60%. As these later thresholds are breached, ecosystem resilience is likely to become compromised and restoration potential more unlikely (Hewitt and Ellis 2010, Hewitt*, et al.* in prep, Thrush*, et al.* 2004). The later muddiness threshold of 60% also aligns with the BHMmud group 4 boundary (the BHMmud index uses the same scale as the BHMmetals but relates effects to muddiness rather than metals – see Hewitt and Ellis (2010)). Therefore, as for the BHMmetals, BHMmud group 3 can also be considered a “critical” group and may also warrant the greatest attention with respect to protection and potential remedial management action (Hewitt*, et al.* in prep).

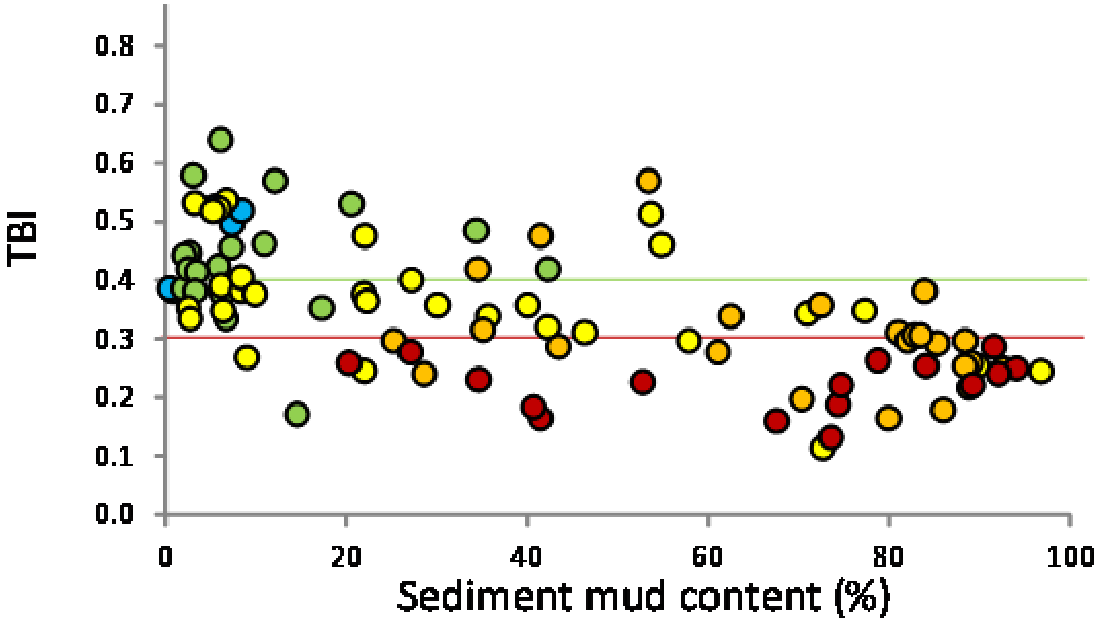


Figure 6-2 Plot of TBI scores versus sediment mud content. The colours of the dots refer to BHMmetals groups as follows: Blue = excellent, green = good, yellow = moderate, orange = poor, red = unhealthy. Note the range of health groupings that fall out against different levels of muddiness.

Sediment Accumulation Rate (SAR)

Based on results from multiple studies across the Auckland region, SARs in low energy estuarine receiving environments in pre-European times were likely in the range of 0.2 to 0.8 mm/yr (Oldman*, et al.* 2009, Swales*, et al.* 2002). Therefore, maintaining a SAR of <1mm/yr is recommended in order to not exceed SARs that benthic communities have naturally evolved to cope with (see Gibbs and Hewitt 2004 and references therein). Rapid per cent increases in SAR (especially in the muddy sediment fraction) or sediment deposition events during storms should also be avoided, as many species struggle to adapt to sudden or rapid changes in sediment exposure (Thrush*, et al.* 2004). Furthermore, increases in SAR on intertidal sand flat areas may make those areas more suitable for mangrove expansion (Swales*, et al.* 2009).

While the UPSW pilot DSS can predict long-term average annual sedimentation rates it cannot predict the occurrence of ‘one off’ sediment events such as could result from a significant storm event or the failure of a treatment pond during the earthworks phase. This is an important point as in the marine environment sediment deposition events of 10 – 20 mm or more are considered catastrophic, whereby the smothered area quickly becomes anaerobic and results in the death of resident benthic fauna (Thrush*, et al.* 2004). Although a deposit 20 mm thick would normally represent many times the long-term average annual sedimentation rate, events of greater magnitude are known to occur (Thrush*, et al.* 2004). Furthermore, as little as 3 mm in one deposition event is enough to alter benthic community structure, including reducing the number of taxa, the density of individuals, and the densities of some common species (Lohrer*, et al.* 2004). Ten days after a 7 mm deposition event experimental plots had also lost approximately 50% of their individuals and species (Lohrer*, et al.* 2004). Recovery from these deposition events can also take a long time (i.e. greater than one year) and if another event occurs before the area has recovered, then effects can be cumulative (Thrush*, et al.* 2004). Therefore, despite the current tool not being able to predict one-off sediment events, another threshold that should be avoided is sediment deposition events of 3 mm or more, and the frequency of any deposition events should be less than once every few years (Thrush*, et al.* 2004).

6.5 Summary of predicted outcomes based on assessment against thresholds

In order to compare ecological outcomes between scenarios and between different levels of treatment a summary of outcomes is provided below based on the number of thresholds breached for the BHMmetals, SAR and muddiness indicators. Note that the current study has made predictions about receiving environment health over a 50 year timeframe and that any differences in the results predicted for different scenarios may become more or less accentuated (or stay the same) over a longer period (see Section 6.2.1).

The **current state** of the study area in regard to thresholds is predicted to be as follows:

- All subestuaries currently have BHMmetals rankings of 3;
- All subestuaries have already breached the 10% muddiness threshold, all subestuaries except 4 and 6 (eastern) have breached the 25% muddiness threshold and subestuaries 1, 2 and 7 (western) have breached the 60% muddiness threshold. Subestuary 5 is currently at 60% muddiness.

Based on the predictions from the current study and the predictions from the previous SEM study (Green 2008b, c), several thresholds are predicted to be breached over the next 50 years even **under the baseline scenario** i.e.

- BHMmetals is predicted to decline from group 3 to group 4 in five out of seven subestuaries (see Table 4-2);
- SARs are predicted to be >1 mm/yr in six out of seven subestuaries and >2 mm/yr in two out of seven subestuaries; SARs are also predicted to increase by 7-9% over the historic rates (last 50 years) estimated in the SEM study (see Table 4-4).
- Muddiness is predicted to be >25% in all subestuaries and greater than 60% in four out of seven subestuaries (see
- Table 4-3).

If **current earthworks and stormwater controls (or worse)** are used for any new development, even just with the Core area developed (Scenario 2), then the following additional thresholds are predicted to be breached:

- BHMmetals is predicted to be reduced to group 5 in up to three subestuaries,

- SARs are predicted to be >1 mm/yr in all subestuaries and are predicted to be > 2 mm/yr in up to three out of seven subestuaries; SARs are also predicted to increase by between 13-45% over the baseline scenario.
- Muddiness is predicted to be slightly worse in all subestuaries than under the baseline scenario, but no extra thresholds are predicted to be breached.

However, if the **best available earthworks and stormwater controls** are used for the Core scenario then threshold exceedances are predicted to be similar (or possibly slightly better) than under the baseline scenario. That is:

- BHMmetals rank is predicted to decline from group 3 to group 4 in three out of seven subestuaries;
- SARs are predicted to be >1 mm /yr in five out of seven subestuaries and >2 mm/yr in two out of seven subestuaries; SARs are also predicted to decrease by between 2-4% from the baseline scenario.
- Muddiness is predicted to be slightly better than under the baseline but still >25% in all subestuaries and greater than 60% in four out of seven subestuaries.

In regard to outcomes from the **three major scenarios** it should be noted that modelling of these scenarios was undertaken assuming current treatment guidelines apply (i.e. 75% TSS removal for earthworks and 75% TSS removal and medium metals removal for stormwater). If the best available controls were used, then threshold exceedances are likely to be held at similar levels to those predicted under the baseline scenario and under the Core scenario using the best available controls. Also note that a larger area and a greater number of dwellings are proposed under Scenarios 6 and 7 than under Scenario 5 (see Table 6-1). Predicted outcomes based on current controls are as follows:

- The BHMmetals group 4 threshold is predicted to be breached in all subestuaries under Scenario 7, six out of seven subestuaries under scenario 6 and five out of seven subestuaries under Scenario 5.
- SARs are predicted to be >1 mm/yr in all subestuaries under all scenarios; SARs are predicted to be > 2 mm/yr in a greater number of western subestuaries under Scenario 7 and a greater number of eastern subestuaries under scenarios 5 and 6; SARs are predicted to increase by between 19-47% over the baseline scenario with spatial differences between the scenarios as previously described.
- Muddiness is predicted to be slightly worse in all subestuaries than under the baseline scenario and the 60% muddiness threshold is also predicted to be breached in subestuary 4 across all scenarios.

6.6 Examples of urban development outcomes in other areas

There are many estuarine receiving environments in the Auckland region that are highly degraded as a result of historic and ongoing urban development. High concentrations of metals, mud and other contaminants (and subsequent poor ecological health) are evident in many muddy upper estuarine areas receiving runoff from older urban and industrial catchments (Hewitt, et al. in prep, Mills, et al. 2012). For example, estuaries along the southern shores of the Waitemata Harbour from Henderson Creek to Coxs Bay (including Whau, Motions, and Meola estuaries), Hobson Bay (Purewa), the upper reaches and side-branches of the Tamaki Estuary (e.g. Middlemore, Panmure, Otahuhu, and Pakuranga) and Mangere Inlet in the Manukau Harbour (Hewitt, et al. in prep, Mills, et al. 2012). In these areas contamination gradients generally extend out from upper estuary settling zones (where concentrations are highest and ecology is poorest) into adjacent outer estuary zones. As these areas are further developed and intensified, or where the estuary has become in-filled, the footprint of effects can also extend well beyond the confines of the estuary (Green 2008d, e). For example: Henderson Creek, Whau estuary and the Upper Waitemata Harbour contribute a significant proportion of the sediment (and associated contaminants) that is deposited in Shoal Bay at the entrance of the Waitemata Harbour (Green 2008d, e).

Lucas Creek estuary also provides an example of outcomes from more recent urban development. An evaluation of land use change in the wider Upper Waitemata Harbour catchment since ecological monitoring began in this area in 2005 shows that the greatest degree of land use change has occurred within the Lucas Creek catchment (Miller*, et al.* 2008) (Fredrickson, pers. comm.). Building consent data reveals that approximately 3650 residential and 450 non-residential buildings (4100 total) were consented in this catchment between 2005 and 2012. During this time, there has also been a significant increase in mud content at monitoring sites in the Lucas Creek estuary (Townsend*, et al.* 2012). Associated benthic community changes in the estuary have also seen sediment tolerant species increase (e.g. *Heteromastus*) while sediment sensitive species have declined (e.g. *Nucula* and the cockle *Austrovenus*) (Townsend*, et al.* 2012). Increases in sediment metal concentrations are also predicted to follow these increases in muddiness as the development phase gives way to the post-development urban stormwater phase (Green*, et al.* 2004).

These examples all suggest that historic and current land development controls were not, and are still not, sufficient to prevent adverse effects on the receiving environment. This conclusion is also borne out by the findings from the current study. In addition to this, the scale of the proposed development in the southern RUB area is probably greater than any level of development the Auckland region has experienced in recent times. This is significant because as the scale of the proposed development increases, so too does the risk that the development will have effects beyond those experienced during previous episodes of urban expansion.

7.0 Recommendations

This chapter provides recommendations arising from the results of this study in relation to the planning and management of existing use and future development in the Southern RUB area. There are several caveats that should be taken into account when considering the recommendations that follow:

- This study should not be considered a comprehensive assessment of the potential effects of the proposed Southern RUB development options. It has been deliberately limited in its scope, focusing on effects on estuarine muddiness and metal level-related indicators.
- The current study presents results from a broad scale modeling assessment which, while based on the best available information and understanding of the systems modelled, does not provide estimates of uncertainty associated with the results. Therefore, interpretation of the results should focus on the relative differences (or similarities) between scenarios rather than on the absolute values.
- The current study has made predictions about receiving environment health over a 50 year timeframe and differences in the results predicted for different scenarios may become more or less accentuated, or stay the same, over a longer period.

Bearing in mind the caveats outlined above the following recommendations regarding the management of environmental effects of the proposed southern RUB scenarios are made:

- Given that this assessment has been limited in its scope, a wider assessment of the full suite of uses and values of the estuarine and freshwater water bodies in the proposed Southern RUB development area should be undertaken.

- Based on the results of this study and supporting information used in the interpretation of its predictions, the Southern RUB planning process should take account of the following implications of the alternative development scenarios. A key consideration in deciding between the options is whether to either **concentrate the bulk of the risk** from the proposed development in eastern subestuaries (as per Scenarios 5 and 6) or alternatively to **spread the risk** across both eastern and western subestuaries (as per Scenario 7). This is because:
    - If the best available earthworks and stormwater controls are utilized then the overall footprint of effects could be minimized by constraining development to the lowest number of catchments possible i.e. choosing Scenarios 5 and 6 over Scenario 7. Given that fewer dwellings and a smaller land area are also proposed under Scenario 5, then the overall risk of effects can be expected to also be less under Scenario 5 than Scenario 6.
    - However, the assertions above are predicated on the best possible earthworks and stormwater controls being applied *and* achieved. As the effects of Scenario 5 and 6 will be more concentrated in the eastern subestuaries (which currently have better

muddiness indicator scores than western subestuaries) this increases the risk to this area if any earthworks or stormwater controls were to fail.
    - Therefore, if eastern subestuaries are found to have greater overall value than western subestuaries additional weight is given to the alternative option of locating some of the development (and thus risk) in western catchments as per Scenario 7. On the other hand if western subestuaries are found to have greater overall value than eastern subestuaries then this would support concentrating the bulk of the development (and thus risk) in eastern catchments as per Scenarios 5 and 6.

- In order to maintain receiving environment health at least at predicted baseline levels (or possibly slightly better) the 'best available' controls for both earthworks (90% TSS removal) and stormwater (90% TSS removal, high metals removal) would need to be applied *and* achieved for any new development. There are a number of reasons for this which include:
    - Using these controls would likely result in the fewest additional thresholds being breached over those predicted under the baseline scenario.
    - The large scale and extended timeframe of the proposed development increases the risk of cumulative effects and the risk of catastrophic sediment deposition events if treatment systems are insufficient.

- If the best available earthworks controls are used (to prevent sedimentation effects) then the best available stormwater controls should also be used so that metals are not concentrated in the receiving environment due to a lack of a sediment 'dilution' effect.

- In order to reduce the risk of significant effects from 'one-off' larger sediment events, or multiple smaller events, it is recommended that earthworks treatment is capable of coping with larger storm events than required by current AC guidelines and of removing the greatest proportion possible (i.e. 90% or more) of any sediment generated (especially fine sediment).This is particularly relevant given the large spatial scale and extended timeframe of the proposed development.

- The effectiveness of currently available earthworks and stormwater treatment systems and devices (e.g. see http://www.bmpdatabase.org/), as well as Low Impact Design (LID) principles (see Lewis*, et al.* (2010)), should be investigated in more detail to assess the practical feasibility of achieving the 'best available' earthworks and stormwater treatment standards proposed in the current study. The results of previous studies into the performance of stormwater treatment devices indicate a need for a significant improvement on historic and current performance, including in the management of treatment devices, if the 'best case' treatment levels applied in this study are to be achieved.

- Management action is required on a macro-catchment scale (i.e. the whole of the wider Southeastern Manukau Harbour catchment area) and not just at the scale of any proposed development, in order to address the substantial underlying effects of existing and ongoing land use (the 'sliding baseline') in this area. Further work is also required to determine how and where the maximum benefit of any management action (such as riparian planting and fencing for sediment reduction) taken on a macro-catchment scale could be realized. This is because:

  - Thresholds in all sub-estuaries are predicted to be breached over the study period with or without additional development and even if the best earthworks and stormwater treatment controls are used for the developed area.
  - Stormwater treatment (or lack of) in current urban areas is not predicted to be sufficient to prevent underlying declines in receiving environment health from metals. Additional stormwater management action taken now could improve this situation however.
  - Current sediment management practices (or lack of) in areas of existing and ongoing rural land use are not predicted to be sufficient to prevent underlying declines in receiving environment health from excess sediment. Additional riparian management action taken now could improve this situation however.

- An analysis of the relative costs and benefits of enhanced earthworks sediment controls vs. riparian management in rural parts of the catchment is recommended to provide guidance on where the greatest sediment load reductions could be achieved and what the associated costs and benefits of the two different approaches might be.

- It is recommended that the thresholds listed below are adopted as targets to be met in the study area so that the basic functionality and resilience required to sustain the receiving environment is maintained:
  - BHMmetals and mud scores should not drop below group 3.
  - Muddiness should not exceed 60% and ideally not exceed 25%.
  - Sediment deposition events should not exceed 3mm in any one event or occur more frequently than once every few years.
  - SARs should be kept to 1-2mm/yr and ideally below 1mm/yr.

- Much of the sediment and metals generated during and after urban development become trapped in the nearshore estuarine receiving environment as a result of increased settling in these areas (ARC 2004). Therefore, the findings from the current study are likely to be applicable to many low energy estuarine receiving environments in the Auckland region. As such the best available earthworks and stormwater treatment controls are also likely to be required to maintain effects close to predicted baseline levels in the north and west RUB investigation areas, given that these areas also drain to low energy estuarine receiving environments.

8.0 Summary

8.1 Overview

NIWA and Cawthron Institute are developing a spatial decision support system (DSS) to help assess the impacts of urban development on attributes such as water and sediment quality; ecosystem health; and cultural, amenity and recreation values. The project (Urban Planning that Sustains Waterbodies – UPSW) is part of the Resilient Urban Futures (RUF) research programme funded by the Ministry for Business, Innovation and Employment (MBIE). Progress to date has resulted in the development of a pilot version of the DSS which is currently being tested and refined through its application in case studies.

Auckland Council (AC) is currently involved in the development of its Unitary Plan (UP). The UP will supersede the operative district plans and several regional plans of the eight legacy councils to provide the principal resource management rule book for the Auckland region. AC is currently engaged in public consultation on the March 2013 draft version of the UP. This includes options for future urban development outside of the current Rural Urban Boundary (RUB) to the south, west and north of the city. The development of the options under consideration is most advanced for the Southern RUB investigation area, extending west from Drury to Karaka and south to Pukekohe. Urban development in the Southern RUB area has the potential to affect the values and services of receiving water bodies and, in particular, south eastern parts of the Manukau Harbour and adjoining tidal creeks. An assessment of the potential for such effects is therefore an important part of the consideration of the Southern RUB development options.

This report has described the application of the UPSW pilot DSS system in a Southern RUB case study. The study aimed to:

- provide an assessment of the potential effects of a range of Southern RUB urban development scenarios on the values of receiving estuarine water bodies relative to the effects predicted by the previous Southeastern Manukau (SEM) Harbour study; and.
- apply the UPSW pilot DSS in an operational setting in order to test its capacity for providing guidance for ‘real world’ planning processes and to inform the further development of the system.

The study has focused on assessing changes to estuarine sediment quality and the health of estuarine benthic invertebrate communities. The pilot DSS makes its predictions of these environmental indicators based on models (or versions of models) that have been previously developed and applied outside of the UPSW research project. The development of these models has involved a significant level of scientific effort to characterise and understand the physical processes and ecology of Auckland’s estuarine environments. As such, these indicators are both well-founded and well-suited for the purpose of informing the Southern RUB investigations.

As noted above, the baseline for this assessment was the set of predictions made in the SEM study. The SEM study used a suite of models to predict the accumulation of the contaminants sediment, copper and zinc in the SEM Harbour over the period 2001 to 2100 for probable future population growth and urban development consistent with the Auckland Regional Growth Strategy

(ARGF, 1999). Accordingly, in the SEM study all future urban development was assumed to occur inside the existing urban footprint as defined by the current Rural Urban Boundary. The study predicted only relatively small increases in sediment accumulation rates (SAR) in the subestuaries of the Harbour. More substantial increases were predicted in concentrations of copper and zinc in estuary bed-sediments. The study predicted that Threshold Effects Level (TEL) of copper and zinc would be exceeded early in the present century in subestuaries adjacent to the northern shoreline of the harbour and later on in tidal creeks along the southern shoreline. These predictions provide a ‘sliding baseline’ for the assessment of environmental outcomes predicted for the Southern RUB urban development scenarios.

8.2 Scenarios assessed

This study involved assessing eleven development scenarios over the period 2012-2062 using the UPSW pilot DSS. The scenarios were:

- Scenario 1, the SEM study baseline scenario;
- Scenarios 2A – 2D, development of the Core development areas, with varying levels of stormwater treatment;
- Scenario 2E, development of the Core development areas with ‘best’ levels of earthworks controls;
- Scenarios 3, 5 and 6, involving development of the Core and additional areas in the centre-south of the study area, including the Pukekohe Focus (Scenario 5) and Corridor Focus (Scenario 6) scenarios; and
- Scenarios 4 and 7, involving development of the Core and additional areas in the north of the study area, including the West-East Focus scenario (Scenario 7).

8.3 Environmental indicators

The pilot DSS made predictions of the following environmental indicators in seven Estuary Reporting Units (ERUs) comprising the principal part of the estuarine receiving environment for the Southern RUB study area:

- concentrations of copper and zinc in estuary bed-sediments;
- a benthic health score, based on sediment metal concentrations (BHMmetals);
- the mud content of estuary bed-sediments;
- a second benthic health score, based on the mud content of estuary bed-sediments (BHMmud), and,
- the sediment accumulation rate (SAR).

With one exception, all of the Southern RUB Core development scenarios are predicted to result in increased rates of copper and zinc accumulation in estuary bed-sediments compared to the SEM study baseline. The exception is Scenario 2B (Core with best case stormwater treatment), although increased metal concentrations (relative to the present day) are still predicted for that scenario. The date of exceedance of TEL concentrations of copper and zinc is predicted to vary with the level of stormwater treatment, being exceeded soonest under Scenario 2D (worst case stormwater treatment). The increased metal concentrations are reflected in predicted reductions in BHMmetal scores, from a current score of 3 (out of 5) to scores of 4 or 5 in some ERUs at the end of the study timeframe. The least and most marked changes from the present day BHMmetal scores are again predicted under the best case and worst case stormwater treatment scenarios, respectively.

The Core development scenarios are also predicted to result in increases in the mud content of estuary bed-sediments and sediment accumulation rates compared to the SEM study baseline. There is relatively little difference between predictions of the change in mud content with variations in stormwater treatment. In contrast, the adoption of best earthworks controls (Scenario 2E) is predicted to maintain the rate of increase in mud content and sediment accumulation rates at approximately the same level as under the SEM baseline scenario. Increases in mud content are predicted to have no effect on the BHMmud group in three ERUs (1, 2 and 7), the bed-sediments of which are predicted to comprise more than 80% mud under the baseline scenario (i.e. these ERUs are predicted to be in the worst group even under the baseline scenario). However, in the remaining ERUs the BHMmud score is predicted to deteriorate by up to 2 groups under all Core development scenarios, other than under Scenario 2E (best earthworks controls).

There are spatial differences in the predictions of environmental indicators under Scenarios 3 to 7 (additions to the Core). The most marked impacts on eastern ERUs (4, 5 and 6) are predicted under the centre-south additions (Scenarios 3, 5 and 6) while the most marked impacts on western ERUs (1, 2, 3 and 7) are predicted under northern additions (Scenarios 4 and 7).

Of the centre-south additions, the greatest rates of increase in sediment metal concentrations are predicted under the Corridor Focus scenario (Scenario 6). Of the northern additions, greater rates of increase in sediment metal concentrations are predicted under the East-West Focus scenario (Scenario 7) than under the Core+Karaka North scenario (Scenario 5). However, for the most part, differences between the predicted metal concentrations under alternative centre-south and alternative northern additions to the Core do not translate into differences between the BHMmetal scores at the end of the study timeframe.

There is also relatively little difference in the predictions of mud content and sediment accumulation rate under the alternative centre-south scenarios. There is more divergence between the rates of increase in mud content and sediment accumulation predicted under the two northern scenarios, with greater rates of increase again predicted under the East-West Focus scenario (Scenario 7) than under the Core+Karaka North scenario (Scenario 5). Predictions of the change in the BHMmud score are the same under all five of the scenarios involving additions to the Core.

8.4 Social and economic indicators

The UPSW pilot DSS also makes predictions for a set of social and economic indicators which assess the costs and benefits of stormwater treatment and associated effects on how communities relate to receiving water bodies. These indicators are, for each ERU under each scenario:

- five social indicators: extraction, contact recreation, partial contact recreation, non-contact recreation and sense-of-place; and
- two economic indicators: costs and benefits, reflecting the lifecycle costs of stormwater treatment and the monetised environmental benefits of the urban development scenario.

The development of the methods by which these indicators are predicted has been and continues to be a significant task for the UPSW project. While the methods are considered to be soundly based and able to play a highly informative role in the use of the DSS, it is emphasised that these methods remain under development and that a number of limitations apply to their application for the Southern RUB case study. Accordingly, it is recommended that caution be applied in the use of the results for these indicators, with any interpretation focusing on their relative values.

Under all scenarios the levels of the five social indicators are predicted to either deteriorate or stay the same over the study timeframe (for instance, where they are already at the lowest level at the start of the study timeframe). Lower indicator levels are predicted in some ERUs at ‘worst case’ and ‘business as usual’ levels of stormwater treatment (Scenarios 2D and 2C) and under four of the scenarios involving additions to the Core (Scenarios 4, 5, 6 and 7) than under the Core development scenario (Scenario 2A).

There is a general lack of discrimination in the predictions of the scores for the economic costs indicator. The exception is the costs indicator for Scenario 2B (Core with best case stormwater treatment) which is two levels lower than under any other scenario, indicating markedly higher lifecycle costs of stormwater treatment. In most ERUs the economic benefits indicator is at the second to lowest level under all or most scenarios. This indicates that environmental benefits are predicted to be negative (i.e. losses), reflecting the fact that the environmental attributes from which the benefits are calculated are predicted to decline from their current state. Differences between the scores predicted for the economic benefits indicator under Scenarios 2A to 2D (Core with variations in stormwater treatment) are generally consistent with greater environmental losses occurring in relation to lower levels of stormwater treatment. There is only limited discrimination between benefits scores predicted under the centre south and northern additions to the Core, indicating that the differences between the precursor environmental attributes predicted in these ERUs are insufficient to translate into difference in the benefits score. Further development of the DSS will include considering ways of providing greater discrimination between economic indicators predicted for different scenarios.

8.5 Key findings - environmental indicators

The modelling results provide the following key findings based on the environmental indicators:

- There are three major scenarios being considered for the southern RUB: Scenario 5 (Pukekohe focus), Scenario 6 (Corridor focus) and Scenario 7 (West-East focus). Key findings when comparing results between these three scenarios are outlined below:
    - Eastern subestuaries currently have better muddiness indicator scores than western subestuaries. Metal indicator scores are similar across all subestuaries.

- Scenarios 5 (Pukekohe focus) and 6 (Corridor focus) are predicted to have a more acute effect on eastern subestuaries than Scenario 7 (West-East focus) as most of the development in Scenarios 5 and 6 is concentrated in catchments draining to eastern subestuaries.
    - Scenario 7 (West-East focus) is predicted to have a greater effect on western subestuaries (and a greater overall footprint of effect) than Scenarios 5 and 6 as some of the development in Scenario 7 also occurs in catchments draining to western subestuaries.
    - Scenario 6 (Corridor focus) is predicted to have a greater overall effect than Scenario 5 (Pukekohe focus) as it covers a greater land area and includes a greater number of dwellings

- Based on the results of Scenarios 2A to 2E (Core with varying earthworks and stormwater treatment options) any new development utilizing current or reduced earthworks and stormwater treatment controls is predicted to have substantial additional effects on the receiving environment over and above predicted baseline effects.

- If the best available earthworks and stormwater treatment controls are utilized then the effects of any new development could be maintained at similar levels to (or even slightly improve on) those predicted under the baseline scenario.

- Effects on the receiving environment in the study area are predicted to increase substantially over time regardless of whether any new development goes ahead (i.e. under 'baseline' Scenario 1). These underlying (or 'sliding' baseline) effects are predicted to primarily occur as a result of inputs of sediment from ongoing rural land use in southern and western catchments and ongoing inputs of metals from existing urban land use in northern and eastern catchments. Any new development in the area will have effects in addition to this underlying effect. However, this sliding baseline of effects could be addressed if additional management action is taken now - such as riparian fencing and planting in existing rural areas and improved stormwater treatment in existing urban areas.

- There are a number of environmental thresholds that should not be breached in order to maintain the basic functionality and resilience of the receiving environment. These are:
    - BHMmetals and BHMmud scores should not drop below group 3.
    - Muddiness should not exceed 60% and ideally not exceed 25%.
    - Sediment deposition events should not exceed 3 mm in any one event or occur more frequently than once every few years.
    - SARs should be kept to 1-2 mm/yr and ideally below 1mm/yr.

- Most of the subestuaries modeled in the current study are already close to breaching thresholds for BHMmetals, muddiness and SARs and some of these thresholds have already been breached in a few subestuaries. Even without any extra development several more thresholds are predicted to be breached in some subestuaries over the study period unless additional management action (as previously described) is taken now. If development does go ahead then the same overall state as the baseline scenario (or possibly slightly better) could be maintained if the best available earthworks and stormwater treatment controls are applied and achieved.

- This study and other examples of current and historic land development outcomes all suggest that historic and current land development controls (or lack of) were not, and are still not, sufficient to prevent adverse effects on the receiving environment.

8.6 Recommendations

There are several caveats that should be taken into account when considering the recommendations that follow:

- This study should not be considered a comprehensive assessment of the potential effects of the proposed Southern RUB development options. It has been deliberately limited in its scope, focusing on effects on estuarine muddiness and metal level-related indicators.
- The current study presents results from a broad scale modeling assessment which, while based on the best available information and understanding of the systems modelled, does not provide estimates of uncertainty associated with the results. Therefore, interpretation of the results should focus on the relative differences (or similarities) between scenarios rather than on the absolute values.
- The current study has made predictions about receiving environment health over a 50 year timeframe and differences in the results predicted for different scenarios may become more or less accentuated, or stay the same, over a longer period.

Bearing in mind the caveats outlined above the following key recommendations regarding the estuarine receiving environment are made:

- A full assessment of all the uses and values of the estuaries and freshwater water bodies in this area is recommended, to allow consideration of matters beyond the scope of the current study.

- If such an assessment suggests that eastern subestuaries have greater overall value than western subestuaries this would support locating some of the development (and thus risk) in western catchments as per Scenario 7 (West-East focus). Alternatively, if western subestuaries are found to have greater overall value than eastern subestuaries this would support concentrating the bulk of the development (and thus risk) in eastern catchments as per Scenarios 5 (Pukekohe focus) and 6 (Corridor focus).

- In order to maintain receiving environment health at least at predicted baseline levels (or possibly slightly better than) the ‘best available’ controls for both earthworks (90% TSS removal) and stormwater (90% TSS removal, high metals removal) would need to be applied *and* achieved for any new development, particularly given the large scale and extended timeframe of the proposed development.

- Currently available earthworks and stormwater treatment systems, as well as Low Impact Design (LID) principles, should be investigated in more detail to assess the feasibility of achieving the ‘best available’ earthworks and stormwater treatment standards proposed in the current study.

- Management action (such as riparian planting and fencing in rural areas and additional stormwater treatment in urban areas) is currently required on the scale of the whole Southeastern Manukau Harbour catchment area in order to address the substantial underlying (or ‘sliding baseline’) effects from existing and ongoing land use in this area.
- An analysis of the relative costs and benefits of enhanced earthworks sediment controls vs. riparian management in rural parts of the catchment is recommended to provide guidance on where the greatest sediment load reductions could be achieved and what the associated costs and benefits of the two different approaches might be.
- It is recommended that the thresholds described in this report are adopted as targets to be met in the study area so that the basic functionality and resilience required to sustain the receiving environment is maintained.

- The findings from the current study are likely to be applicable to many low energy estuarine receiving environments in the Auckland region. As such the best available earthworks and stormwater treatment controls and additional catchment management outside the area to be developed are also likely to be required in the north and west RUB investigation areas, given that these areas also drain to low energy estuarine receiving environments.

9.0 References

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Appendix A - Input data

The following tables summarise input data to the pilot DSS for scenarios 1, 2A-E, 3, 4, 5, 6 and 7.

Scenario 1 – SEM baseline

	PLU	1		2		3		4		5		6		7		8		9	
Scenario 1 - SEM baseline	Area (ha)	2791		1323		1983		3709		735		1249		1893		12373		500	
		BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO
Land use (% of PLU area)	Rural	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	88.2%	86.1%	100.0%	100.0%	100.0%	100.0%	66.8%	65.3%	99.5%	99.5%	86.0%	84.8%
	Residential	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	8.7%	10.3%	0.0%	0.0%	0.0%	0.0%	27.9%	28.6%	0.0%	0.0%	6.8%	7.6%
	Commercial	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.9%	0.9%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.0%	0.0%	1.5%	1.5%
	Industrial	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.2%	2.6%	0.0%	0.0%	0.0%	0.0%	5.2%	6.0%	0.0%	0.0%	4.6%	4.6%
	Major roads	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.5%	1.2%	1.5%
Rural sub-classes (% of total rural)	Pasture	92.3%	92.3%	73.5%	73.5%	97.5%	97.5%	78.6%	78.1%	93.0%	93.0%	94.2%	94.2%	94.4%	94.3%	72.3%	72.3%	94.9%	94.8%
	Exotic Forest	0.1%	0.1%	0.0%	0.0%	0.2%	0.2%	0.4%	0.4%	0.6%	0.6%	0.8%	0.8%	0.7%	0.7%	2.7%	2.7%	0.0%	0.0%
	Native Forest	0.4%	0.4%	1.3%	1.3%	0.2%	0.2%	1.6%	1.7%	0.3%	0.3%	4.4%	4.4%	1.2%	1.3%	17.3%	17.3%	0.0%	0.0%
	Horticulture	7.2%	7.2%	25.2%	25.2%	2.2%	2.2%	19.4%	19.9%	6.1%	6.1%	0.6%	0.6%	3.7%	3.7%	7.6%	7.6%	5.1%	5.2%
Residential sub-classes (% of total residential)	Medium density suburb	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	16.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Low density suburb	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	83.9%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	0.0%	0.0%	100.0%	100.0%
	High density suburb	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	High density CBD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	High density suburb with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Commercial sub-classes (% of total commercial)	Suburban	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	0.0%	0.0%	100.0%	100.0%
	Commercial with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Commercial CBD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Industrial sub-classes (% of total industrial)	Traditional industrial	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	0.0%	0.0%	100.0%	100.0%
	Industrial with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Stormwater treatment	Sediment removal	none	none	none	none	none	none	25.0%	25.0%	none	none	none	none	25.0%	25.0%	25.0%	25.0%	25.0%	25.0%
	Metals removal	none	none	none	none	none	none	low	low	none	none	none	none	low	low	low	low	low	low
Earthworks controls	Sediment removal	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%
Traffic	Increase in vehicle numbers	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%

BUS = Baseline Urban State (pre-development, 2012), UDO = Urban Development Option (end of the development phase, 2041)

Scenario 2A – Core

Scenario 2A - Core	PLU	1		2		3		4		5		6		7		8		9	
	Area (ha)	2791		1323		1983		3709		735		1249		1893		12373		500	
		BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO
Land use (% of PLU area)	Rural	100.0%	100.0%	100.0%	100.0%	100.0%	98.7%	88.2%	66.3%	100.0%	20.3%	100.0%	96.0%	66.8%	27.5%	99.5%	94.3%	86.0%	84.8%
	Residential	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%	8.7%	27.0%	0.0%	77.8%	0.0%	3.7%	27.9%	63.0%	0.0%	3.4%	6.8%	7.6%
	Commercial	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.9%	1.3%	0.0%	1.9%	0.0%	0.3%	0.1%	3.5%	0.0%	0.1%	1.5%	1.5%
	Industrial	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.2%	5.3%	0.0%	0.0%	0.0%	0.0%	5.2%	6.0%	0.0%	1.7%	4.6%	4.6%
	Major roads	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.5%	1.2%	1.5%
Rural sub-classes (% of total rural)	Pasture	92.3%	92.3%	73.5%	73.5%	97.5%	97.4%	78.6%	71.5%	93.0%	65.5%	94.2%	94.0%	94.4%	86.4%	72.3%	70.8%	94.9%	94.8%
	Exotic Forest	0.1%	0.1%	0.0%	0.0%	0.2%	0.2%	0.4%	0.5%	0.6%	3.2%	0.8%	0.8%	0.7%	1.7%	2.7%	2.9%	0.0%	0.0%
	Native Forest	0.4%	0.4%	1.3%	1.3%	0.2%	0.2%	1.6%	2.2%	0.3%	1.3%	4.4%	4.6%	1.2%	3.0%	17.3%	18.3%	0.0%	0.0%
	Horticulture	7.2%	7.2%	25.2%	25.2%	2.2%	2.2%	19.4%	25.8%	6.1%	30.0%	0.6%	0.6%	3.7%	8.9%	7.6%	8.0%	5.1%	5.2%
Residential sub-classes (% of total residential)	Medium density suburb	0.0%	0.0%	0.0%	0.0%	0.0%	4.3%	0.0%	7.0%	0.0%	10.2%	0.0%	4.3%	0.0%	5.8%	0.0%	19.6%	0.0%	0.0%
	Low density suburb	0.0%	0.0%	0.0%	0.0%	0.0%	93.6%	100.0%	92.7%	0.0%	88.7%	0.0%	93.6%	100.0%	93.3%	0.0%	78.5%	100.0%	100.0%
	High density suburb	0.0%	0.0%	0.0%	0.0%	0.0%	2.1%	0.0%	0.4%	0.0%	1.1%	0.0%	2.1%	0.0%	0.9%	0.0%	1.9%	0.0%	0.0%
	High density CBD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	High density suburb with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Commercial sub-classes (% of total commercial)	Suburban	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	100.0%	0.0%	100.0%	0.0%	100.0%	100.0%	100.0%	0.0%	100.0%	100.0%	100.0%
	Commercial with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Commercial CBD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Industrial sub-classes (% of total industrial)	Traditional industrial	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	0.0%	100.0%	100.0%	100.0%
	Industrial with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Stormwater treatment	Sediment removal	none	none	none	none	none	75.0%	25.0%	75.0%	none	75.0%	none	75.0%	25.0%	75.0%	25.0%	75.0%	25.0%	25.0%
	Metals removal	none	none	none	none	none	medium	low	medium	none	medium	none	medium	low	medium	low	medium	low	low
Earthworks controls	Sediment removal	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%
Traffic	Increase in vehicle numbers	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%

BUS = Baseline Urban State (pre-development, 2012), UDO = Urban Development Option (end of the development phase, 2041)

Scenario 2B – Core (best case stormwater treatment)

Scenario 2B - Core (best case)	PLU	1		2		3		4		5		6		7		8		9	
	Area (ha)	2791		1323		1983		3709		735		1249		1893		12373		500	
		BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO
Land use (% of PLU area)	Rural	100.0%	100.0%	100.0%	100.0%	100.0%	98.7%	88.2%	66.3%	100.0%	20.3%	100.0%	96.0%	66.8%	27.5%	99.5%	94.3%	86.0%	84.8%
	Residential	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%	8.7%	27.0%	0.0%	77.8%	0.0%	3.7%	27.9%	63.0%	0.0%	3.4%	6.8%	7.6%
	Commercial	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.9%	1.3%	0.0%	1.9%	0.0%	0.3%	0.1%	3.5%	0.0%	0.1%	1.5%	1.5%
	Industrial	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.2%	5.3%	0.0%	0.0%	0.0%	0.0%	5.2%	6.0%	0.0%	1.7%	4.6%	4.6%
	Major roads	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.5%	1.2%	1.5%
Rural sub-classes (% of total rural)	Pasture	92.3%	92.3%	73.5%	73.5%	97.5%	97.4%	78.6%	71.5%	93.0%	65.5%	94.2%	94.0%	94.4%	86.4%	72.3%	70.8%	94.9%	94.8%
	Exotic Forest	0.1%	0.1%	0.0%	0.0%	0.2%	0.2%	0.4%	0.5%	0.6%	3.2%	0.8%	0.8%	0.7%	1.7%	2.7%	2.9%	0.0%	0.0%
	Native Forest	0.4%	0.4%	1.3%	1.3%	0.2%	0.2%	1.6%	2.2%	0.3%	1.3%	4.4%	4.6%	1.2%	3.0%	17.3%	18.3%	0.0%	0.0%
	Horticulture	7.2%	7.2%	25.2%	25.2%	2.2%	2.2%	19.4%	25.8%	6.1%	30.0%	0.6%	0.6%	3.7%	8.9%	7.6%	8.0%	5.1%	5.2%
Residential sub-classes (% of total residential)	Medium density suburb	0.0%	0.0%	0.0%	0.0%	0.0%	4.3%	0.0%	7.0%	0.0%	10.2%	0.0%	4.3%	0.0%	5.8%	0.0%	19.6%	0.0%	0.0%
	Low density suburb	0.0%	0.0%	0.0%	0.0%	0.0%	93.6%	100.0%	92.7%	0.0%	88.7%	0.0%	93.6%	100.0%	93.3%	0.0%	78.5%	100.0%	100.0%
	High density suburb	0.0%	0.0%	0.0%	0.0%	0.0%	2.1%	0.0%	0.4%	0.0%	1.1%	0.0%	2.1%	0.0%	0.9%	0.0%	1.9%	0.0%	0.0%
	High density CBD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	High density suburb with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Commercial sub-classes (% of total commercial)	Suburban	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	100.0%	0.0%	100.0%	0.0%	100.0%	100.0%	100.0%	0.0%	100.0%	100.0%	100.0%
	Commercial with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Commercial CBD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Industrial sub-classes (% of total industrial)	Traditional industrial	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	0.0%	100.0%	100.0%	100.0%
	Industrial with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Stormwater treatment	Sediment removal	none	none	none	none	none	90.0%	25.0%	90.0%	none	90.0%	none	90.0%	25.0%	90.0%	25.0%	90.0%	25.0%	25.0%
	Metals removal	none	none	none	none	none	high	low	high	none	high	none	high	low	high	low	high	low	low
Earthworks controls	Sediment removal	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%
Traffic	Increase in vehicle numbers	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%

BUS = Baseline Urban State (pre-development, 2012), UDO = Urban Development Option (end of the development phase, 2041)

Scenario 2C – Core (business as usual stormwater treatment)

Scenario 2C - Core (business as usual)	PLU	1		2		3		4		5		6		7		8		9	
	Area (ha)	2791		1323		1983		3709		735		1249		1893		12373		500	
		BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO
Land use (% of PLU area)	Rural	100.0%	100.0%	100.0%	100.0%	100.0%	98.7%	88.2%	66.3%	100.0%	20.3%	100.0%	96.0%	66.8%	27.5%	99.5%	94.3%	86.0%	84.8%
	Residential	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%	8.7%	27.0%	0.0%	77.8%	0.0%	3.7%	27.9%	63.0%	0.0%	3.4%	6.8%	7.6%
	Commercial	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.9%	1.3%	0.0%	1.9%	0.0%	0.3%	0.1%	3.5%	0.0%	0.1%	1.5%	1.5%
	Industrial	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.2%	5.3%	0.0%	0.0%	0.0%	0.0%	5.2%	6.0%	0.0%	1.7%	4.6%	4.6%
	Major roads	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.5%	1.2%	1.5%
Rural sub-classes (% of total rural)	Pasture	92.3%	92.3%	73.5%	73.5%	97.5%	97.4%	78.6%	71.5%	93.0%	65.5%	94.2%	94.0%	94.4%	86.4%	72.3%	70.8%	94.9%	94.8%
	Exotic Forest	0.1%	0.1%	0.0%	0.0%	0.2%	0.2%	0.4%	0.5%	0.6%	3.2%	0.8%	0.8%	0.7%	1.7%	2.7%	2.9%	0.0%	0.0%
	Native Forest	0.4%	0.4%	1.3%	1.3%	0.2%	0.2%	1.6%	2.2%	0.3%	1.3%	4.4%	4.6%	1.2%	3.0%	17.3%	18.3%	0.0%	0.0%
	Horticulture	7.2%	7.2%	25.2%	25.2%	2.2%	2.2%	19.4%	25.8%	6.1%	30.0%	0.6%	0.6%	3.7%	8.9%	7.6%	8.0%	5.1%	5.2%
Residential sub-classes (% of total residential)	Medium density suburb	0.0%	0.0%	0.0%	0.0%	0.0%	4.3%	0.0%	7.0%	0.0%	10.2%	0.0%	4.3%	0.0%	5.8%	0.0%	19.6%	0.0%	0.0%
	Low density suburb	0.0%	0.0%	0.0%	0.0%	0.0%	93.6%	100.0%	92.7%	0.0%	88.7%	0.0%	93.6%	100.0%	93.3%	0.0%	78.5%	100.0%	100.0%
	High density suburb	0.0%	0.0%	0.0%	0.0%	0.0%	2.1%	0.0%	0.4%	0.0%	1.1%	0.0%	2.1%	0.0%	0.9%	0.0%	1.9%	0.0%	0.0%
	High density CBD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	High density suburb with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Commercial sub-classes (% of total commercial)	Suburban	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	100.0%	0.0%	100.0%	0.0%	100.0%	100.0%	100.0%	0.0%	100.0%	100.0%	100.0%
	Commercial with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Commercial CBD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Industrial sub-classes (% of total industrial)	Traditional industrial	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	0.0%	100.0%	100.0%	100.0%
	Industrial with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Stormwater treatment	Sediment removal	none	none	none	none	none	50.0%	25.0%	50.0%	none	50.0%	none	50.0%	25.0%	50.0%	25.0%	50.0%	25.0%	50.0%
	Metals removal	none	none	none	none	none	low	low	low	none	low	none	low	low	low	low	low	low	low
Earthworks controls	Sediment removal	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%
Traffic	Increase in vehicle numbers	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%

BUS = Baseline Urban State (pre-development, 2012), UDO = Urban Development Option (end of the development phase, 2041)

Scenario 2D – Core (worst case stormwater treatment)

Scenario 2D - Core (worst case)	PLU	1		2		3		4		5		6		7		8		9	
	Area (ha)	2791		1323		1983		3709		735		1249		1893		12373		500	
		BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO
Land use (% of PLU area)	Rural	100.0%	100.0%	100.0%	100.0%	100.0%	98.7%	88.2%	66.3%	100.0%	20.3%	100.0%	96.0%	66.8%	27.5%	99.5%	94.3%	86.0%	84.8%
	Residential	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%	8.7%	27.0%	0.0%	77.8%	0.0%	3.7%	27.9%	63.0%	0.0%	3.4%	6.8%	7.6%
	Commercial	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.9%	1.3%	0.0%	1.9%	0.0%	0.3%	0.1%	3.5%	0.0%	0.1%	1.5%	1.5%
	Industrial	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.2%	5.3%	0.0%	0.0%	0.0%	0.0%	5.2%	6.0%	0.0%	1.7%	4.6%	4.6%
	Major roads	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.5%	1.2%	1.5%
Rural sub-classes (% of total rural)	Pasture	92.3%	92.3%	73.5%	73.5%	97.5%	97.4%	78.6%	71.5%	93.0%	65.5%	94.2%	94.0%	94.4%	86.4%	72.3%	70.8%	94.9%	94.8%
	Exotic Forest	0.1%	0.1%	0.0%	0.0%	0.2%	0.2%	0.4%	0.5%	0.6%	3.2%	0.8%	0.8%	0.7%	1.7%	2.7%	2.9%	0.0%	0.0%
	Native Forest	0.4%	0.4%	1.3%	1.3%	0.2%	0.2%	1.6%	2.2%	0.3%	1.3%	4.4%	4.6%	1.2%	3.0%	17.3%	18.3%	0.0%	0.0%
	Horticulture	7.2%	7.2%	25.2%	25.2%	2.2%	2.2%	19.4%	25.8%	6.1%	30.0%	0.6%	0.6%	3.7%	8.9%	7.6%	8.0%	5.1%	5.2%
Residential sub-classes (% of total residential)	Medium density suburb	0.0%	0.0%	0.0%	0.0%	0.0%	4.3%	0.0%	7.0%	0.0%	10.2%	0.0%	4.3%	0.0%	5.8%	0.0%	19.6%	0.0%	0.0%
	Low density suburb	0.0%	0.0%	0.0%	0.0%	0.0%	93.6%	100.0%	92.7%	0.0%	88.7%	0.0%	93.6%	100.0%	93.3%	0.0%	78.5%	100.0%	100.0%
	High density suburb	0.0%	0.0%	0.0%	0.0%	0.0%	2.1%	0.0%	0.4%	0.0%	1.1%	0.0%	2.1%	0.0%	0.9%	0.0%	1.9%	0.0%	0.0%
	High density CBD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	High density suburb with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Commercial sub-classes (% of total commercial)	Suburban	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	100.0%	0.0%	100.0%	0.0%	100.0%	100.0%	100.0%	0.0%	100.0%	100.0%	100.0%
	Commercial with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Commercial CBD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Industrial sub-classes (% of total industrial)	Traditional industrial	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	0.0%	100.0%	100.0%	100.0%
	Industrial with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Stormwater treatment	Sediment removal	none	none	none	none	none	none	25.0%	none	none	none	none	none	25.0%	none	25.0%	none	25.0%	25.0%
	Metals removal	none	none	none	none	none	none	low	none	none	none	none	none	low	none	low	none	low	low
Earthworks controls	Sediment removal	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%
Traffic	Increase in vehicle numbers	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%

BUS = Baseline Urban State (pre-development, 2012), UDO = Urban Development Option (end of the development phase, 2041)

Scenario 2E – Core (Best earthworks controls)

Scenario 2E - Core (best earthworks)	PLU	1		2		3		4		5		6		7		8		9	
	Area (ha)	2791		1323		1983		3709		735		1249		1893		12373		500	
		BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO
Land use (% of PLU area)	Rural	100.0%	100.0%	100.0%	100.0%	100.0%	98.7%	88.2%	66.3%	100.0%	20.3%	100.0%	96.0%	66.8%	27.5%	99.5%	94.3%	86.0%	84.8%
	Residential	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%	8.7%	27.0%	0.0%	77.8%	0.0%	3.7%	27.9%	63.0%	0.0%	3.4%	6.8%	7.6%
	Commercial	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.9%	1.3%	0.0%	1.9%	0.0%	0.3%	0.1%	3.5%	0.0%	0.1%	1.5%	1.5%
	Industrial	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.2%	5.3%	0.0%	0.0%	0.0%	0.0%	5.2%	6.0%	0.0%	1.7%	4.6%	4.6%
	Major roads	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.5%	1.2%	1.5%
Rural sub-classes (% of total rural)	Pasture	92.3%	92.3%	73.5%	73.5%	97.5%	97.4%	78.6%	71.5%	93.0%	65.5%	94.2%	94.0%	94.4%	86.4%	72.3%	70.8%	94.9%	94.8%
	Exotic Forest	0.1%	0.1%	0.0%	0.0%	0.2%	0.2%	0.4%	0.5%	0.6%	3.2%	0.8%	0.8%	0.7%	1.7%	2.7%	2.9%	0.0%	0.0%
	Native Forest	0.4%	0.4%	1.3%	1.3%	0.2%	0.2%	1.6%	2.2%	0.3%	1.3%	4.4%	4.6%	1.2%	3.0%	17.3%	18.3%	0.0%	0.0%
	Horticulture	7.2%	7.2%	25.2%	25.2%	2.2%	2.2%	19.4%	25.8%	6.1%	30.0%	0.6%	0.6%	3.7%	8.9%	7.6%	8.0%	5.1%	5.2%
Residential sub-classes (% of total residential)	Medium density suburb	0.0%	0.0%	0.0%	0.0%	0.0%	4.3%	0.0%	7.0%	0.0%	10.2%	0.0%	4.3%	0.0%	5.8%	0.0%	19.6%	0.0%	0.0%
	Low density suburb	0.0%	0.0%	0.0%	0.0%	0.0%	93.6%	100.0%	92.7%	0.0%	88.7%	0.0%	93.6%	100.0%	93.3%	0.0%	78.5%	100.0%	100.0%
	High density suburb	0.0%	0.0%	0.0%	0.0%	0.0%	2.1%	0.0%	0.4%	0.0%	1.1%	0.0%	2.1%	0.0%	0.9%	0.0%	1.9%	0.0%	0.0%
	High density CBD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	High density suburb with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Commercial sub-classes (% of total commercial)	Suburban	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	100.0%	0.0%	100.0%	0.0%	100.0%	100.0%	100.0%	0.0%	100.0%	100.0%	100.0%
	Commercial with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Commercial CBD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Industrial sub-classes (% of total industrial)	Traditional industrial	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	0.0%	100.0%	100.0%	100.0%
	Industrial with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Stormwater treatment	Sediment removal	none	none	none	none	none	75.0%	25.0%	75.0%	none	75.0%	none	75.0%	25.0%	75.0%	25.0%	75.0%	25.0%	25.0%
	Metals removal	none	none	none	none	none	medium	low	medium	none	medium	none	medium	low	medium	low	medium	low	low
Earthworks controls	Sediment removal	-	90.0%	-	90.0%	-	90.0%	-	90.0%	-	90.0%	-	90.0%	-	90.0%	-	90.0%	-	90.0%
Traffic	Increase in vehicle numbers	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%

BUS = Baseline Urban State (pre-development, 2012), UDO = Urban Development Option (end of the development phase, 2041)

Scenario 3 – Core + Pukekohe North East

Scenario 3 - Core + Pukekohe-Paerata B	PLU	1		2		3		4		5		6		7		8		9	
	Area (ha)	2791		1323		1983		3709		735		1249		1893		12373		500	
		BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO
Land use (% of PLU area)	Rural	100.0%	100.0%	100.0%	100.0%	100.0%	98.7%	88.2%	66.3%	100.0%	20.3%	100.0%	55.4%	66.8%	27.5%	99.5%	93.5%	86.0%	84.8%
	Residential	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%	8.7%	27.0%	0.0%	77.8%	0.0%	43.4%	27.9%	63.0%	0.0%	3.9%	6.8%	7.6%
	Commercial	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.9%	1.3%	0.0%	1.9%	0.0%	1.2%	0.1%	3.5%	0.0%	0.2%	1.5%	1.5%
	Industrial	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.2%	5.3%	0.0%	0.0%	0.0%	0.0%	5.2%	6.0%	0.0%	1.9%	4.6%	4.6%
	Major roads	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.5%	1.2%	1.5%
Rural sub-classes (% of total rural)	Pasture	92.3%	92.3%	73.5%	73.5%	97.5%	97.4%	78.6%	71.5%	93.0%	65.5%	94.2%	89.6%	94.4%	86.4%	72.3%	70.5%	94.9%	94.8%
	Exotic Forest	0.1%	0.1%	0.0%	0.0%	0.2%	0.2%	0.4%	0.5%	0.6%	3.2%	0.8%	1.4%	0.7%	1.7%	2.7%	2.9%	0.0%	0.0%
	Native Forest	0.4%	0.4%	1.3%	1.3%	0.2%	0.2%	1.6%	2.2%	0.3%	1.3%	4.4%	7.9%	1.2%	3.0%	17.3%	18.4%	0.0%	0.0%
	Horticulture	7.2%	7.2%	25.2%	25.2%	2.2%	2.2%	19.4%	25.8%	6.1%	30.0%	0.6%	1.0%	3.7%	8.9%	7.6%	8.1%	5.1%	5.2%
Residential sub-classes (% of total residential)	Medium density suburb	0.0%	0.0%	0.0%	0.0%	0.0%	4.3%	0.0%	7.0%	0.0%	10.2%	0.0%	1.7%	0.0%	5.8%	0.0%	17.5%	0.0%	0.0%
	Low density suburb	0.0%	0.0%	0.0%	0.0%	0.0%	93.6%	100.0%	92.7%	0.0%	88.7%	0.0%	97.5%	100.0%	93.3%	0.0%	80.5%	100.0%	100.0%
	High density suburb	0.0%	0.0%	0.0%	0.0%	0.0%	2.1%	0.0%	0.4%	0.0%	1.1%	0.0%	0.8%	0.0%	0.9%	0.0%	1.9%	0.0%	0.0%
	High density CBD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	High density suburb with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Commercial sub-classes (% of total commercial)	Suburban	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	100.0%	0.0%	100.0%	0.0%	100.0%	100.0%	100.0%	0.0%	100.0%	100.0%	100.0%
	Commercial with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Commercial CBD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Industrial sub-classes (% of total industrial)	Traditional industrial	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	0.0%	100.0%	100.0%	100.0%
	Industrial with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Stormwater treatment	Sediment removal	none	none	none	none	none	75.0%	25.0%	75.0%	none	75.0%	none	75.0%	25.0%	75.0%	25.0%	75.0%	25.0%	25.0%
	Metals removal	none	none	none	none	none	medium	low	medium	none	medium	none	medium	low	medium	low	medium	low	low
Earthworks controls	Sediment removal	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%
Traffic	Increase in vehicle numbers	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%

BUS = Baseline Urban State (pre-development, 2012), UDO = Urban Development Option (end of the development phase, 2041)

Scenario 4 – Core + Karaka North

Scenario 4 - Core + Karaka North	PLU	1		2		3		4		5		6		7		8		9	
	Area (ha)	2791		1323		1983		3709		735		1249		1893		12373		500	
		BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO
Land use (% of PLU area)	Rural	100.0%	78.7%	100.0%	100.0%	100.0%	88.0%	88.2%	66.3%	100.0%	20.3%	100.0%	96.0%	66.8%	27.5%	99.5%	94.3%	86.0%	84.8%
	Residential	0.0%	20.8%	0.0%	0.0%	0.0%	11.6%	8.7%	27.0%	0.0%	77.8%	0.0%	3.7%	27.9%	63.0%	0.0%	3.4%	6.8%	7.6%
	Commercial	0.0%	0.5%	0.0%	0.0%	0.0%	0.4%	0.9%	1.3%	0.0%	1.9%	0.0%	0.3%	0.1%	3.5%	0.0%	0.1%	1.5%	1.5%
	Industrial	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.2%	5.3%	0.0%	0.0%	0.0%	0.0%	5.2%	6.0%	0.0%	1.7%	4.6%	4.6%
	Major roads	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.5%	1.2%	1.5%
Rural sub-classes (% of total rural)	Pasture	92.3%	90.2%	73.5%	73.5%	97.5%	97.1%	78.6%	71.5%	93.0%	65.5%	94.2%	94.0%	94.4%	86.4%	72.3%	70.8%	94.9%	94.8%
	Exotic Forest	0.1%	0.1%	0.0%	0.0%	0.2%	0.2%	0.4%	0.5%	0.6%	3.2%	0.8%	0.8%	0.7%	1.7%	2.7%	2.9%	0.0%	0.0%
	Native Forest	0.4%	0.5%	1.3%	1.3%	0.2%	0.2%	1.6%	2.2%	0.3%	1.3%	4.4%	4.6%	1.2%	3.0%	17.3%	18.3%	0.0%	0.0%
	Horticulture	7.2%	9.2%	25.2%	25.2%	2.2%	2.5%	19.4%	25.8%	6.1%	30.0%	0.6%	0.6%	3.7%	8.9%	7.6%	8.0%	5.1%	5.2%
Residential sub-classes (% of total residential)	Medium density suburb	0.0%	1.4%	0.0%	0.0%	0.0%	2.2%	0.0%	7.0%	0.0%	10.2%	0.0%	4.3%	0.0%	5.8%	0.0%	19.6%	0.0%	0.0%
	Low density suburb	0.0%	97.9%	0.0%	0.0%	0.0%	96.7%	100.0%	92.7%	0.0%	88.7%	0.0%	93.6%	100.0%	93.3%	0.0%	78.5%	100.0%	100.0%
	High density suburb	0.0%	0.7%	0.0%	0.0%	0.0%	1.1%	0.0%	0.4%	0.0%	1.1%	0.0%	2.1%	0.0%	0.9%	0.0%	1.9%	0.0%	0.0%
	High density CBD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	High density suburb with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Commercial sub-classes (% of total commercial)	Suburban	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%	100.0%	100.0%	0.0%	100.0%	0.0%	100.0%	100.0%	100.0%	0.0%	100.0%	100.0%	100.0%
	Commercial with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Commercial CBD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Industrial sub-classes (% of total industrial)	Traditional industrial	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	0.0%	100.0%	100.0%	100.0%
	Industrial with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Stormwater treatment	Sediment removal	none	75.0%	none	none	none	75.0%	25.0%	75.0%	none	75.0%	none	75.0%	25.0%	75.0%	25.0%	75.0%	25.0%	25.0%
	Metals removal	none	medium	none	none	none	medium	low	medium	none	medium	none	medium	low	medium	low	medium	low	low
Earthworks controls	Sediment removal	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%
Traffic	Increase in vehicle numbers	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%

BUS = Baseline Urban State (pre-development, 2012), UDO = Urban Development Option (end of the development phase, 2041)

Scenario 5 – Core with Pukekohe Focus

Scenario 5 - Core with Pukekohe Focus	PLU	1		2		3		4		5		6		7		8		9	
	Area (ha)	2791		1323		1983		3709		735		1249		1893		12373		500	
		BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO
Land use (% of PLU area)	Rural	100.0%	100.0%	100.0%	100.0%	100.0%	98.7%	88.2%	58.4%	100.0%	20.3%	100.0%	55.4%	66.8%	27.5%	99.5%	93.5%	86.0%	84.8%
	Residential	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%	8.7%	34.8%	0.0%	77.8%	0.0%	43.4%	27.9%	63.0%	0.0%	3.9%	6.8%	7.6%
	Commercial	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.9%	1.4%	0.0%	1.9%	0.0%	1.2%	0.1%	3.5%	0.0%	0.2%	1.5%	1.5%
	Industrial	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.2%	5.3%	0.0%	0.0%	0.0%	0.0%	5.2%	6.0%	0.0%	1.9%	4.6%	4.6%
	Major roads	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.5%	1.2%	1.5%
Rural sub-classes (% of total rural)	Pasture	92.3%	92.3%	73.5%	73.5%	97.5%	97.4%	78.6%	67.6%	93.0%	65.5%	94.2%	89.6%	94.4%	86.4%	72.3%	70.5%	94.9%	94.8%
	Exotic Forest	0.1%	0.1%	0.0%	0.0%	0.2%	0.2%	0.4%	0.6%	0.6%	3.2%	0.8%	1.4%	0.7%	1.7%	2.7%	2.9%	0.0%	0.0%
	Native Forest	0.4%	0.4%	1.3%	1.3%	0.2%	0.2%	1.6%	2.4%	0.3%	1.3%	4.4%	7.9%	1.2%	3.0%	17.3%	18.4%	0.0%	0.0%
	Horticulture	7.2%	7.2%	25.2%	25.2%	2.2%	2.2%	19.4%	29.3%	6.1%	30.0%	0.6%	1.0%	3.7%	8.9%	7.6%	8.1%	5.1%	5.2%
Residential sub-classes (% of total residential)	Medium density suburb	0.0%	0.0%	0.0%	0.0%	0.0%	4.3%	0.0%	5.7%	0.0%	10.2%	0.0%	1.7%	0.0%	5.8%	0.0%	17.5%	0.0%	0.0%
	Low density suburb	0.0%	0.0%	0.0%	0.0%	0.0%	93.6%	100.0%	93.8%	0.0%	88.7%	0.0%	97.5%	100.0%	93.3%	0.0%	80.5%	100.0%	100.0%
	High density suburb	0.0%	0.0%	0.0%	0.0%	0.0%	2.1%	0.0%	0.5%	0.0%	1.1%	0.0%	0.8%	0.0%	0.9%	0.0%	1.9%	0.0%	0.0%
	High density CBD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	High density suburb with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Commercial sub-classes (% of total commercial)	Suburban	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	100.0%	0.0%	100.0%	0.0%	100.0%	100.0%	100.0%	0.0%	100.0%	100.0%	100.0%
	Commercial with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Commercial CBD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Industrial sub-classes (% of total industrial)	Traditional industrial	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	0.0%	100.0%	100.0%	100.0%
	Industrial with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Stormwater treatment	Sediment removal	none	none	none	none	none	75.0%	25.0%	75.0%	none	75.0%	none	75.0%	25.0%	75.0%	25.0%	75.0%	25.0%	25.0%
	Metals removal	none	none	none	none	none	medium	low	medium	none	medium	none	medium	low	medium	low	medium	low	low
Earthworks controls	Sediment removal	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%
Traffic	Increase in vehicle numbers	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%

BUS = Baseline Urban State (pre-development, 2012), UDO = Urban Development Option (end of the development phase, 2041)

Scenario 6 – Core with Corridor Focus

Scenario 6 with Corridor Focus	PLU	1		2		3		4		5		6		7		8		9	
	Area (ha)	2791		1323		1983		3709		735		1249		1893		12373		500	
		BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO
Land use (% of PLU area)	Rural	100.0%	100.0%	100.0%	100.0%	100.0%	76.3%	88.2%	66.3%	100.0%	20.3%	100.0%	26.5%	66.8%	27.5%	99.5%	93.5%	86.0%	84.8%
	Residential	0.0%	0.0%	0.0%	0.0%	0.0%	22.9%	8.7%	27.0%	0.0%	77.8%	0.0%	71.3%	27.9%	63.0%	0.0%	3.9%	6.8%	7.6%
	Commercial	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%	0.9%	1.3%	0.0%	1.9%	0.0%	2.2%	0.1%	3.5%	0.0%	0.2%	1.5%	1.5%
	Industrial	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.2%	5.3%	0.0%	0.0%	0.0%	0.0%	5.2%	6.0%	0.0%	1.9%	4.6%	4.6%
	Major roads	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.5%	1.2%	1.5%
Rural sub-classes (% of total rural)	Pasture	92.3%	92.3%	73.5%	73.5%	97.5%	96.7%	78.6%	71.5%	93.0%	65.5%	94.2%	78.3%	94.4%	86.4%	72.3%	70.5%	94.9%	94.8%
	Exotic Forest	0.1%	0.1%	0.0%	0.0%	0.2%	0.2%	0.4%	0.5%	0.6%	3.2%	0.8%	3.0%	0.7%	1.7%	2.7%	2.9%	0.0%	0.0%
	Native Forest	0.4%	0.4%	1.3%	1.3%	0.2%	0.3%	1.6%	2.2%	0.3%	1.3%	4.4%	16.6%	1.2%	3.0%	17.3%	18.4%	0.0%	0.0%
	Horticulture	7.2%	7.2%	25.2%	25.2%	2.2%	2.8%	19.4%	25.8%	6.1%	30.0%	0.6%	2.2%	3.7%	8.9%	7.6%	8.1%	5.1%	5.2%
Residential sub-classes (% of total residential)	Medium density suburb	0.0%	0.0%	0.0%	0.0%	0.0%	2.2%	0.0%	7.0%	0.0%	10.2%	0.0%	7.3%	0.0%	5.8%	0.0%	17.5%	0.0%	0.0%
	Low density suburb	0.0%	0.0%	0.0%	0.0%	0.0%	96.7%	100.0%	92.7%	0.0%	88.7%	0.0%	91.5%	100.0%	93.3%	0.0%	80.5%	100.0%	100.0%
	High density suburb	0.0%	0.0%	0.0%	0.0%	0.0%	1.1%	0.0%	0.4%	0.0%	1.1%	0.0%	1.2%	0.0%	0.9%	0.0%	1.9%	0.0%	0.0%
	High density CBD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	High density suburb with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Commercial sub-classes (% of total commercial)	Suburban	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	100.0%	0.0%	100.0%	0.0%	100.0%	100.0%	100.0%	0.0%	100.0%	100.0%	100.0%
	Commercial with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Commercial CBD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Industrial sub-classes (% of total industrial)	Traditional industrial	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	0.0%	100.0%	100.0%	100.0%
	Industrial with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Stormwater treatment	Sediment removal	none	none	none	none	none	75.0%	25.0%	75.0%	none	75.0%	none	75.0%	25.0%	75.0%	25.0%	75.0%	25.0%	25.0%
	Metals removal	none	none	none	none	none	medium	low	medium	none	medium	none	medium	low	medium	low	medium	low	low
Earthworks controls	Sediment removal	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%
Traffic	Increase in vehicle numbers	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%

BUS = Baseline Urban State (pre-development, 2012), UDO = Urban Development Option (end of the development phase, 2041)

Scenario 7 – Core with West-East Focus

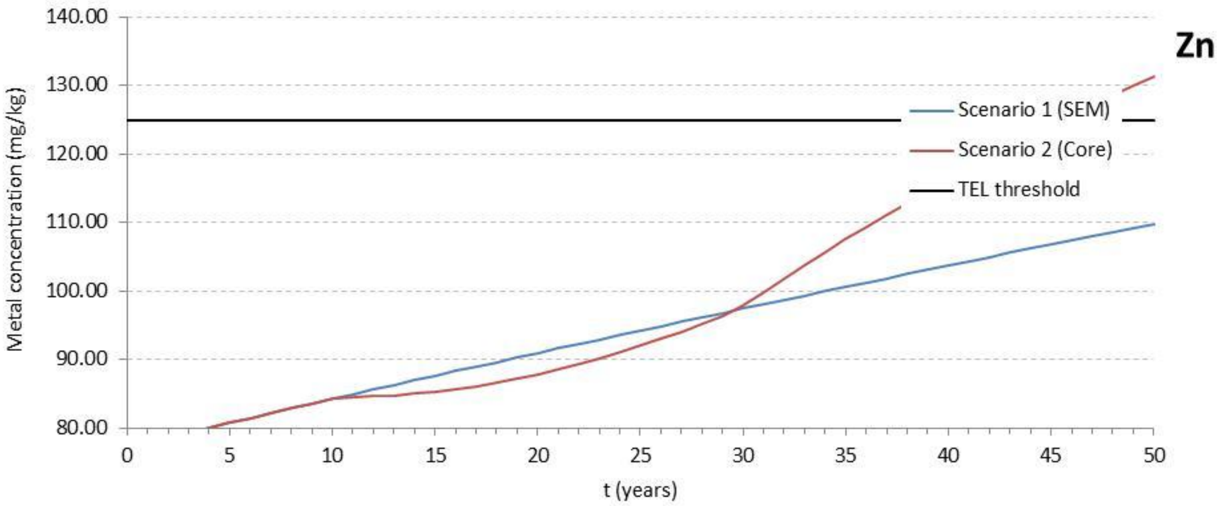
Scenario 4 - Core with West-East Focus	PLU	1		2		3		4		5		6		7		8		9	
	Area (ha)	2791		1323		1983		3709		735		1249		1893		12373		500	
		BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO	BUS	UDO
Land use (% of PLU area)	Rural	100.0%	64.8%	100.0%	100.0%	100.0%	88.0%	88.2%	66.3%	100.0%	20.3%	100.0%	96.0%	66.8%	27.5%	99.5%	94.3%	86.0%	84.8%
	Residential	0.0%	34.5%	0.0%	0.0%	0.0%	11.6%	8.7%	27.0%	0.0%	77.8%	0.0%	3.7%	27.9%	63.0%	0.0%	3.4%	6.8%	7.6%
	Commercial	0.0%	0.7%	0.0%	0.0%	0.0%	0.4%	0.9%	1.3%	0.0%	1.9%	0.0%	0.3%	0.1%	3.5%	0.0%	0.1%	1.5%	1.5%
	Industrial	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.2%	5.3%	0.0%	0.0%	0.0%	0.0%	5.2%	6.0%	0.0%	1.7%	4.6%	4.6%
	Major roads	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.5%	1.2%	1.5%
Rural sub-classes (% of total rural)	Pasture	92.3%	88.1%	73.5%	73.5%	97.5%	97.1%	78.6%	71.5%	93.0%	65.5%	94.2%	94.0%	94.4%	86.4%	72.3%	70.8%	94.9%	94.8%
	Exotic Forest	0.1%	0.2%	0.0%	0.0%	0.2%	0.2%	0.4%	0.5%	0.6%	3.2%	0.8%	0.8%	0.7%	1.7%	2.7%	2.9%	0.0%	0.0%
	Native Forest	0.4%	0.6%	1.3%	1.3%	0.2%	0.2%	1.6%	2.2%	0.3%	1.3%	4.4%	4.6%	1.2%	3.0%	17.3%	18.3%	0.0%	0.0%
	Horticulture	7.2%	11.2%	25.2%	25.2%	2.2%	2.5%	19.4%	25.8%	6.1%	30.0%	0.6%	0.6%	3.7%	8.9%	7.6%	8.0%	5.1%	5.2%
Residential sub-classes (% of total residential)	Medium density suburb	0.0%	1.2%	0.0%	0.0%	0.0%	2.2%	0.0%	7.0%	0.0%	10.2%	0.0%	4.3%	0.0%	5.8%	0.0%	19.6%	0.0%	0.0%
	Low density suburb	0.0%	98.1%	0.0%	0.0%	0.0%	96.7%	100.0%	92.7%	0.0%	88.7%	0.0%	93.6%	100.0%	93.3%	0.0%	78.5%	100.0%	100.0%
	High density suburb	0.0%	0.6%	0.0%	0.0%	0.0%	1.1%	0.0%	0.4%	0.0%	1.1%	0.0%	2.1%	0.0%	0.9%	0.0%	1.9%	0.0%	0.0%
	High density CBD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	High density suburb with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Commercial sub-classes (% of total commercial)	Suburban	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%	100.0%	100.0%	0.0%	100.0%	0.0%	100.0%	100.0%	100.0%	0.0%	100.0%	100.0%	100.0%
	Commercial with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Commercial CBD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Industrial sub-classes (% of total industrial)	Traditional industrial	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	0.0%	100.0%	100.0%	100.0%
	Industrial with LID	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Stormwater treatment	Sediment removal	none	75.0%	none	none	none	75.0%	25.0%	75.0%	none	75.0%	none	75.0%	25.0%	75.0%	25.0%	75.0%	25.0%	25.0%
	Metals removal	none	medium	none	none	none	medium	low	medium	none	medium	none	medium	low	medium	low	medium	low	low
Earthworks controls	Sediment removal	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%	-	75.0%
Traffic	Increase in vehicle numbers	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%	-	100.0%

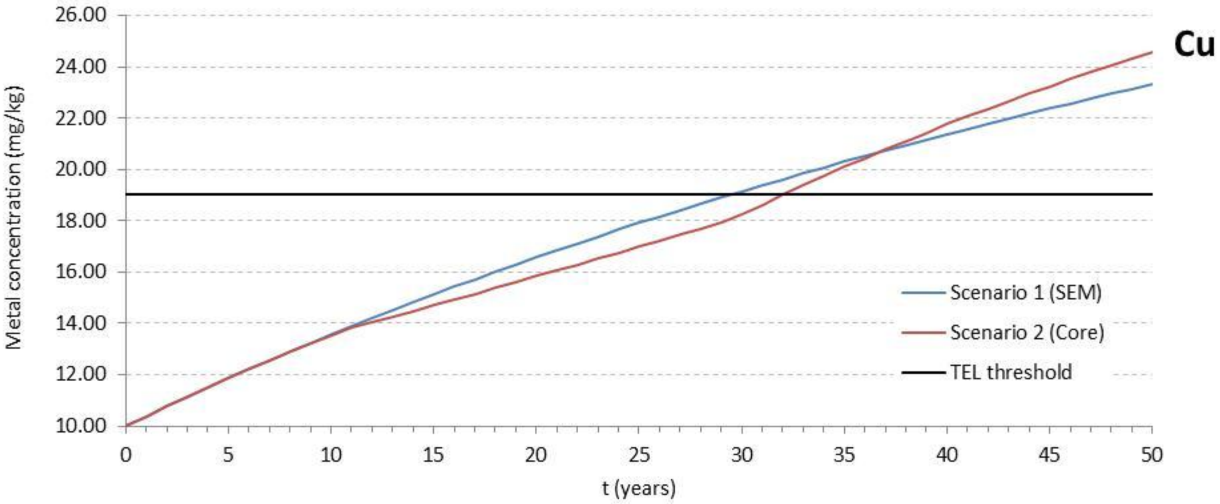
BUS = Baseline Urban State (pre-development, 2012), UDO = Urban Development Option (end of the development phase, 2041)

Appendix B – time series plots of environmental indicators

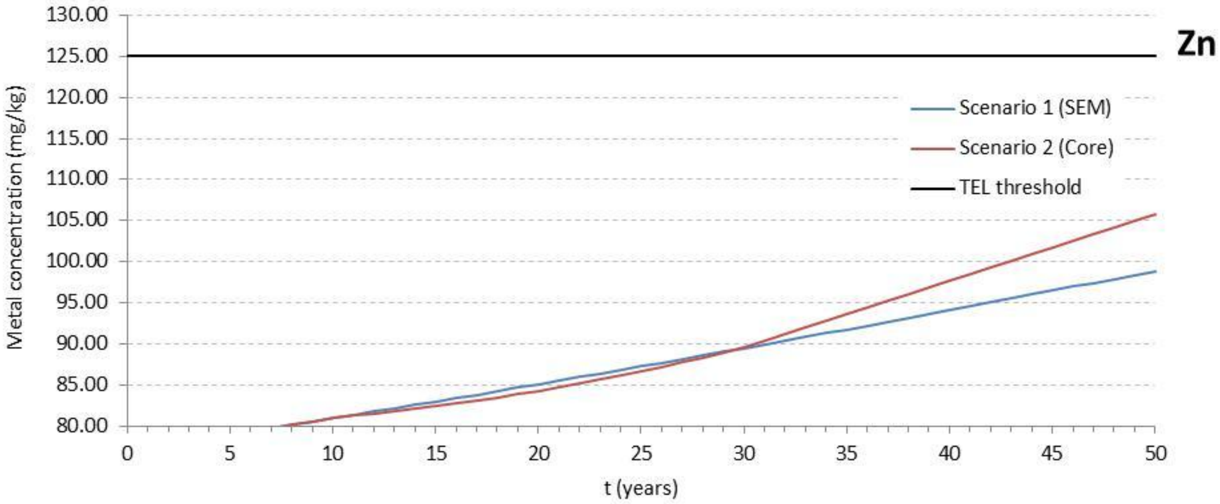
B.1 Predicted sediment metal concentrations, Scenario 2A (Core) compared to Scenario 1 (SEM study)

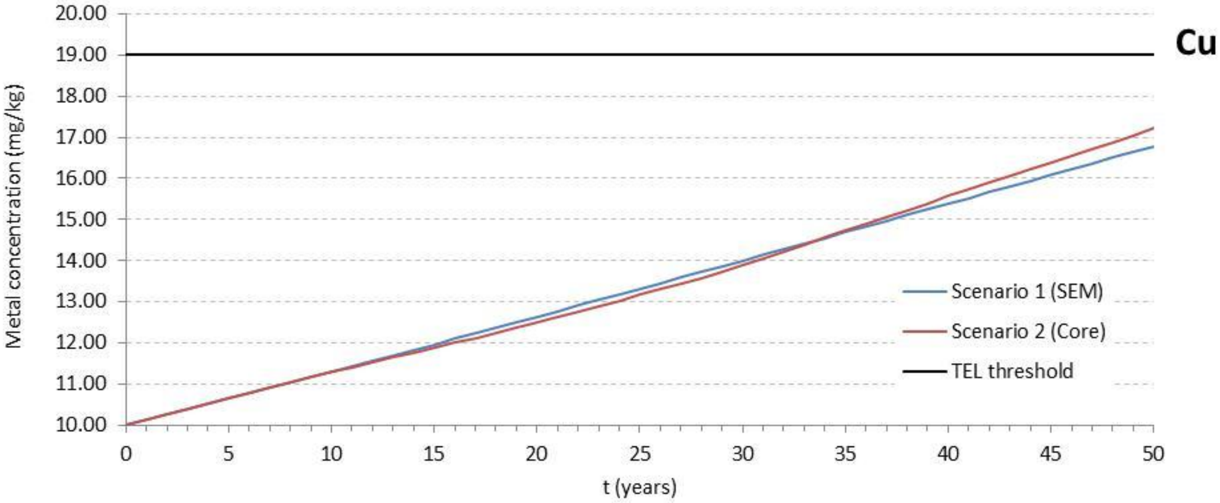
ERU 1 – Glassons Mouth West (SEM subestuary 3-GMW)



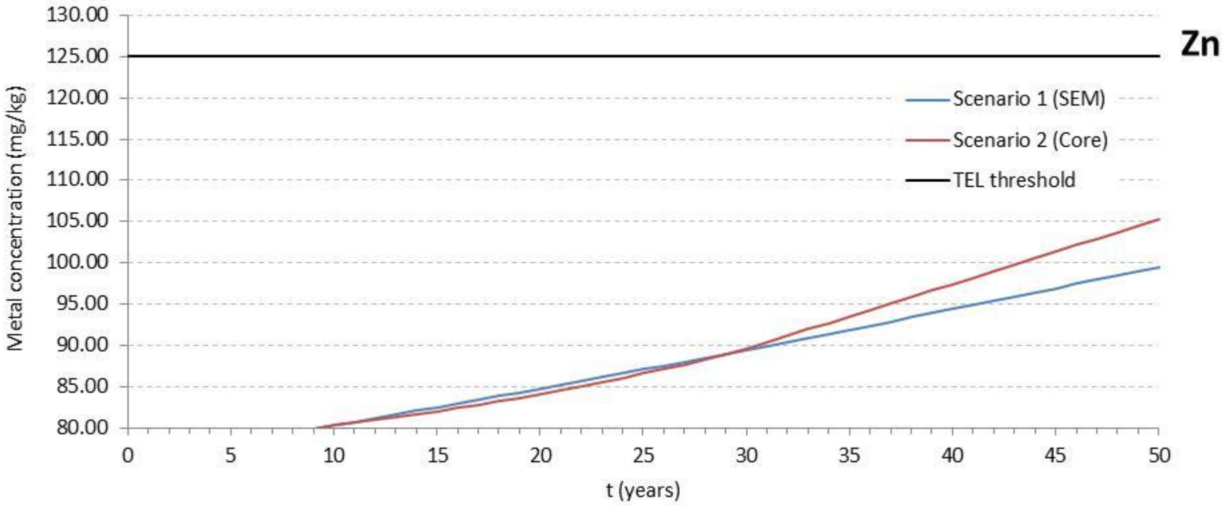


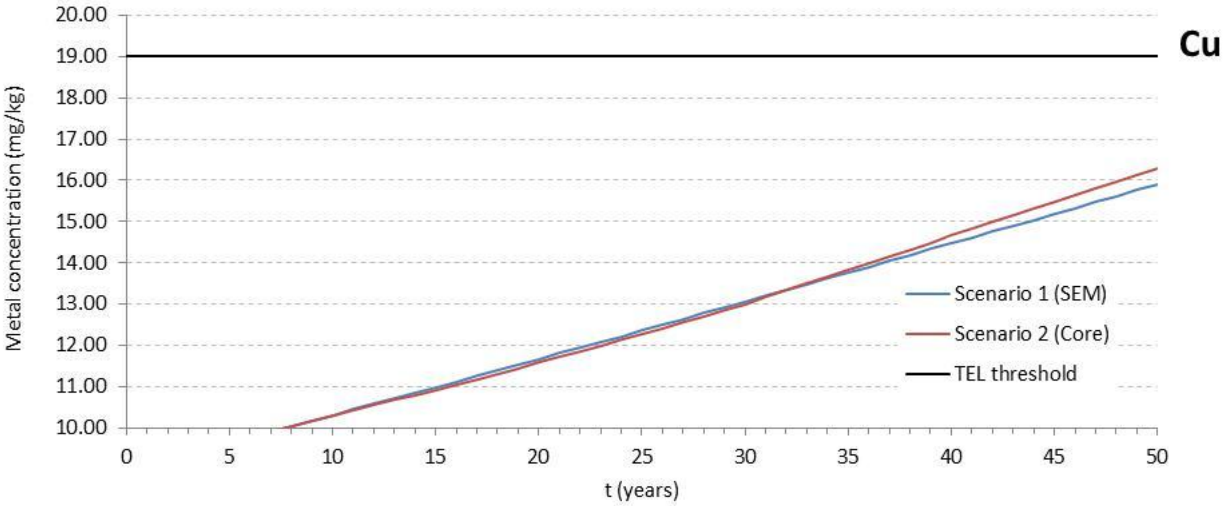
ERU 2 – Glassons Mouth East (SEM subestuary 4-GME)



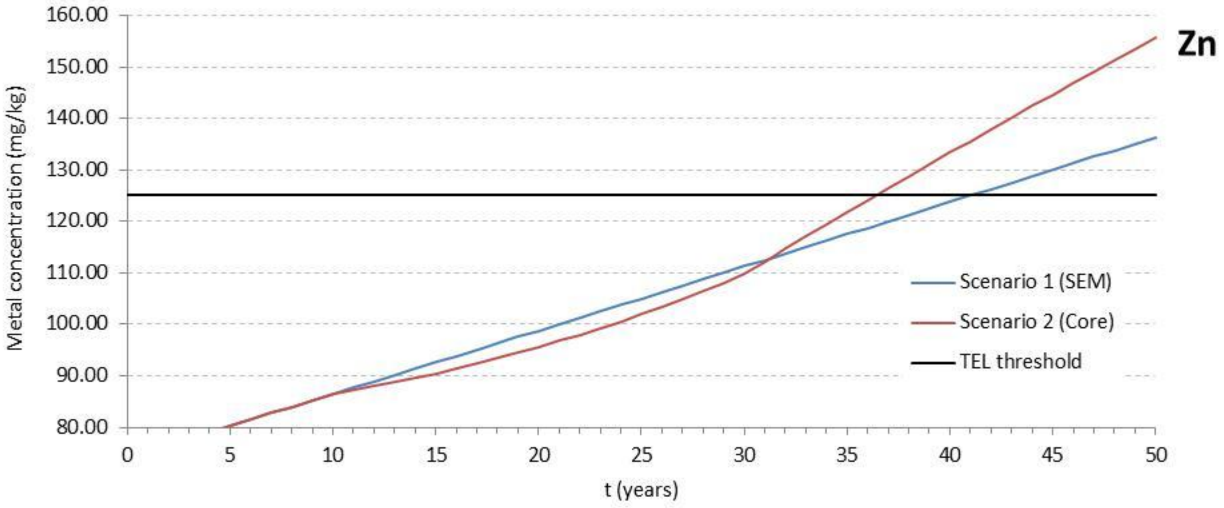


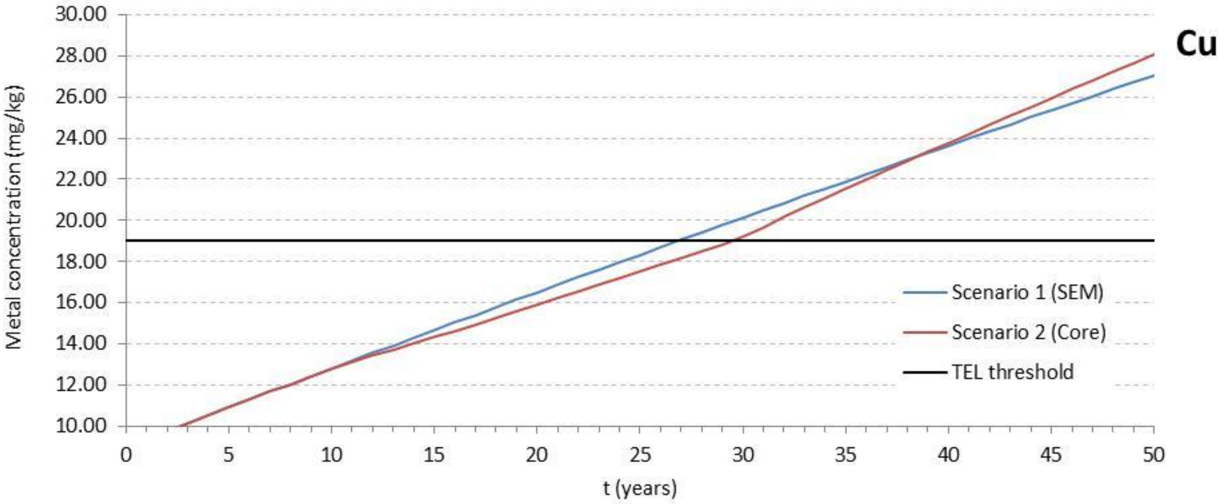
ERU 3 – Cape Horn (SEM subestuary 5-CHN)



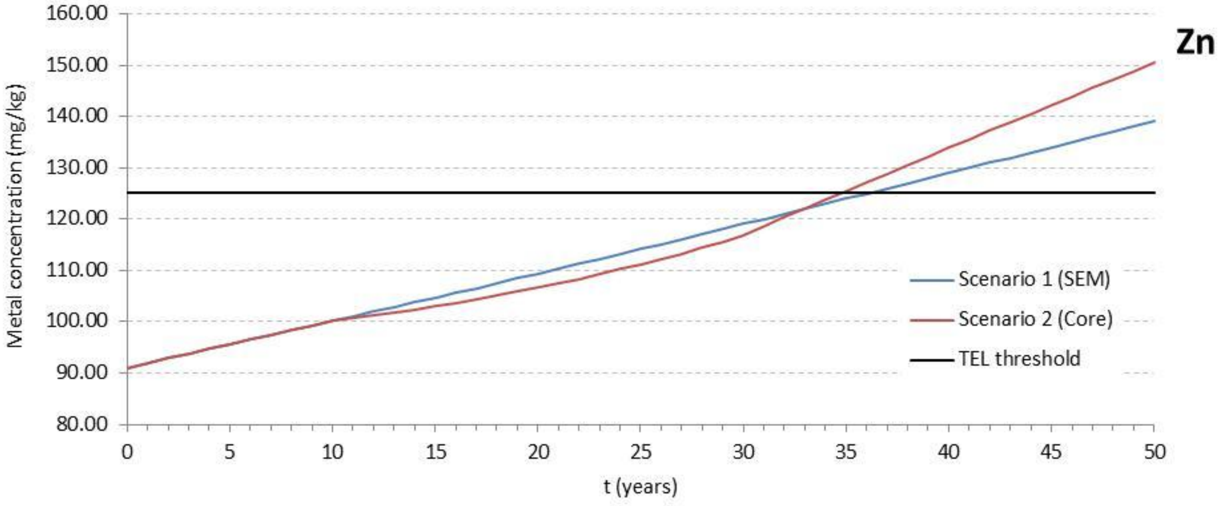


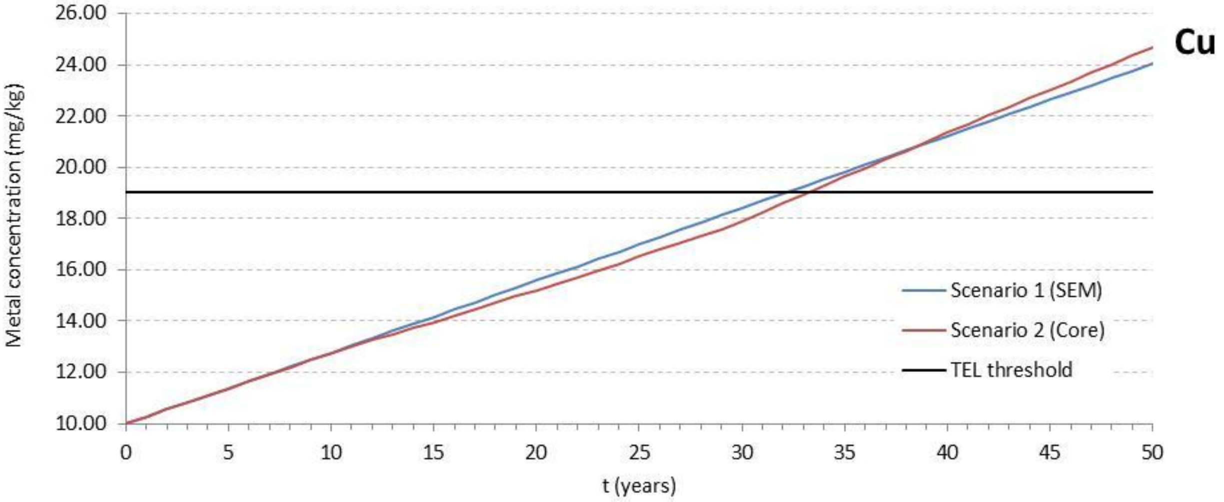
ERU 4 – Drury Creek Outer (SEM subestuary 6-DCO)



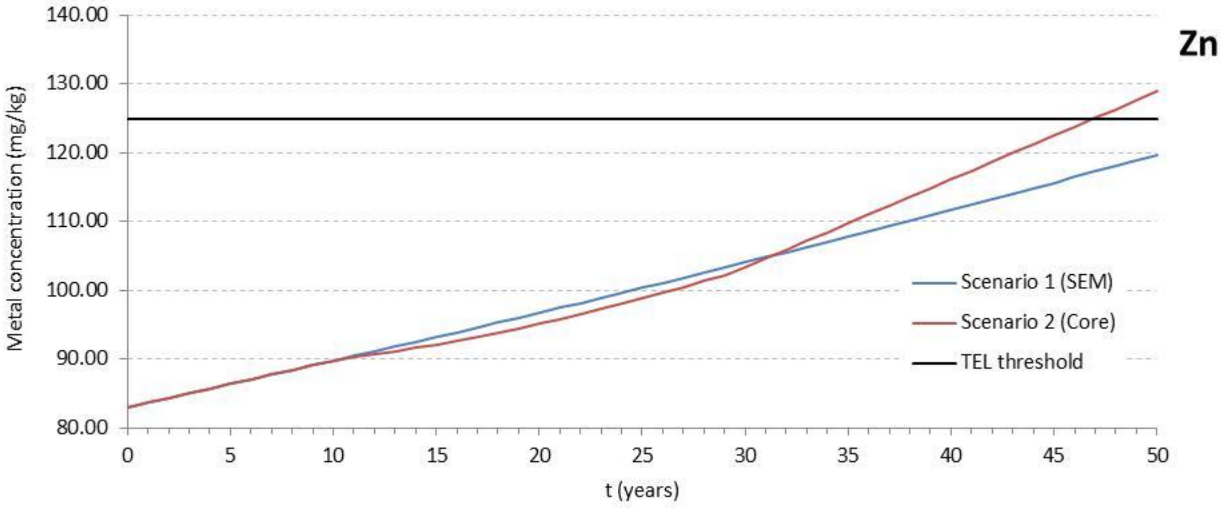


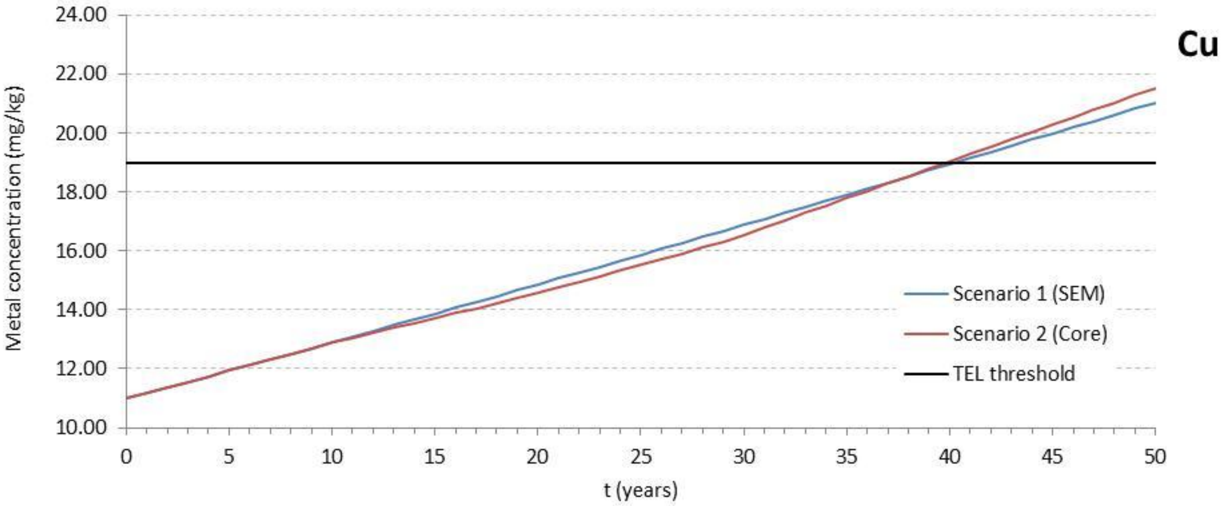
ERU 5 – Pahurehure Inner (SEM subestuary 7-PHI)



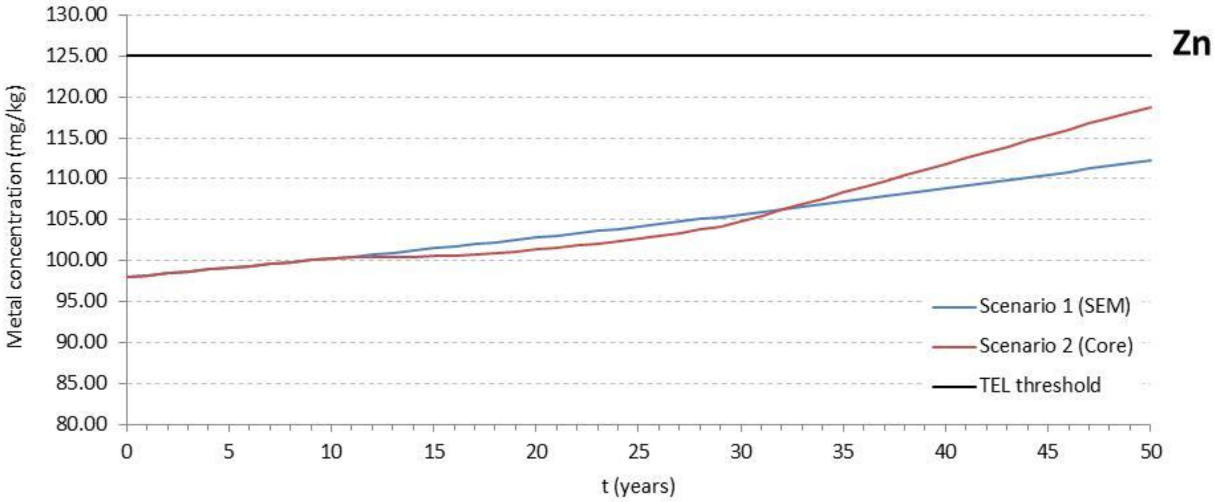


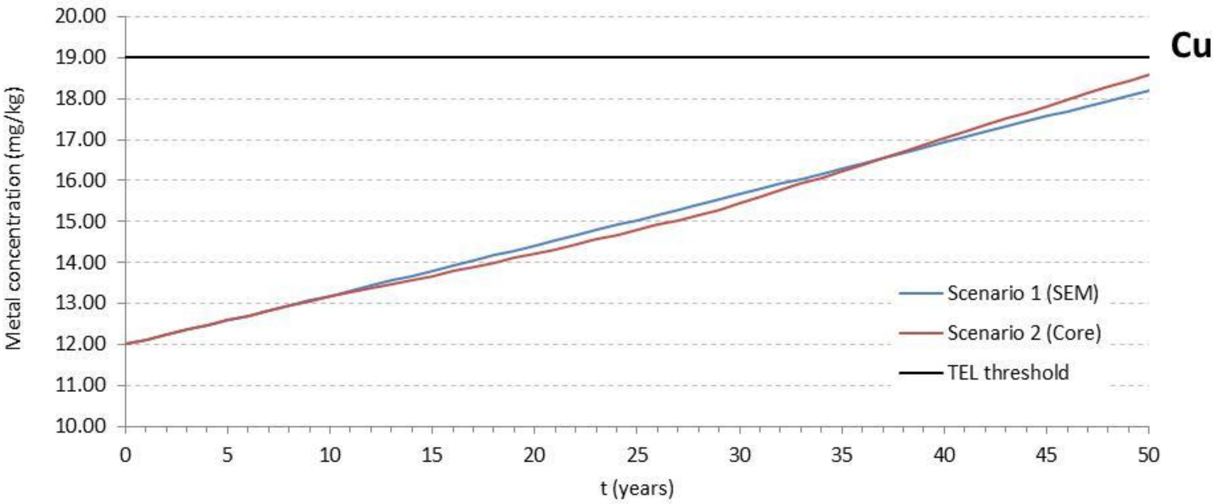
ERU 6 – Drury Creek Inner (SEM subestuary 16-DCI)





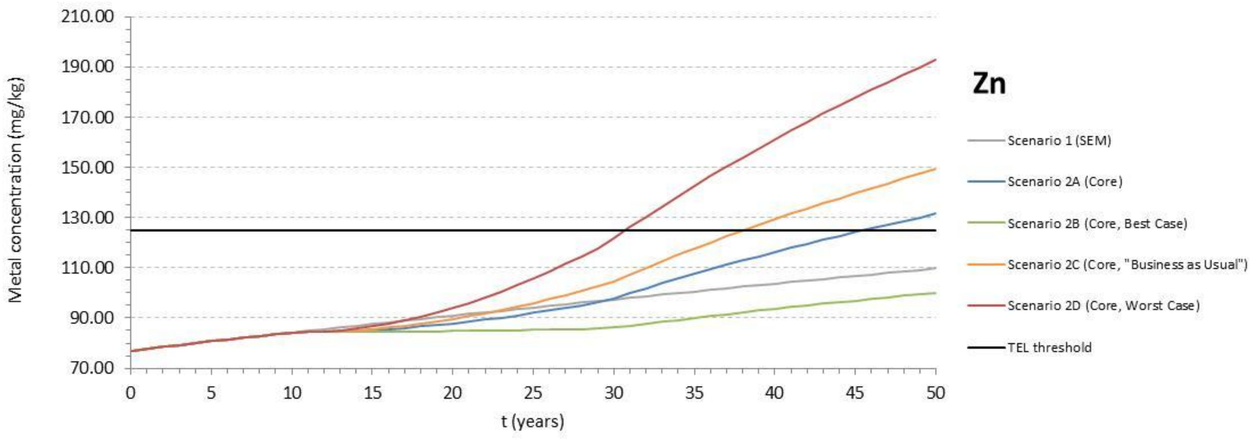
ERU 7 – Glasson Creek Inner (SEM subestuary 17-GCK)

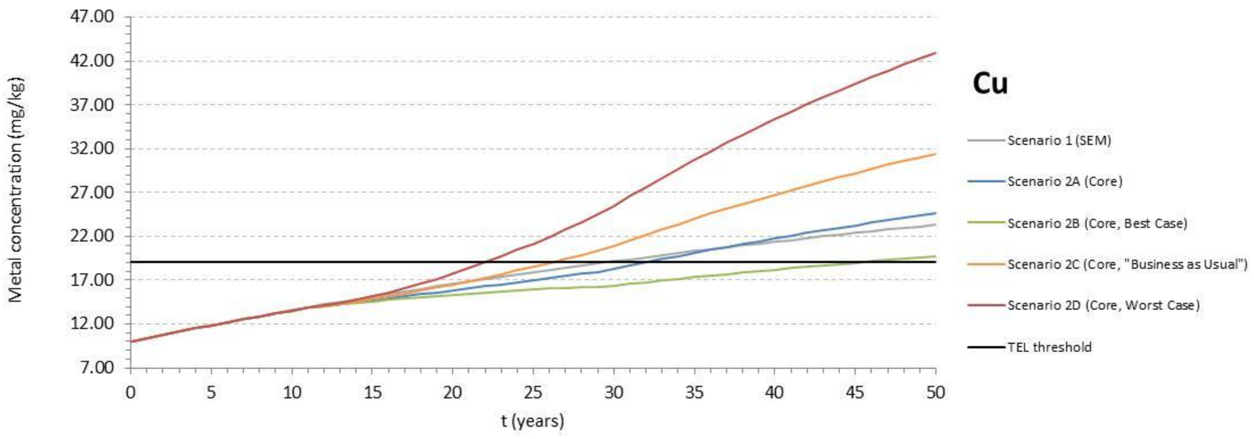




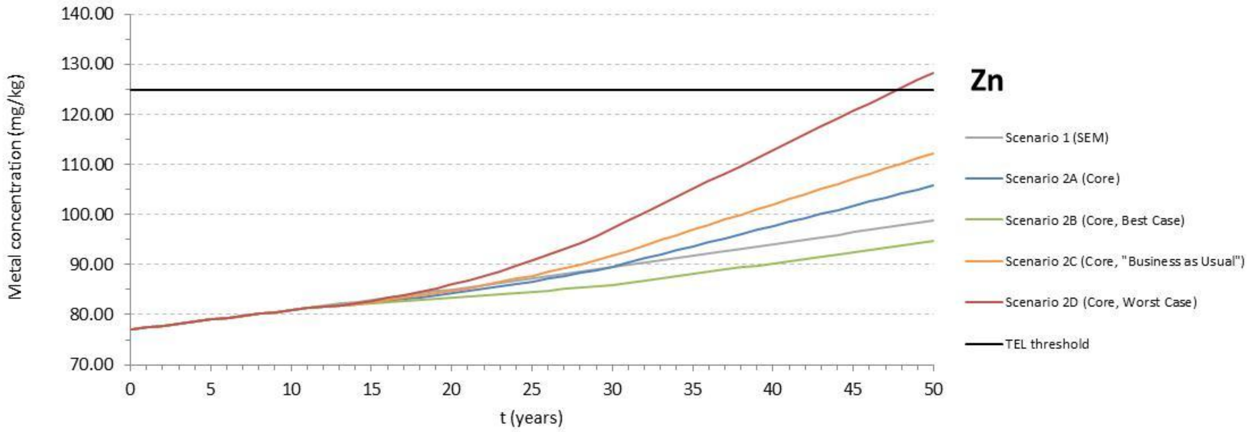
B.2 Predicted sediment metal concentrations, Scenarios 2A-2D (Core with varying levels of stormwater treatment) compared to Scenario 1 (SEM study)

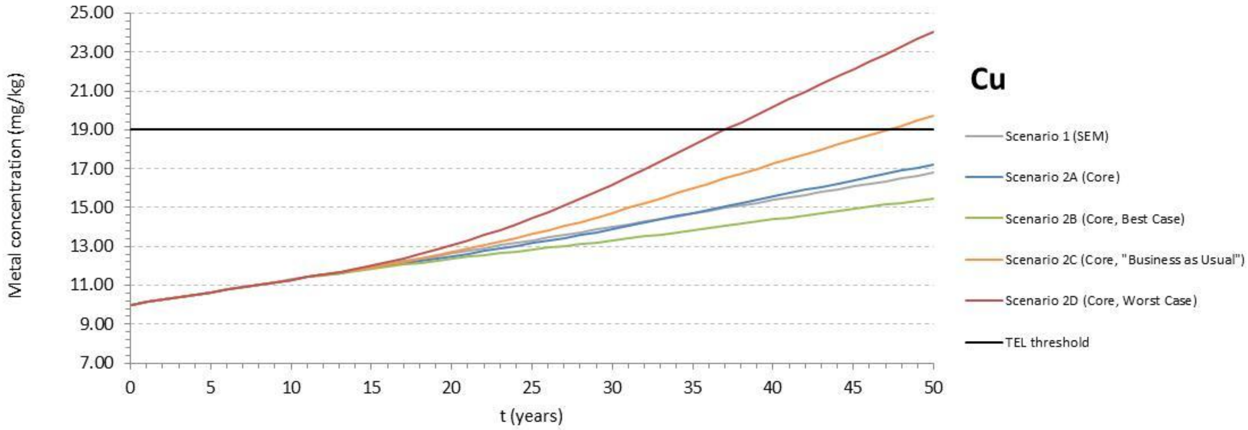
ERU 1 – Glassons Mouth West (SEM subestuary 3-GMW)



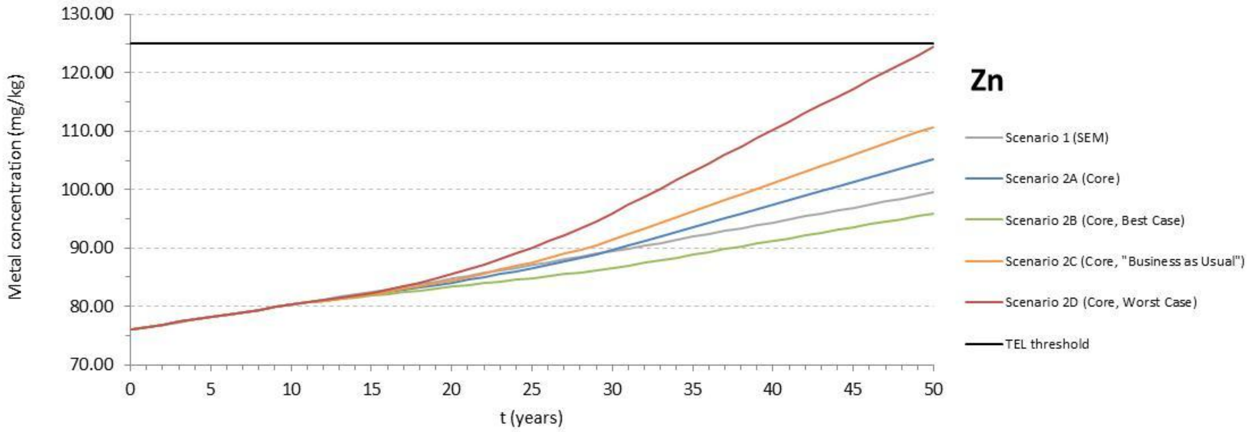


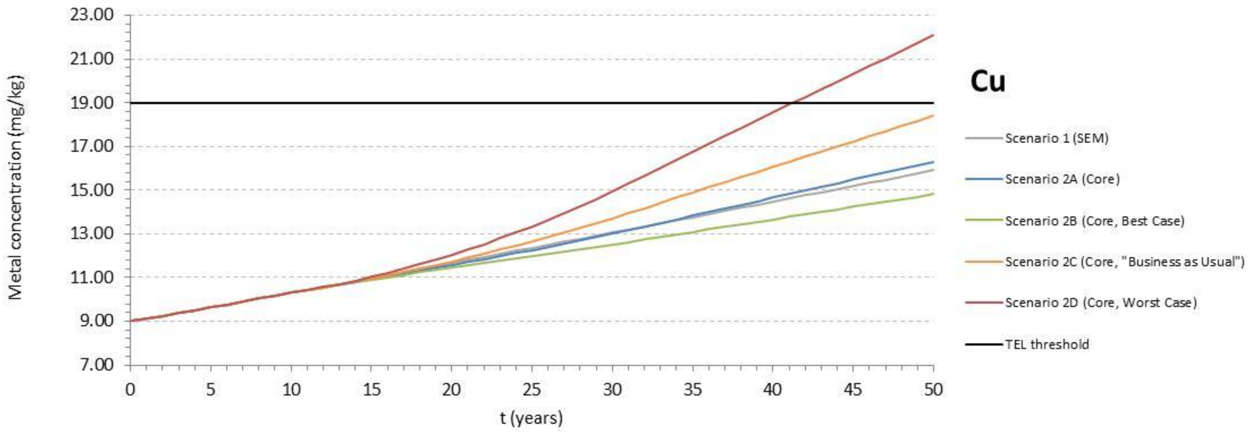
ERU 2 – Glassons Mouth East (SEM subestuary 4-GME)



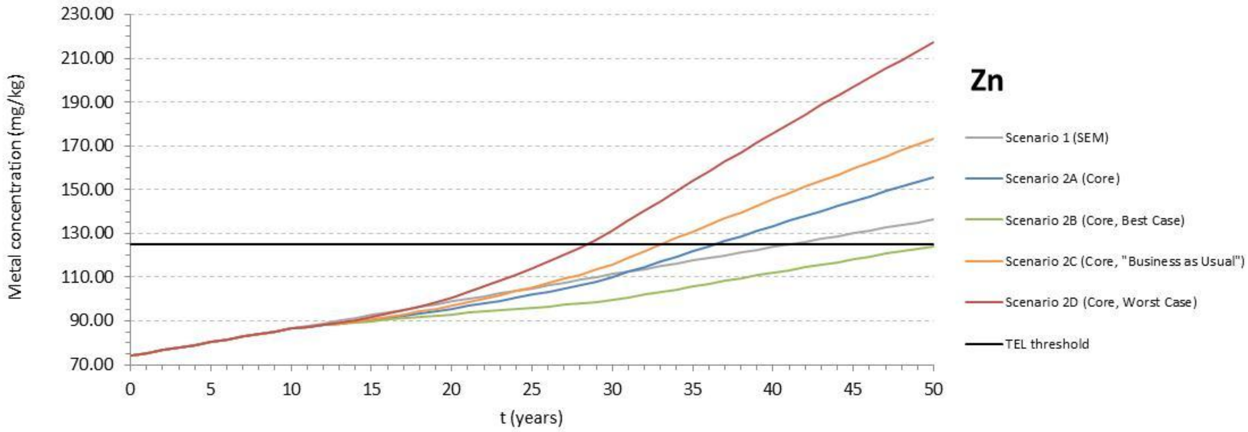


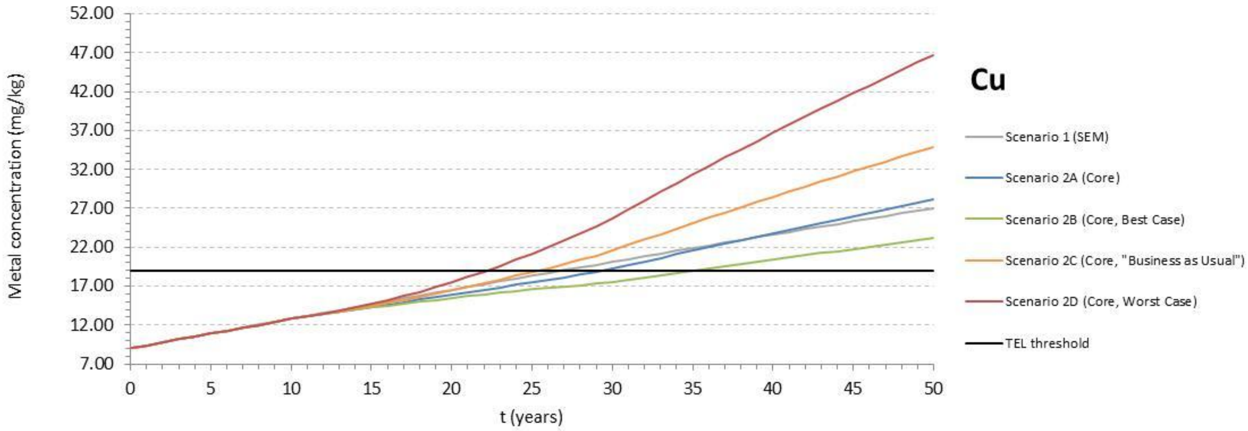
ERU 3 – Cape Horn (SEM subestuary 5-CHN)



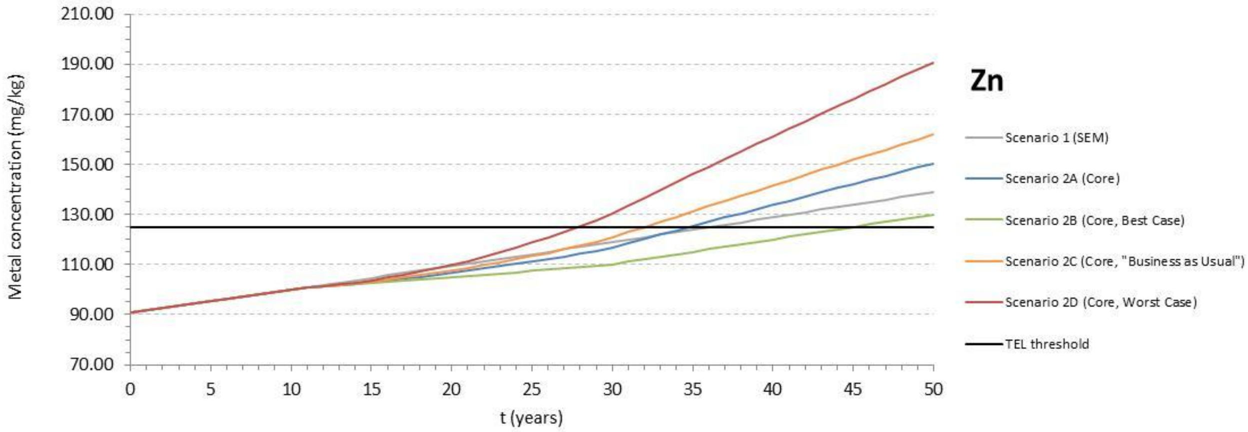


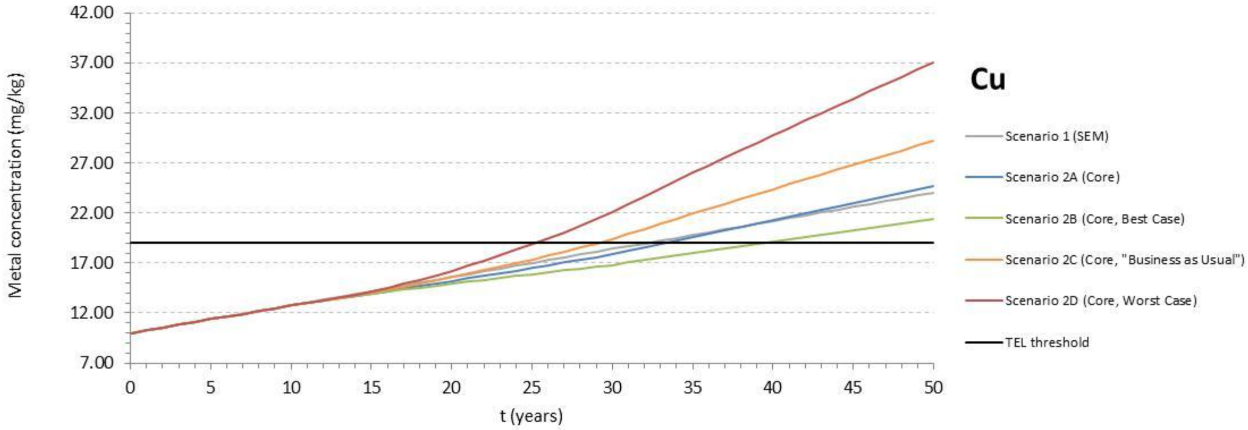
ERU 4 – Drury Creek Outer (SEM subestuary 6-DCO)



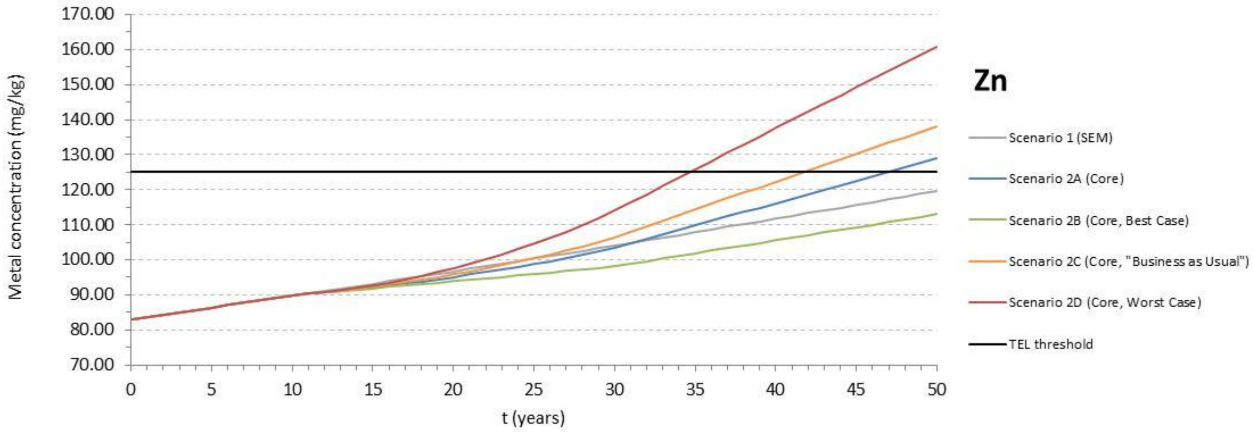


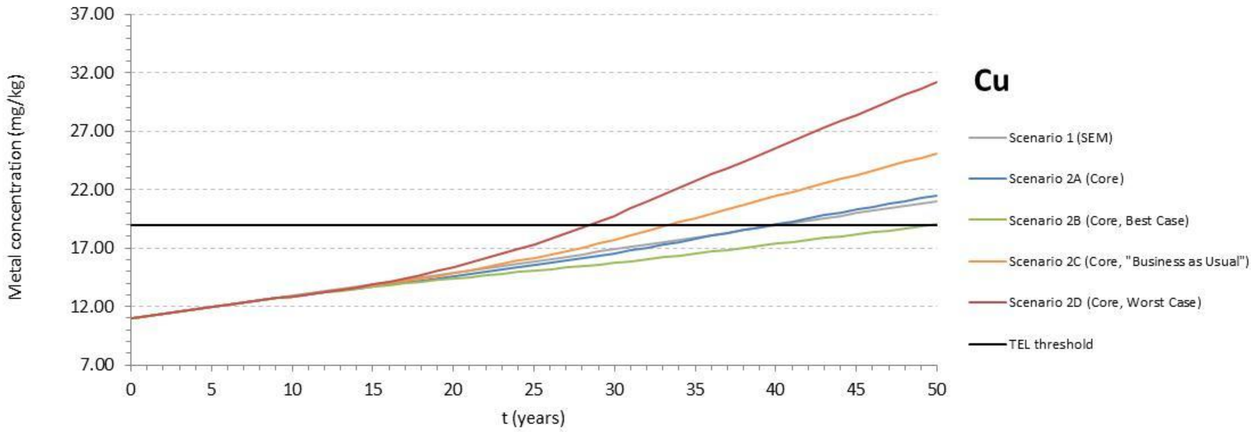
ERU 5 – Pahurehure Inner (SEM subestuary 7-PHI)



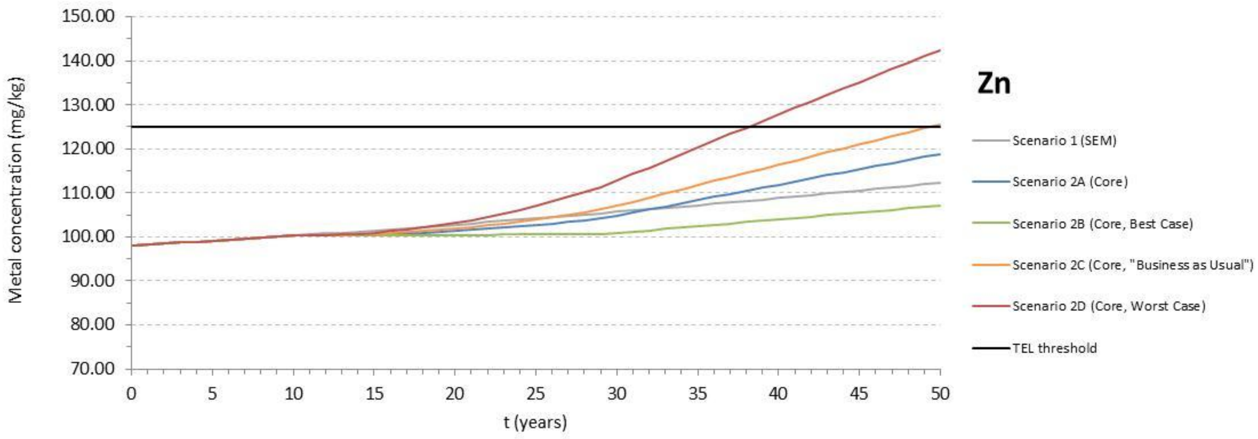


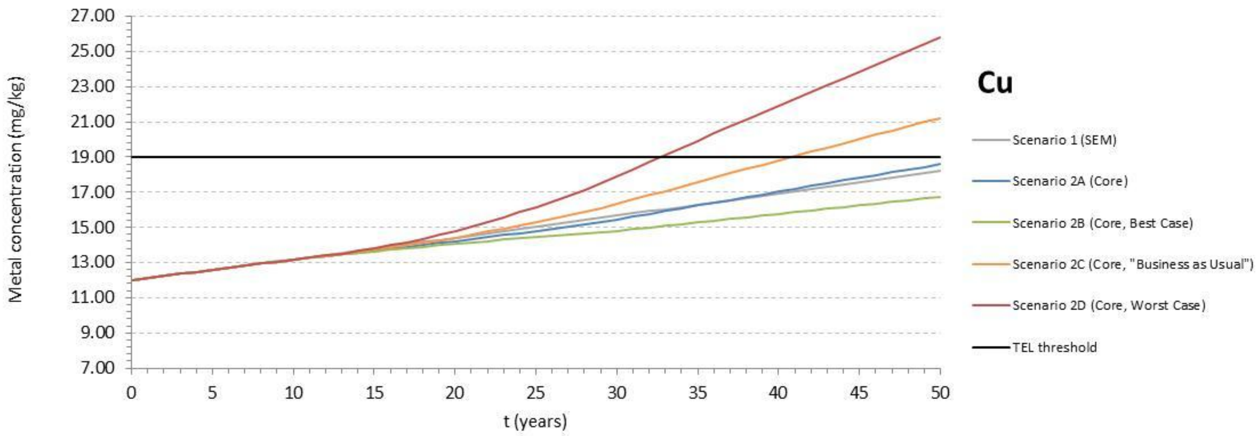
ERU 6 – Drury Creek Inner (SEM subestuary 16-DCI)





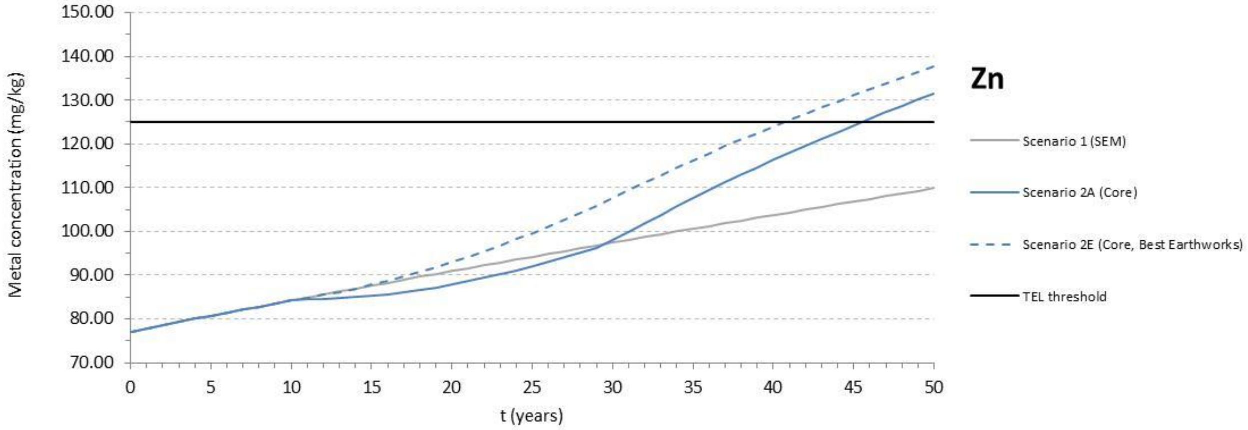
ERU 7 – Glasson Creek Inner (SEM subestuary 17-GCK)

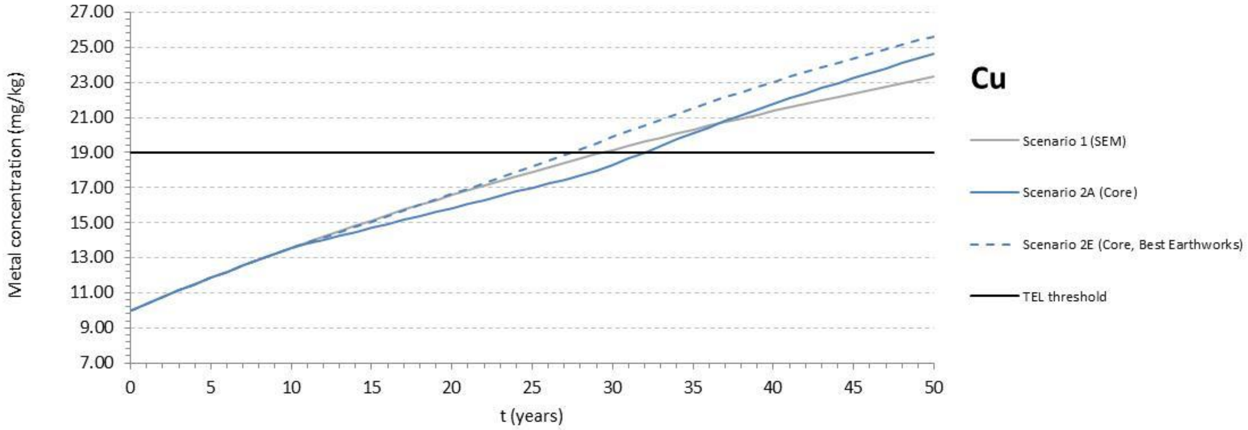




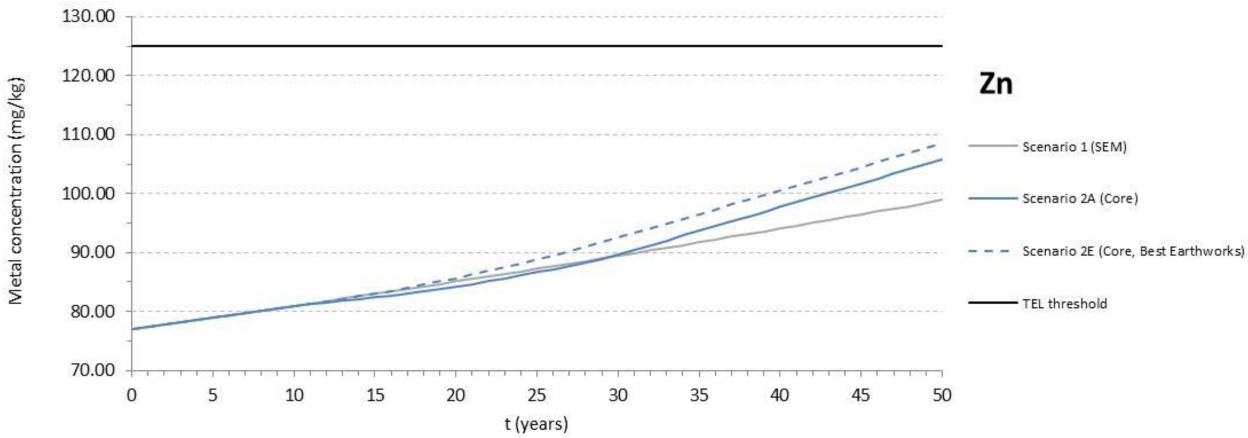
B.3 Predicted sediment metal concentrations, Scenarios 2A and 2E (Core with varying levels of earthworks controls) compared to Scenario 1 (SEM study)

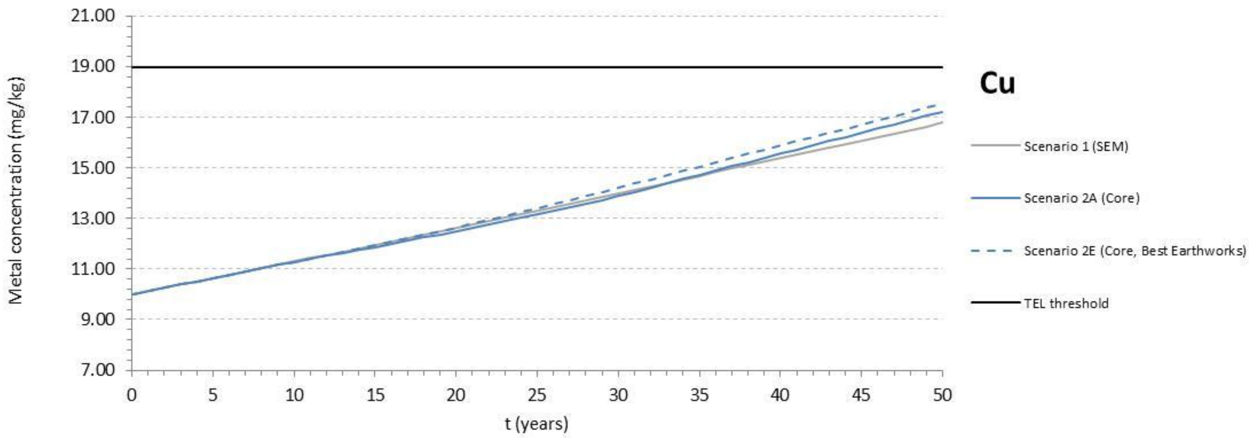
ERU 1 – Glassons Mouth West (SEM subestuary 3-GMW)



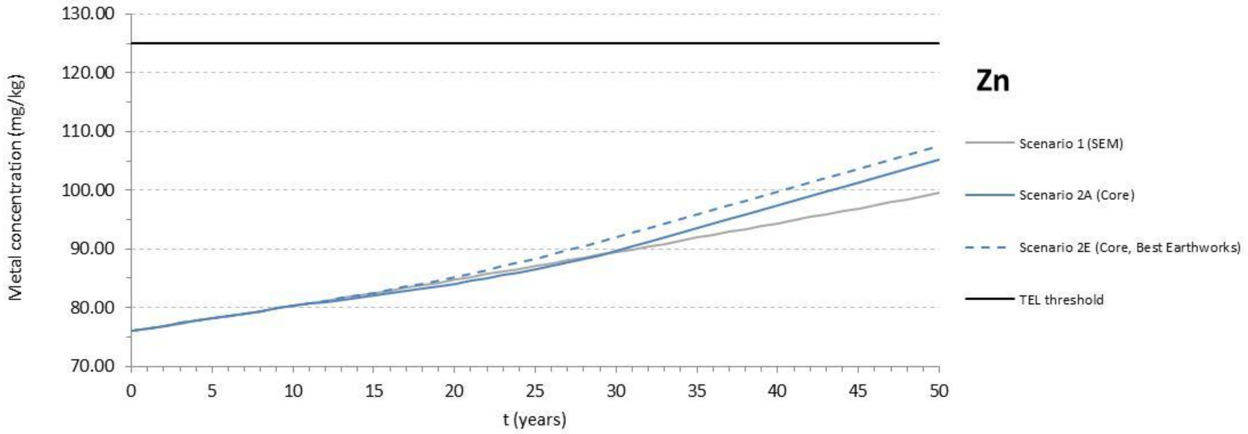


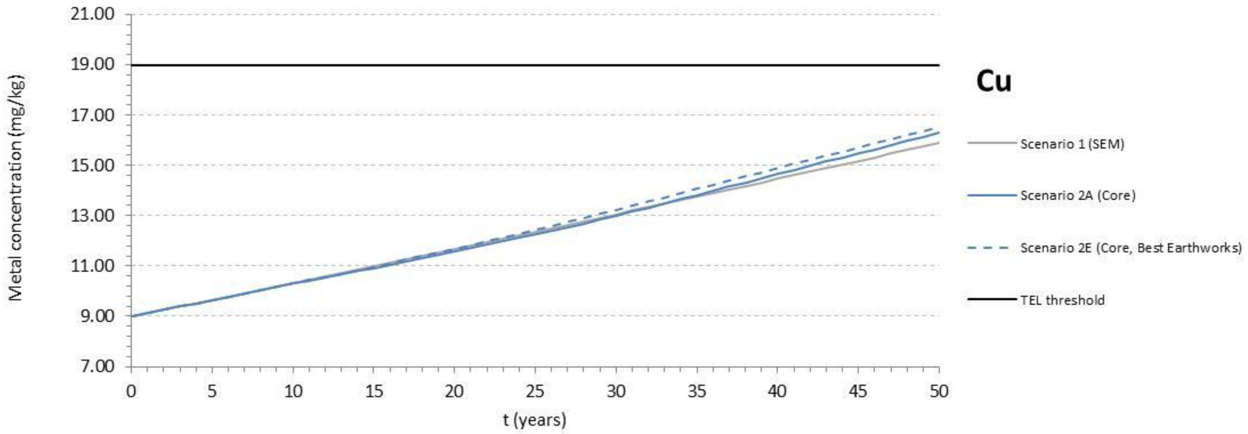
ERU 2 – Glassons Mouth East (SEM subestuary 4-GME)



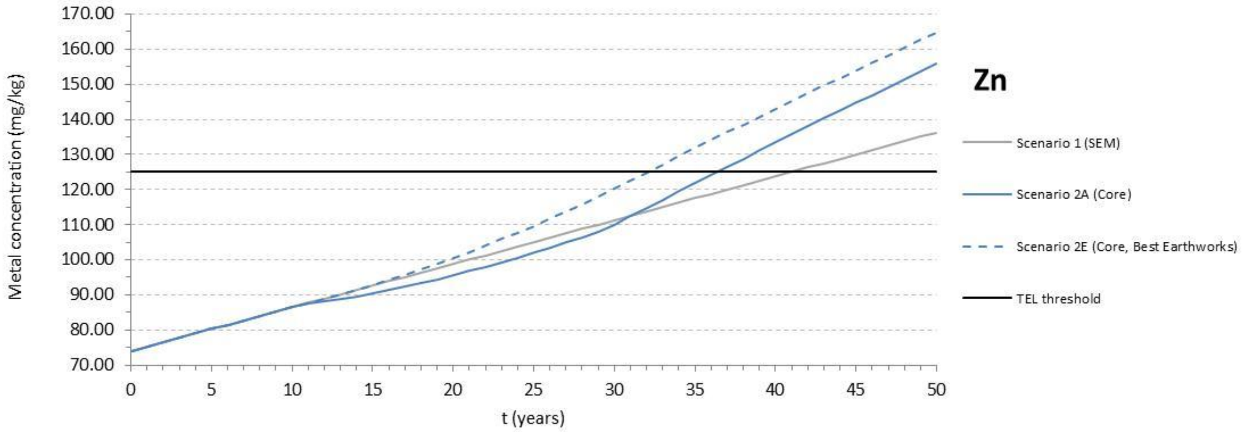


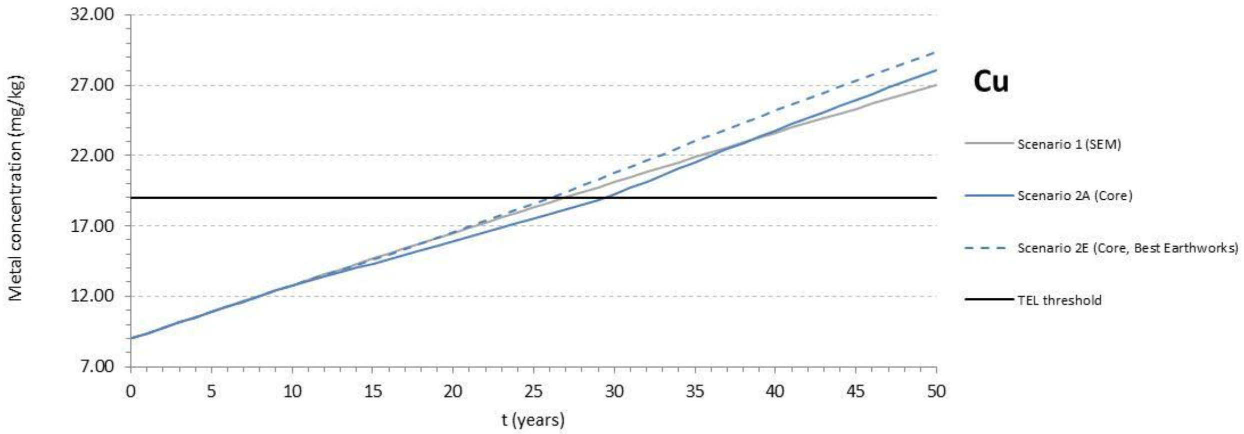
ERU 3 – Cape Horn (SEM subestuary 5-CHN)



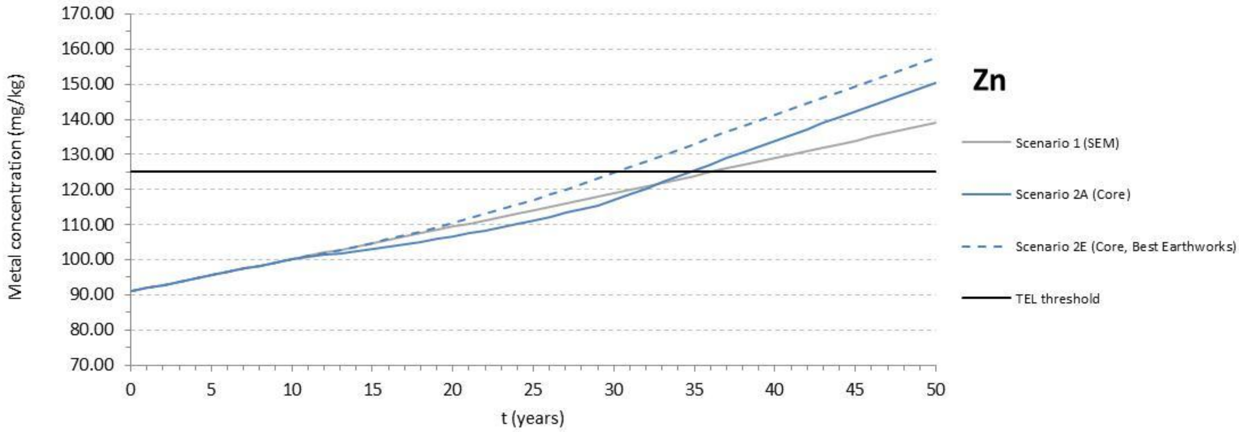


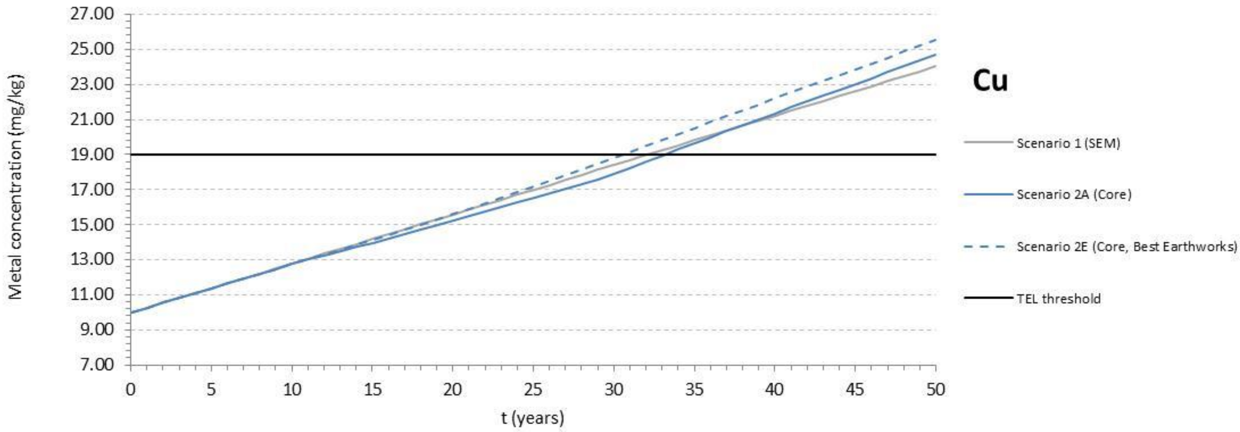
ERU 4 – Drury Creek Outer (SEM subestuary 6-DCO)



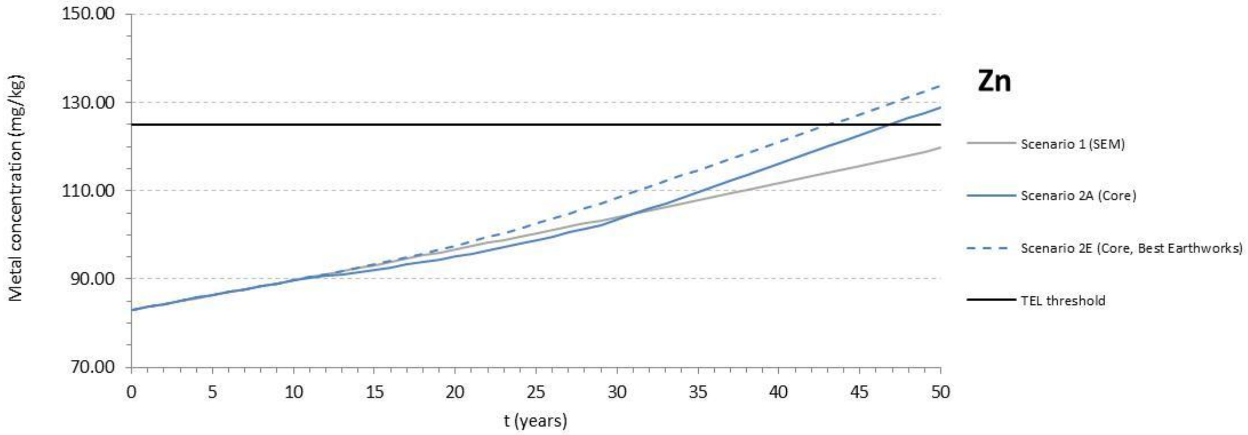


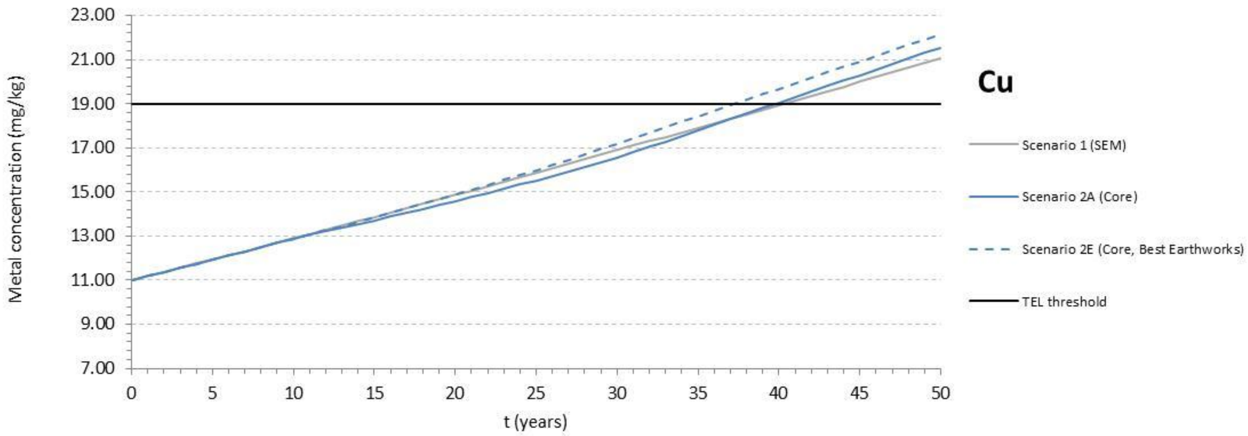
ERU 5 – Pahurehure Inner (SEM subestuary 7-PHI)



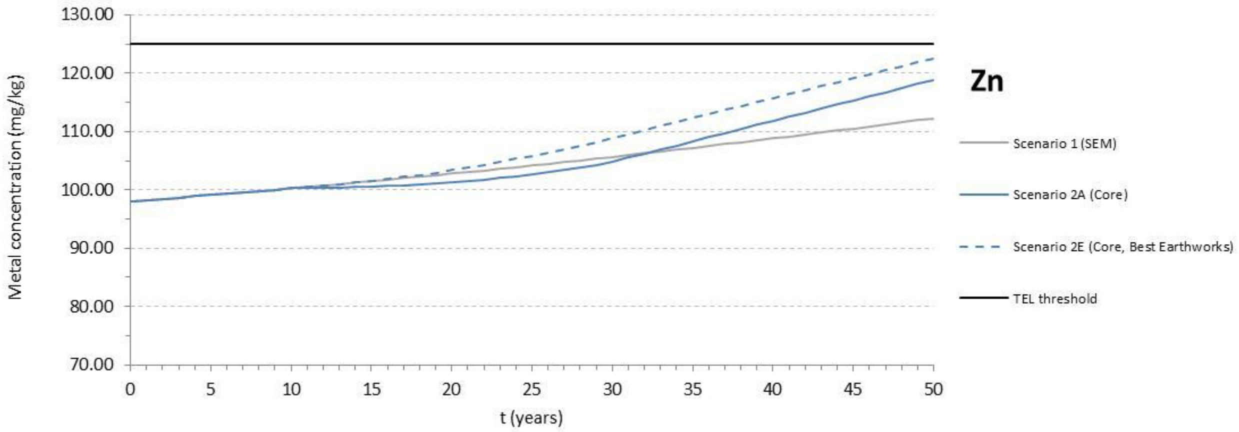


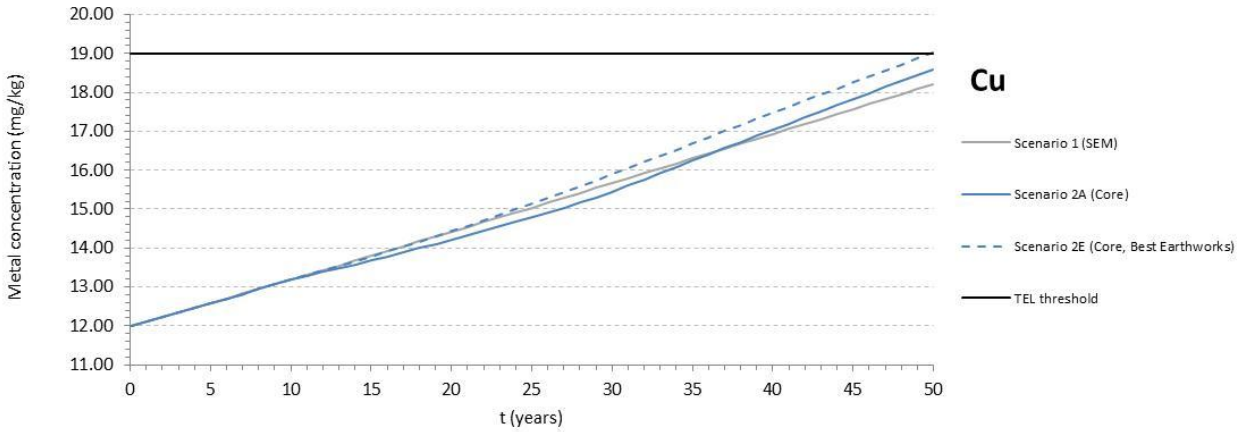
ERU 6 – Drury Creek Inner (SEM subestuary 16-DCI)





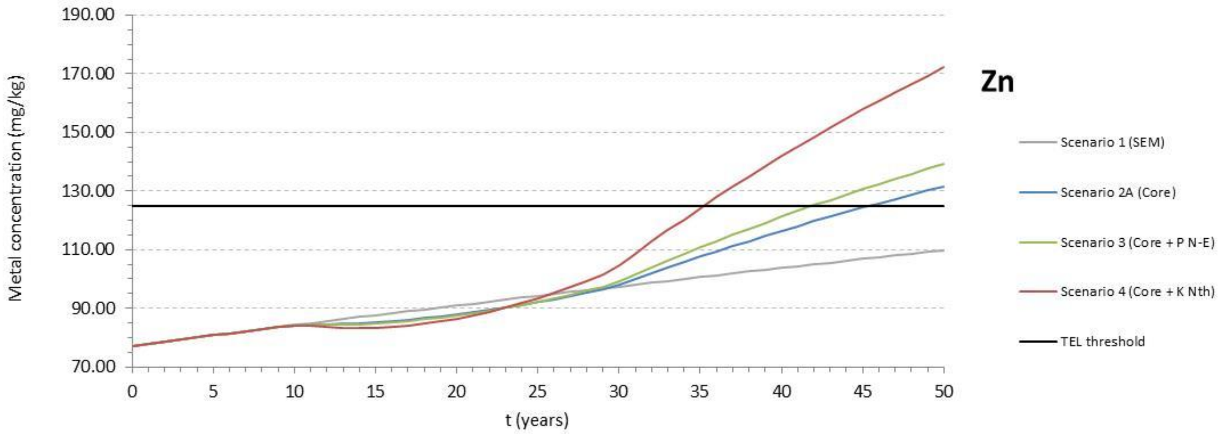
ERU 7 – Glasson Creek Inner (SEM subestuary 17-GCK)

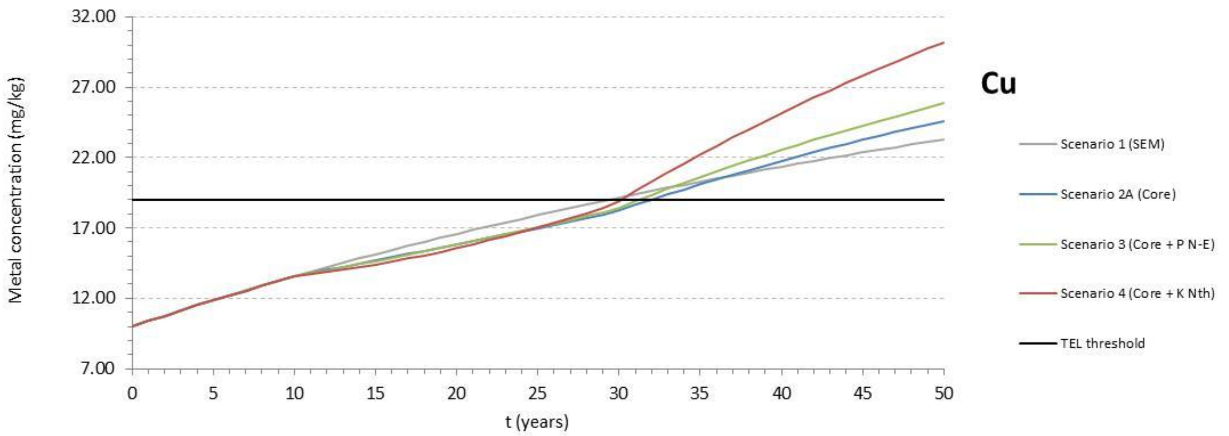




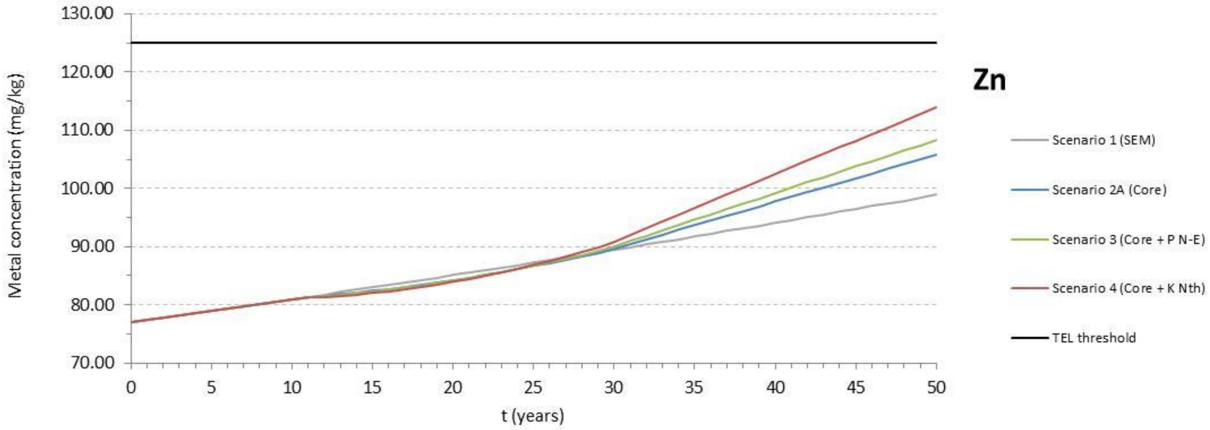
B.4 Predicted sediment metal concentrations, Scenarios 2A, 3 and 4 (Core with additions) compared to Scenario 1 (SEM study)

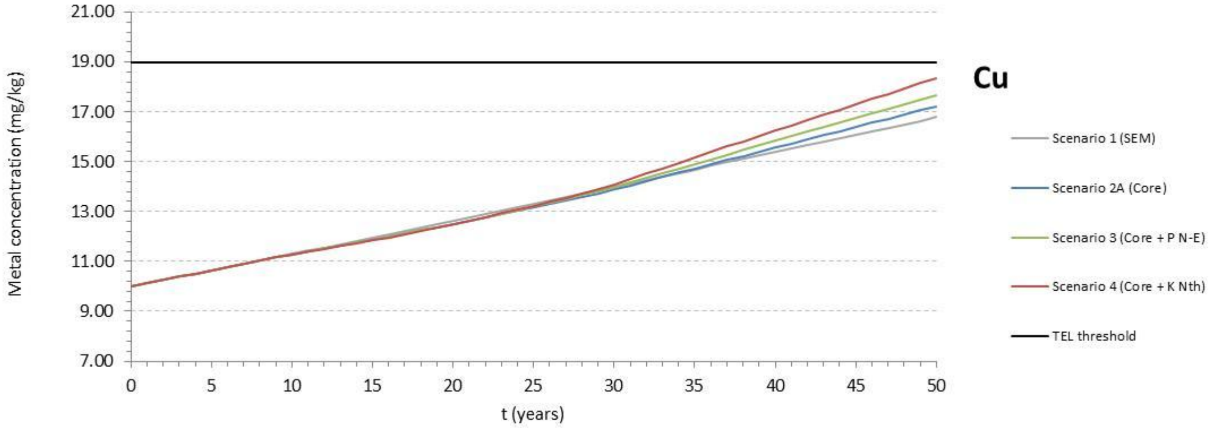
ERU 1 – Glassons Mouth West (SEM subestuary 3-GMW)



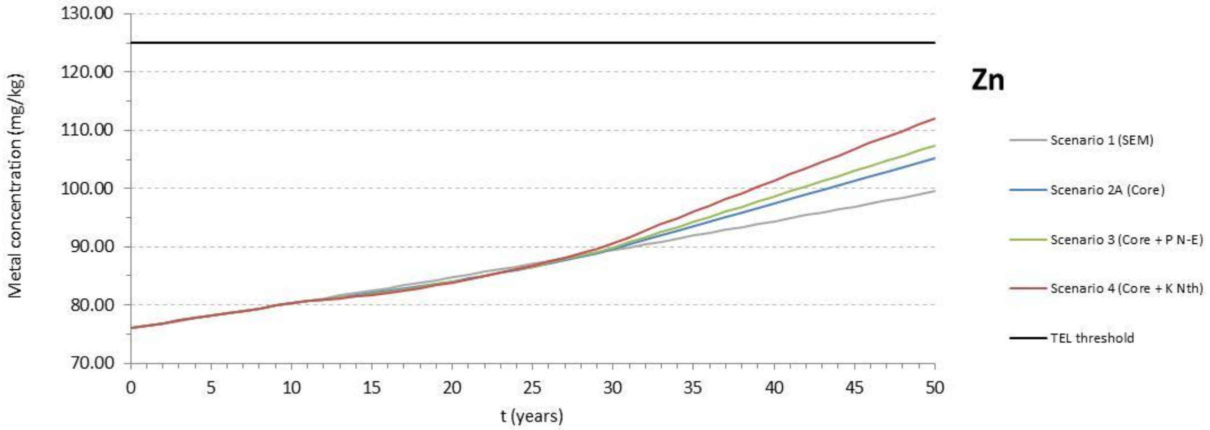


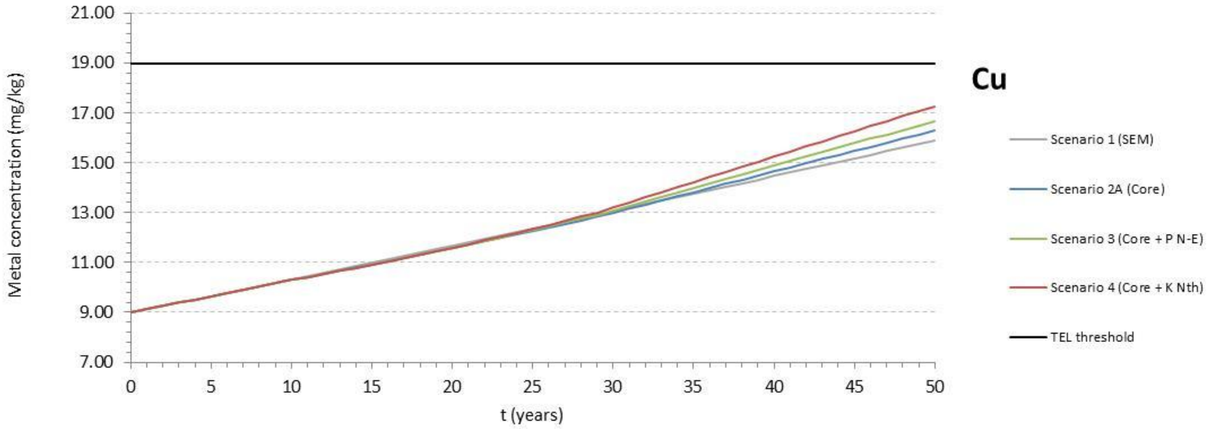
ERU 2 – Glassons Mouth East (SEM subestuary 4-GME)



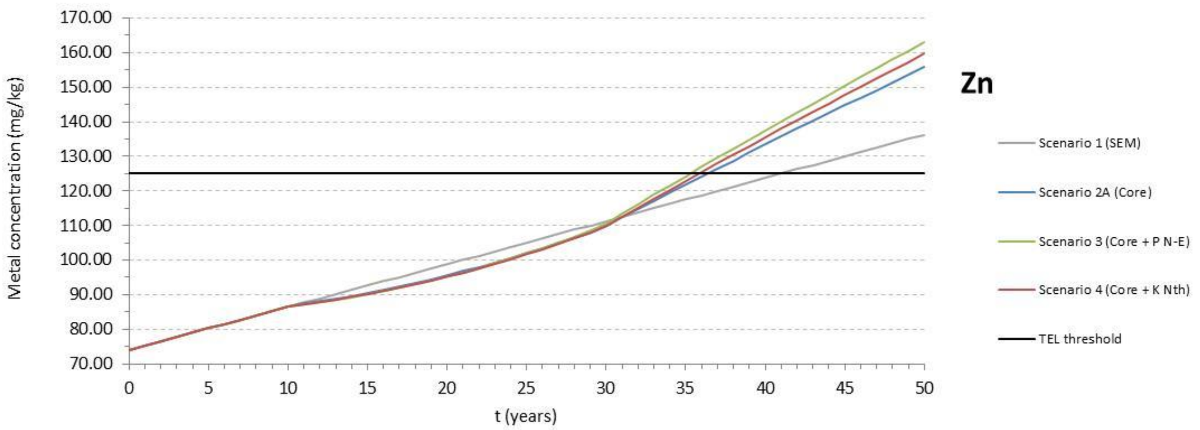


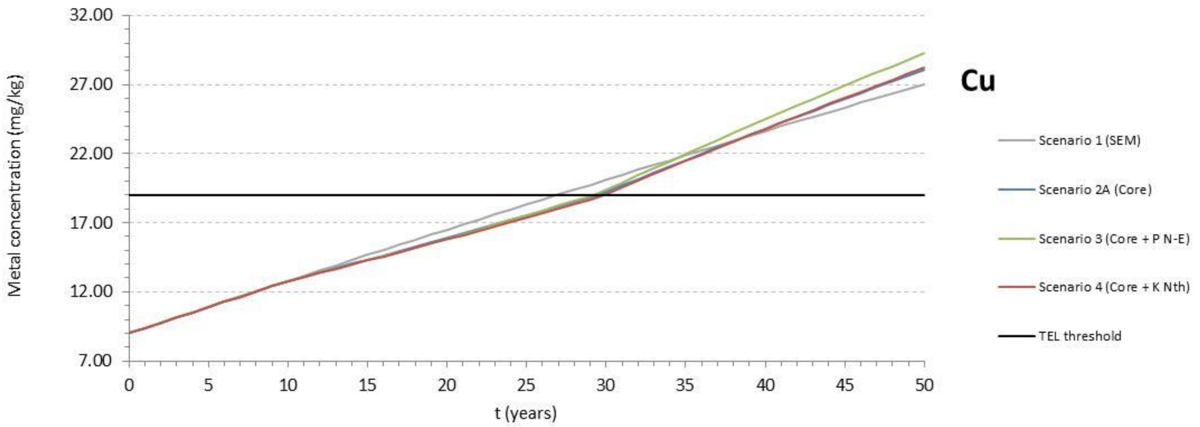
ERU 3 – Cape Horn (SEM subestuary 5-CHN)



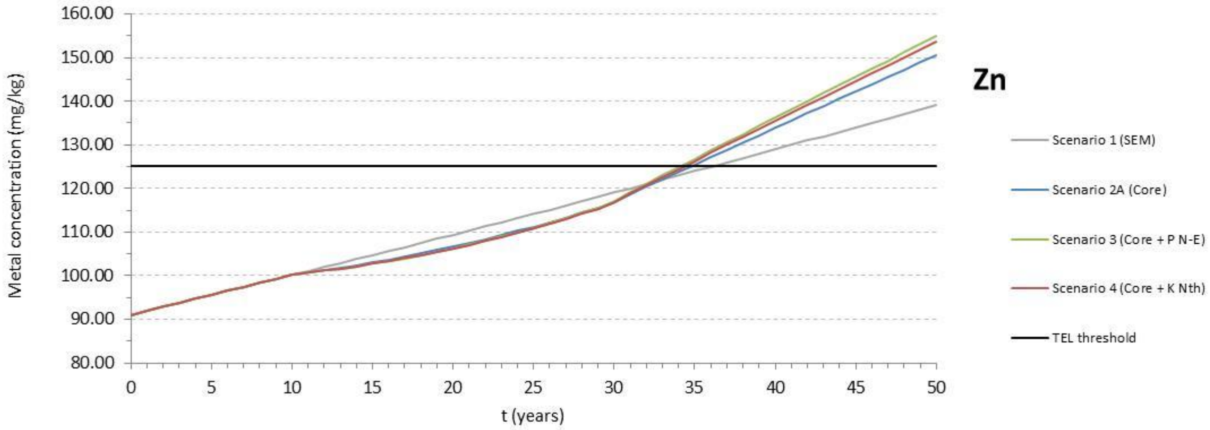


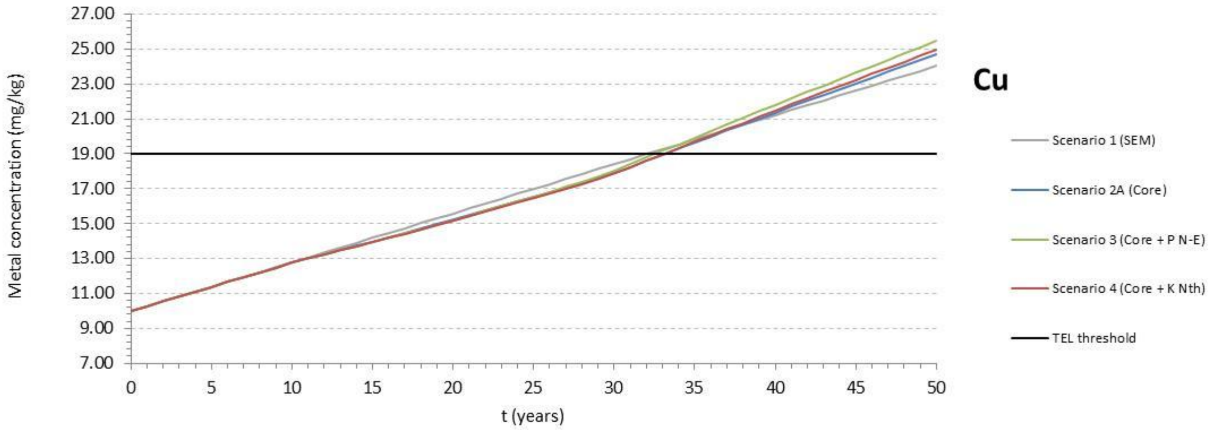
ERU 4 – Drury Creek Outer (SEM subestuary 6-DCO)



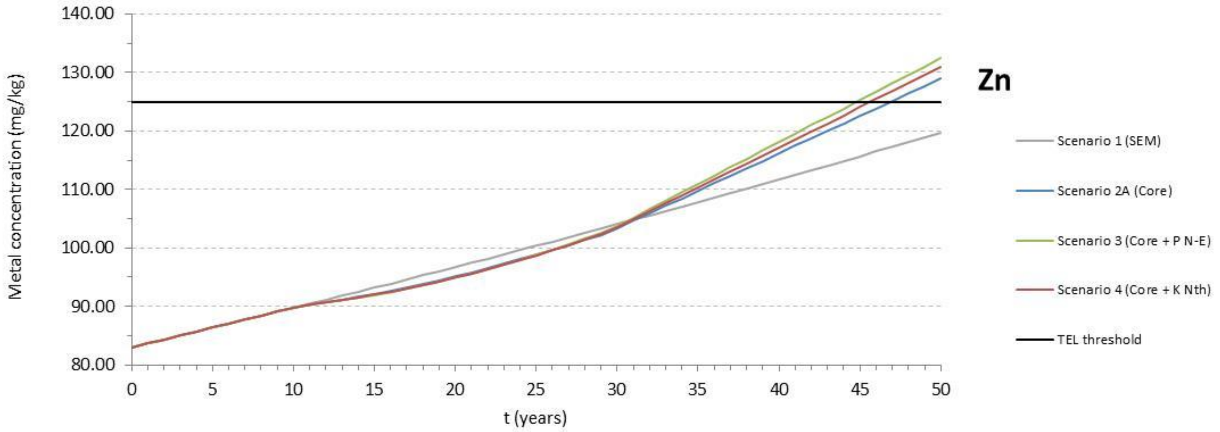


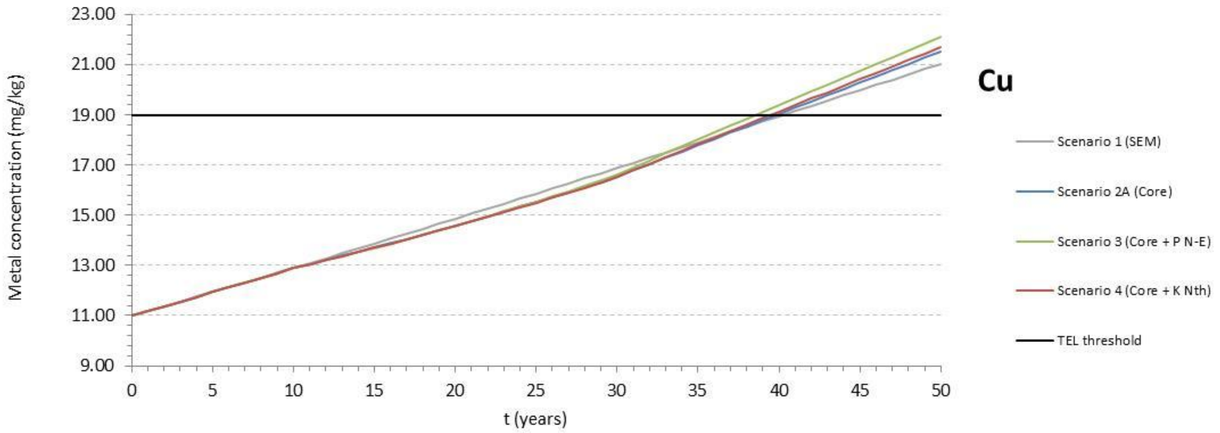
ERU 5 – Pahurehure Inner (SEM subestuary 7-PHI)



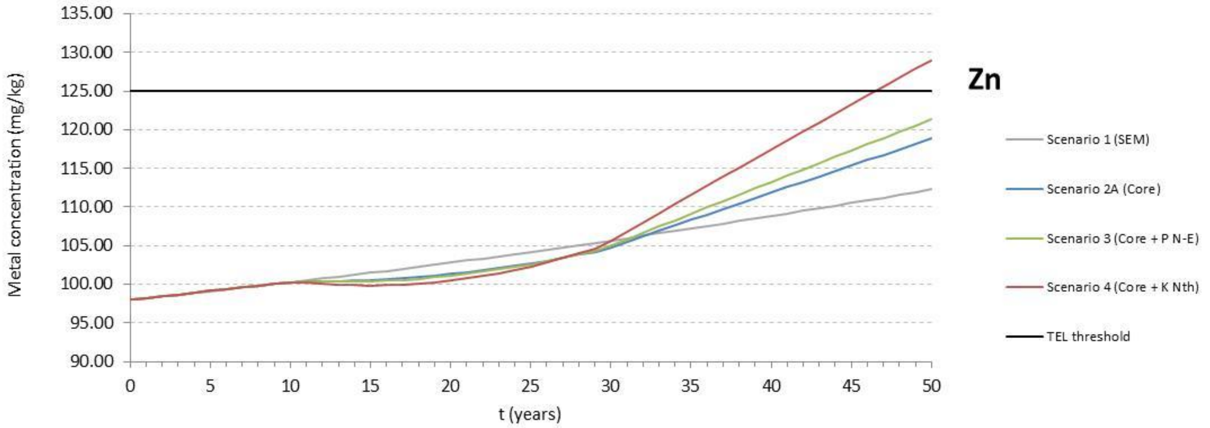


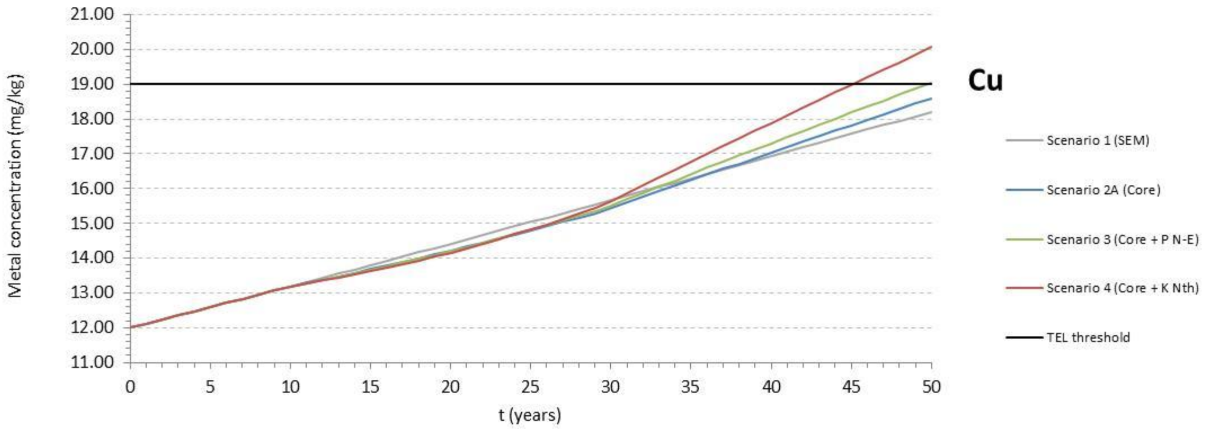
ERU 6 – Drury Creek Inner (SEM subestuary 16-DCI)





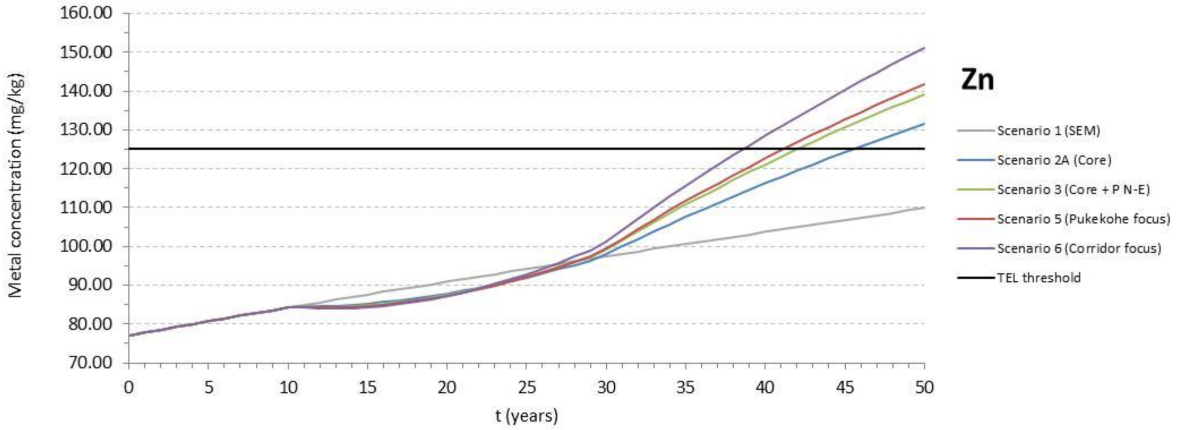
ERU 7 – Glasson Creek Inner (SEM subestuary 17-GCK)

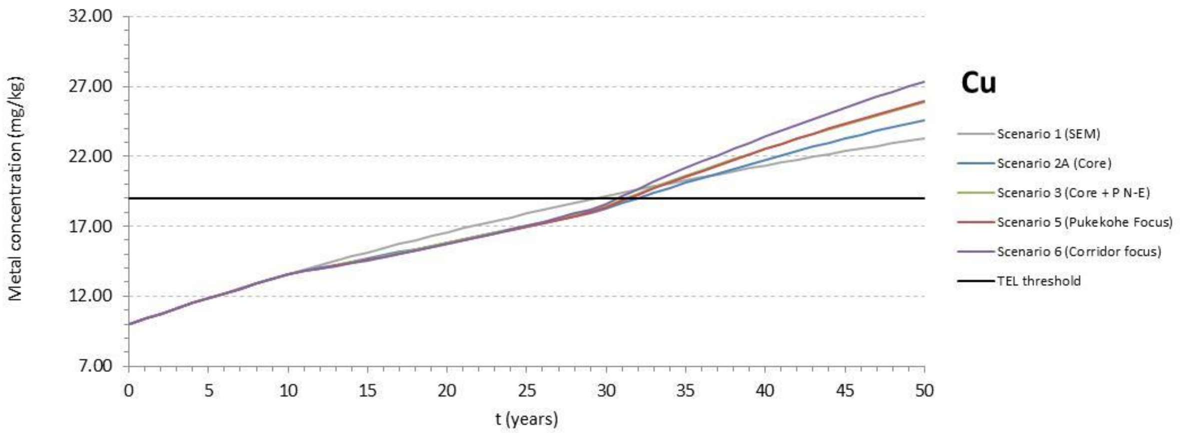




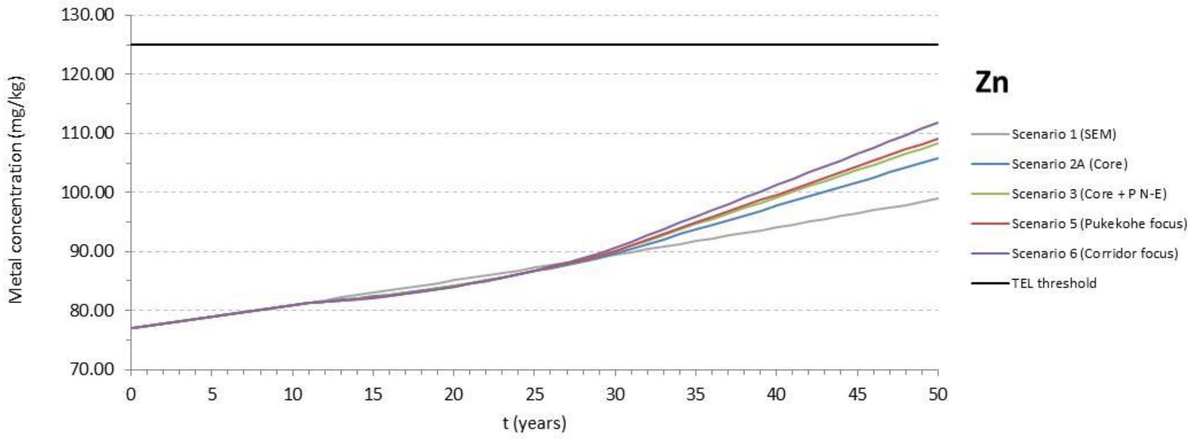
B.5 Predicted sediment metal concentrations, Scenarios 2A, 3, 5 and 6 (Core with centre-south additions) compared to Scenario 1 (SEM study)

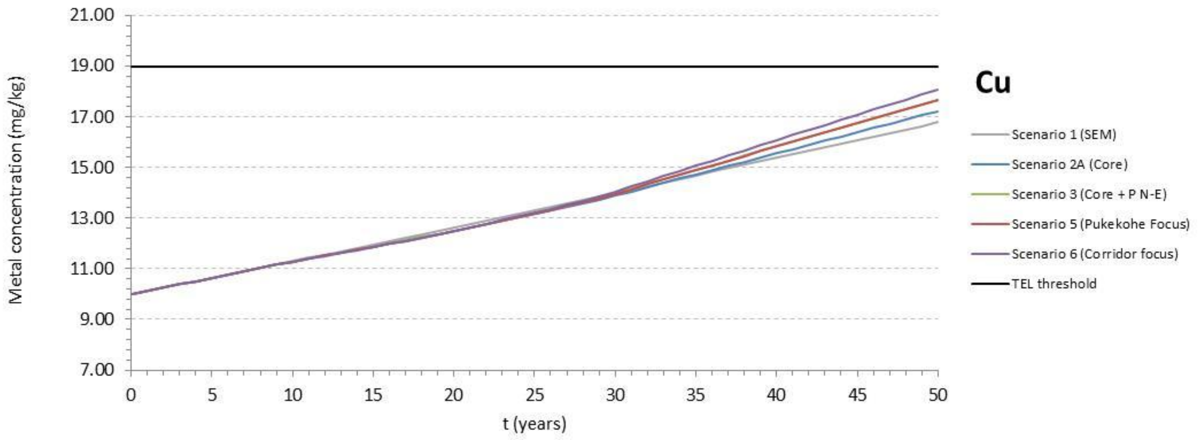
ERU 1 – Glassons Mouth West (SEM subestuary 3-GMW)



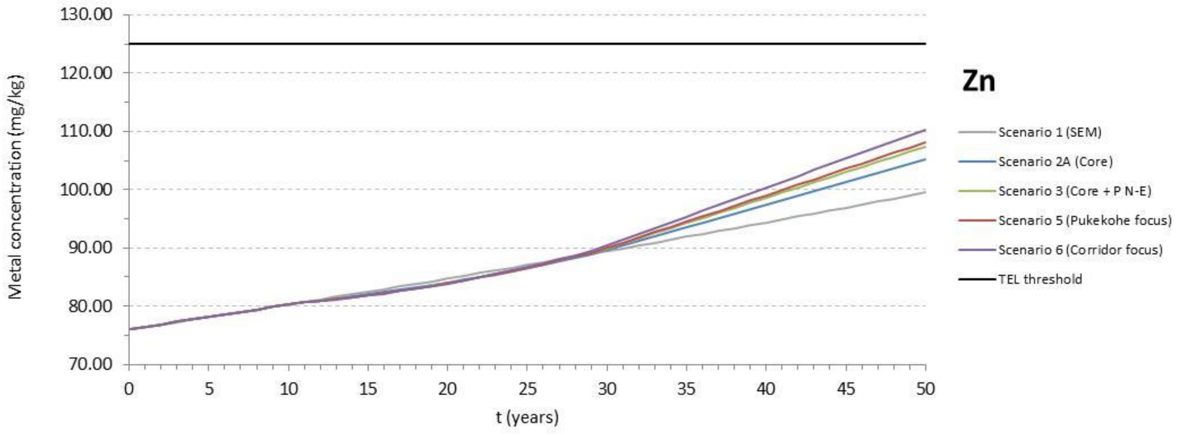


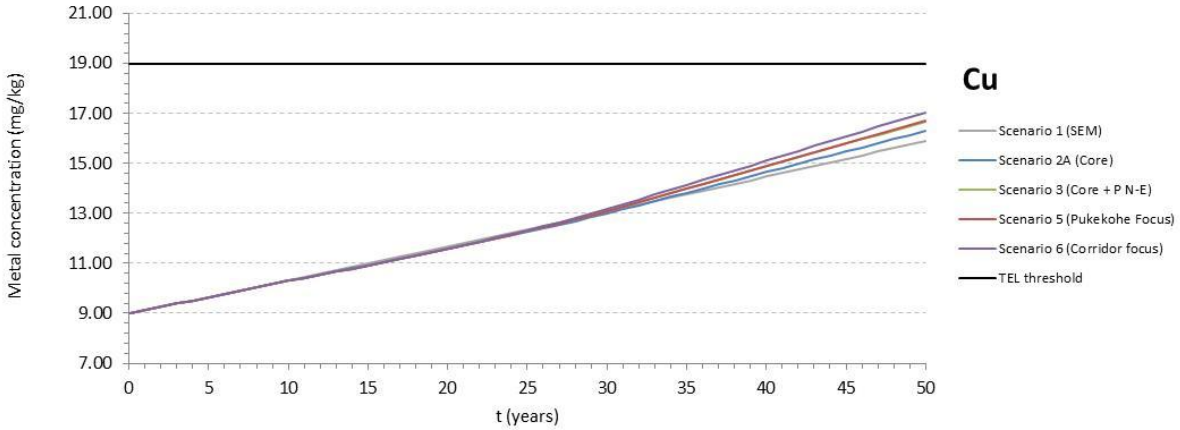
ERU 2 – Glassons Mouth East (SEM subestuary 4-GME)



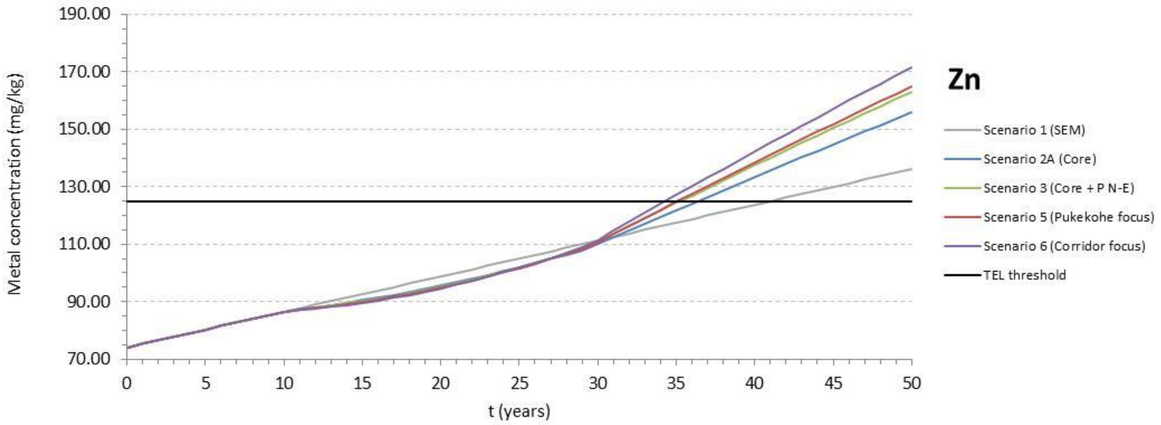


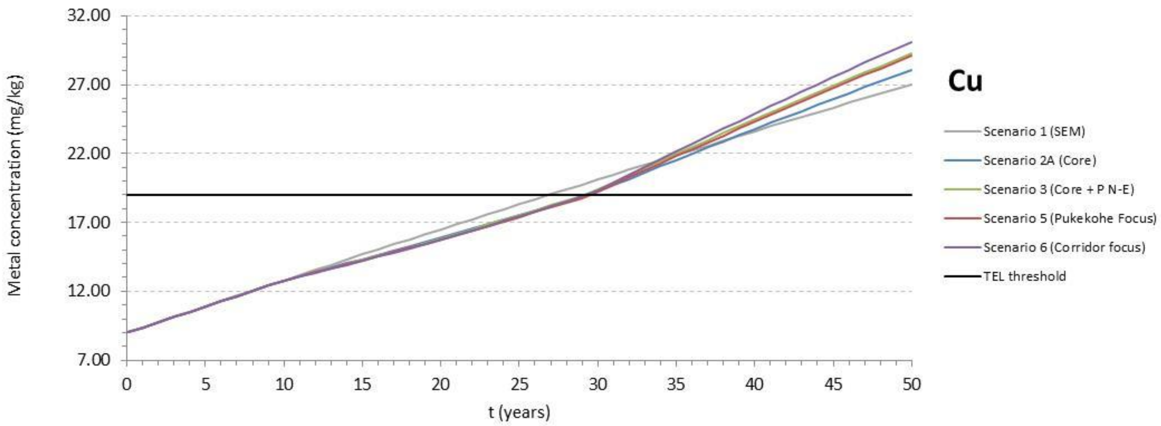
ERU 3 – Cape Horn (SEM subestuary 5-CHN)



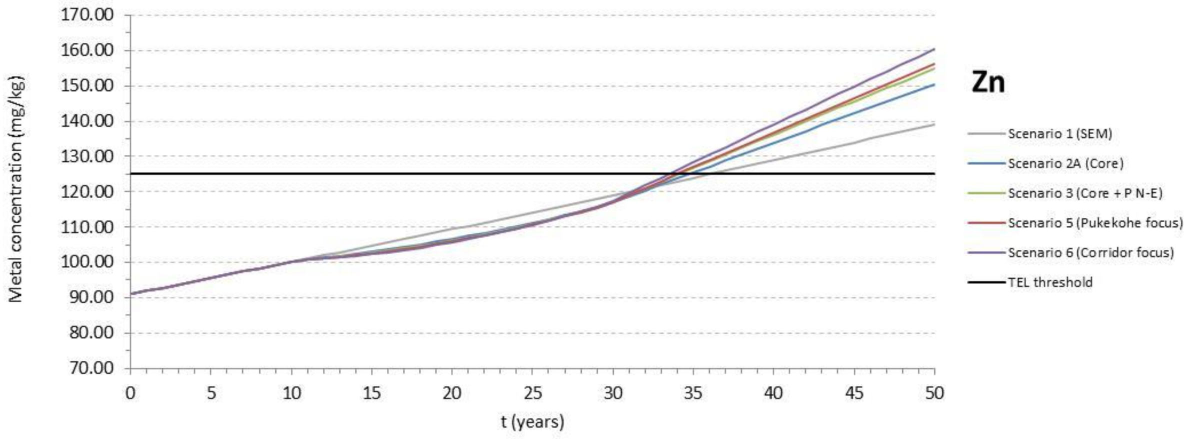


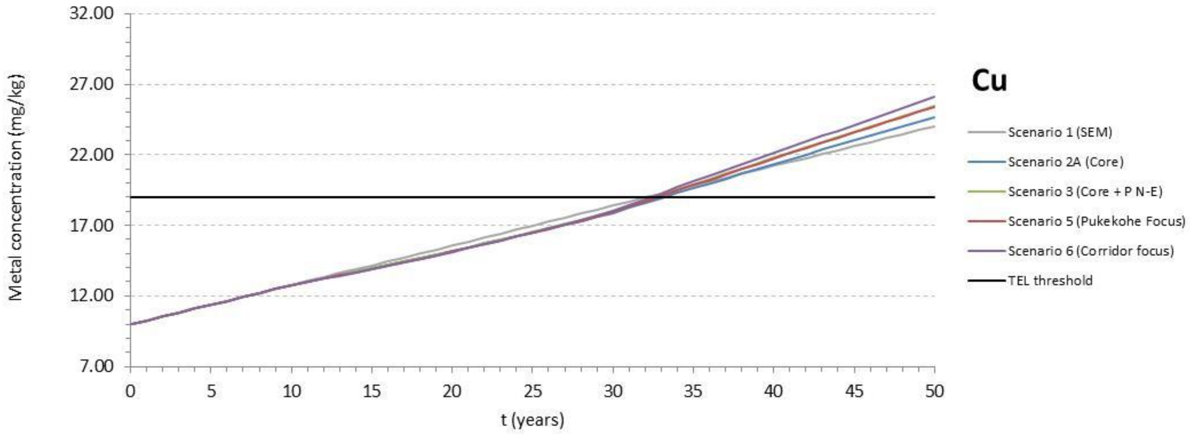
ERU 4 – Drury Creek Outer (SEM subestuary 6-DCO)



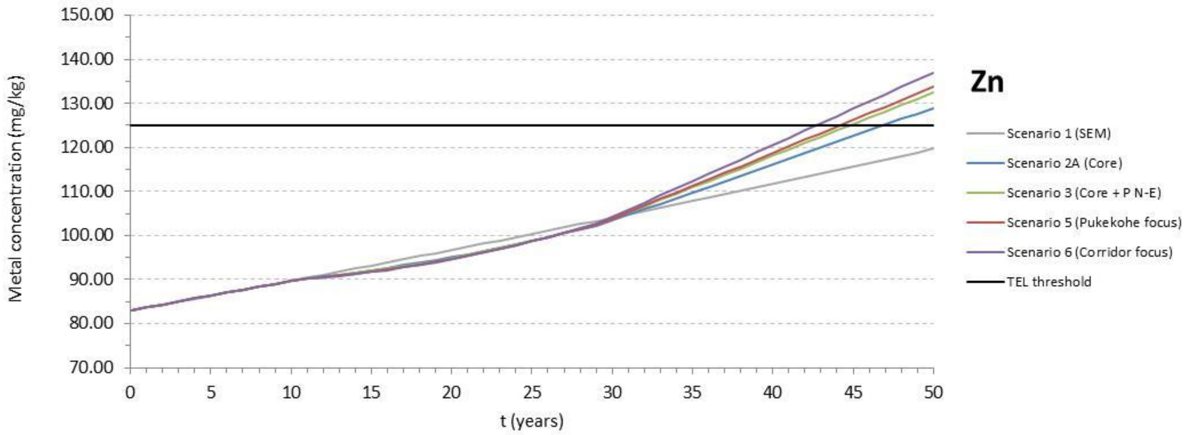


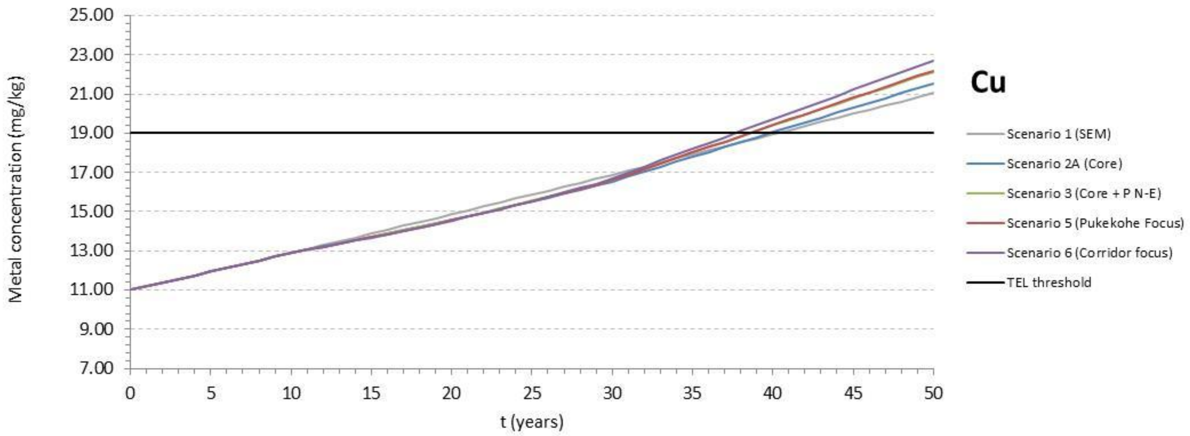
ERU 5 – Pahurehure Inner (SEM subestuary 7-PHI)



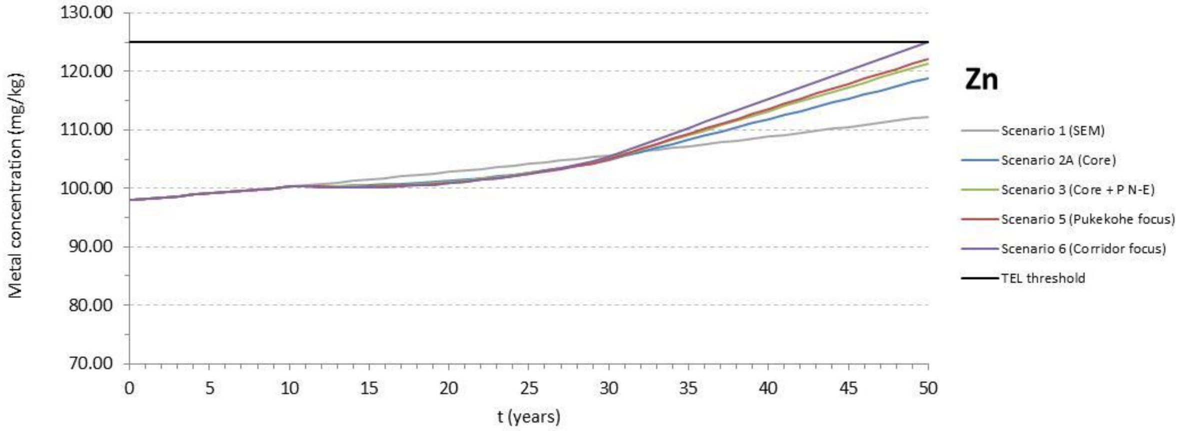


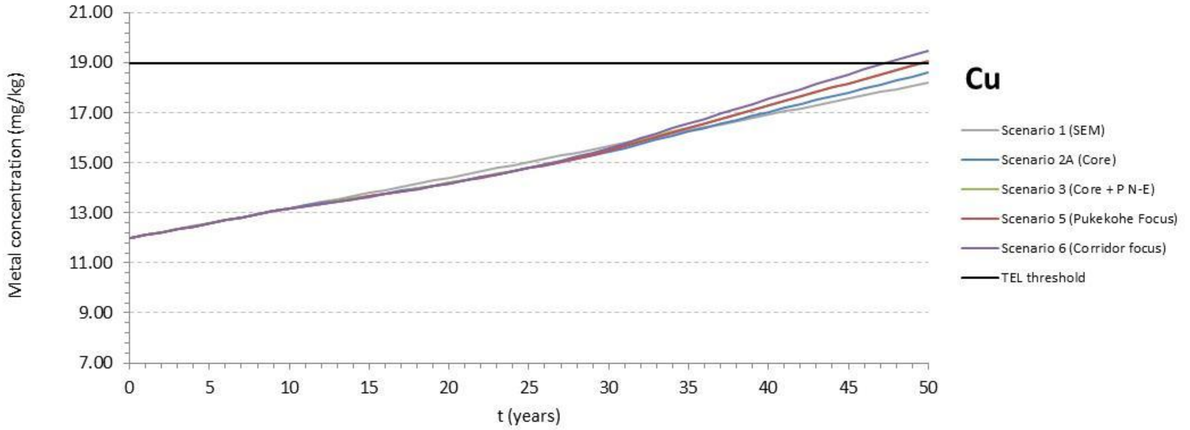
ERU 6 – Drury Creek Inner (SEM subestuary 16-DCI)





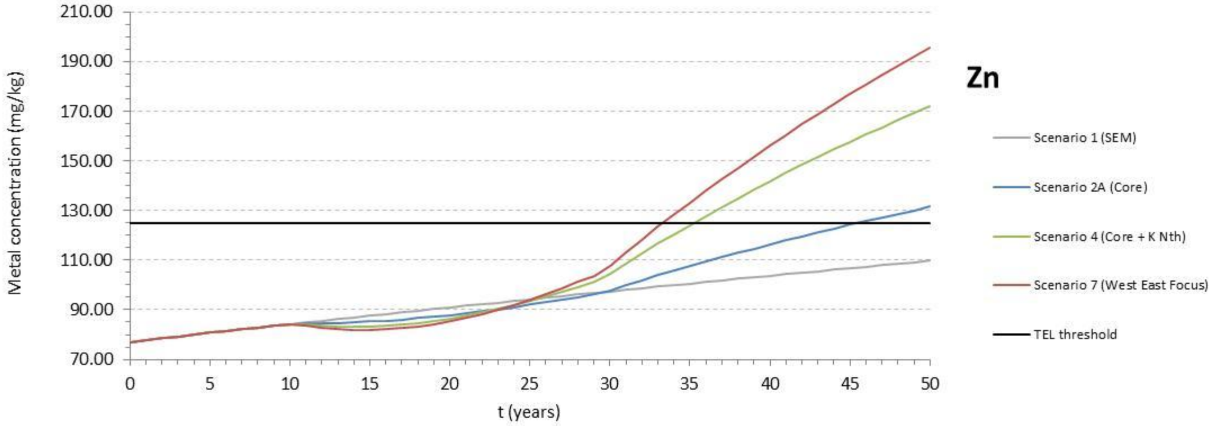
ERU 7 – Glasson Creek Inner (SEM subestuary 17-GCK)

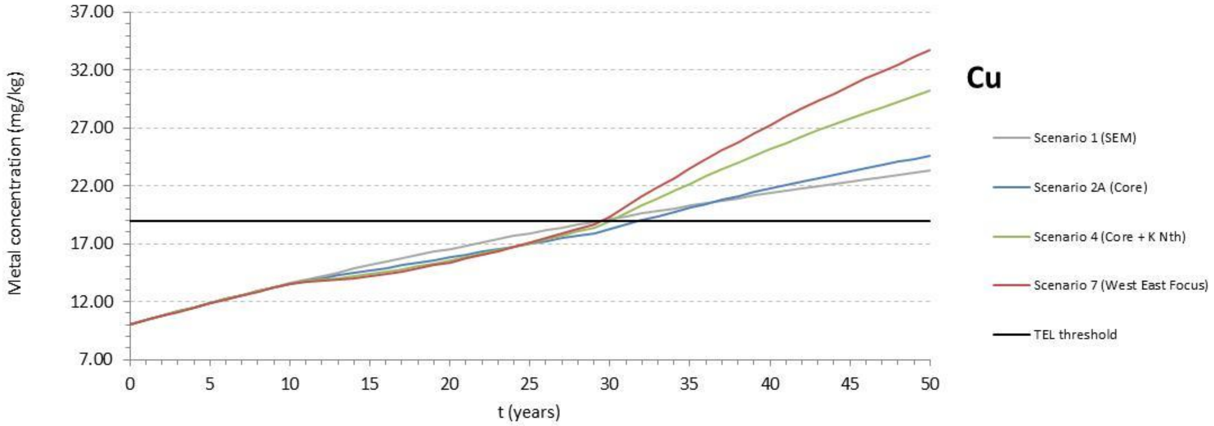




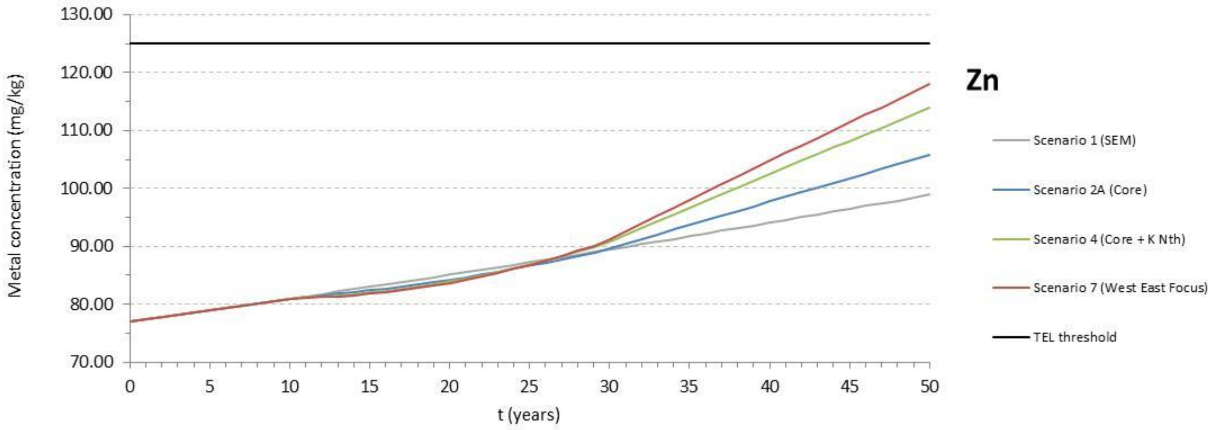
B.6 Predicted sediment metal concentrations, Scenarios 2A, 4 and 7 (Core with northern additions) compared to Scenario 1 (SEM study)

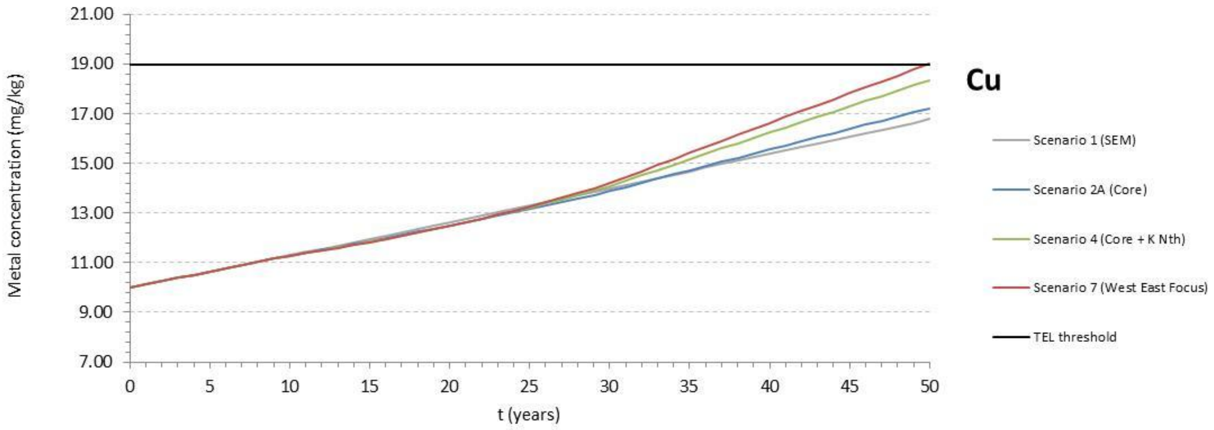
ERU 1 – Glassons Mouth West (SEM subestuary 3-GMW)



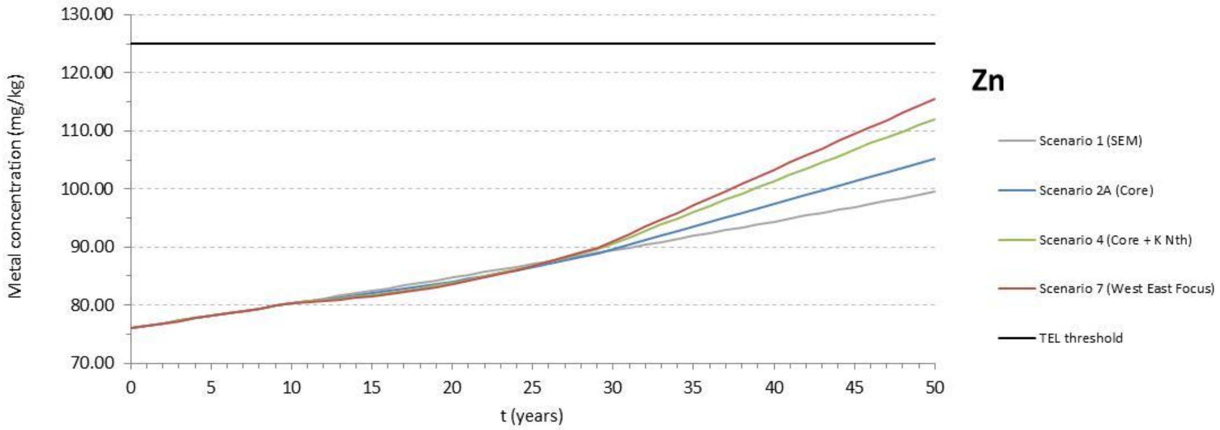


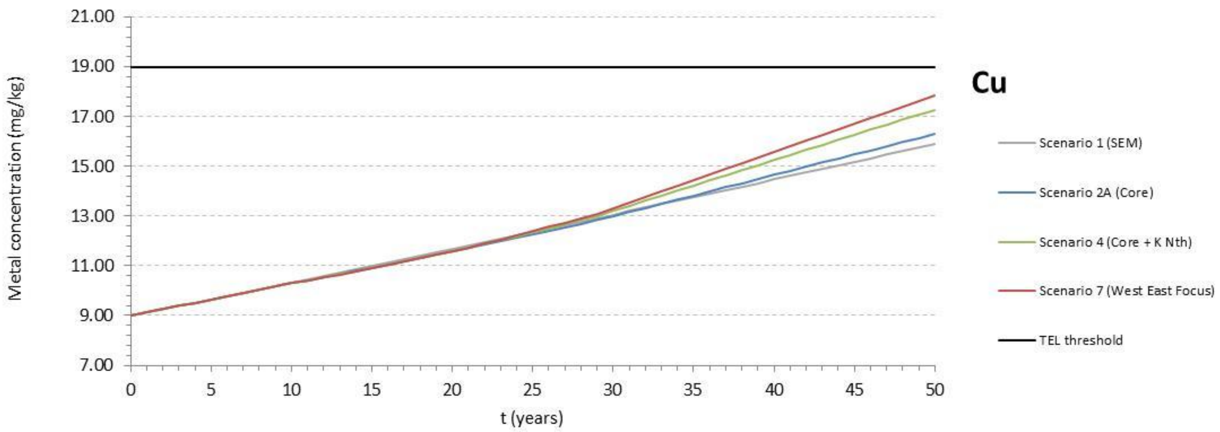
ERU 2 – Glassons Mouth East (SEM subestuary 4-GME)



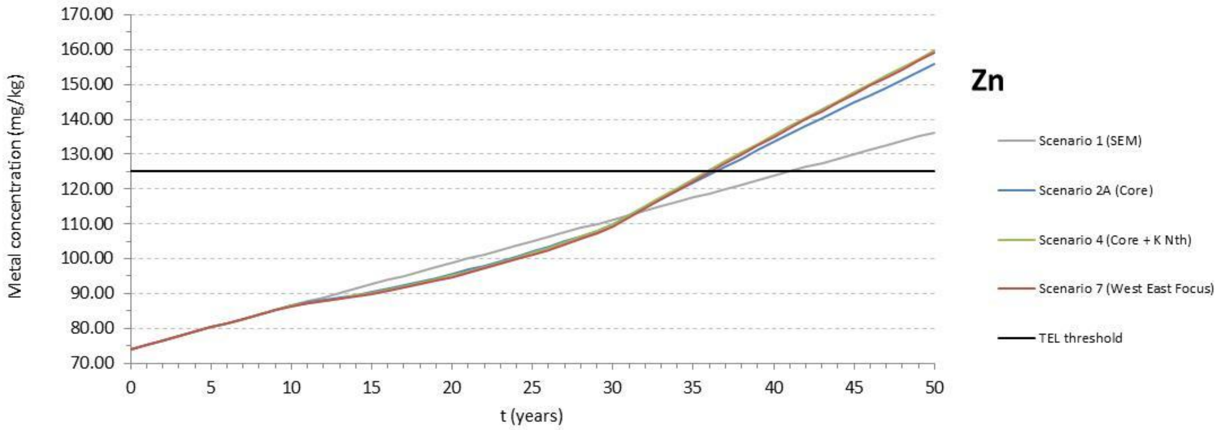


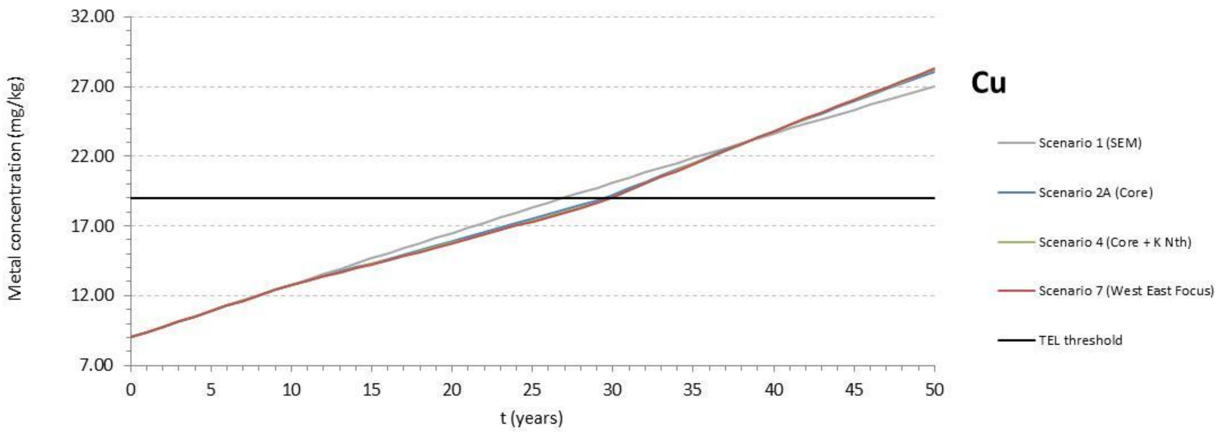
ERU 3 – Cape Horn (SEM subestuary 5-CHN)



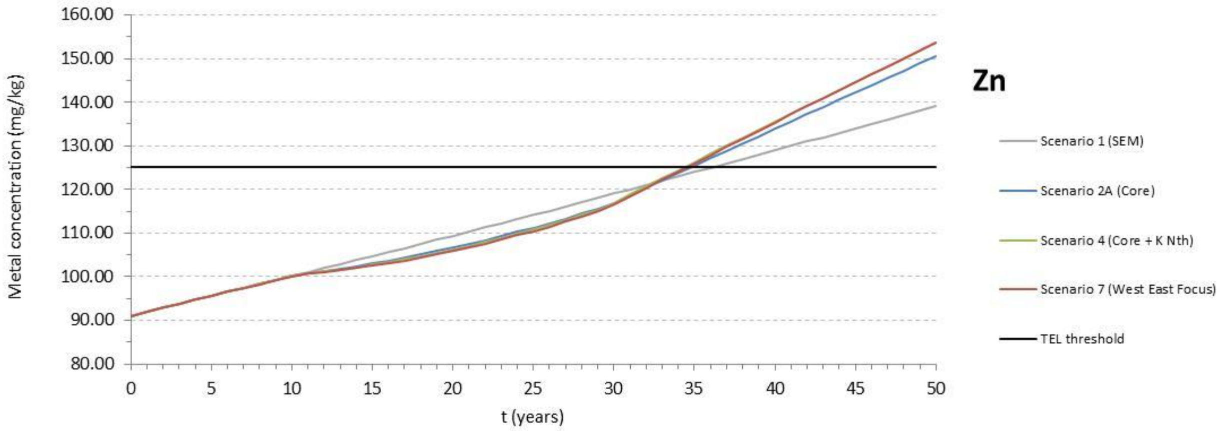


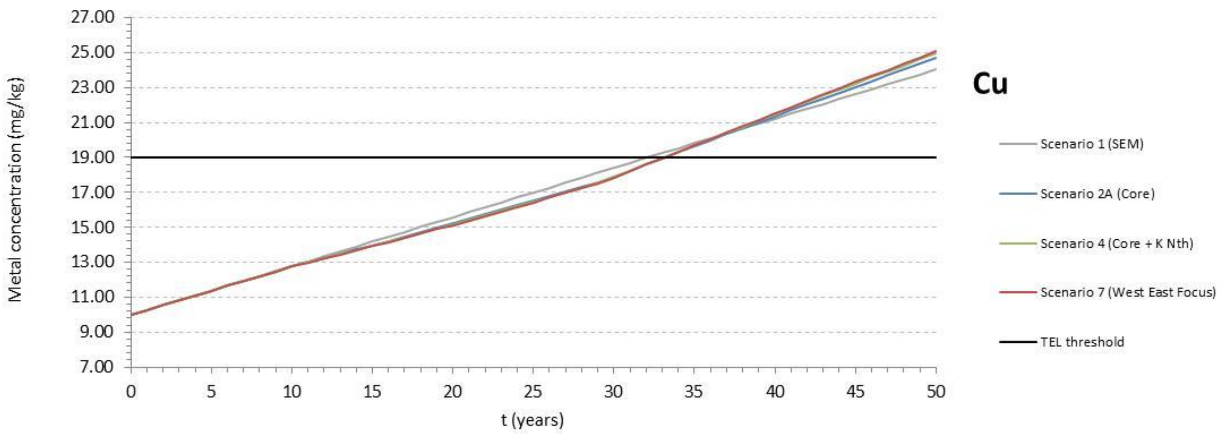
ERU 4 – Drury Creek Outer (SEM subestuary 6-DCO)



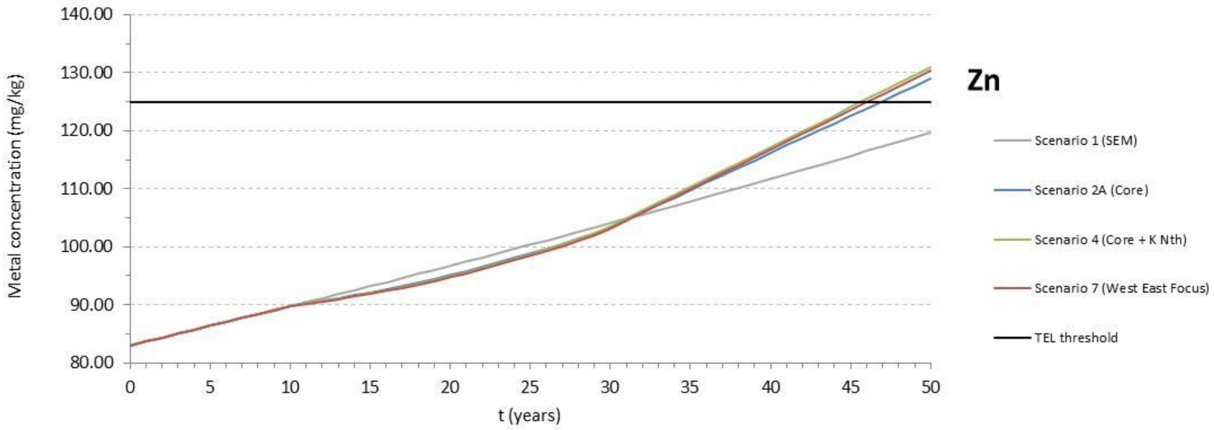


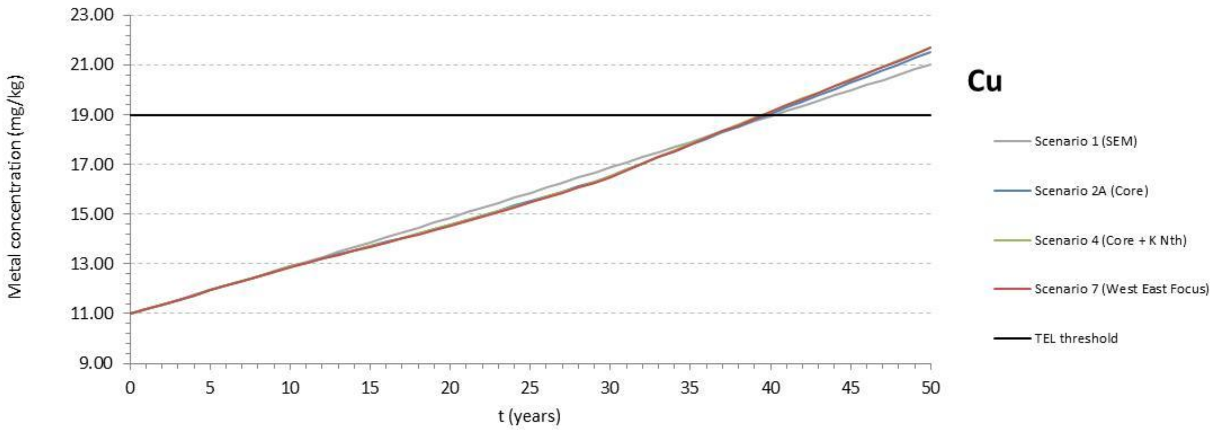
ERU 5 – Pahurehure Inner (SEM subestuary 7-PHI)



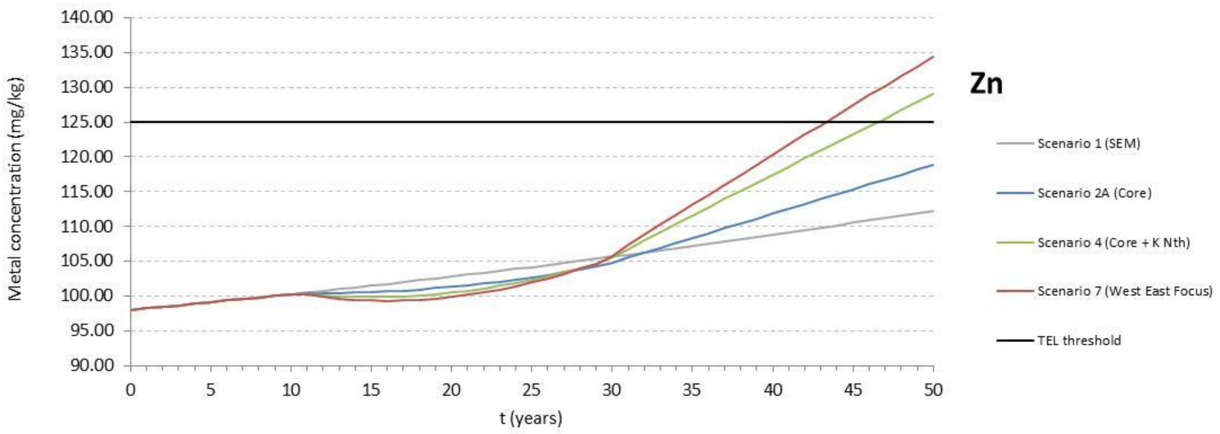


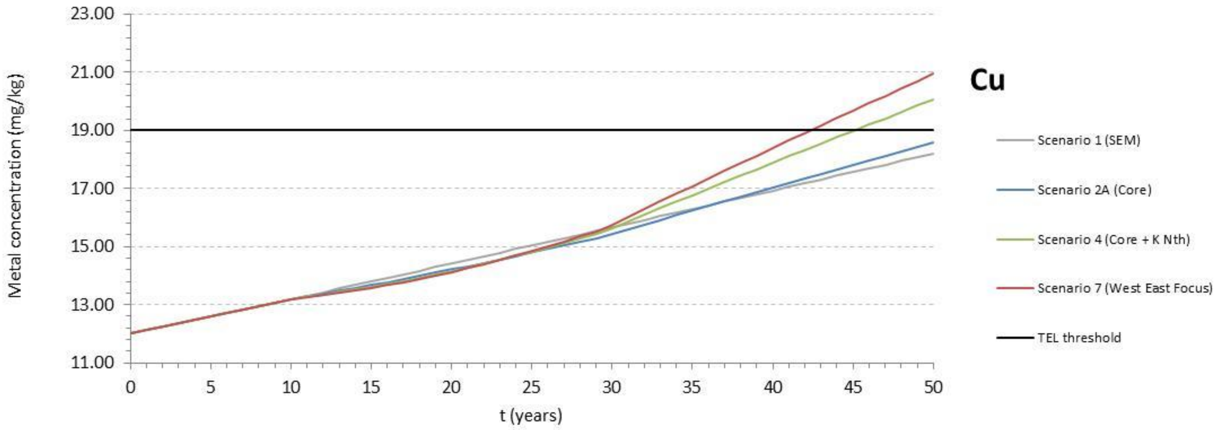
ERU 6 – Drury Creek Inner (SEM subestuary 16-DCI)





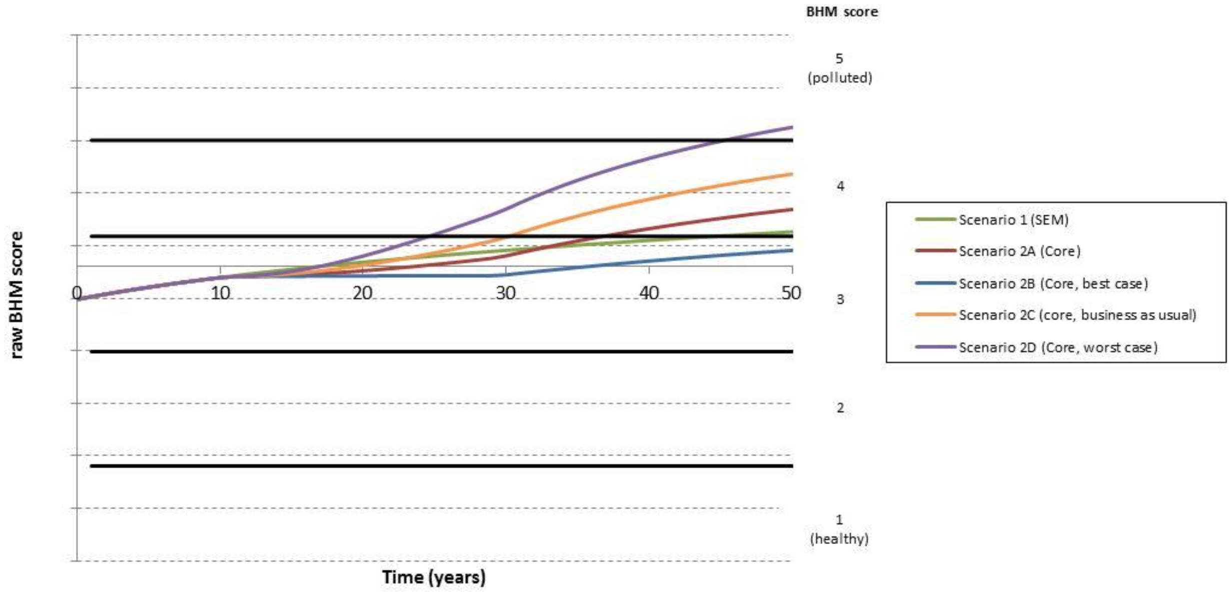
ERU 7 – Glasson Creek Inner (SEM subestuary 17-GCK)



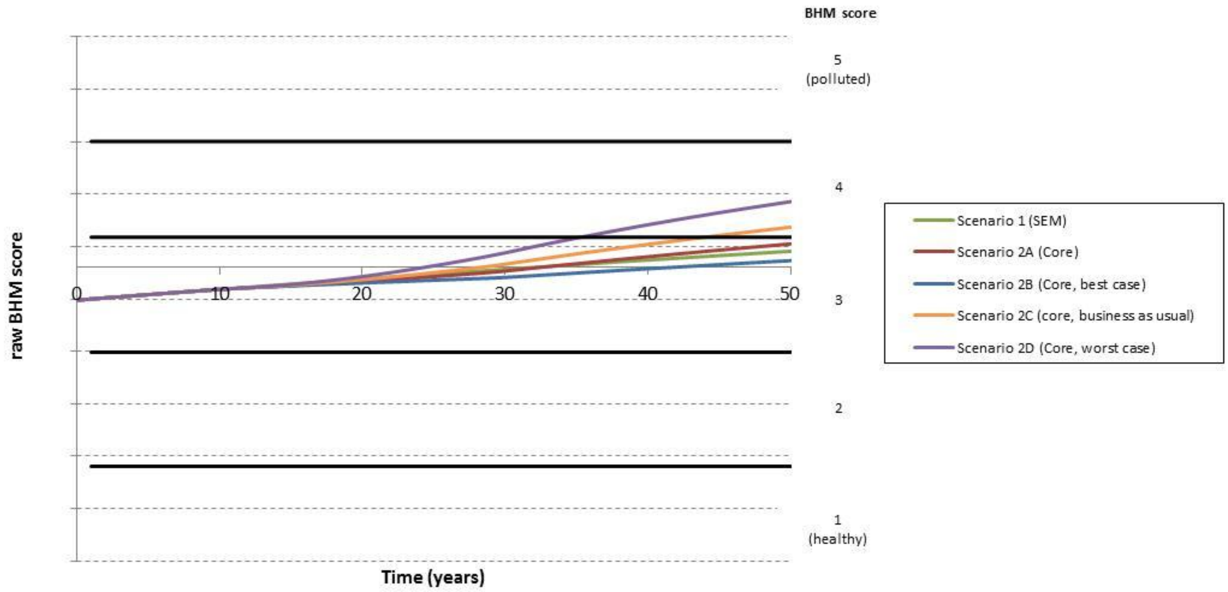


B.7 Predicted benthic health (metals) scores, Scenarios 2A to 2D (Core with varying stormwater treatment) compared to Scenario 1 (SEM study)

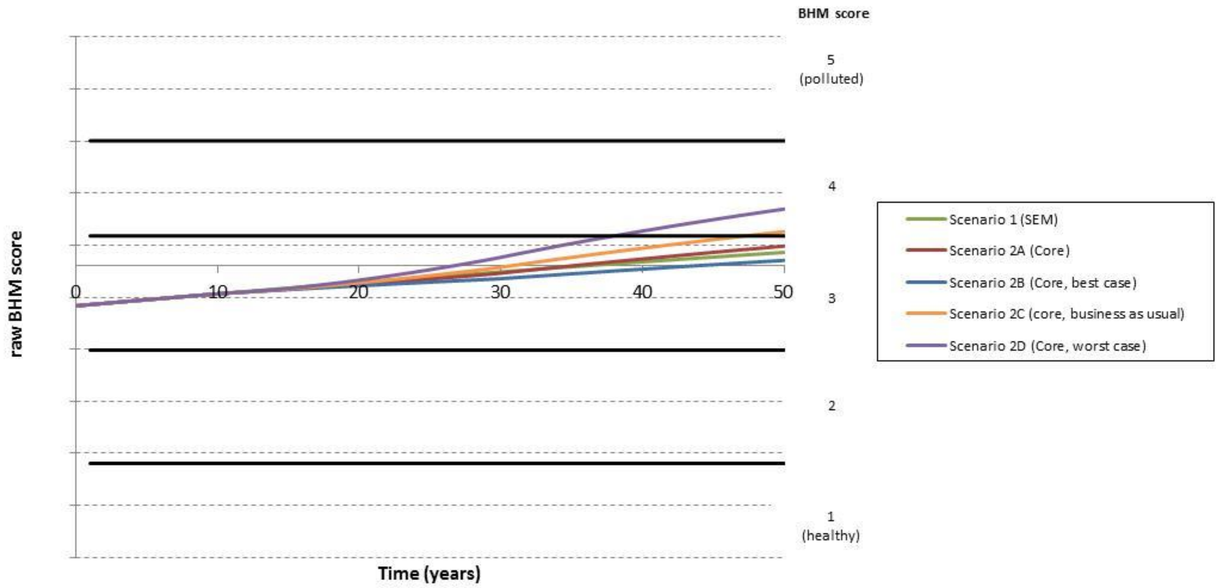
ERU 1 – Glassons Mouth West (SEM subestuary 3-GMW)



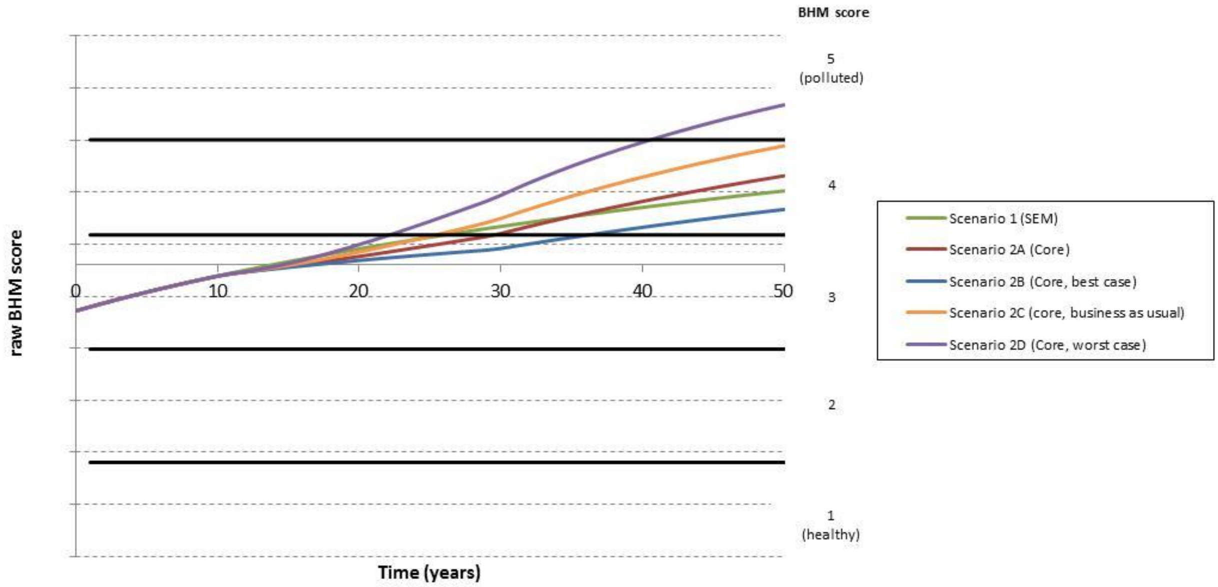
ERU 2 – Glassons Mouth East (SEM subestuary 4-GME)



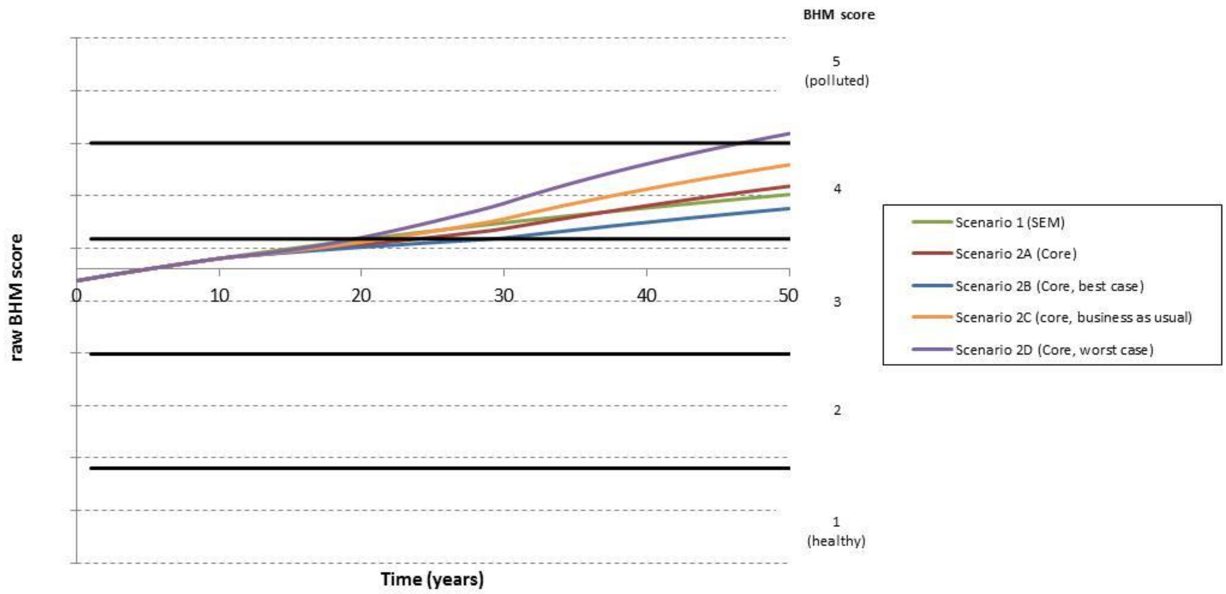
ERU 3 – Cape Horn (SEM subestuary 5-CHN)



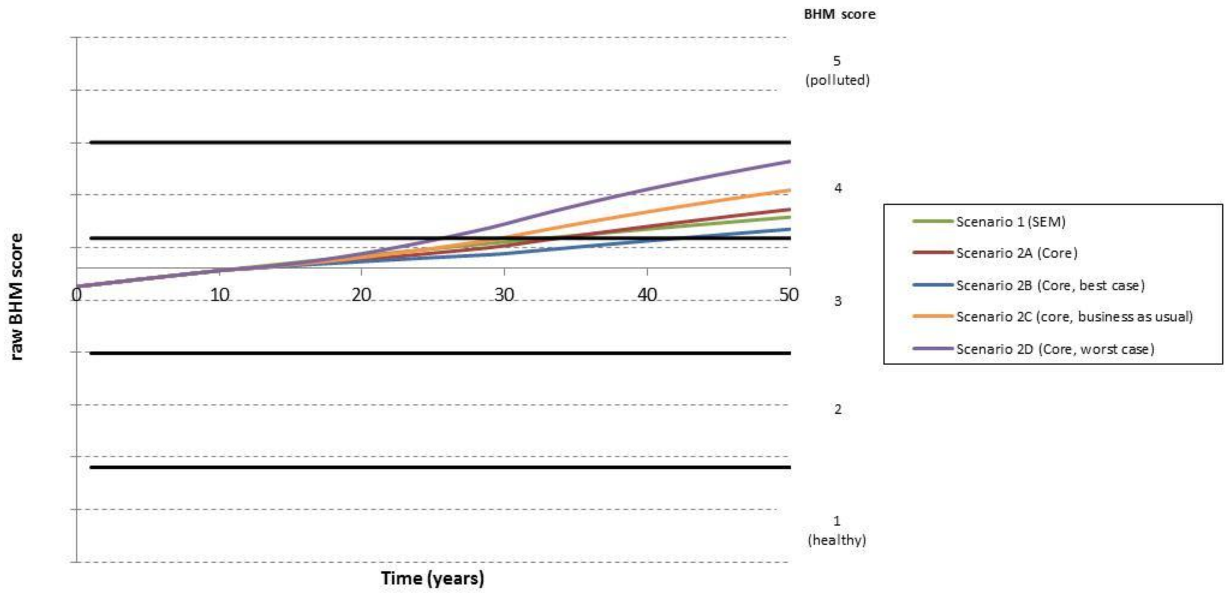
ERU 4 – Drury Creek Outer (SEM subestuary 6-DCO)



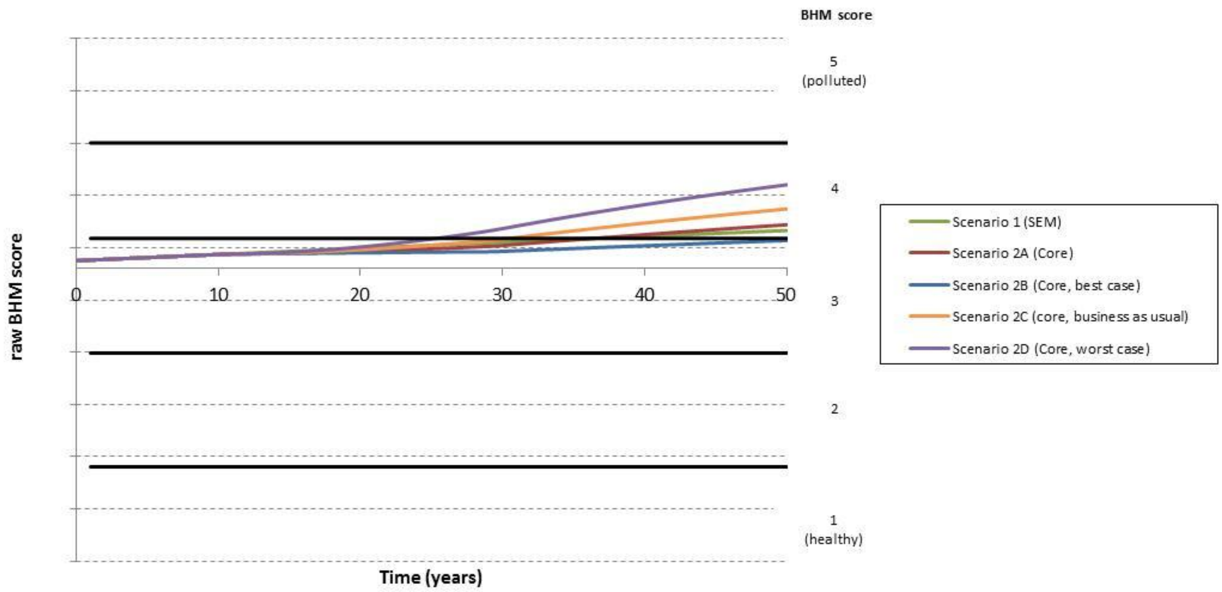
ERU 5 – Pahurehure Inner (SEM subestuary 7-PHI)



ERU 6 – Drury Creek Inner (SEM subestuary 16-DCI)

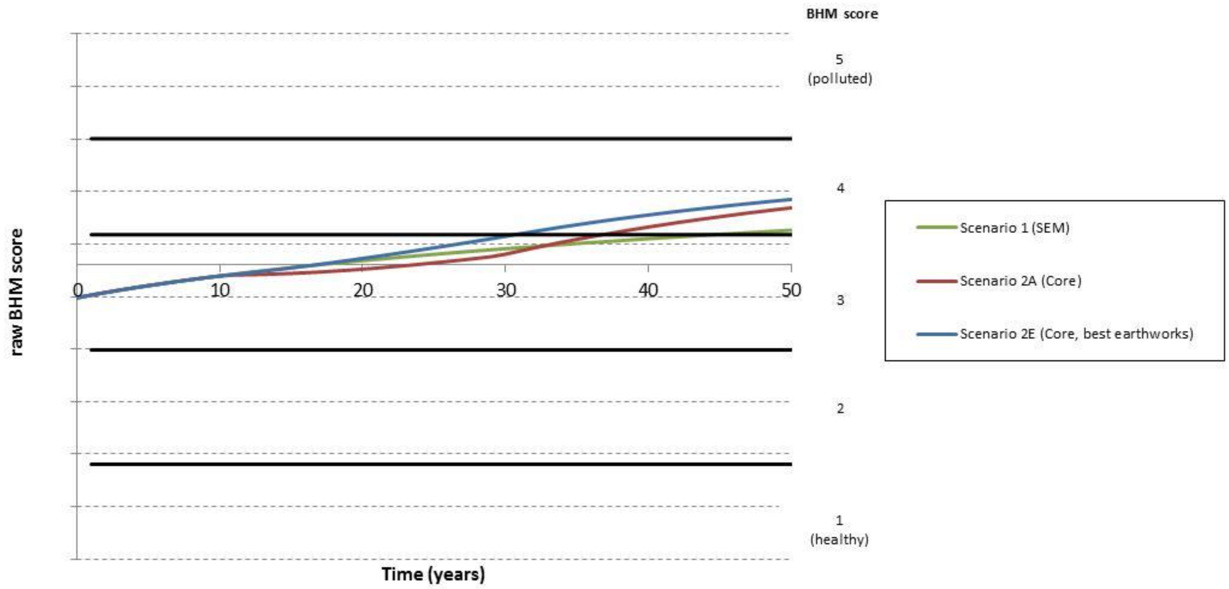


ERU 7 – Glasson Creek Inner (SEM subestuary 17-GCK)

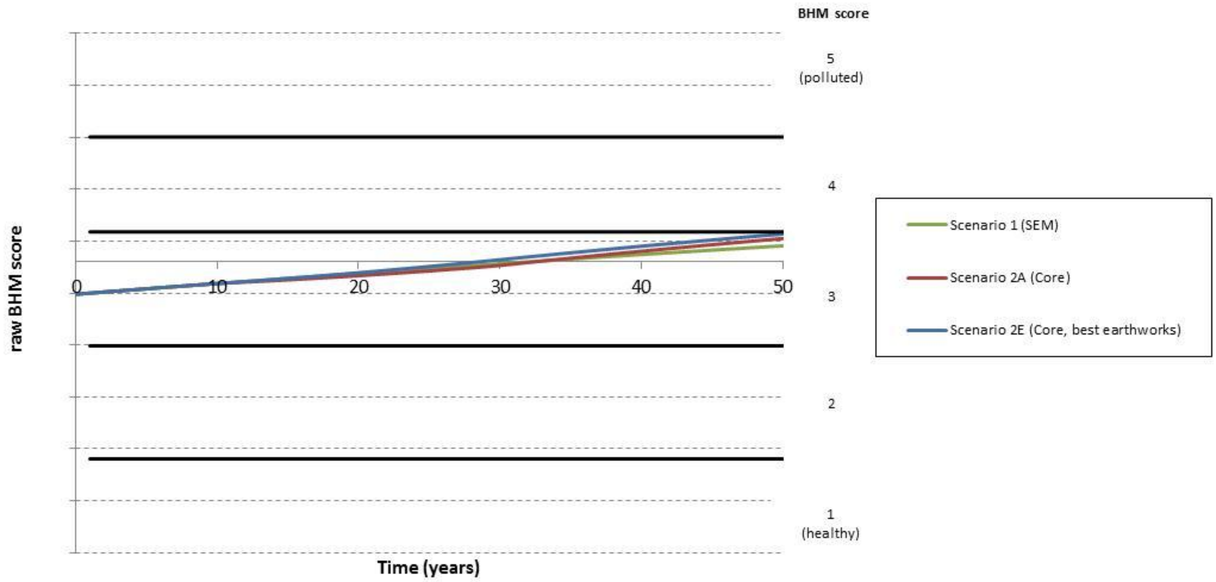


B.8 Predicted benthic health (metals) scores, Scenarios 2A and 2E (Core with varying earthworks controls) compared to Scenario 1 (SEM study)

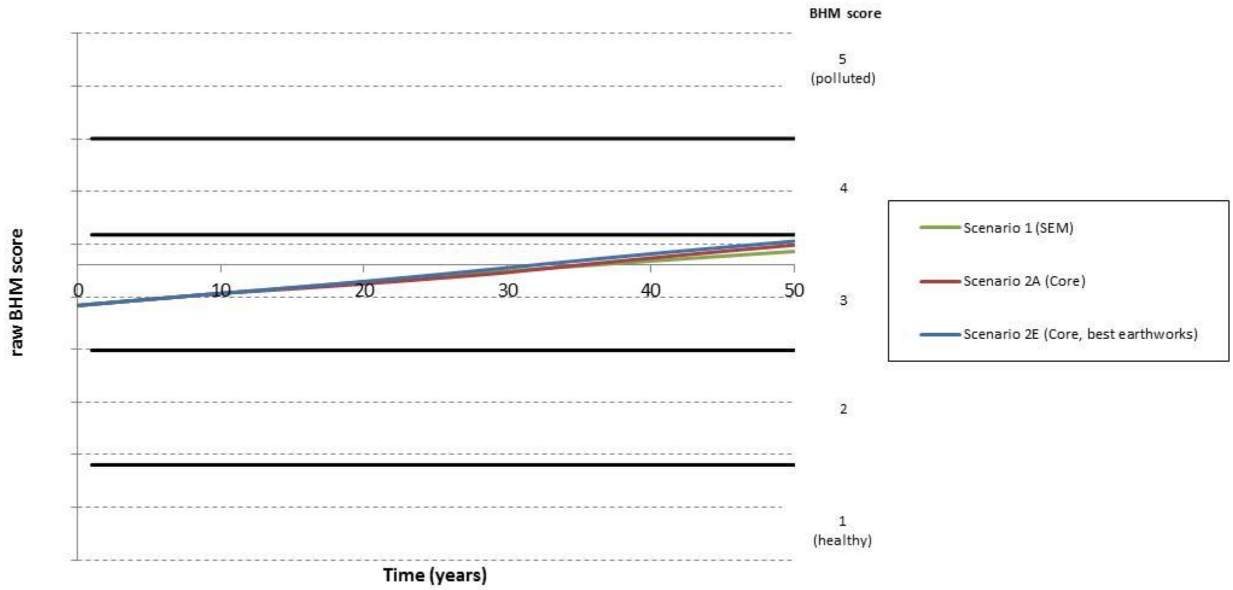
ERU 1 – Glassons Mouth West (SEM subestuary 3-GMW)



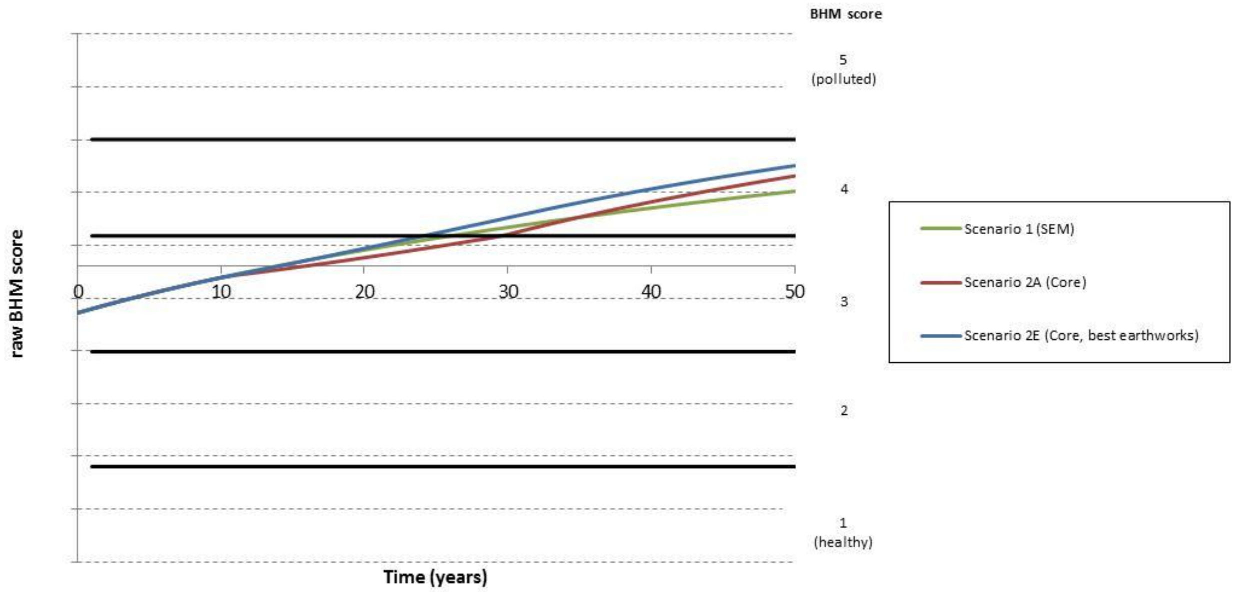
ERU 2 – Glassons Mouth East (SEM subestuary 4-GME)



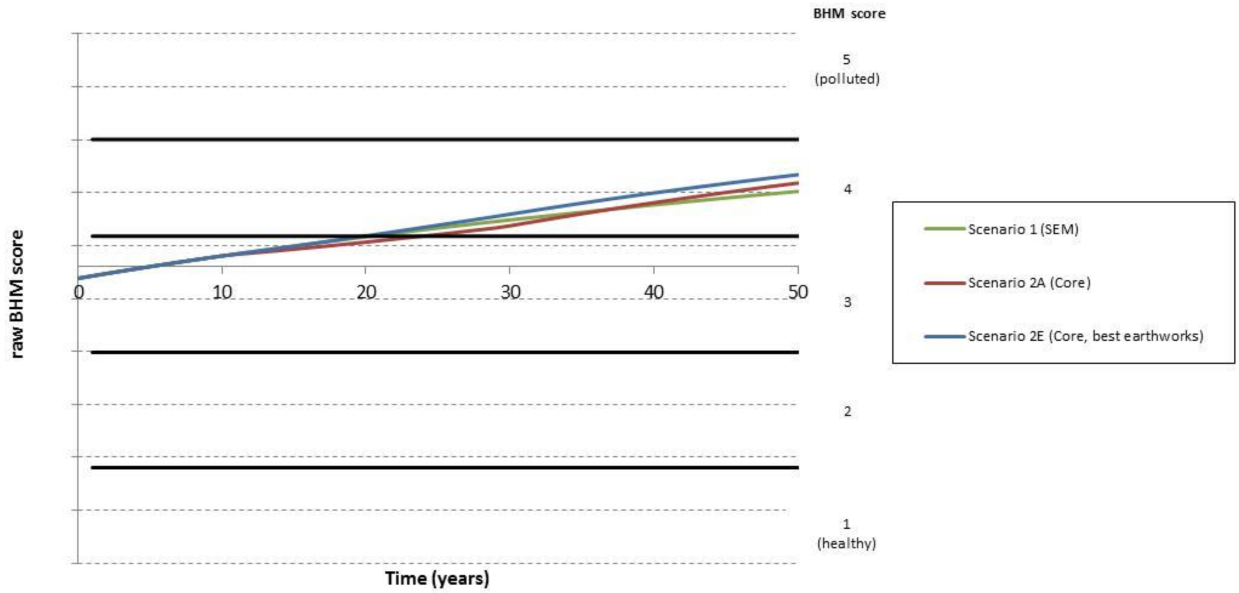
ERU 3 – Cape Horn (SEM subestuary 5-CHN)



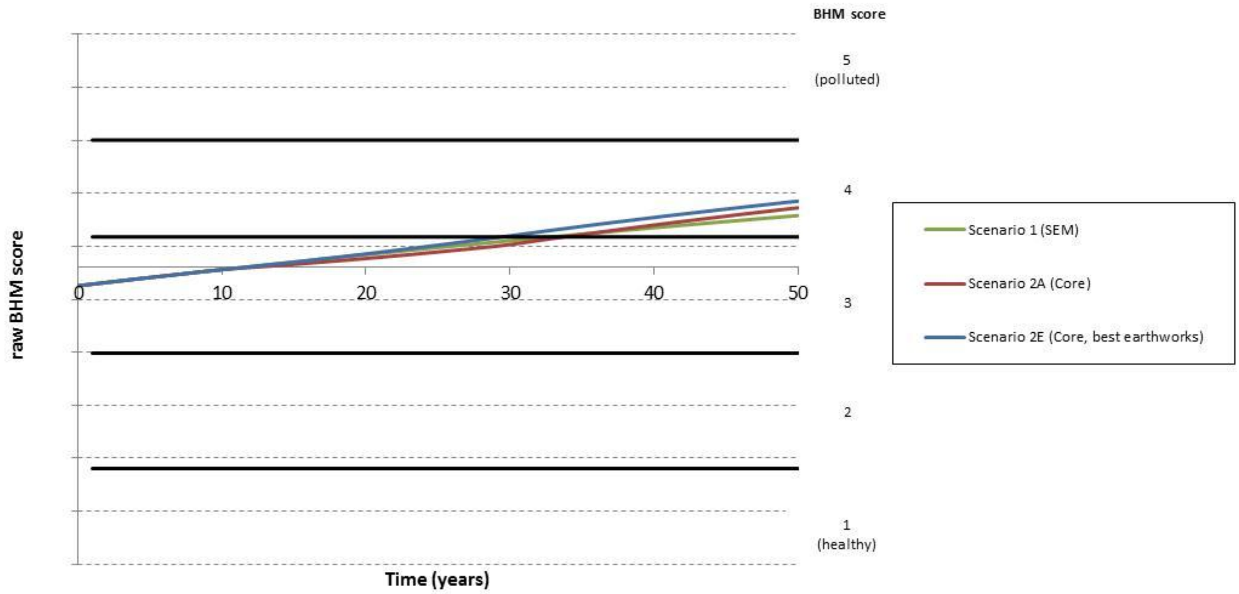
ERU 4 – Drury Creek Outer (SEM subestuary 6-DCO)



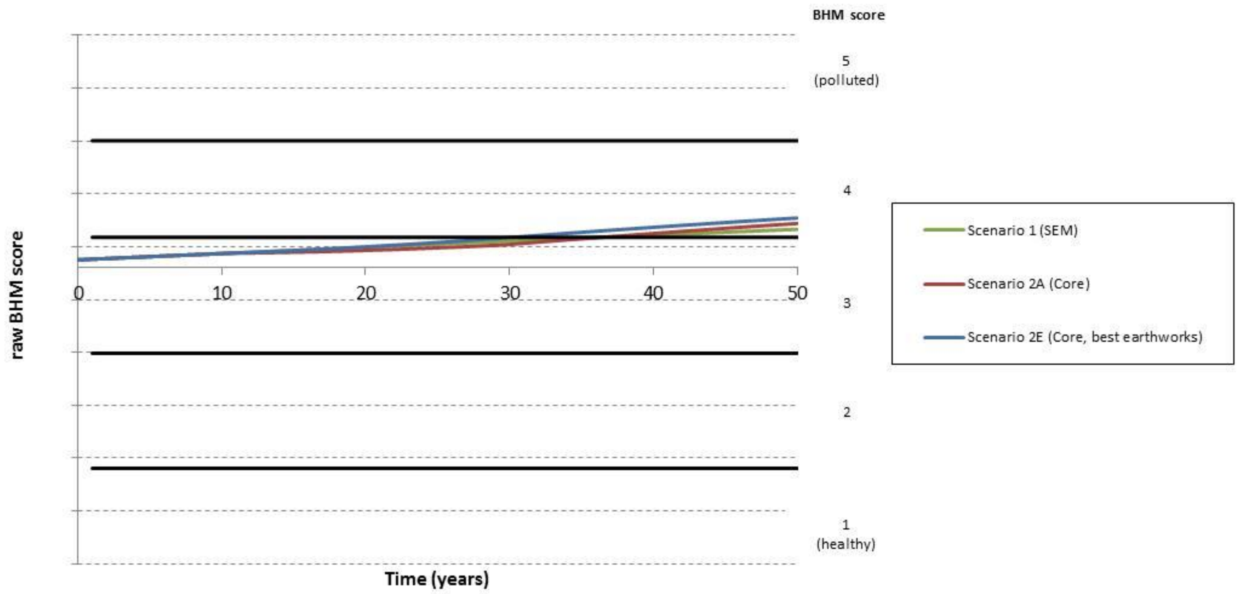
ERU 5 – Pahurehure Inner (SEM subestuary 7-PHI)



ERU 6 – Drury Creek Inner (SEM subestuary 16-DCI)

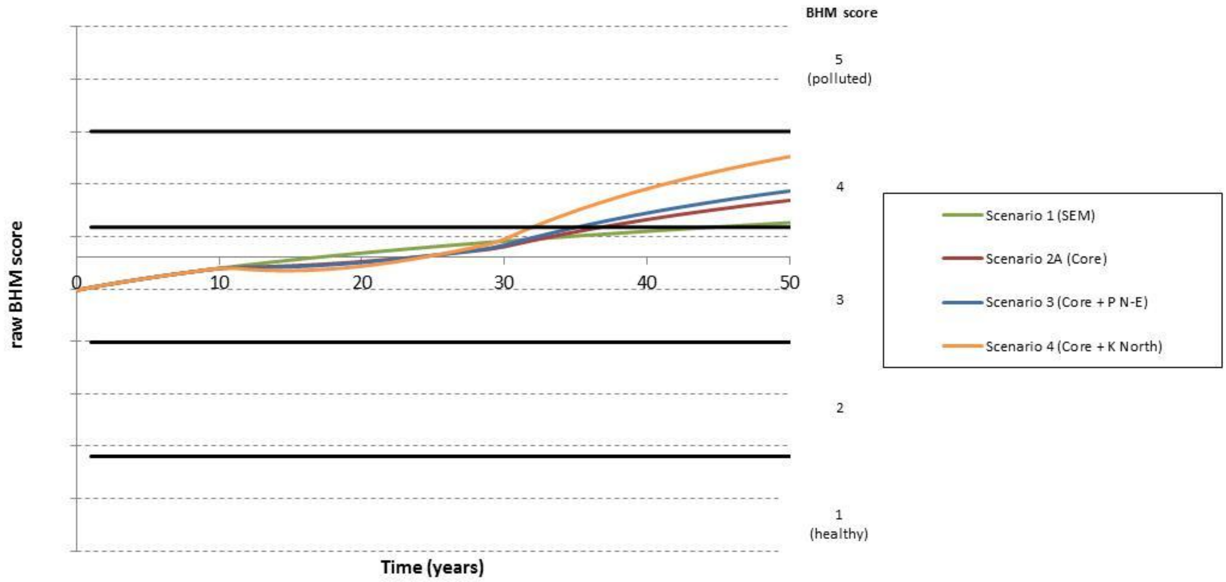


ERU 7 – Glasson Creek Inner (SEM subestuary 17-GCK)

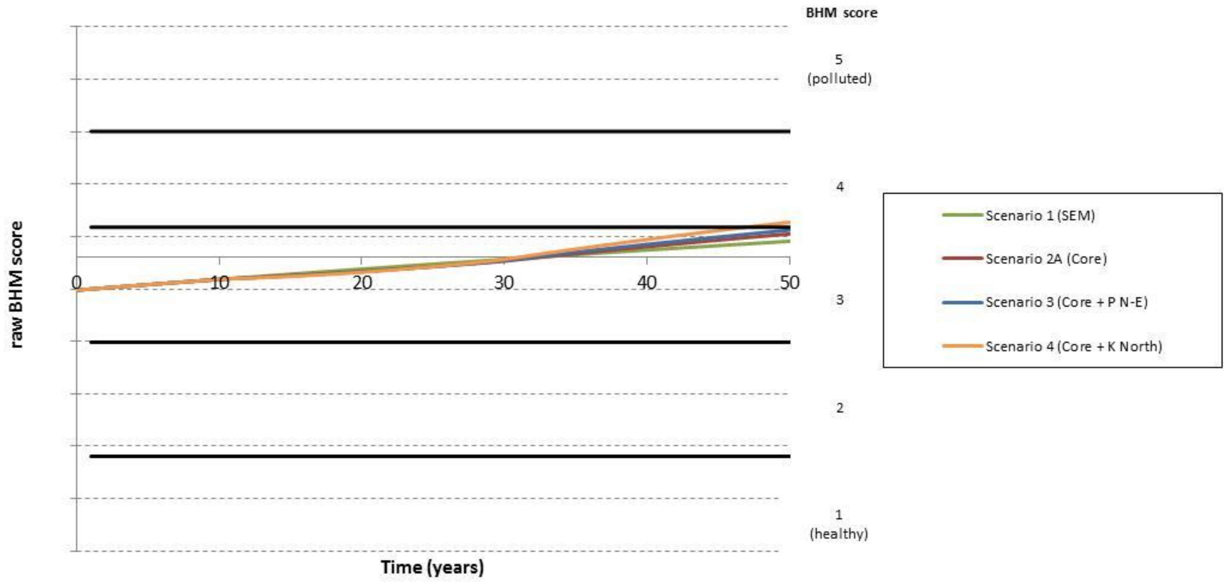


B.9 Predicted benthic health (metals) scores, Scenarios 2A, 3 and 4 (Core with additions) compared to Scenario 1 (SEM study)

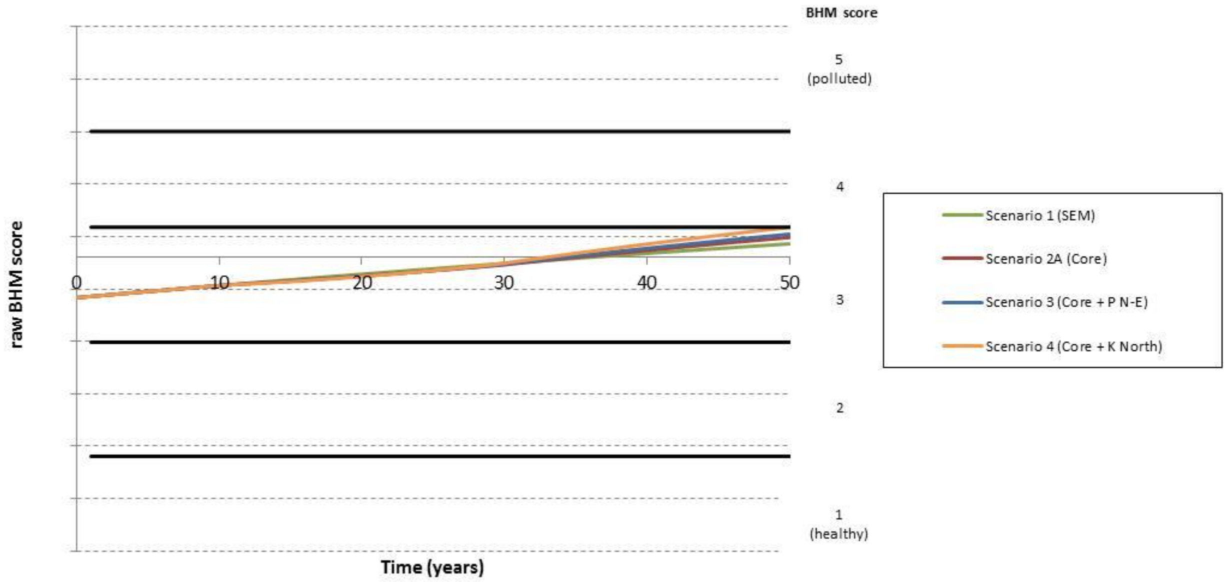
ERU 1 – Glassons Mouth West (SEM subestuary 3-GMW)



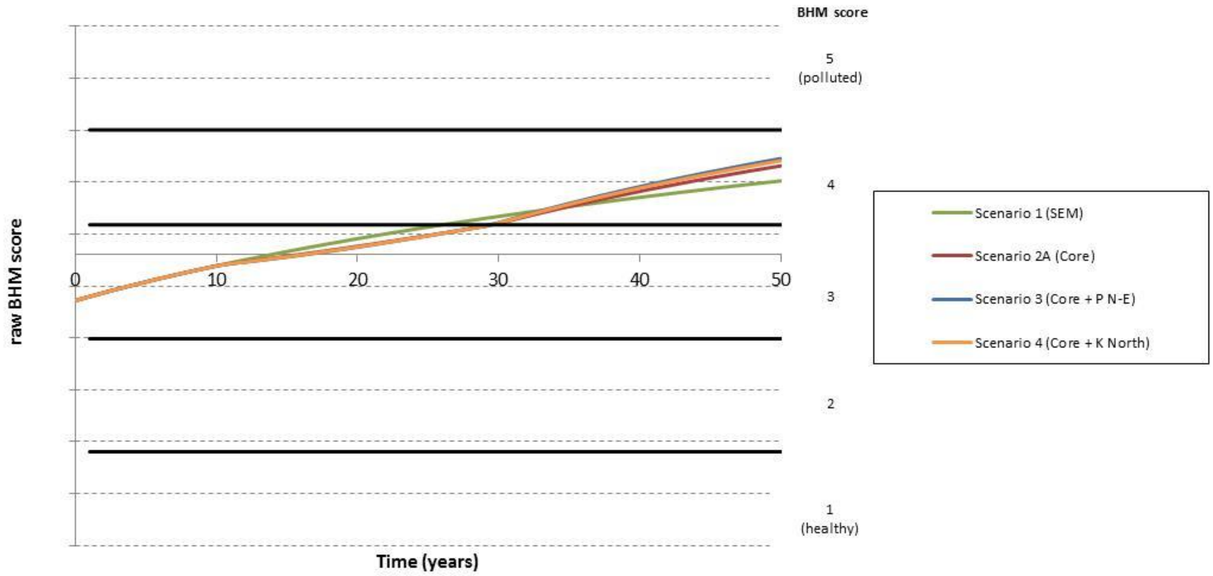
ERU 2 – Glassons Mouth East (SEM subestuary 4-GME)



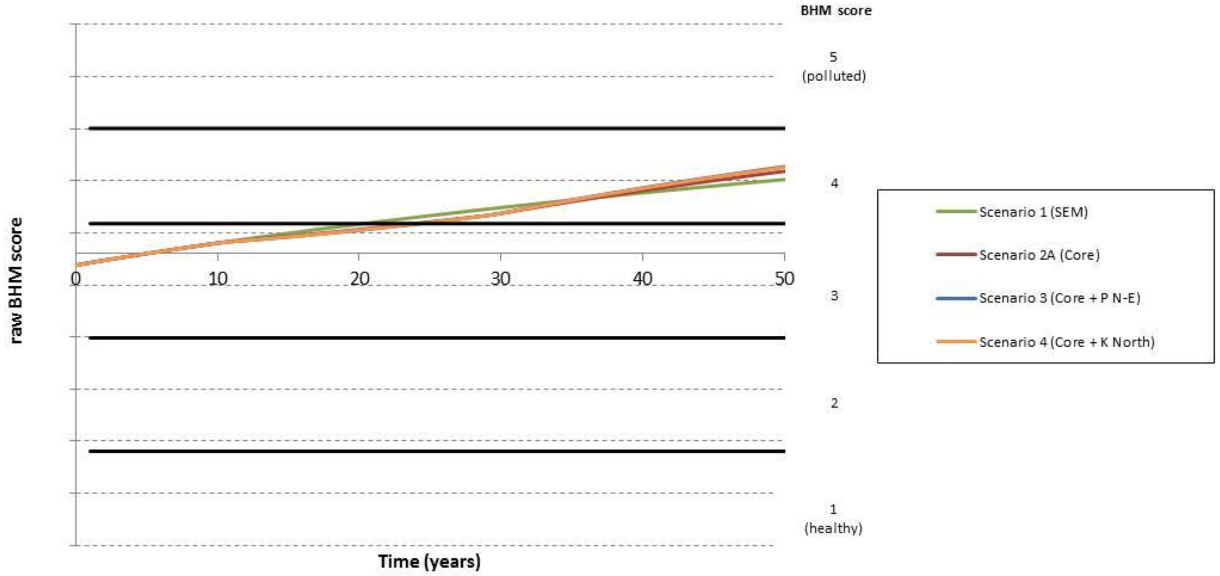
ERU 3 – Cape Horn (SEM subestuary 5-CHN)



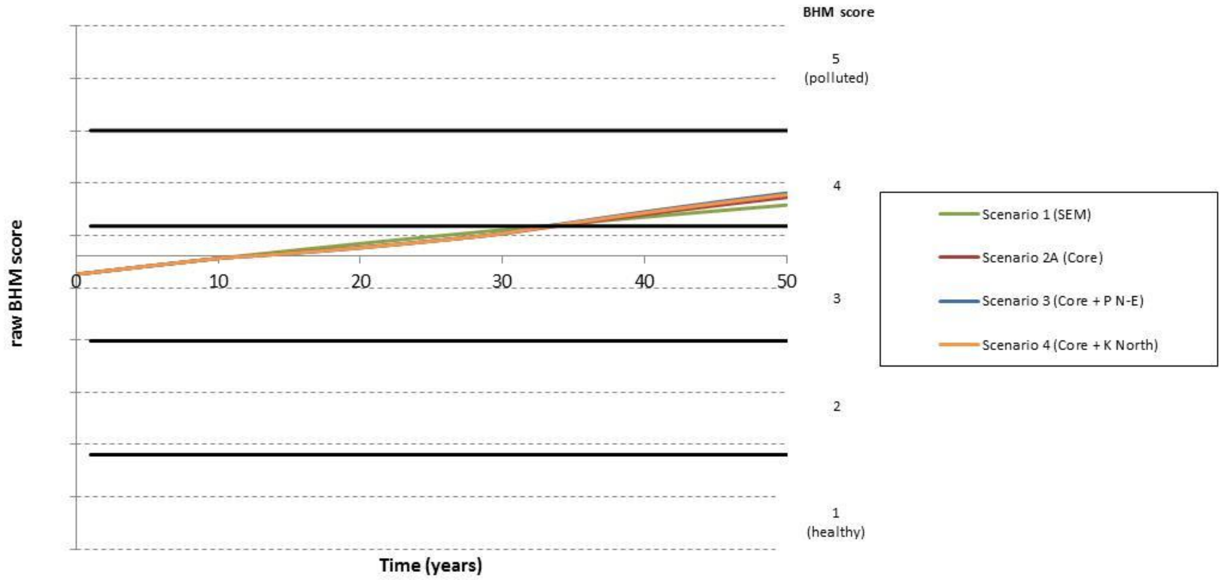
ERU 4 – Drury Creek Outer (SEM subestuary 6-DCO)



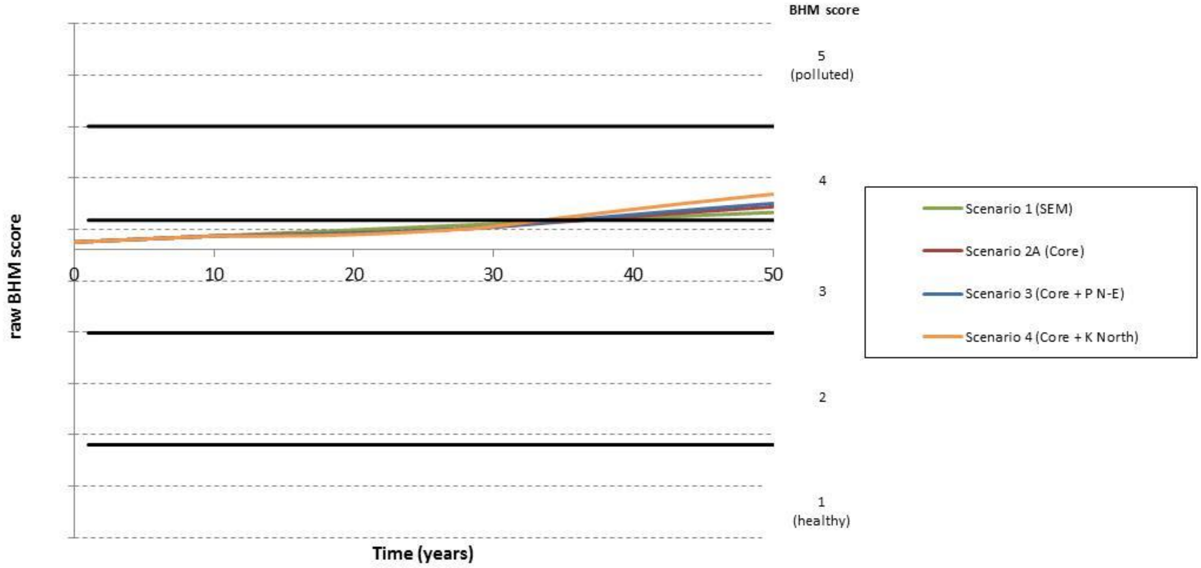
ERU 5 – Pahurehure Inner (SEM subestuary 7-PHI)



ERU 6 – Drury Creek Inner (SEM subestuary 16-DCI)

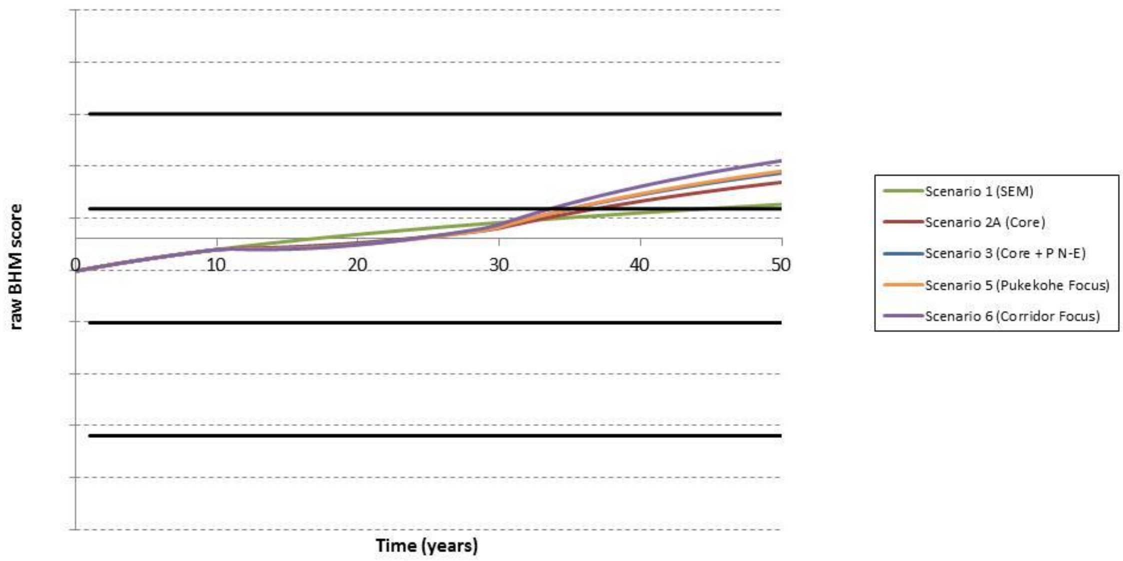


ERU 7 – Glasson Creek Inner (SEM subestuary 17-GCK)

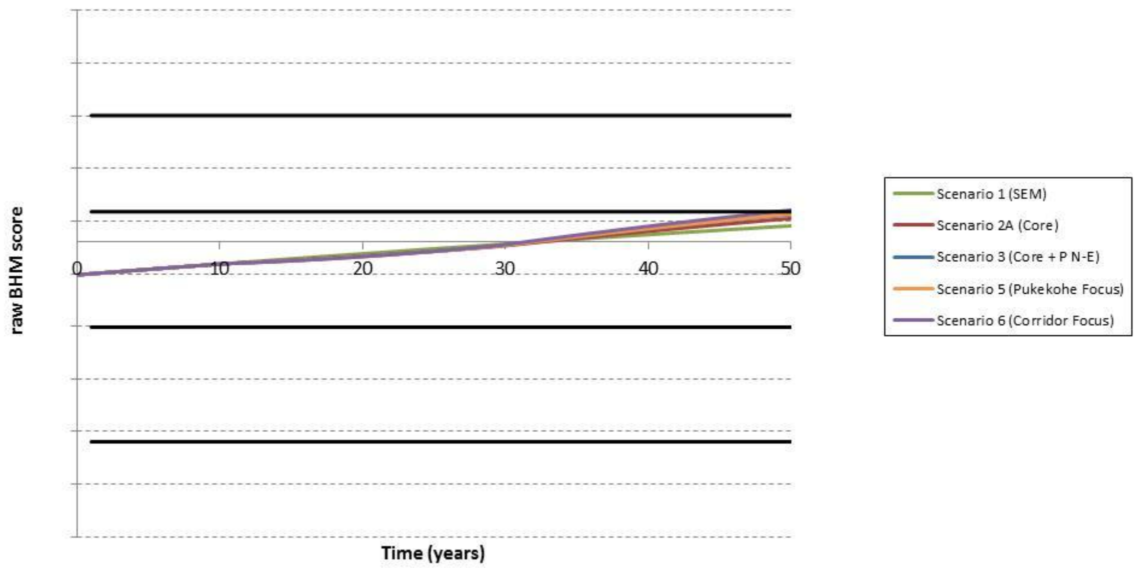


B.10 Predicted benthic health (metals) scores, Scenarios 2A, 3, 5 and 6 (Core with centre-south additions) compared to Scenario 1 (SEM study)

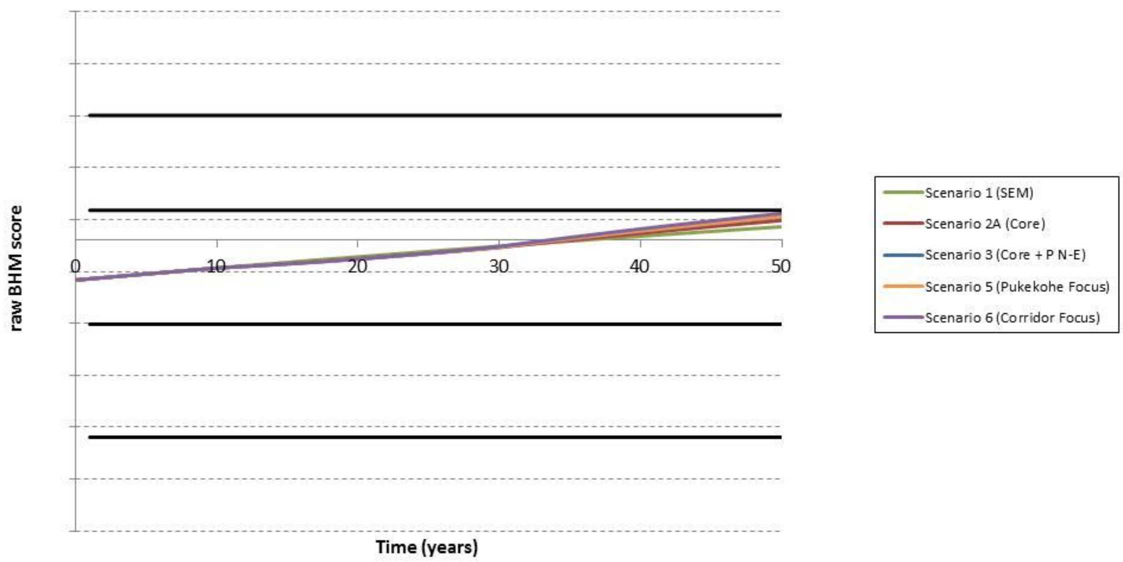
ERU 1 – Glassons Mouth West (SEM subestuary 3-GMW)



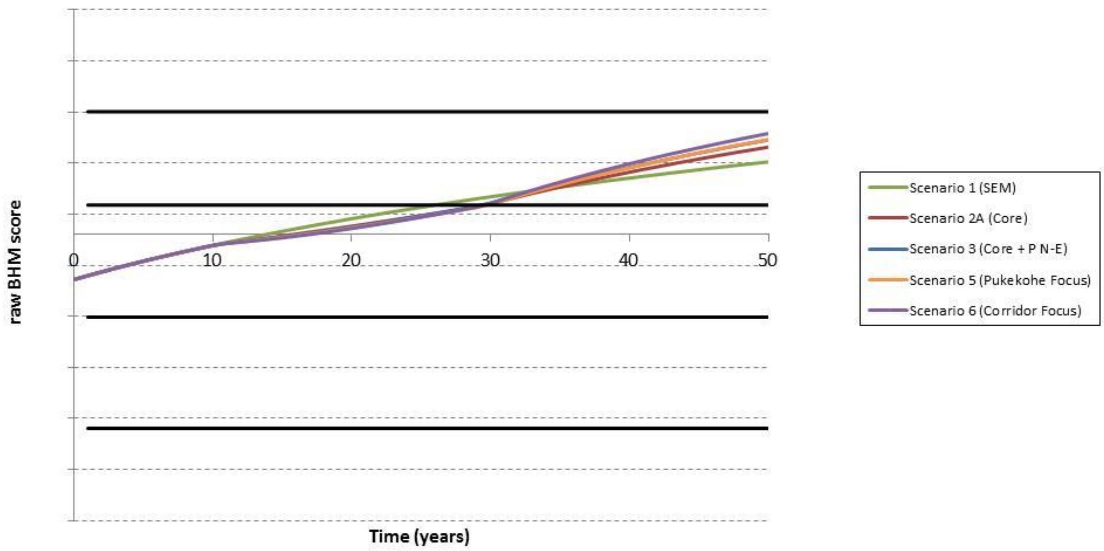
ERU 2 – Glassons Mouth East (SEM subestuary 4-GME)



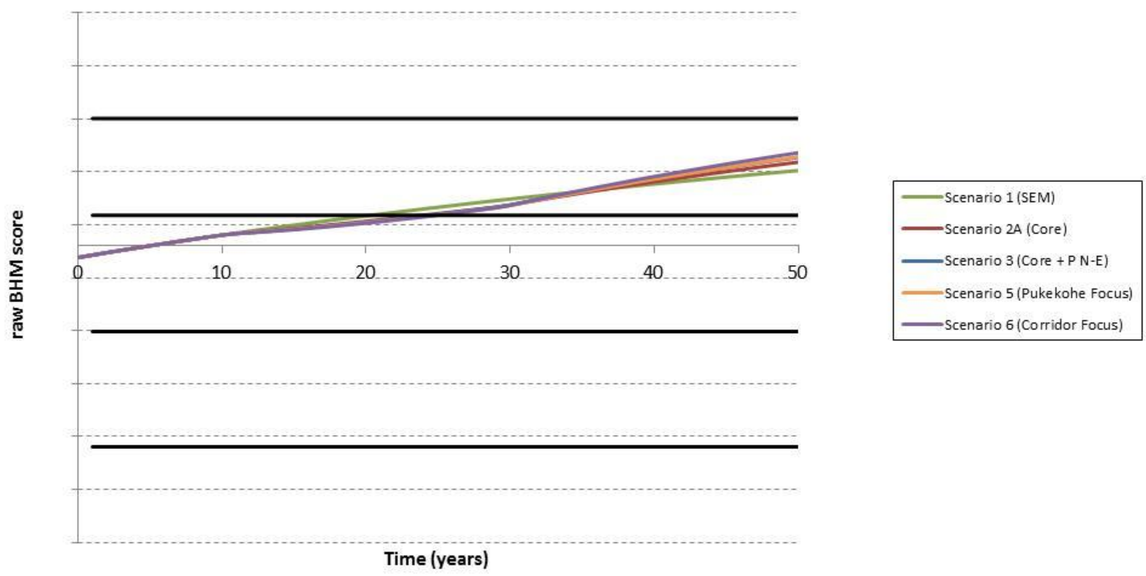
ERU 3 – Cape Horn (SEM subestuary 5-CHN)



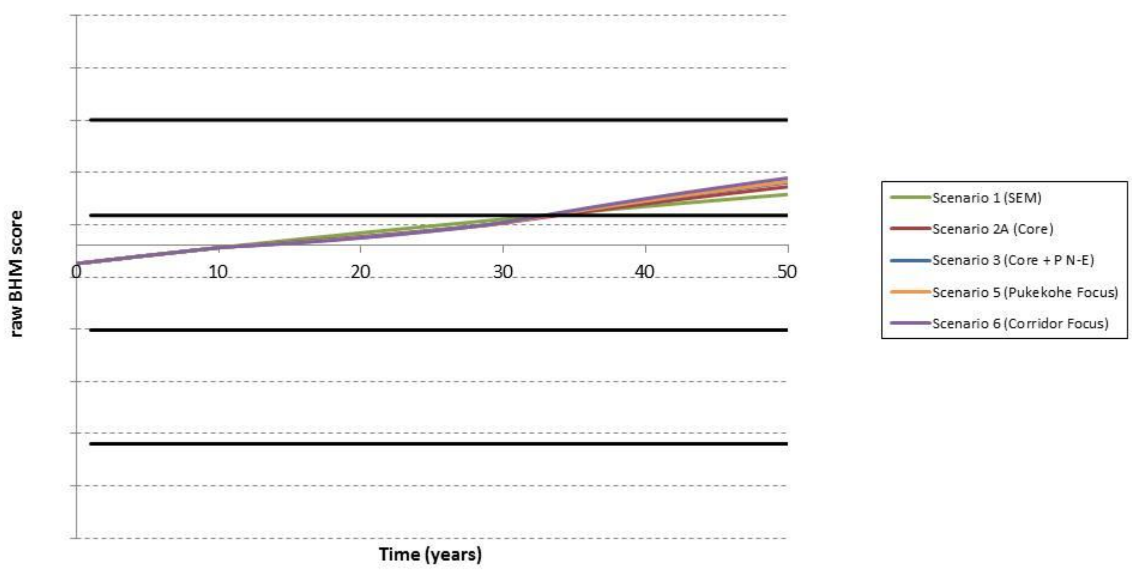
ERU 4 – Drury Creek Outer (SEM subestuary 6-DCO)



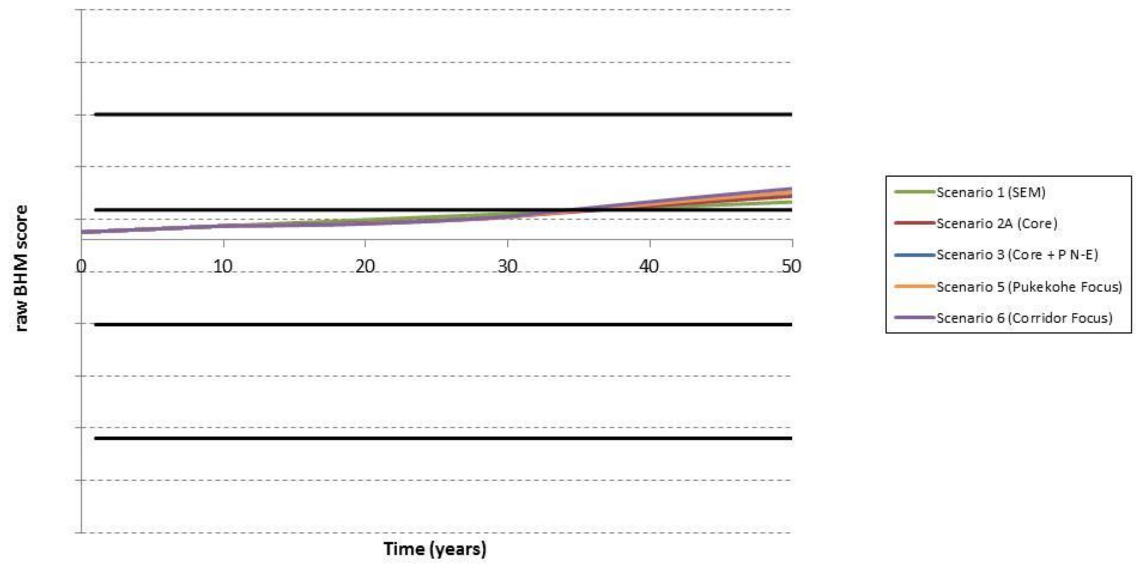
ERU 5 – Pahurehure Inner (SEM subestuary 7-PHI)



ERU 6 – Drury Creek Inner (SEM subestuary 16-DCI)

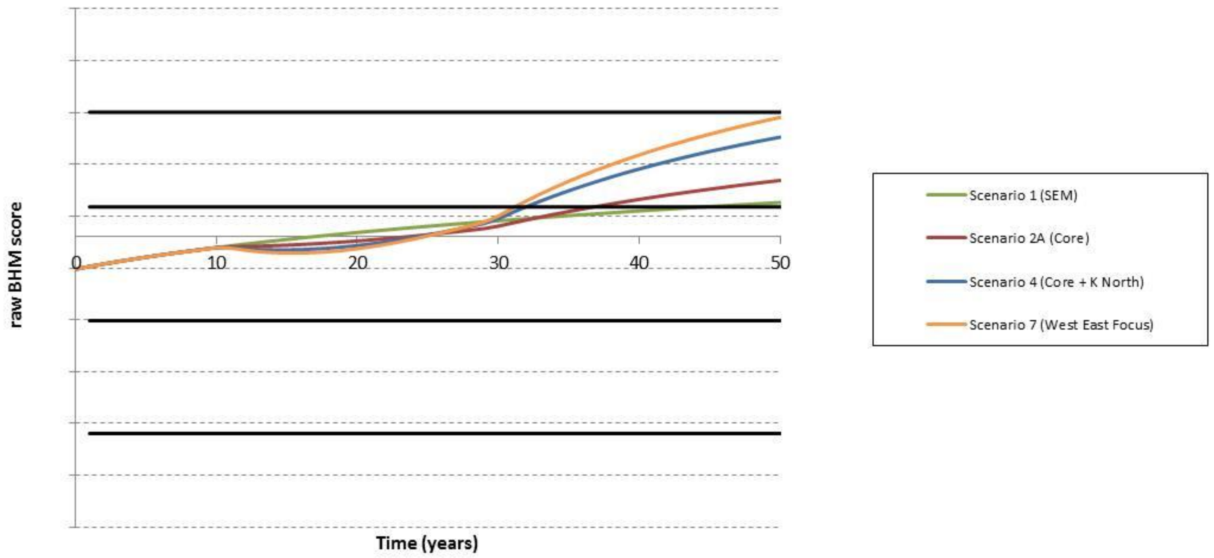


ERU 7 – Glasson Creek Inner (SEM subestuary 17-GCK)

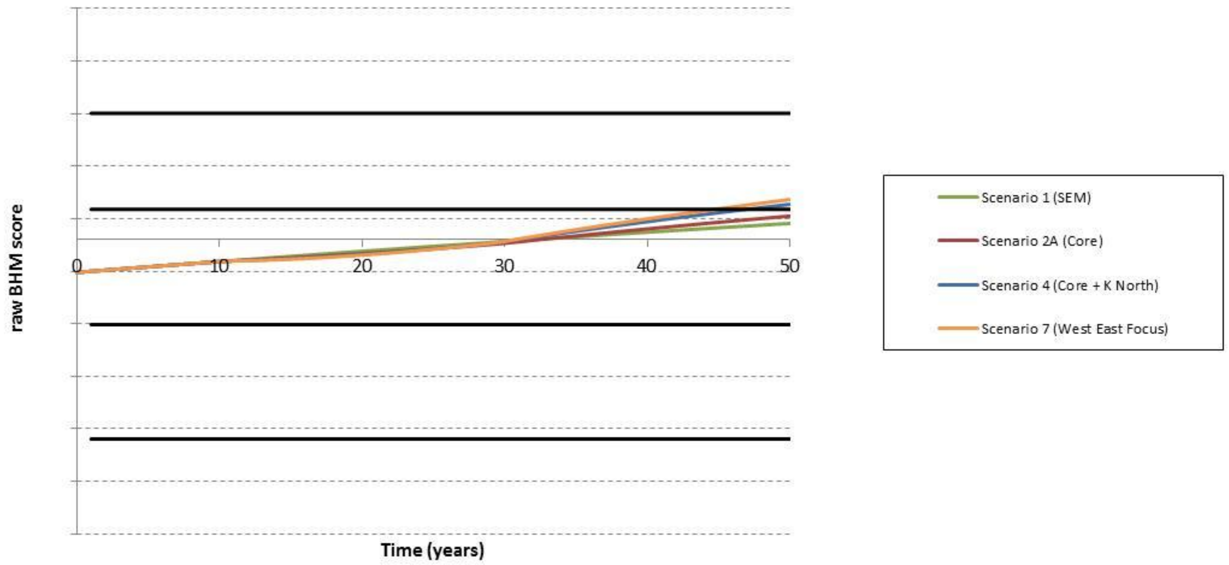


B.11 Predicted benthic health (metals) scores, Scenarios 2A, 4 and 7 (Core with northern additions) compared to Scenario 1 (SEM study)

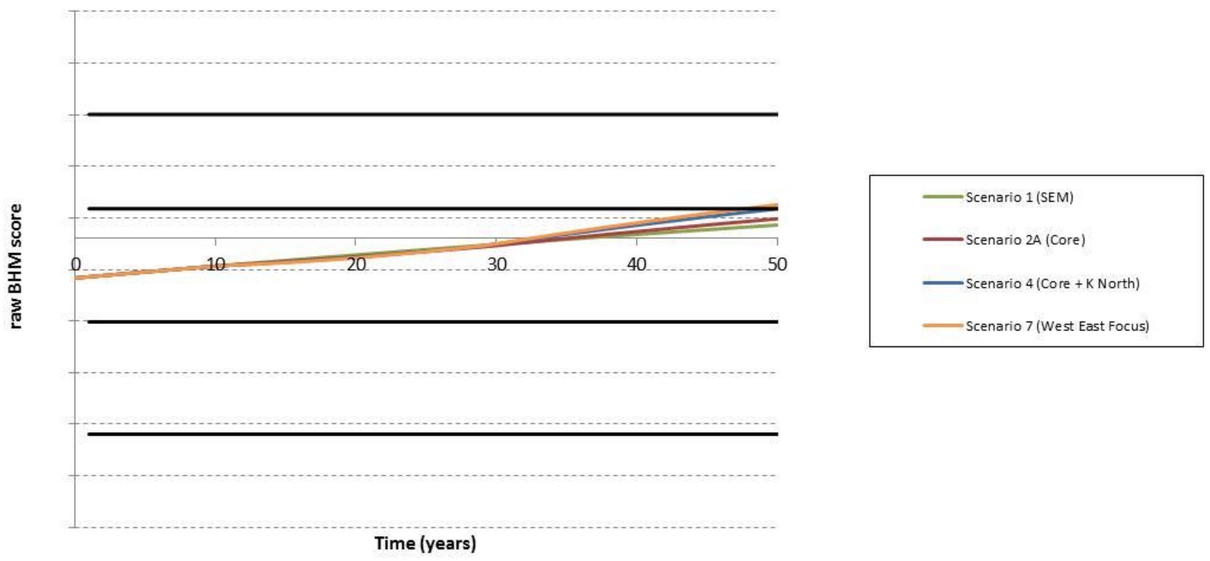
ERU 1 – Glassons Mouth West (SEM subestuary 3-GMW)



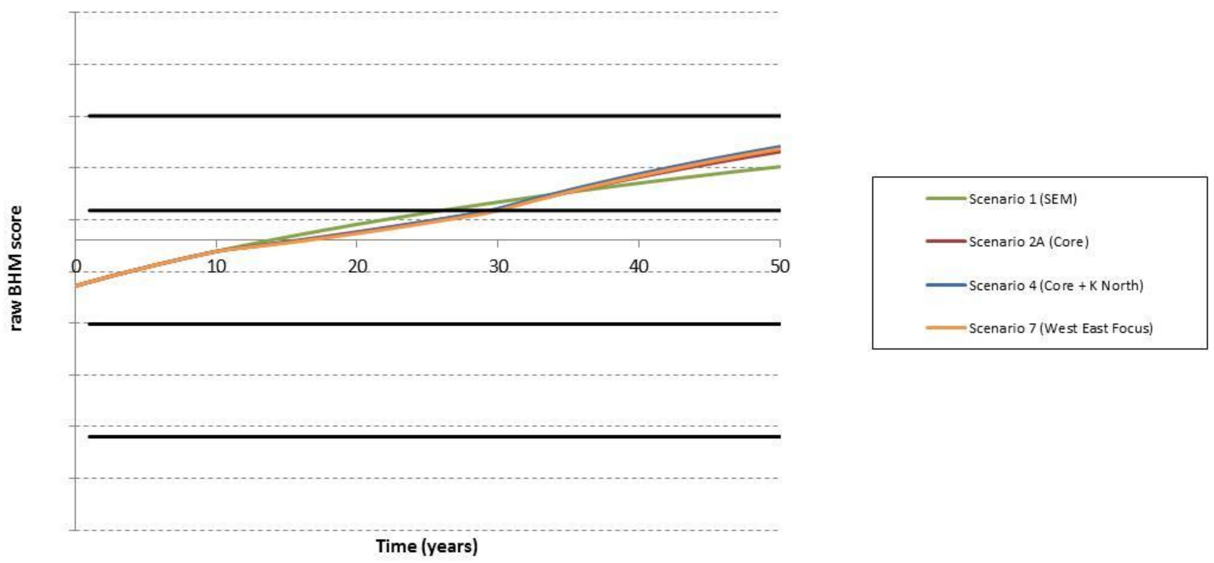
ERU 2 – Glassons Mouth East (SEM subestuary 4-GME)



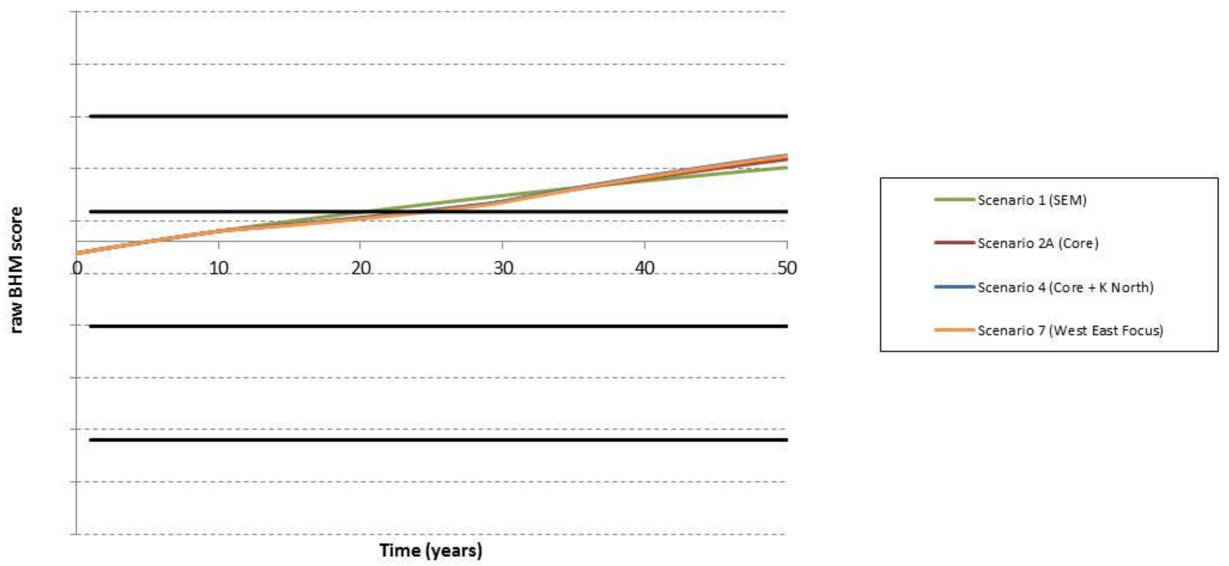
ERU 3 – Cape Horn (SEM subestuary 5-CHN)



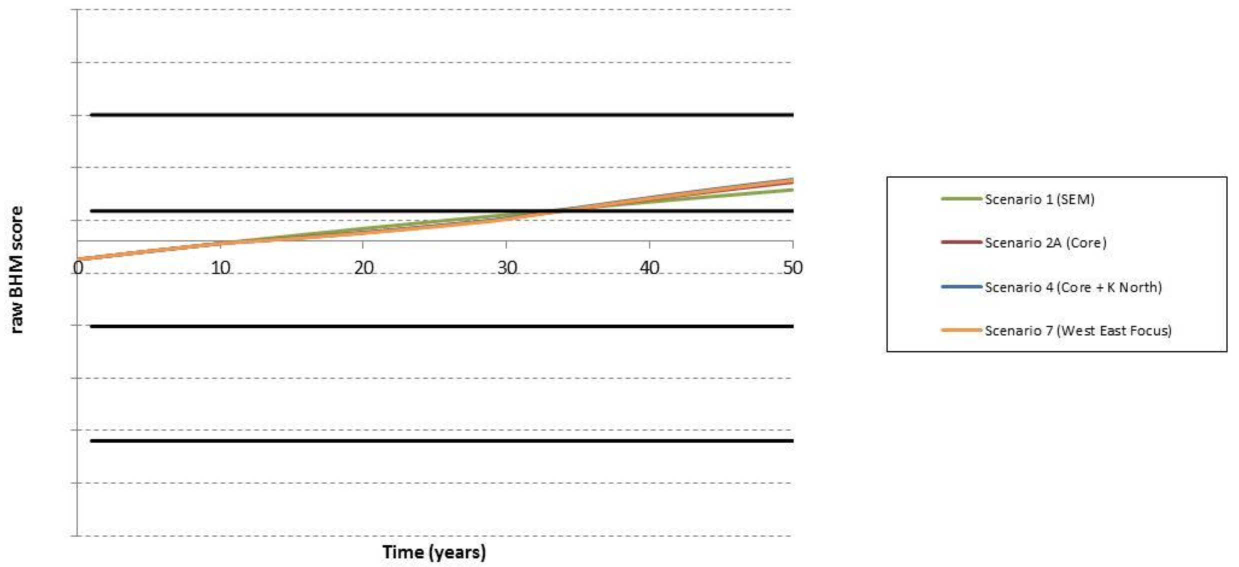
ERU 4 – Drury Creek Outer (SEM subestuary 6-DCO)



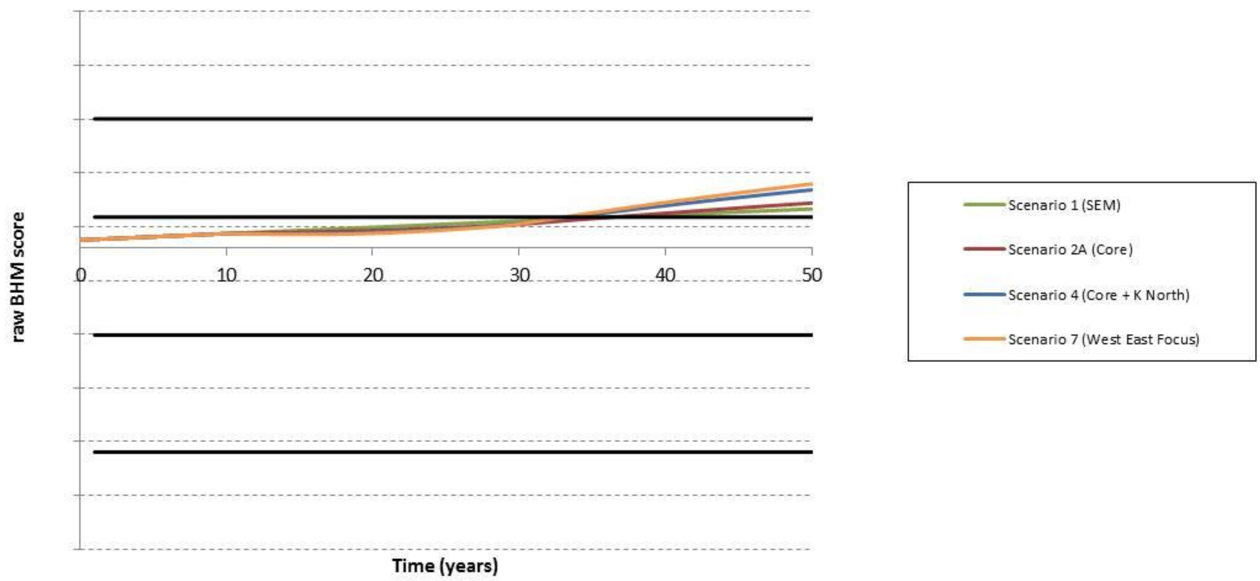
ERU 5 – Pahurehure Inner (SEM subestuary 7-PHI)



ERU 6 – Drury Creek Inner (SEM subestuary 16-DCI)

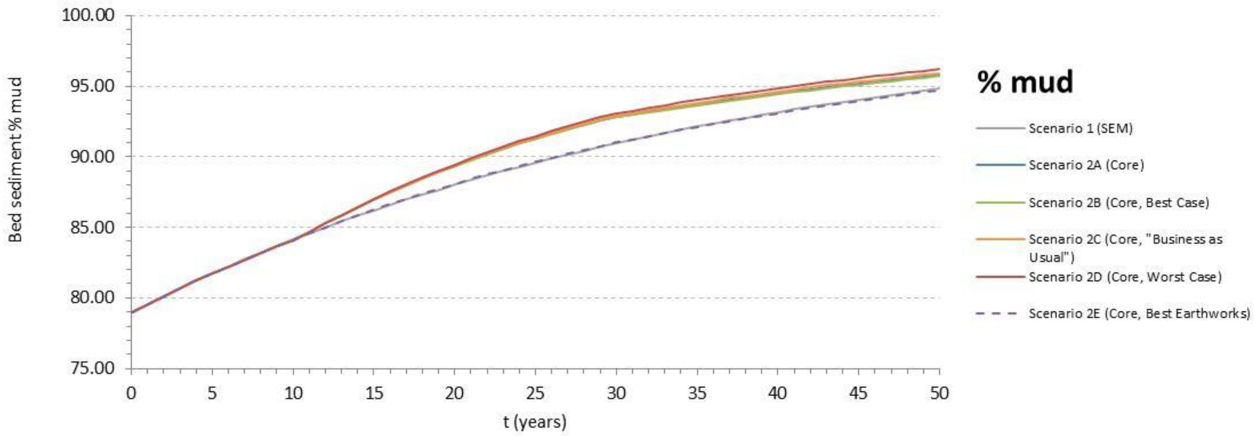


ERU 7 – Glasson Creek Inner (SEM subestuary 17-GCK)

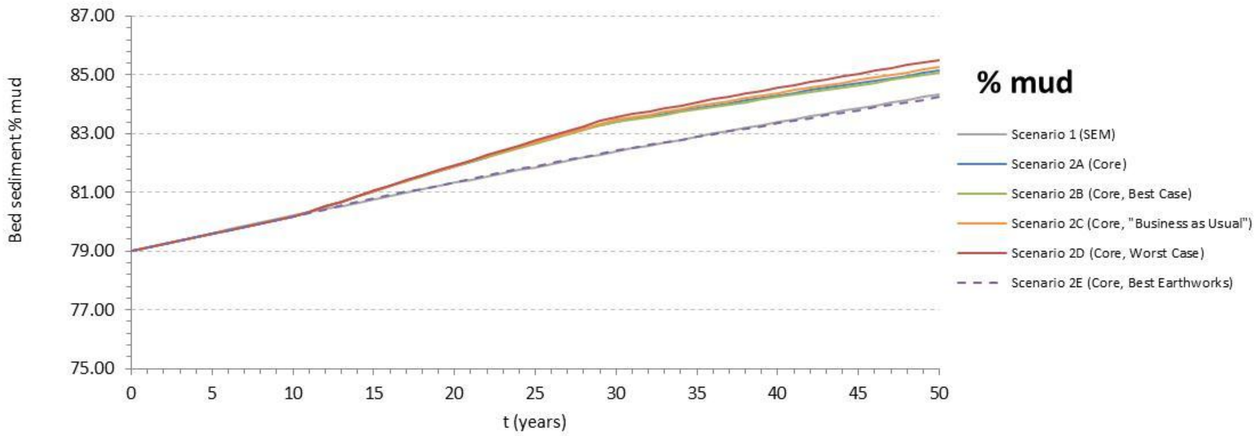


B.12 Predicted % mud in estuary bed-sediments, Scenarios 2A to 2E (Core with varying stormwater treatment and earthworks controls) compared to Scenario 1 (SEM study)

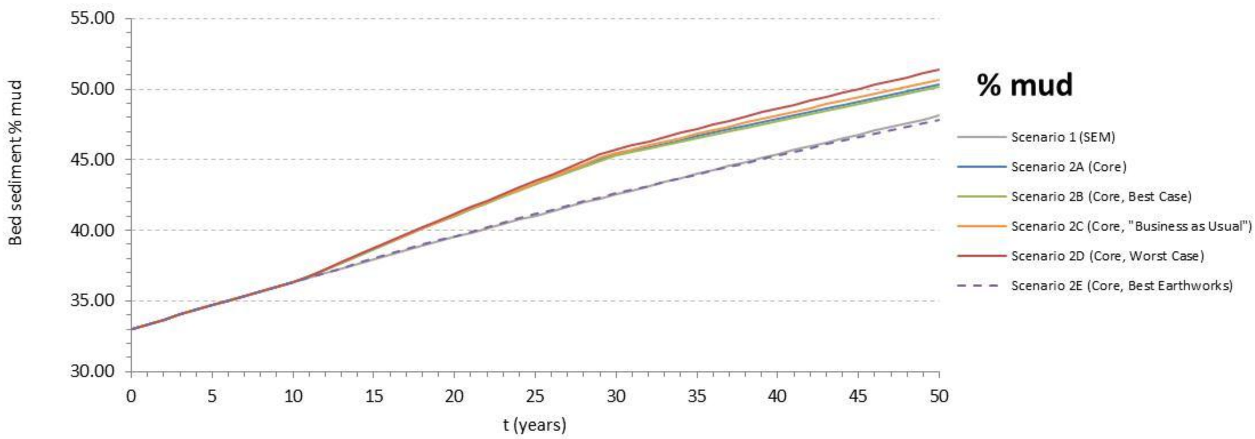
ERU 1 – Glassons Mouth West (SEM subestuary 3-GMW)



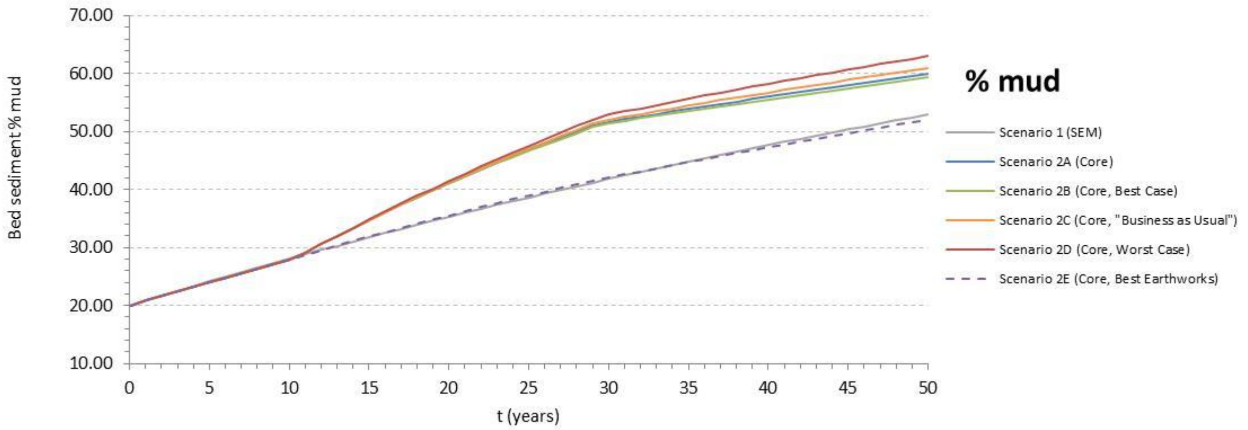
ERU 2 – Glassons Mouth East (SEM subestuary 4-GME)



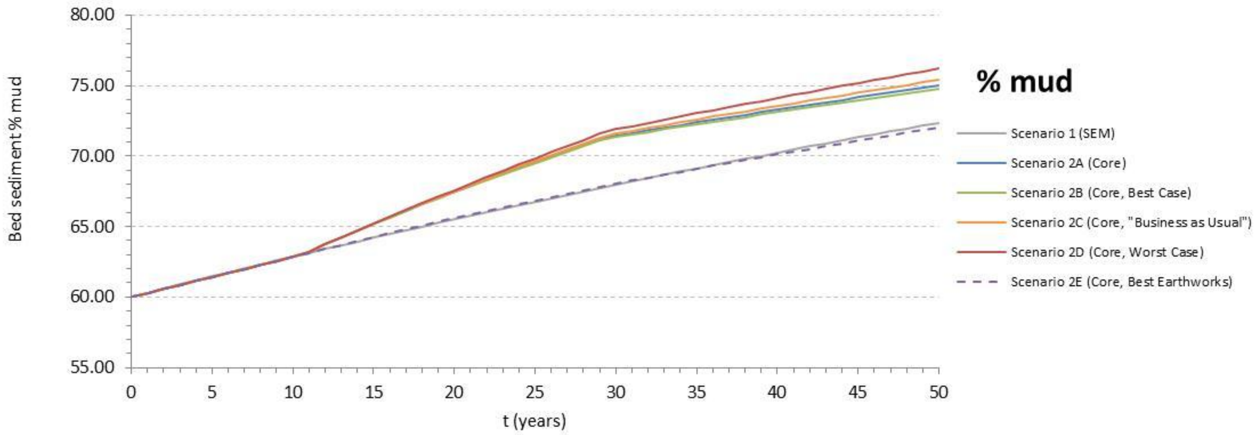
ERU 3 – Cape Horn (SEM subestuary 5-CHN)



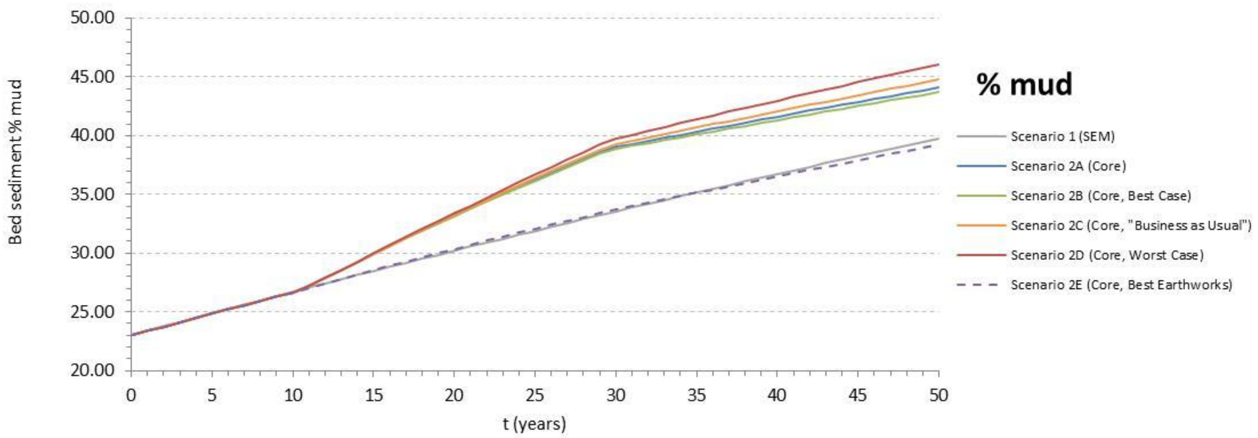
ERU 4 – Drury Creek Outer (SEM subestuary 6-DCO)



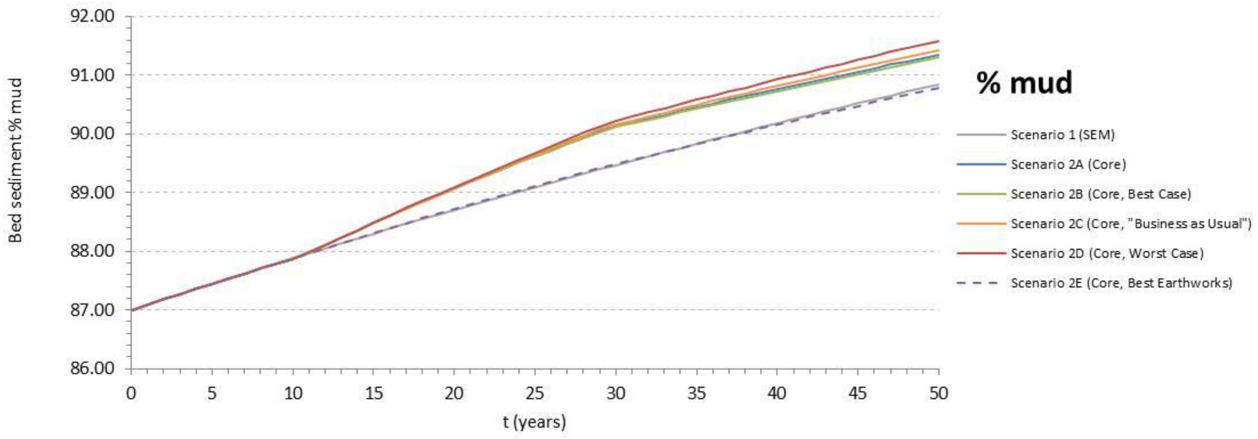
ERU 5 – Pahurehure Inner (SEM subestuary 7-PHI)



ERU 6 – Drury Creek Inner (SEM subestuary 16-DCI)

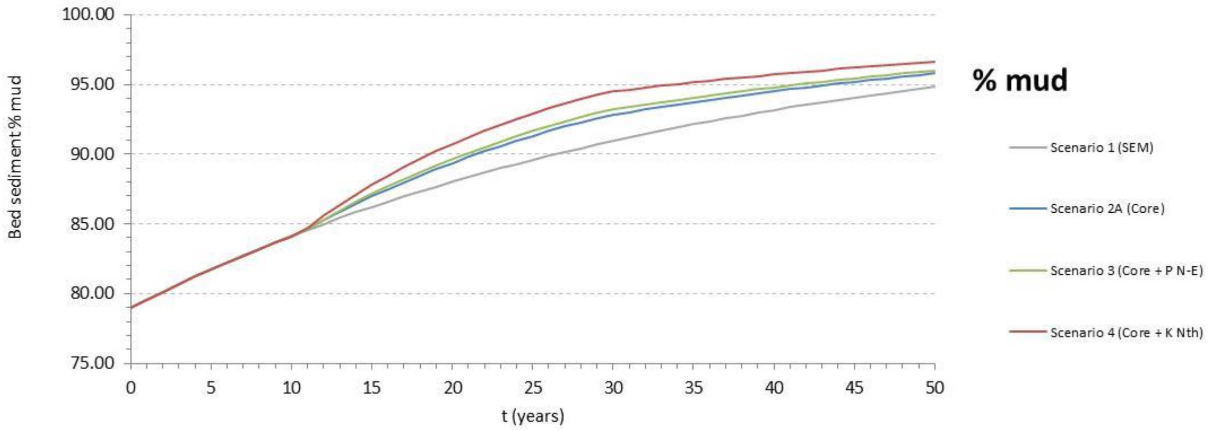


ERU 7 – Glasson Creek Inner (SEM subestuary 17-GCK)

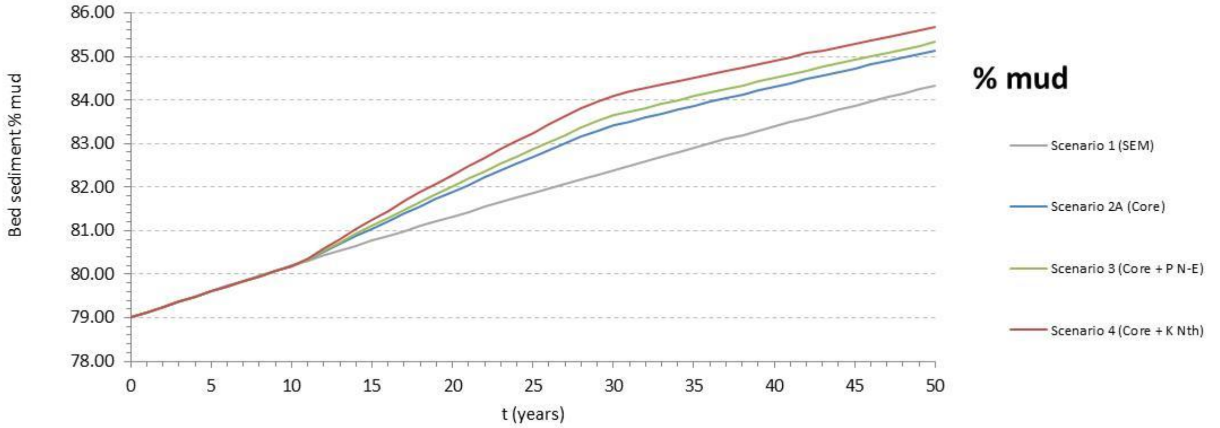


B.13 Predicted % mud in estuary bed-sediments, Scenarios 2A, 3 and 4 (Core with additions) compared to Scenario 1 (SEM study)

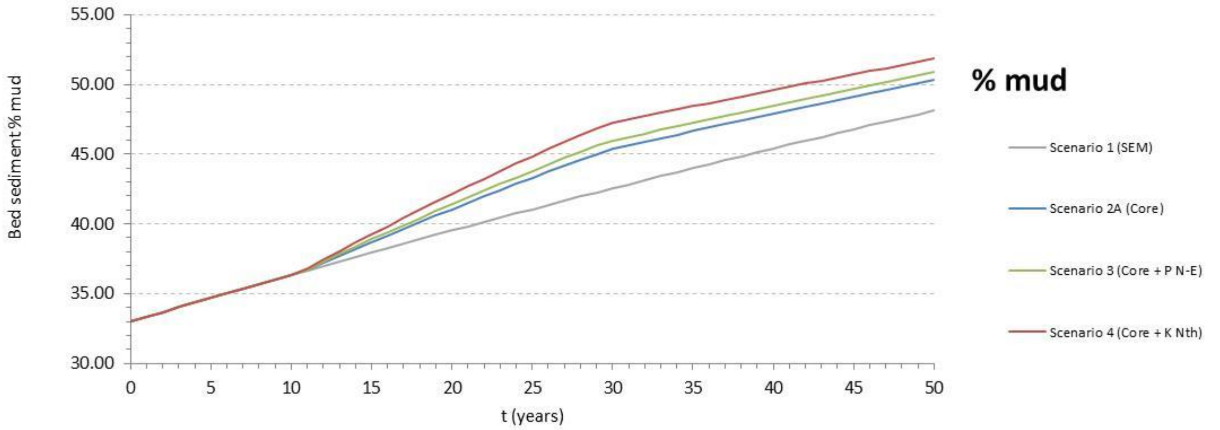
ERU 1 – Glassons Mouth West (SEM subestuary 3-GMW)



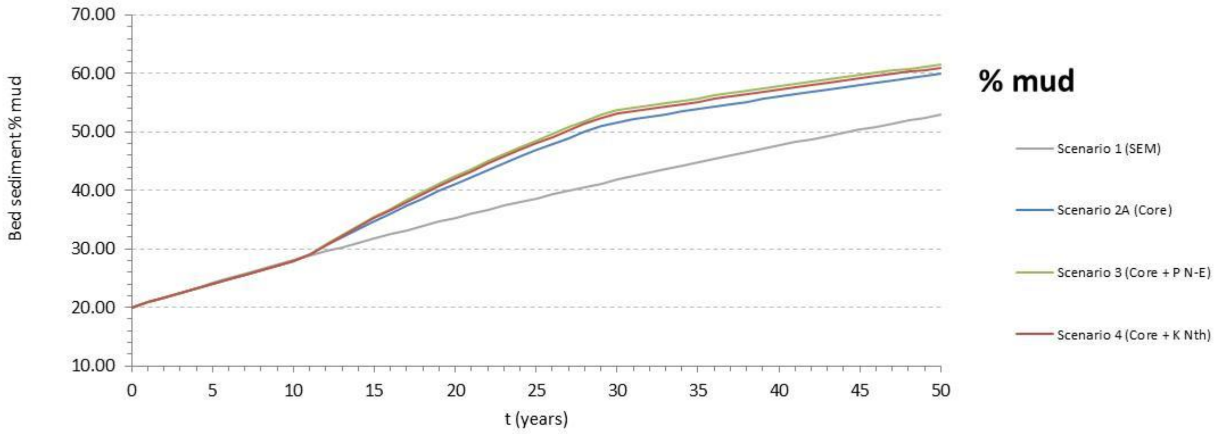
ERU 2 – Glassons Mouth East (SEM subestuary 4-GME)



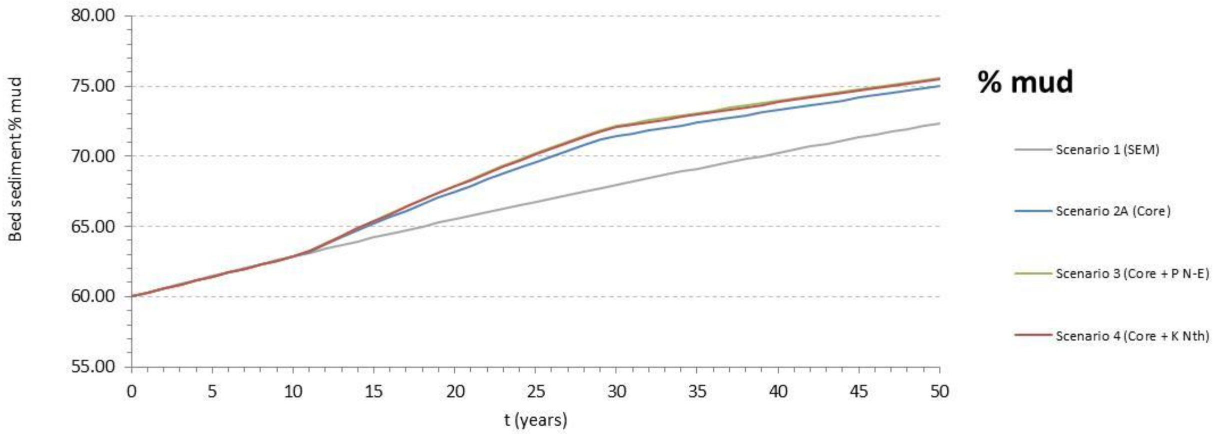
ERU 3 – Cape Horn (SEM subestuary 5-CHN)



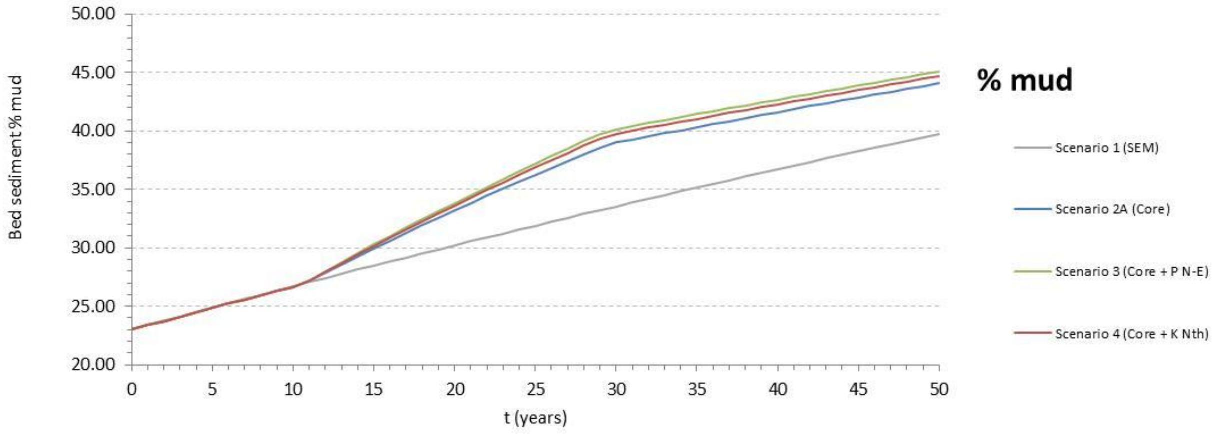
ERU 4 – Drury Creek Outer (SEM subestuary 6-DCO)



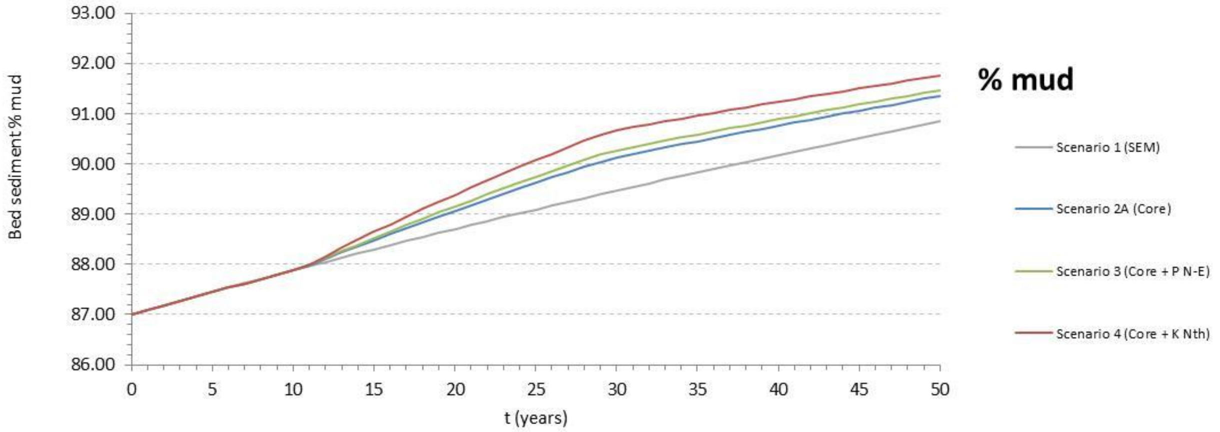
ERU 5 – Pahurehure Inner (SEM subestuary 7-PHI)



ERU 6 – Drury Creek Inner (SEM subestuary 16-DCI)

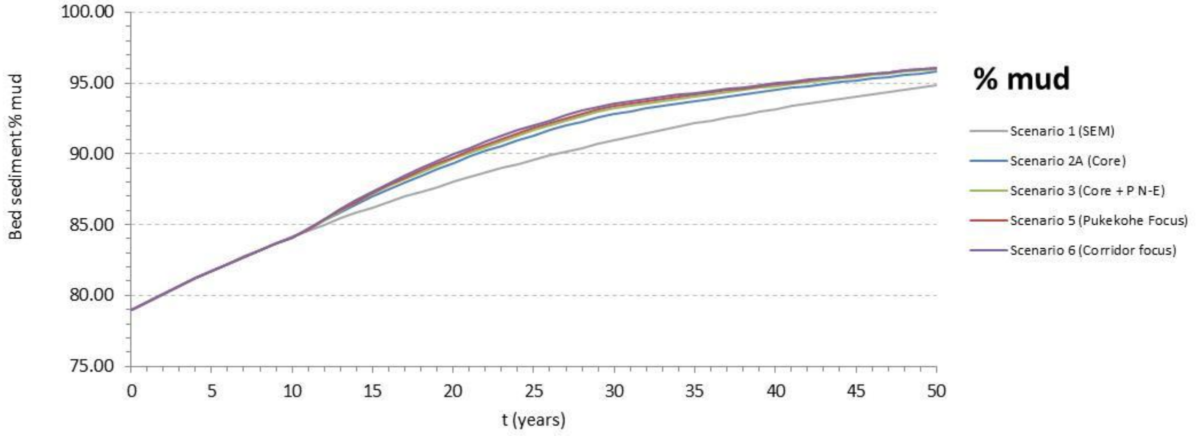


ERU 7 – Glasson Creek Inner (SEM subestuary 17-GCK)

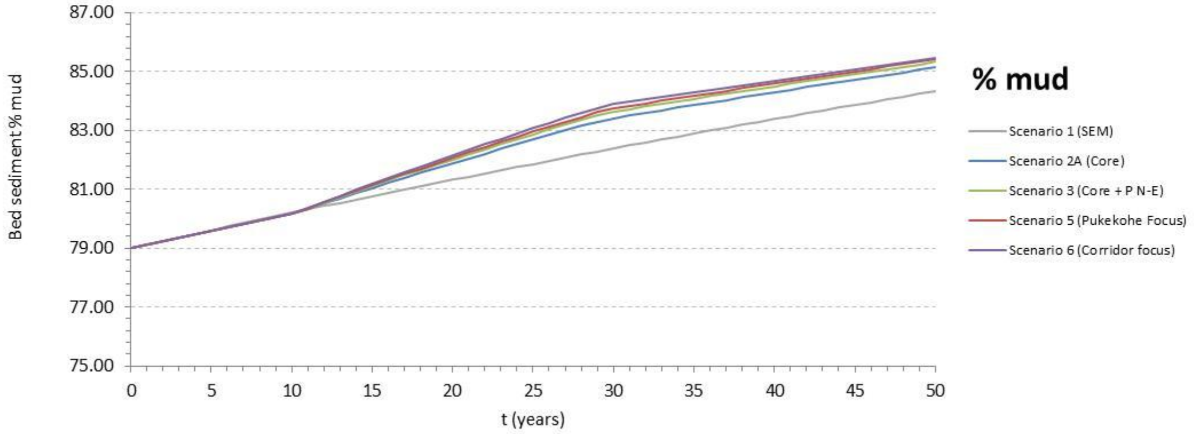


B.14 Predicted % mud in estuary bed-sediments, Scenarios 2A, 3, 5 and 6 (Core with centre-south additions) compared to Scenario 1 (SEM study)

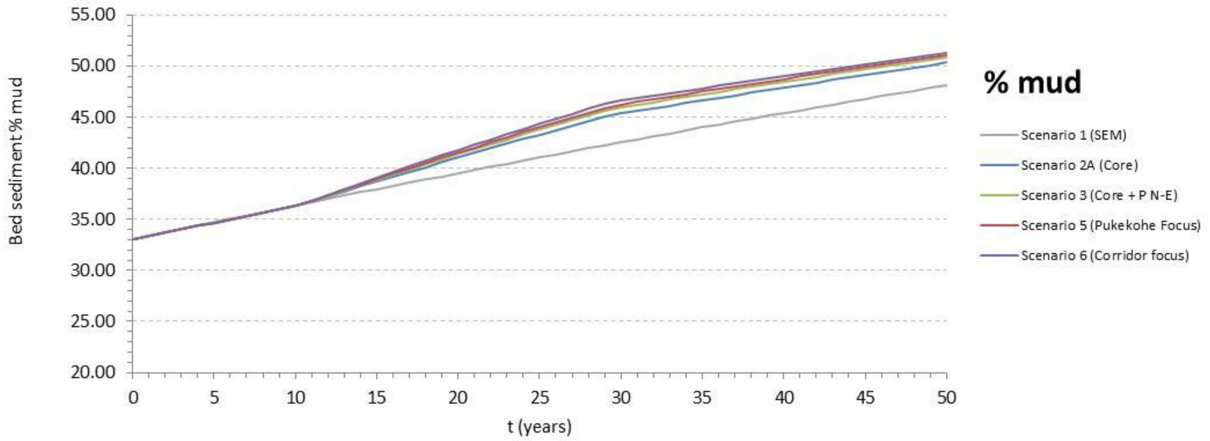
ERU 1 – Glassons Mouth West (SEM subestuary 3-GMW)



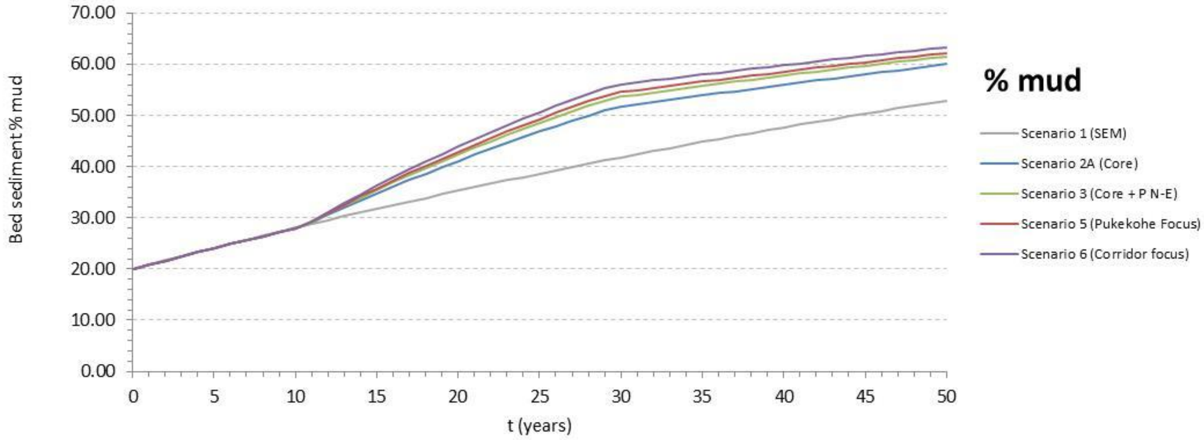
ERU 2 – Glassons Mouth East (SEM subestuary 4-GME)



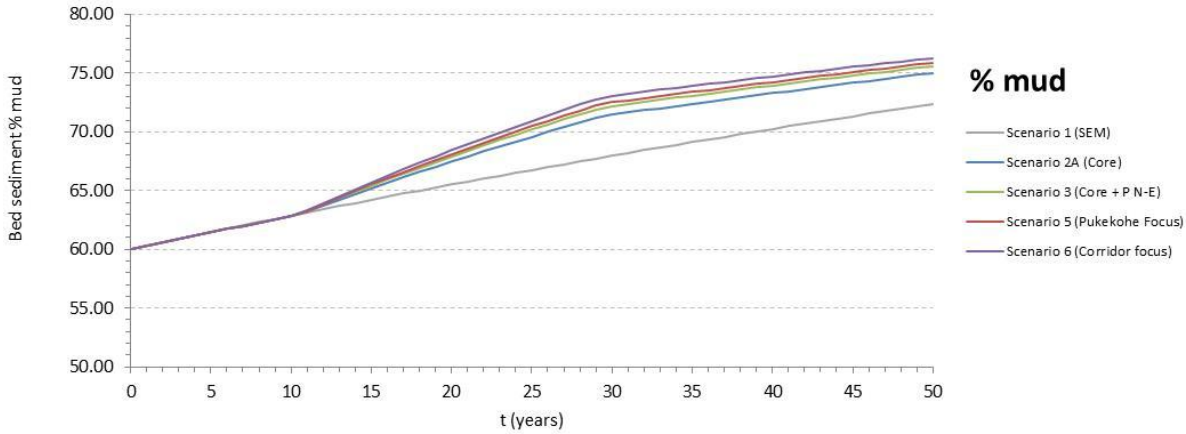
ERU 3 – Cape Horn (SEM subestuary 5-CHN)



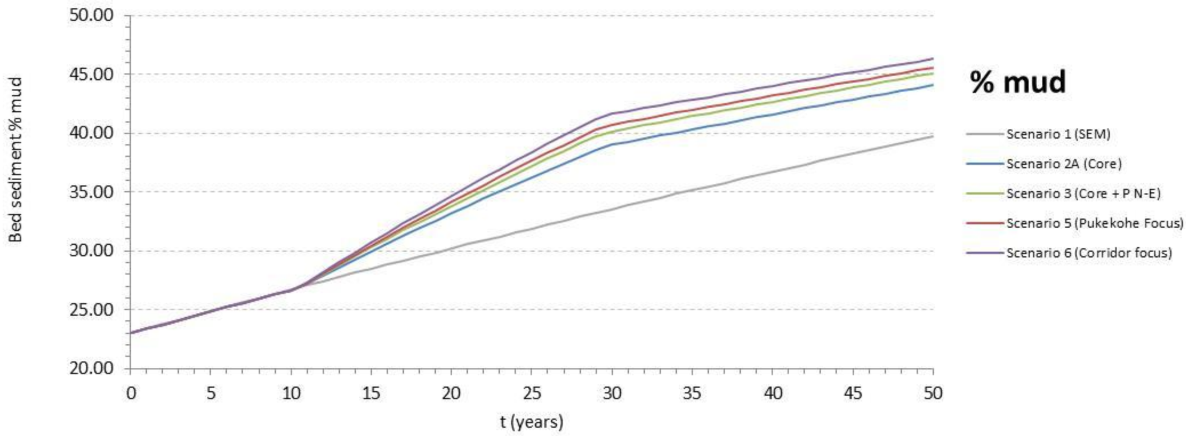
ERU 4 – Drury Creek Outer (SEM subestuary 6-DCO)



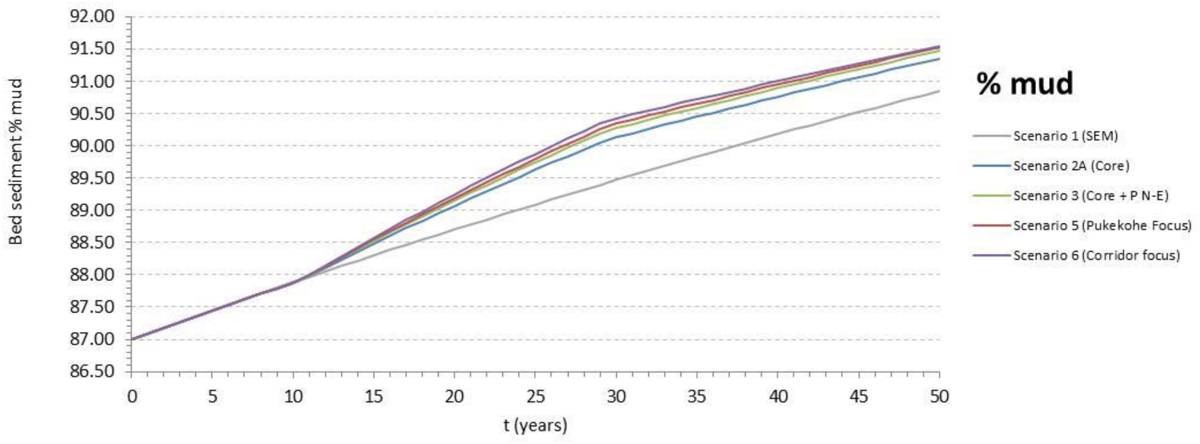
ERU 5 – Pahurehure Inner (SEM subestuary 7-PHI)



ERU 6 – Drury Creek Inner (SEM subestuary 16-DCI)

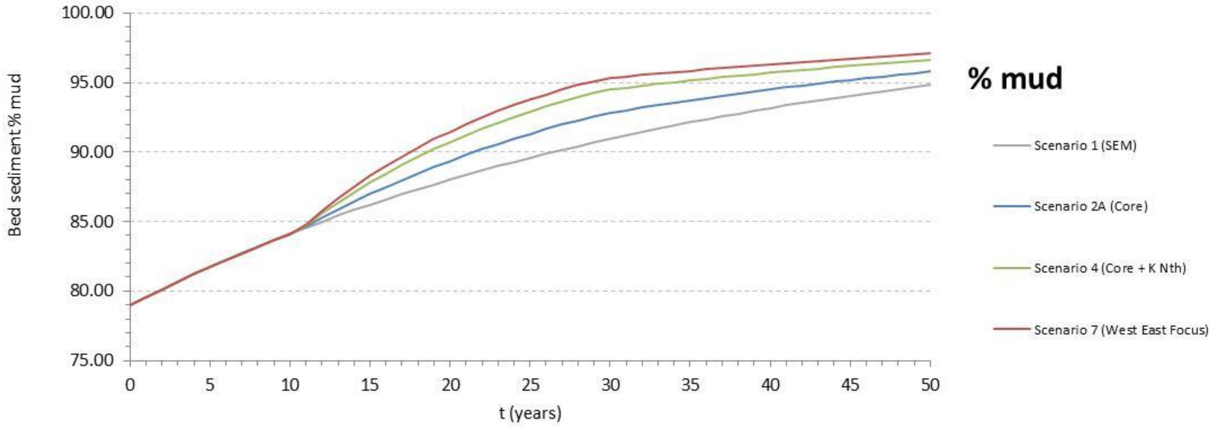


ERU 7 – Glasson Creek Inner (SEM subestuary 17-GCK)

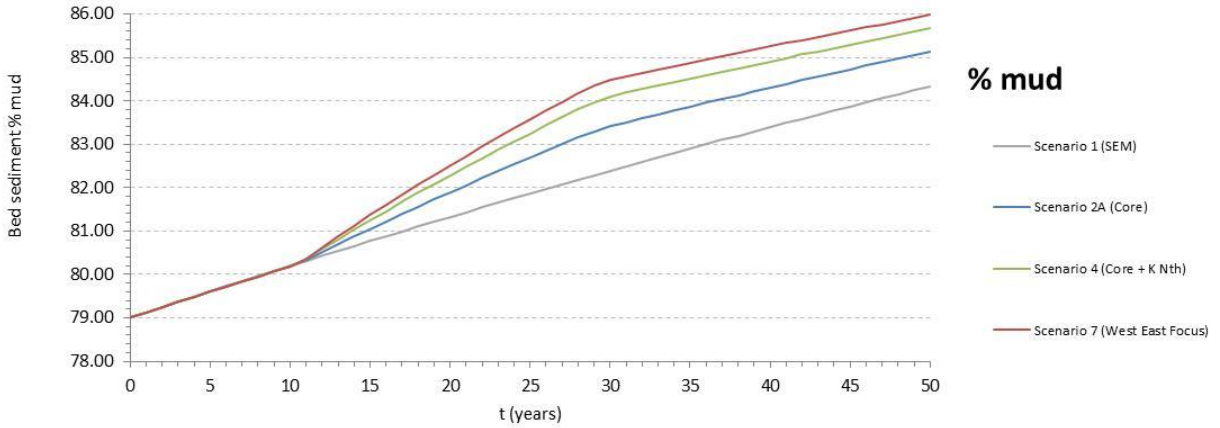


B.15 Predicted % mud in estuary bed-sediments, Scenarios 2A, 4 and 7 (Core with northern additions) compared to Scenario 1 (SEM study)

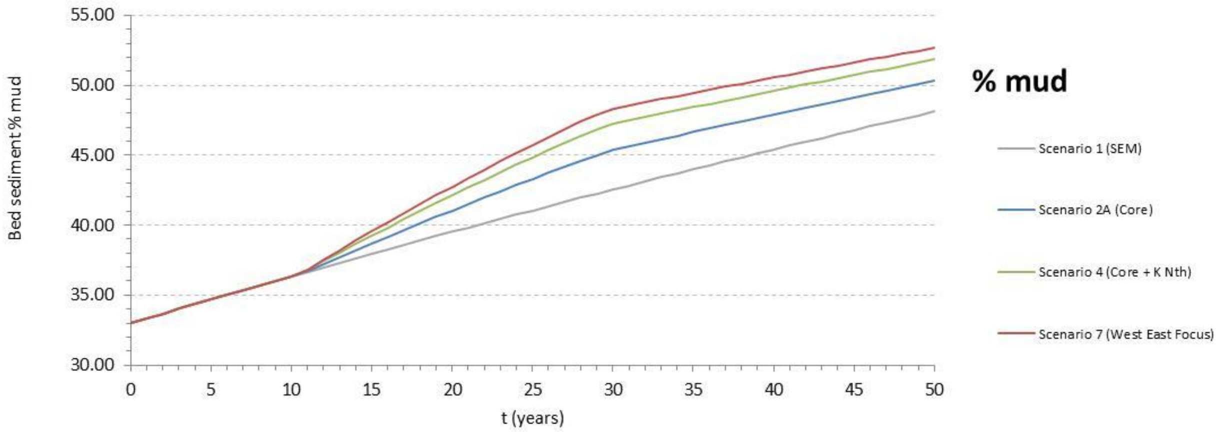
ERU 1 – Glassons Mouth West (SEM subestuary 3-GMW)



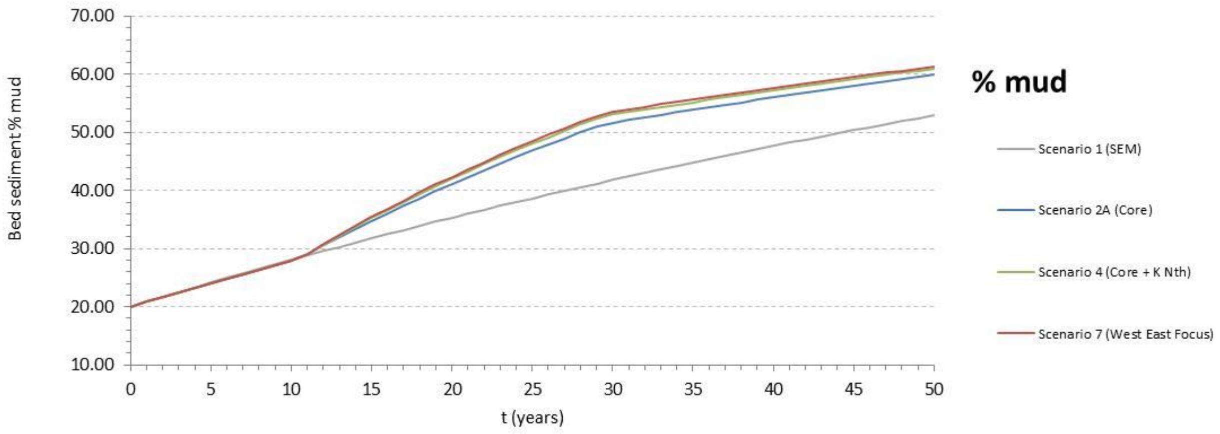
ERU 2 – Glassons Mouth East (SEM subestuary 4-GME)



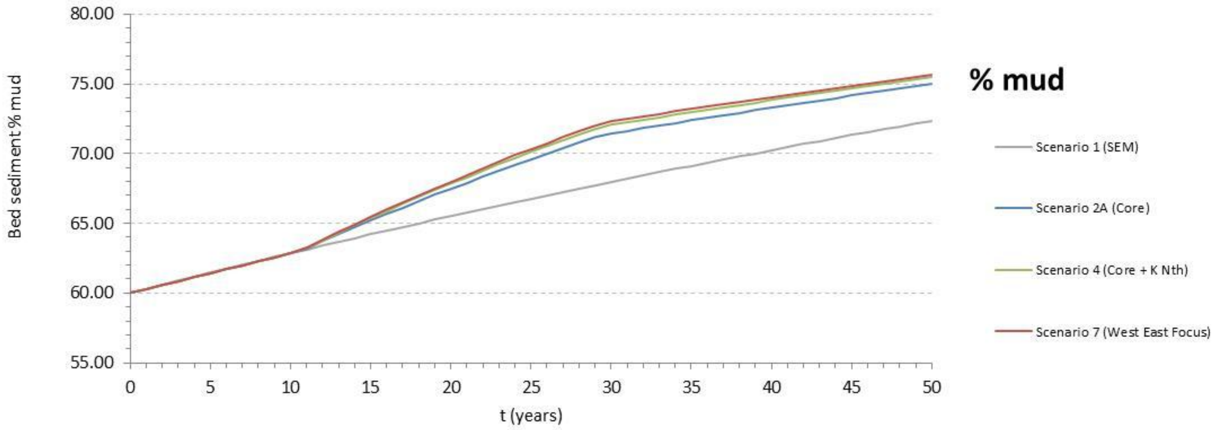
ERU 3 – Cape Horn (SEM subestuary 5-CHN)



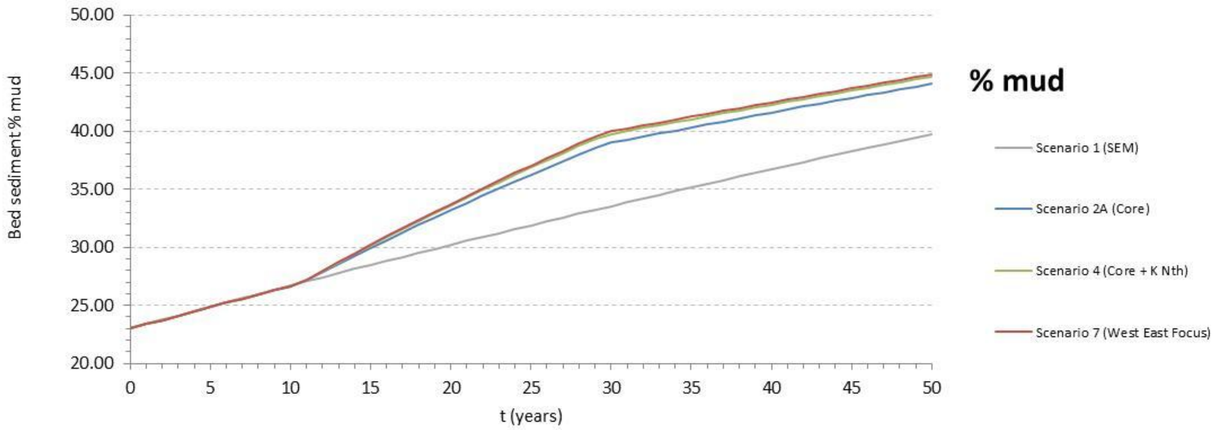
ERU 4 – Drury Creek Outer (SEM subestuary 6-DCO)



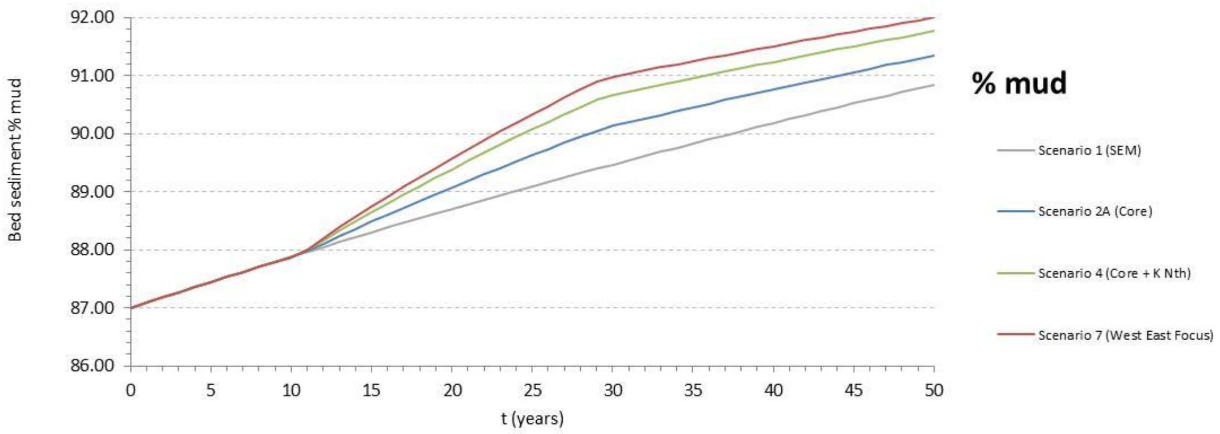
ERU 5 – Pahurehure Inner (SEM subestuary 7-PHI)



ERU 6 – Drury Creek Inner (SEM subestuary 16-DCI)

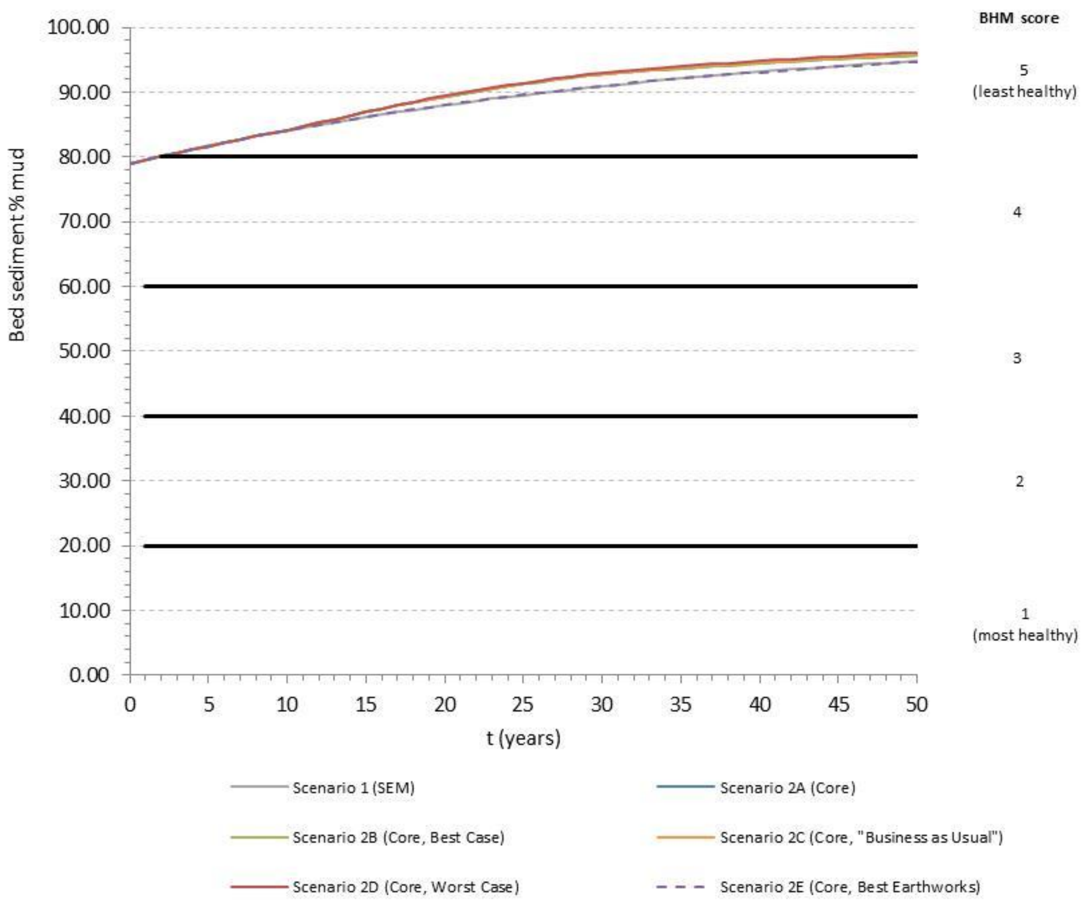


ERU 7 – Glasson Creek Inner (SEM subestuary 17-GCK)

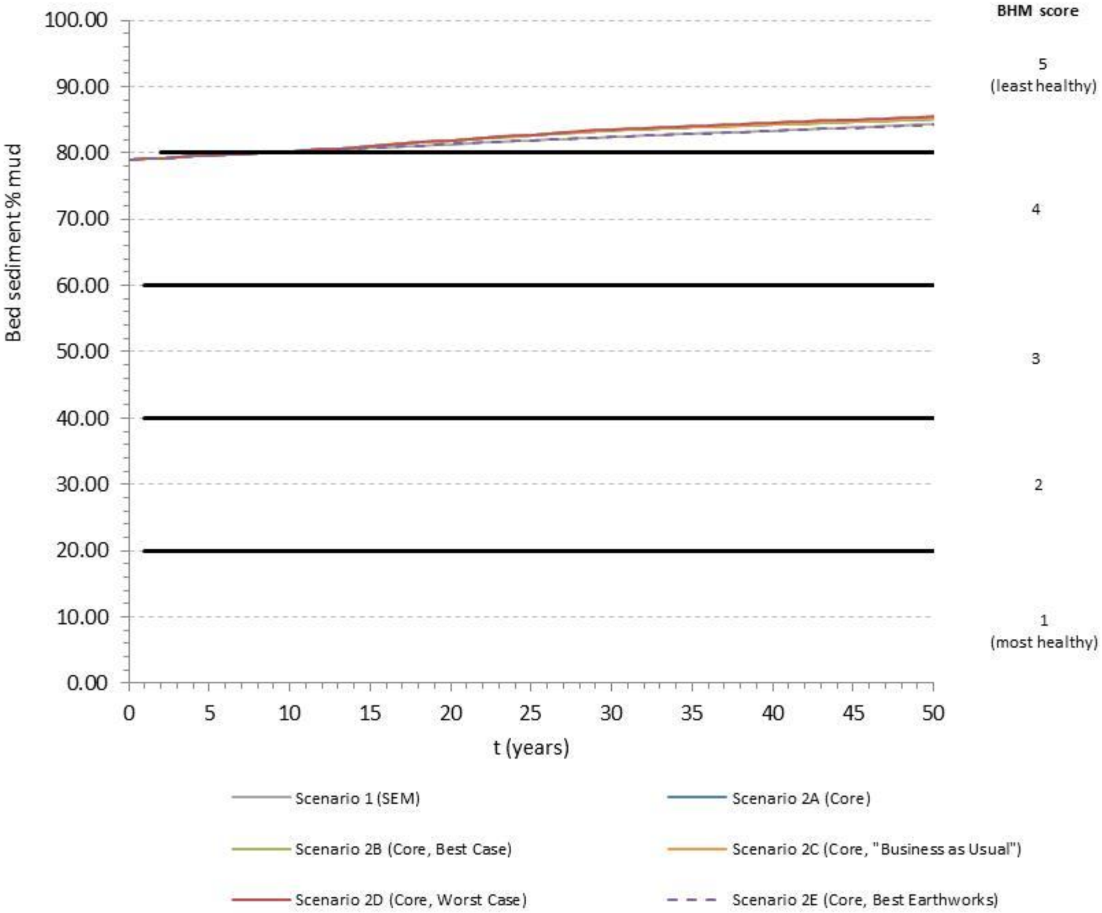


B.16 Predicted benthic health (mud) scores, Scenarios 2A to 2E (Core with varying stormwater treatment and earthworks controls) compared to Scenario 1 (SEM study)

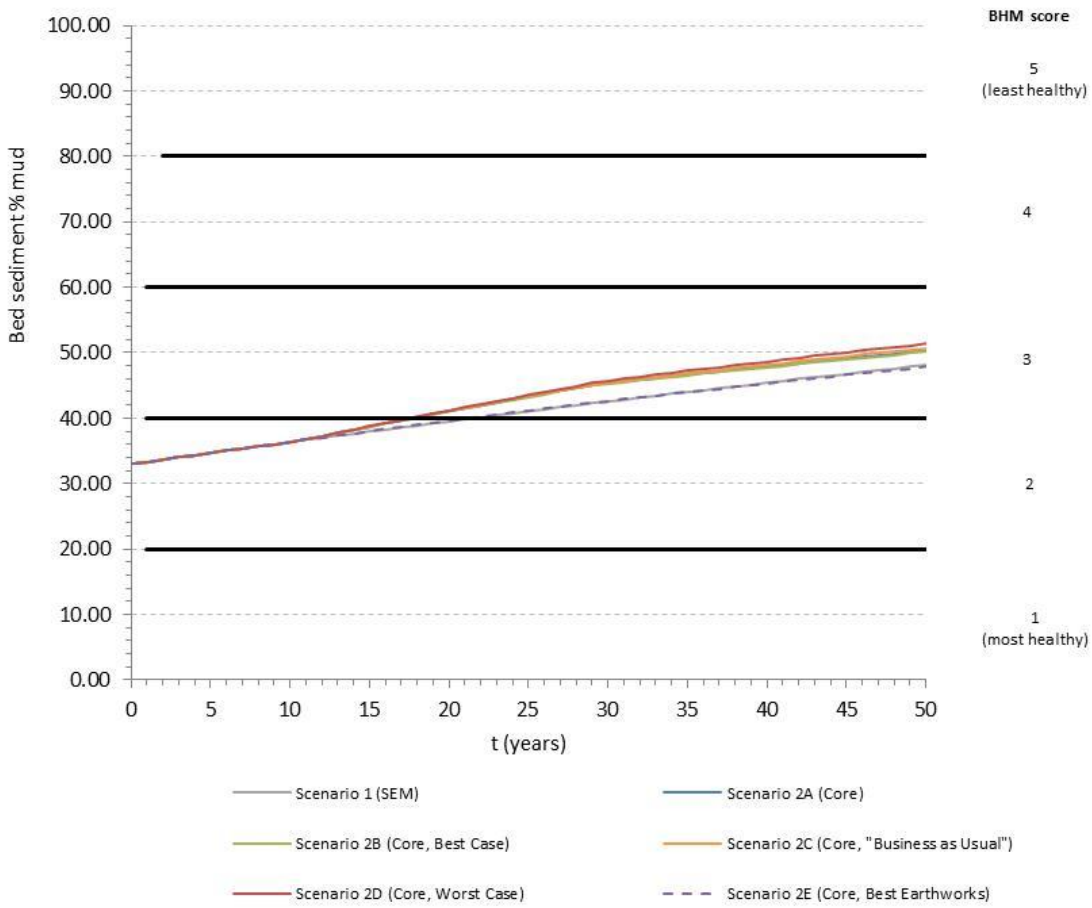
ERU 1 – Glassons Mouth West (SEM subestuary 3-GMW)



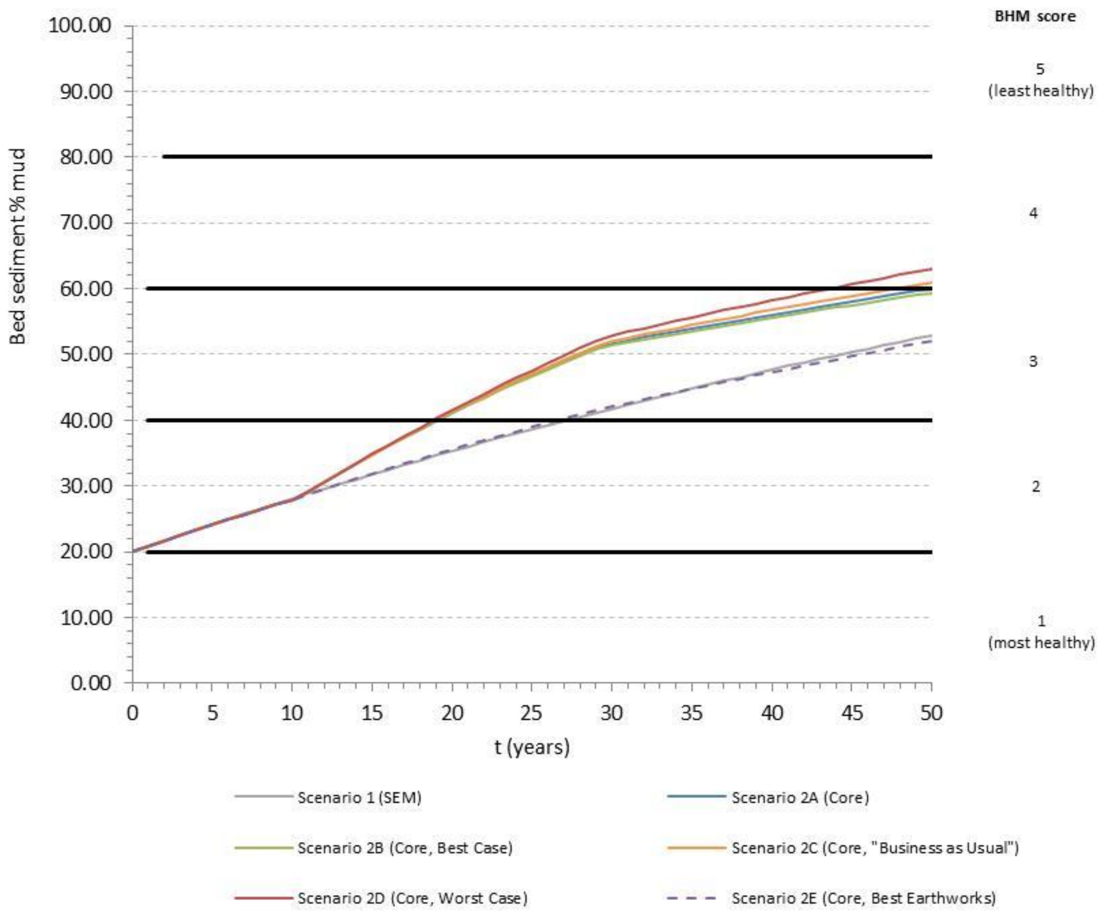
ERU 2 – Glassons Mouth East (SEM subestuary 4-GME)



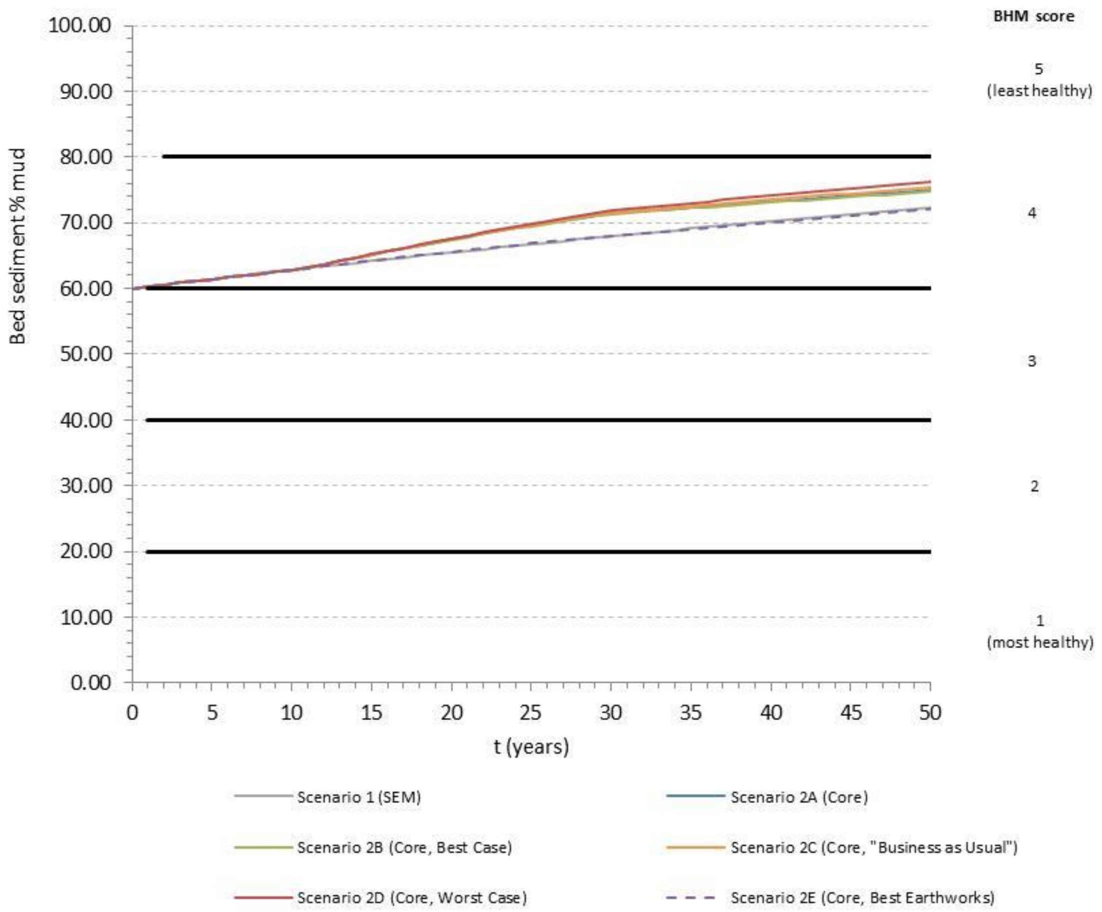
ERU 3 – Cape Horn (SEM subestuary 5-CHN)



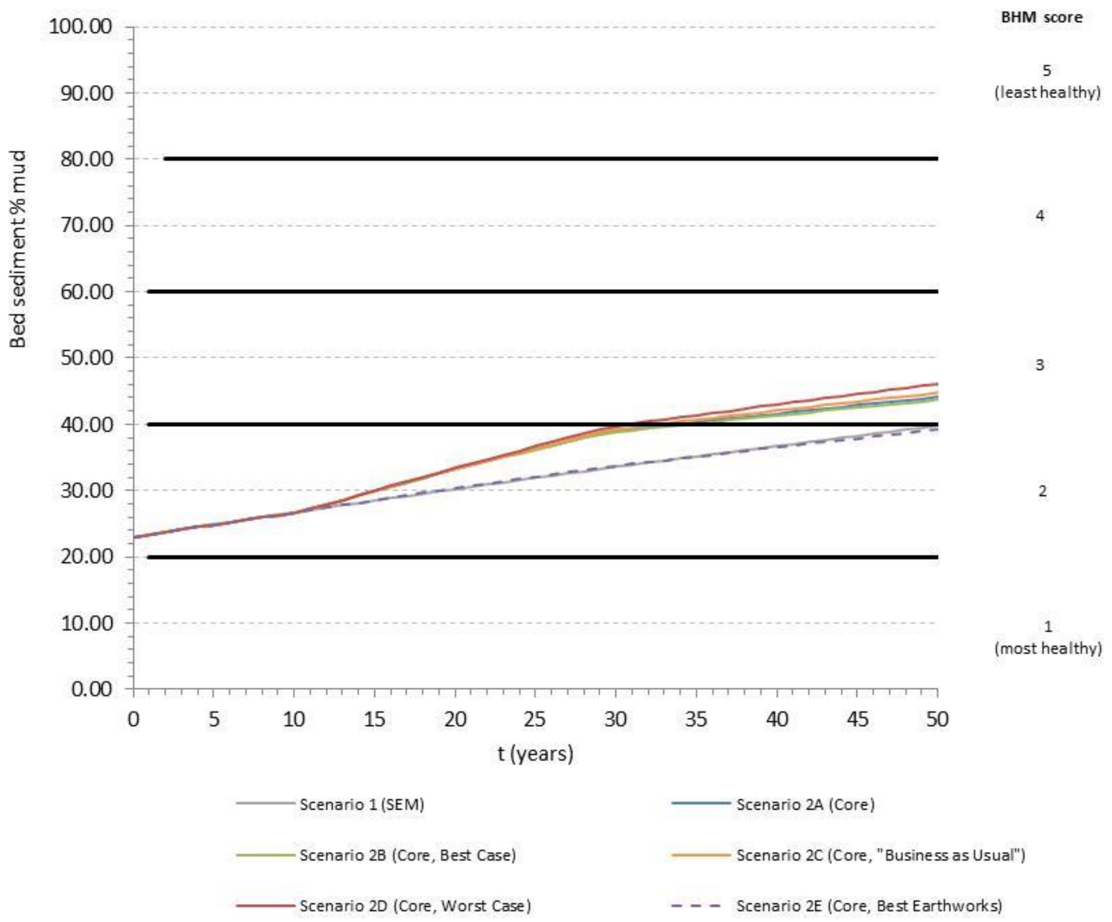
ERU 4 – Drury Creek Outer (SEM subestuary 6-DCO)



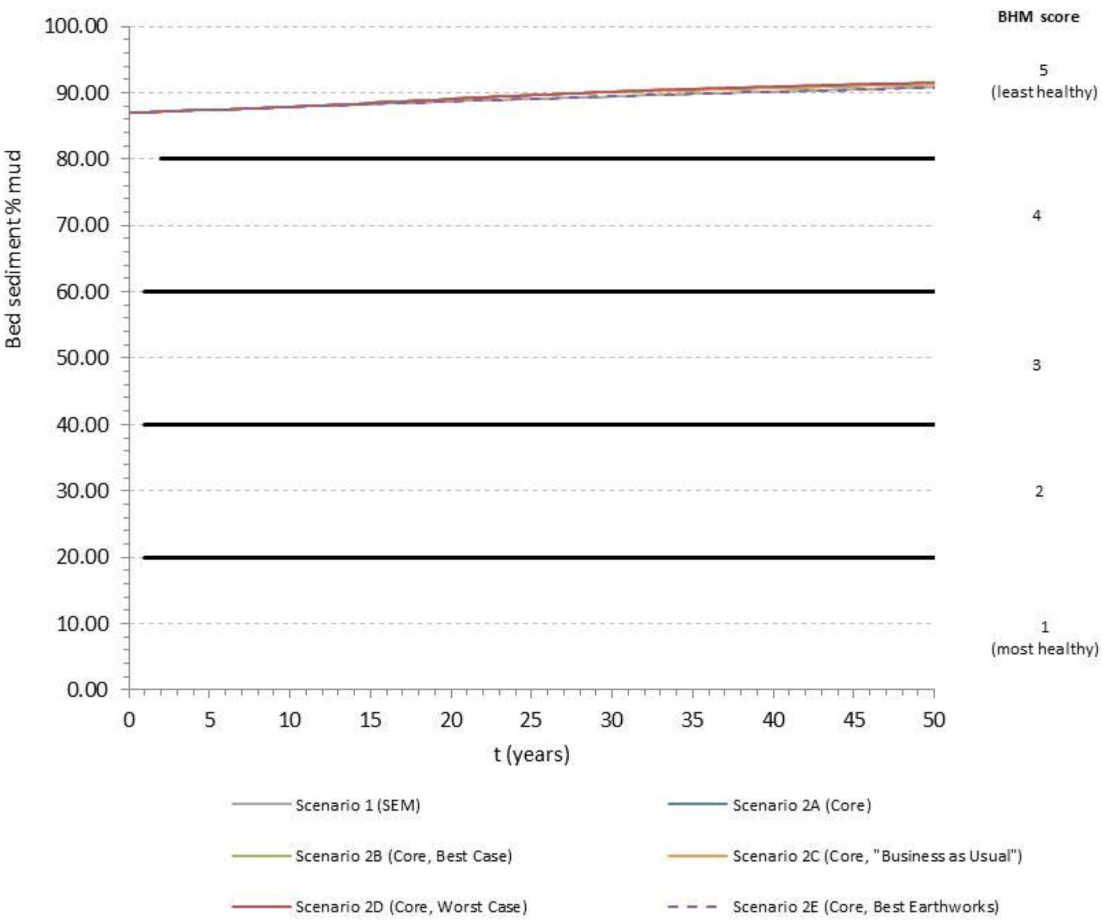
ERU 5 – Pahurehure Inner (SEM subestuary 7-PHI)



ERU 6 – Drury Creek Inner (SEM subestuary 16-DCI)

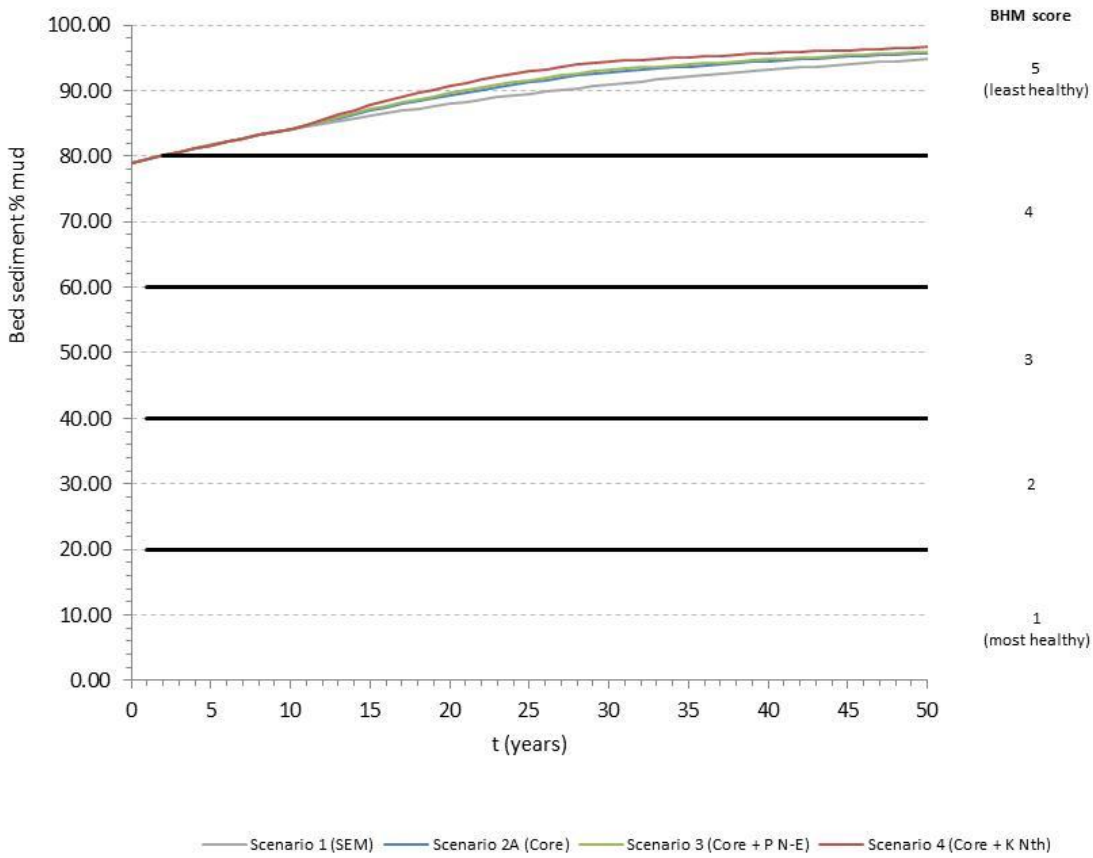


ERU 7 – Glasson Creek Inner (SEM subestuary 17-GCK)

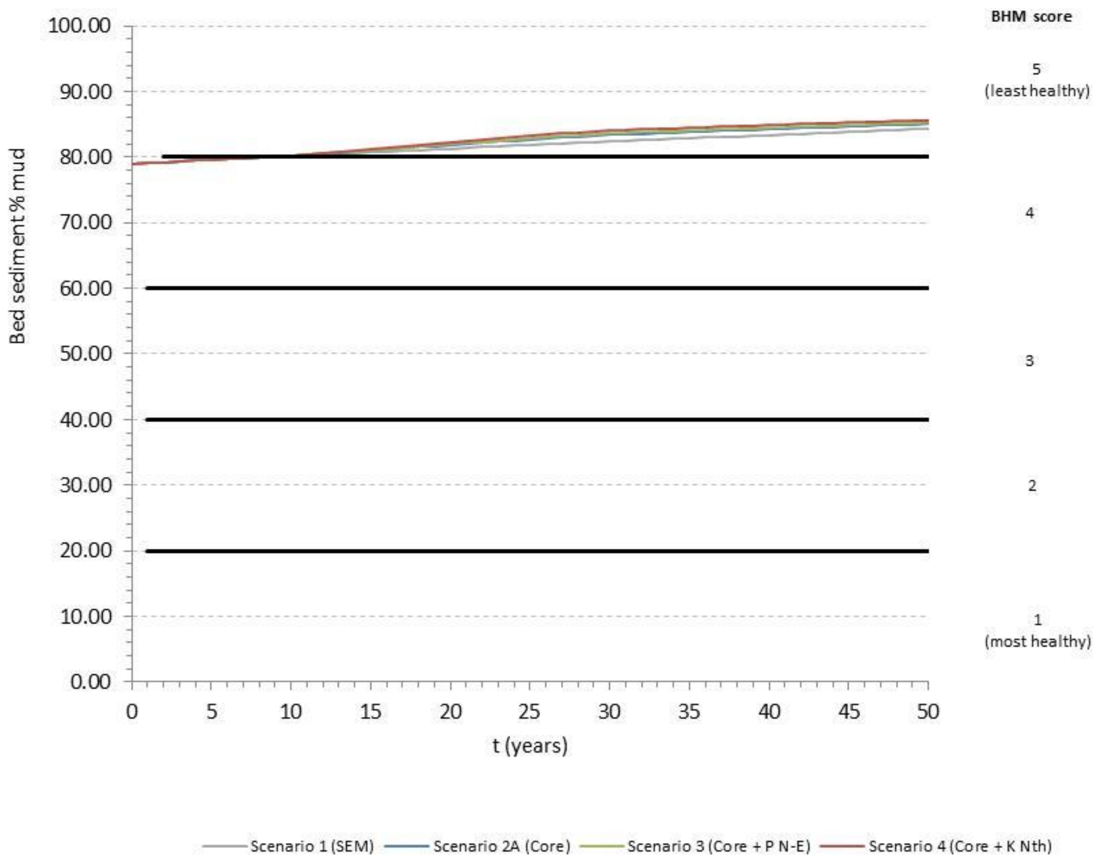


B.17 Predicted benthic health (mud) scores, Scenarios 2A, 3 and 4 (Core with additions) compared to Scenario 1 (SEM study)

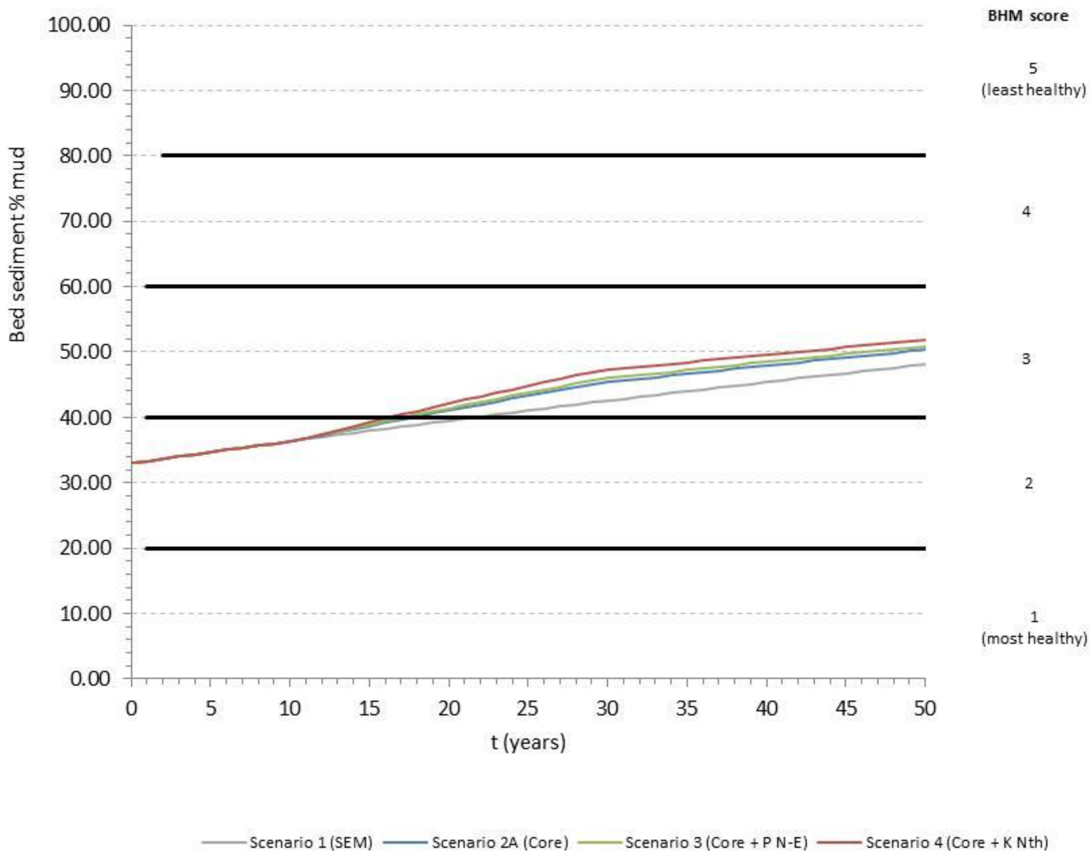
ERU 1 – Glassons Mouth West (SEM subestuary 3-GMW)



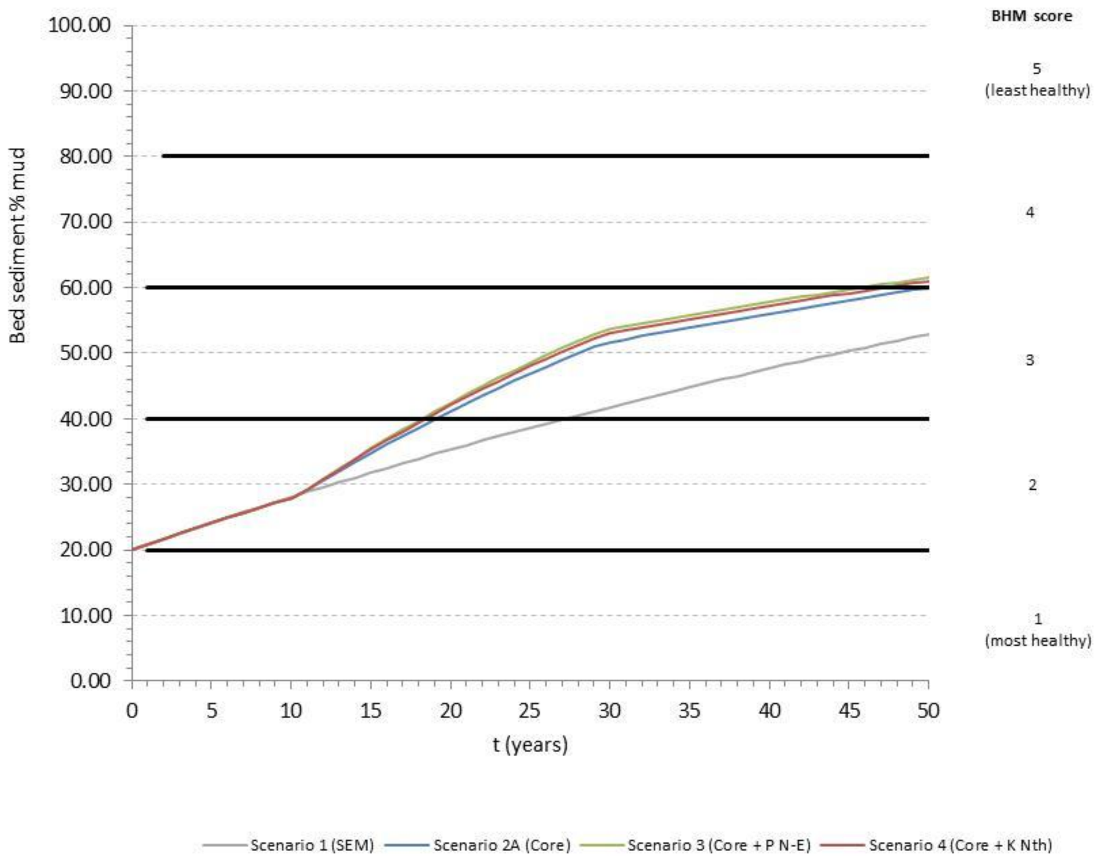
ERU 2 – Glassons Mouth East (SEM subestuary 4-GME)



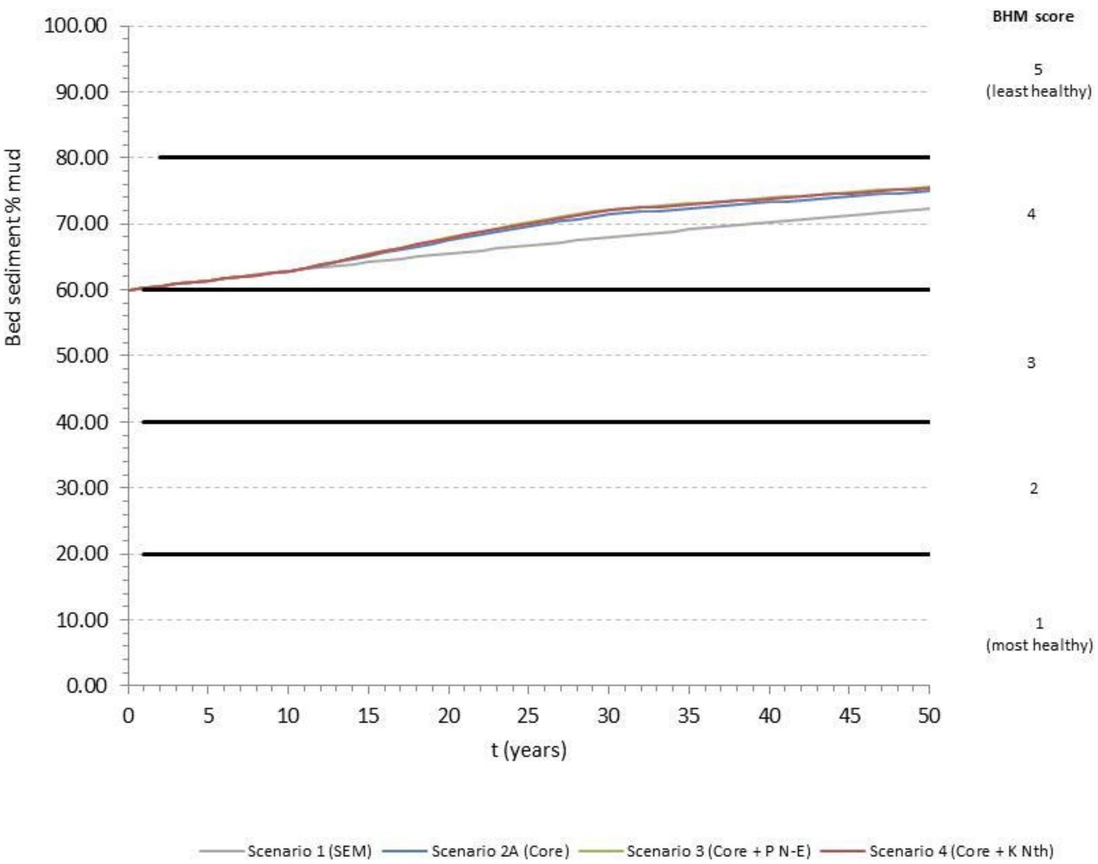
ERU 3 – Cape Horn (SEM subestuary 5-CHN)



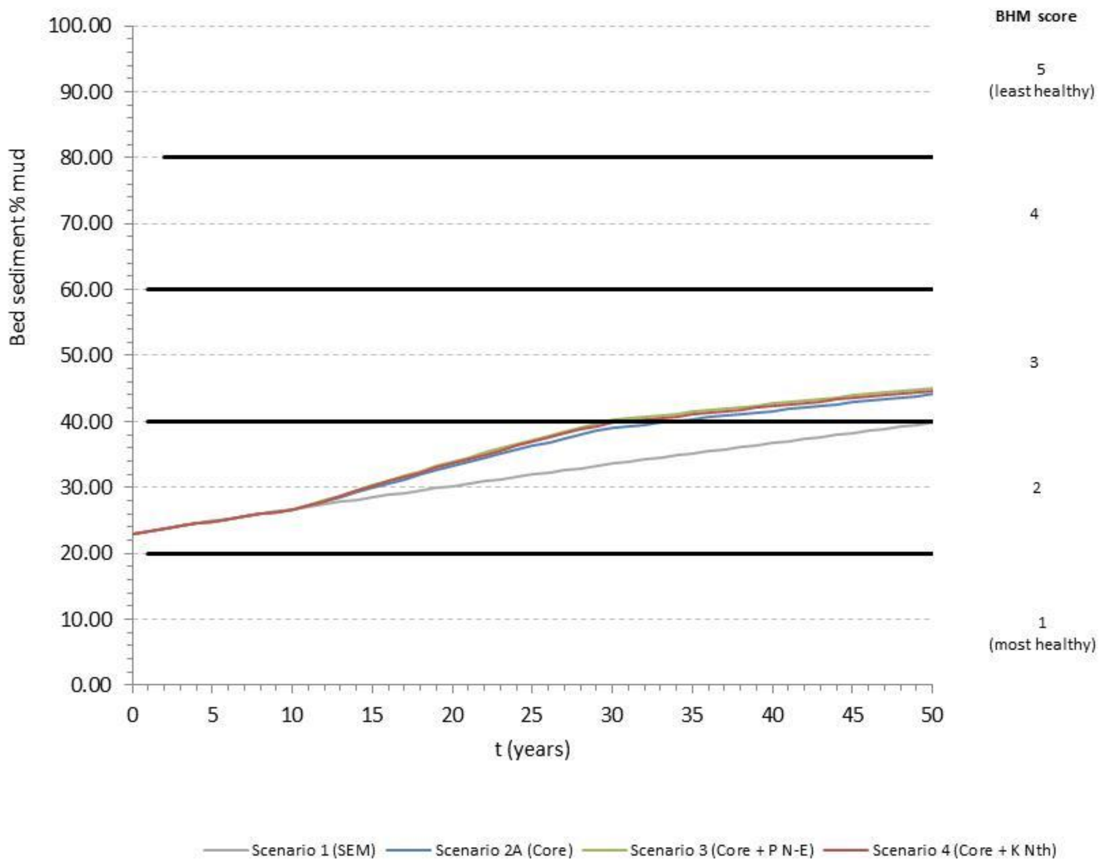
ERU 4 – Drury Creek Outer (SEM subestuary 6-DCO)



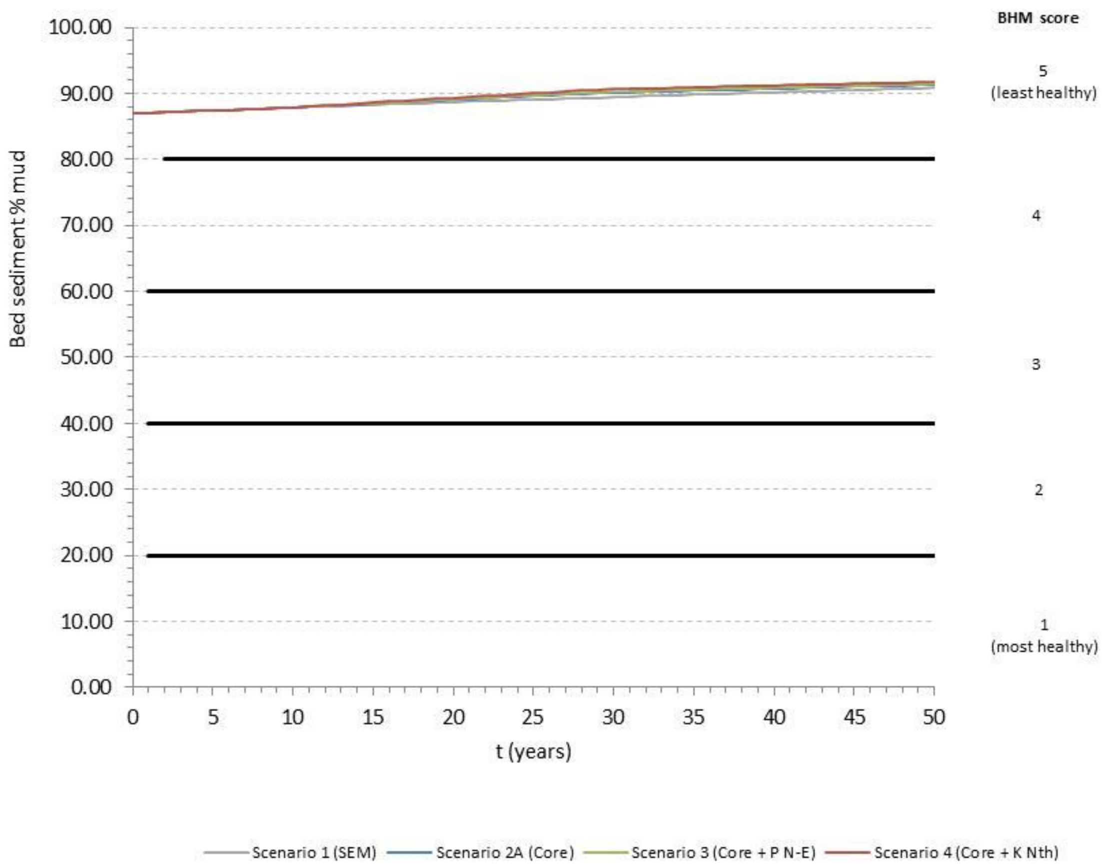
ERU 5 – Pahurehure Inner (SEM subestuary 7-PHI)



ERU 6 – Drury Creek Inner (SEM subestuary 16-DCI)

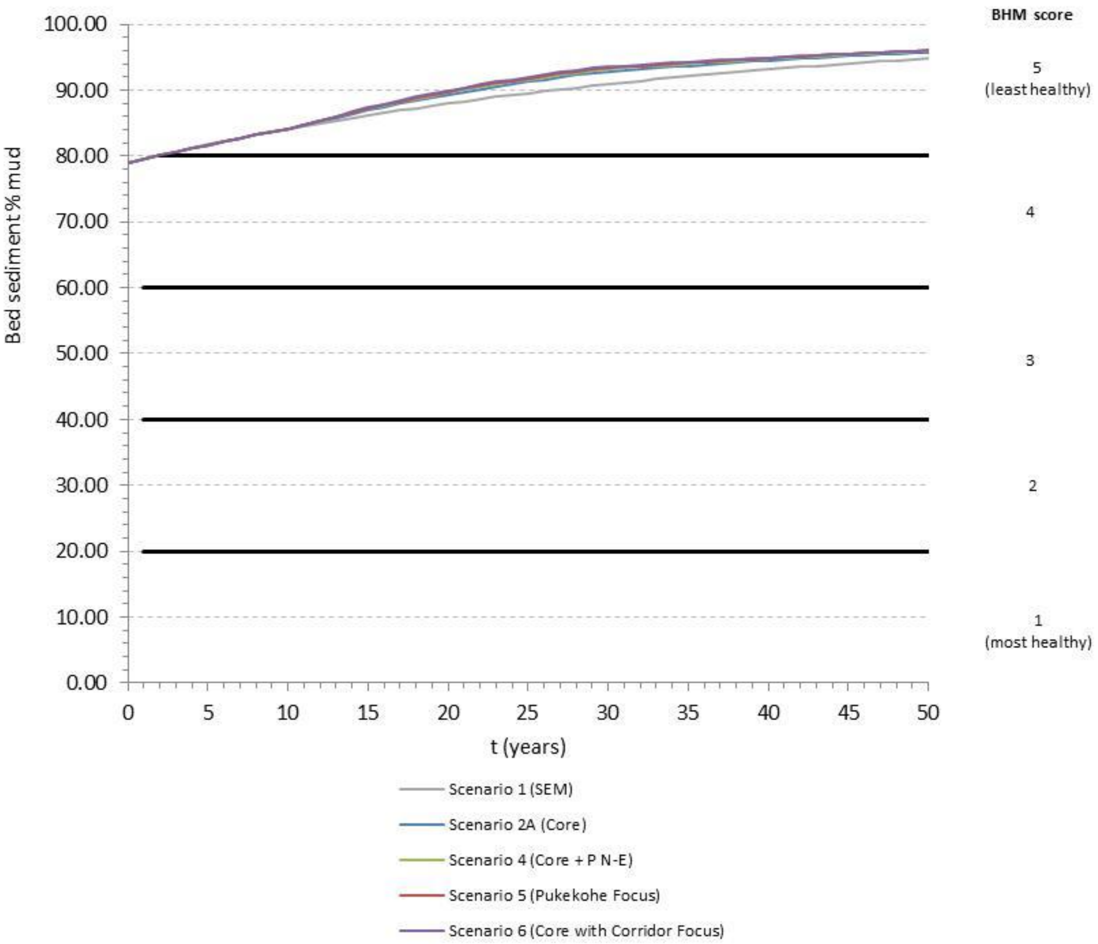


ERU 7 – Glasson Creek Inner (SEM subestuary 17-GCK)

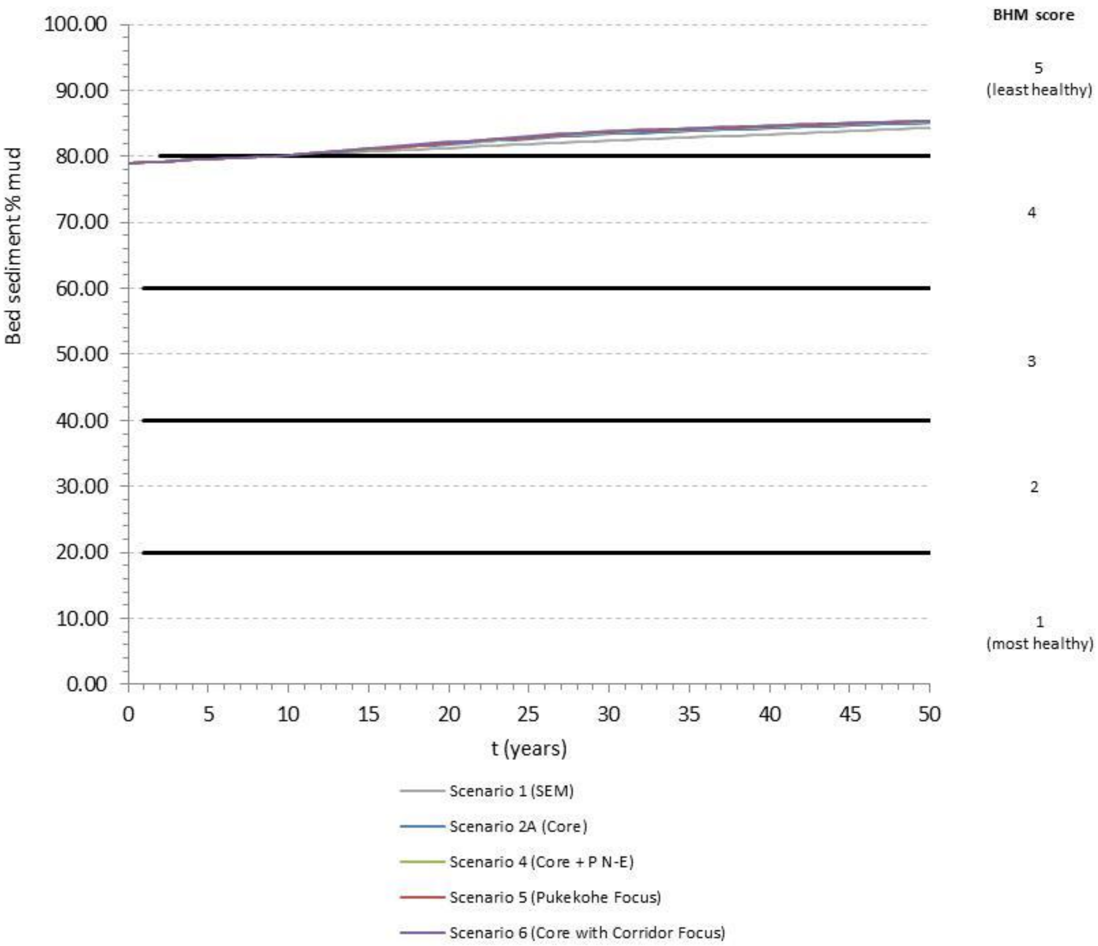


B.18 Predicted benthic health (mud) scores, Scenarios 2A, 3, 5 and 6 (Core with centre-south additions) compared to Scenario 1 (SEM study)

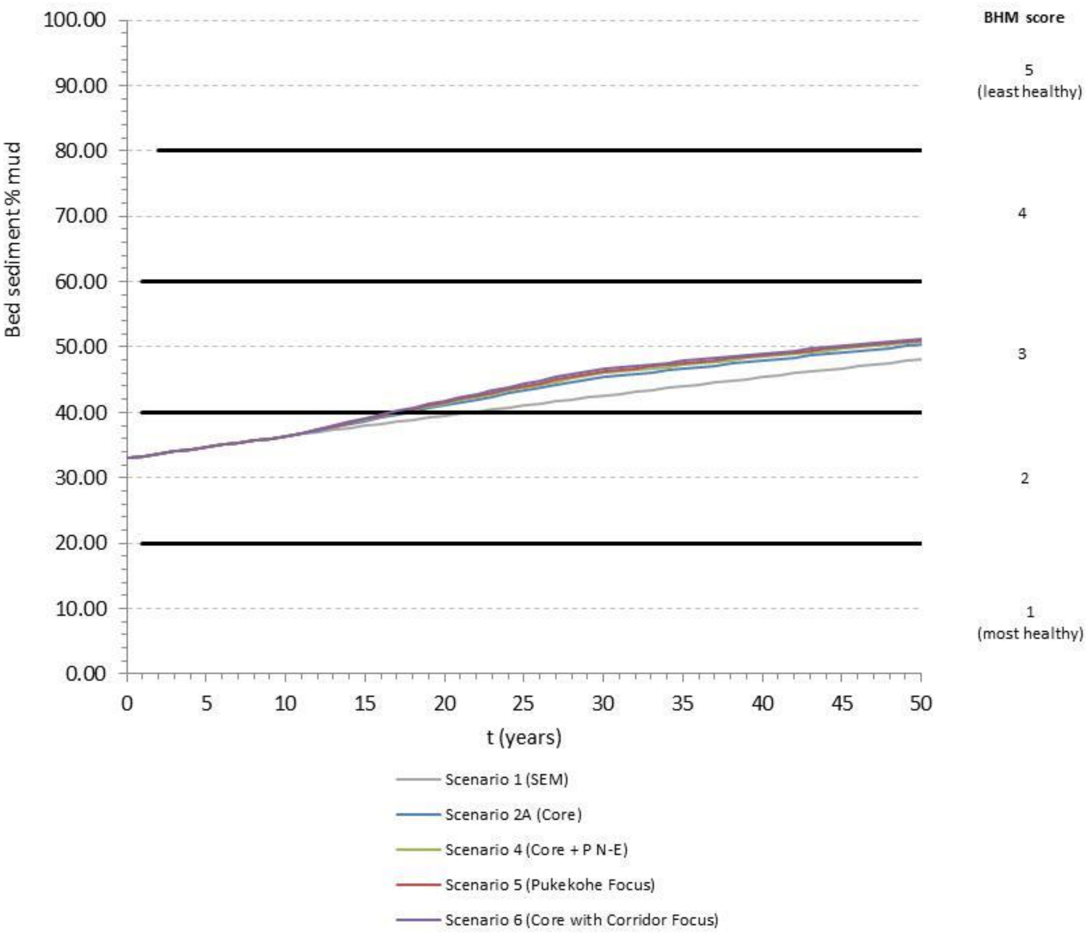
ERU 1 – Glassons Mouth West (SEM subestuary 3-GMW)



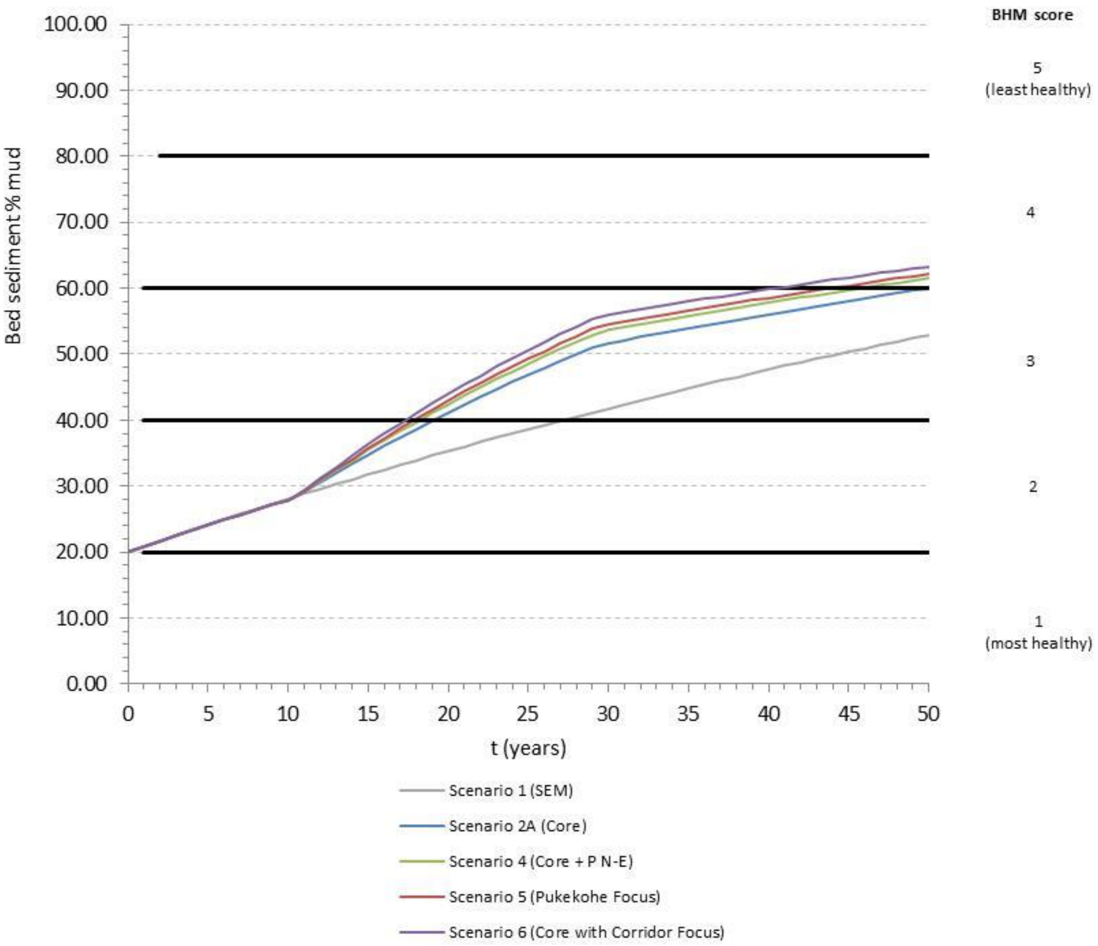
ERU 2 – Glassons Mouth East (SEM subestuary 4-GME)



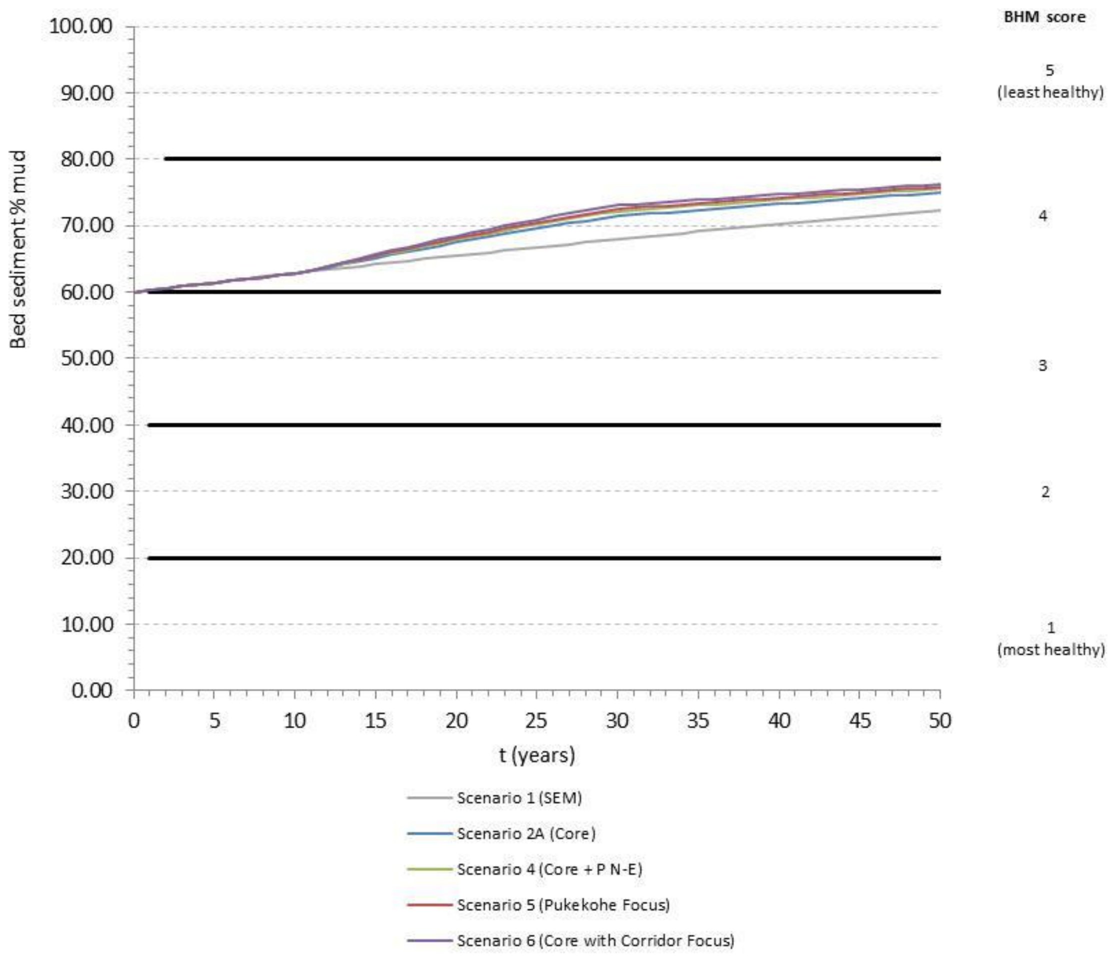
ERU 3 – Cape Horn (SEM subestuary 5-CHN)



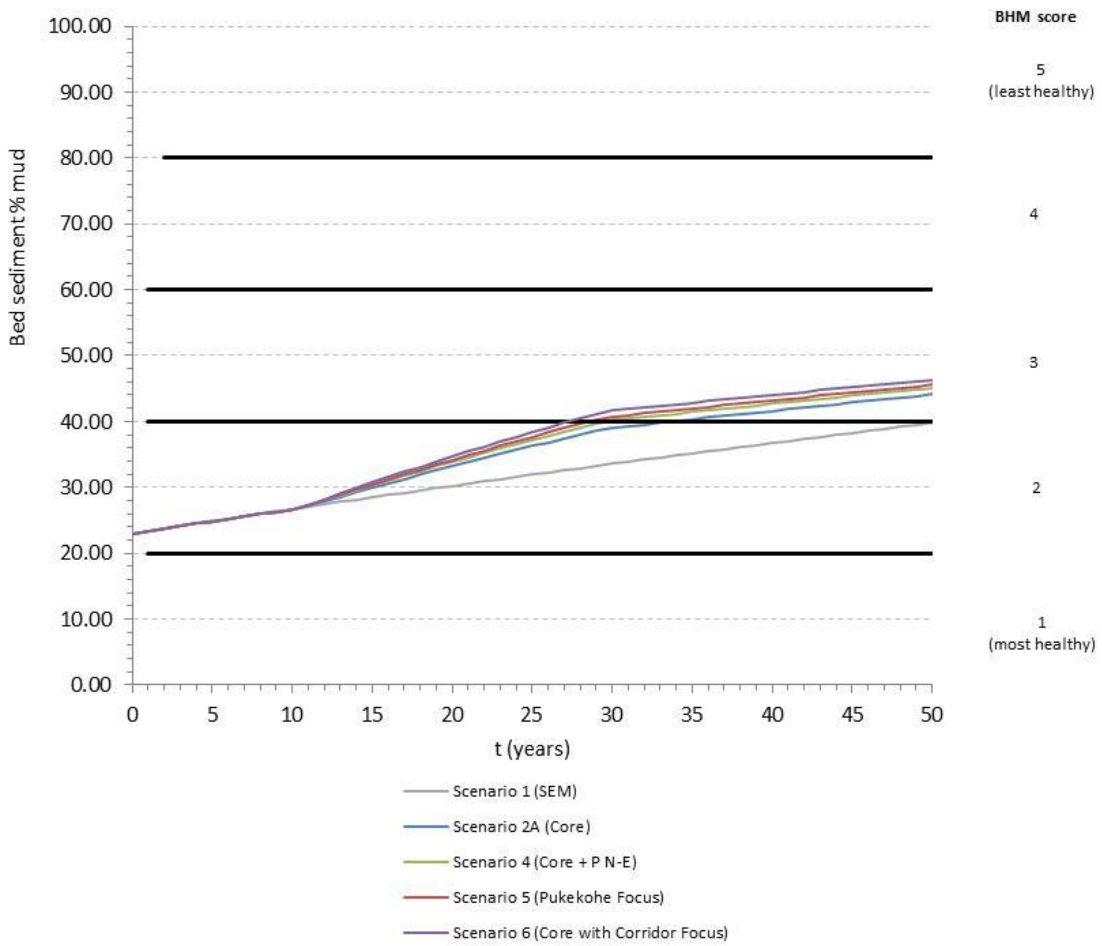
ERU 4 – Drury Creek Outer (SEM subestuary 6-DCO)



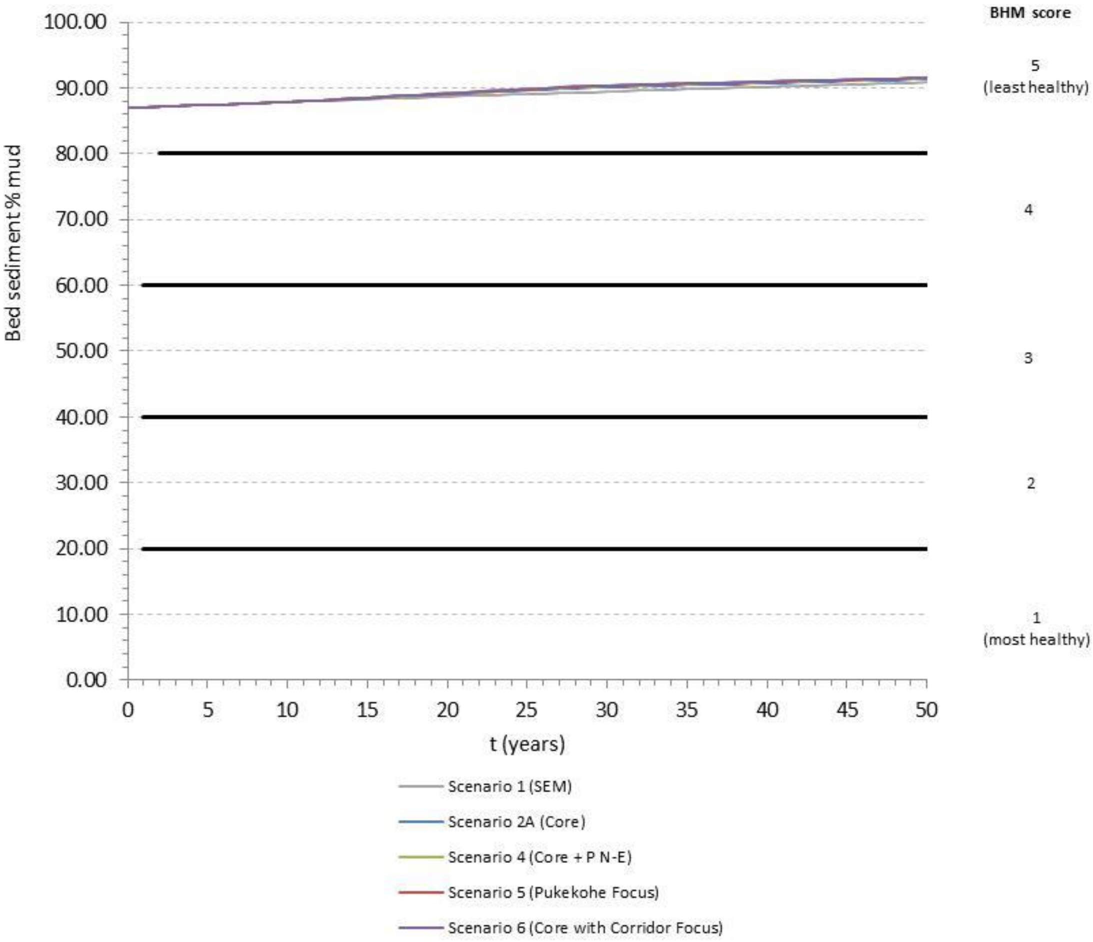
ERU 5 – Pahurehure Inner (SEM subestuary 7-PHI)



ERU 6 – Drury Creek Inner (SEM subestuary 16-DCI)

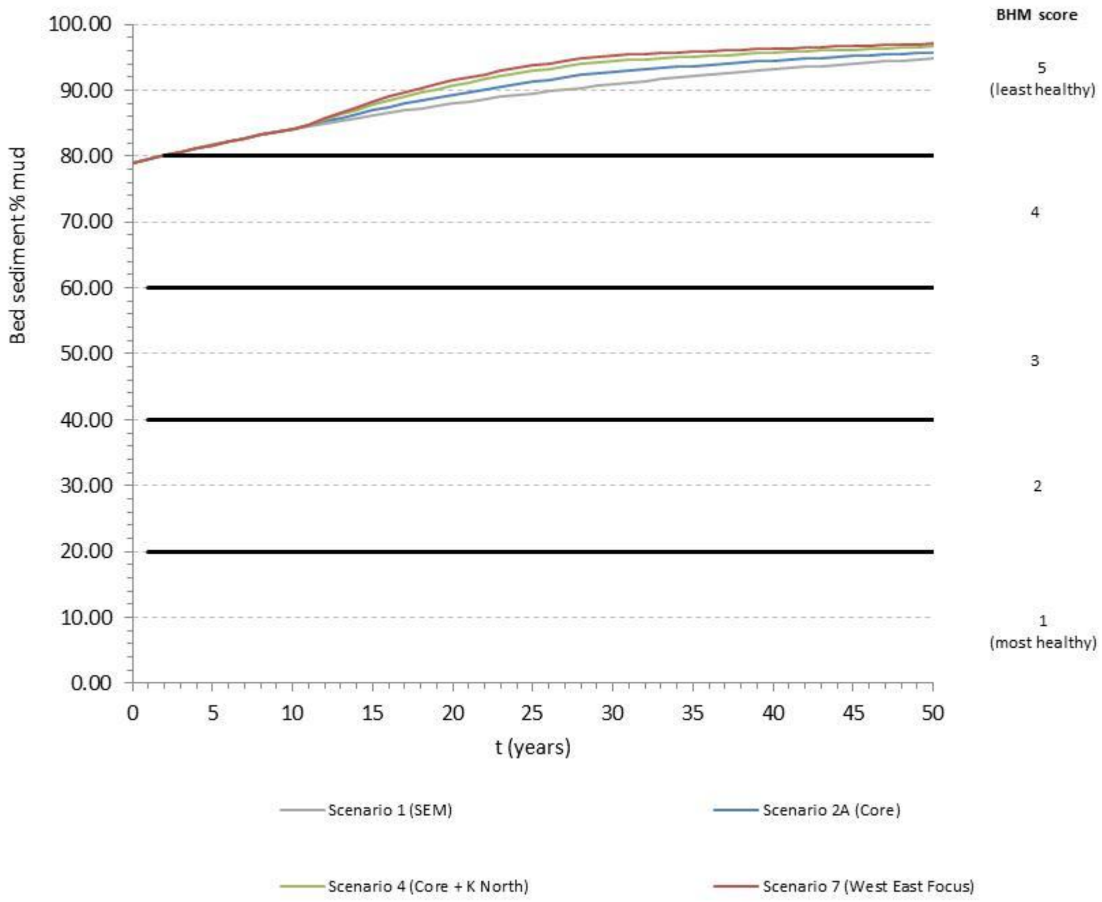


ERU 7 – Glasson Creek Inner (SEM subestuary 17-GCK)

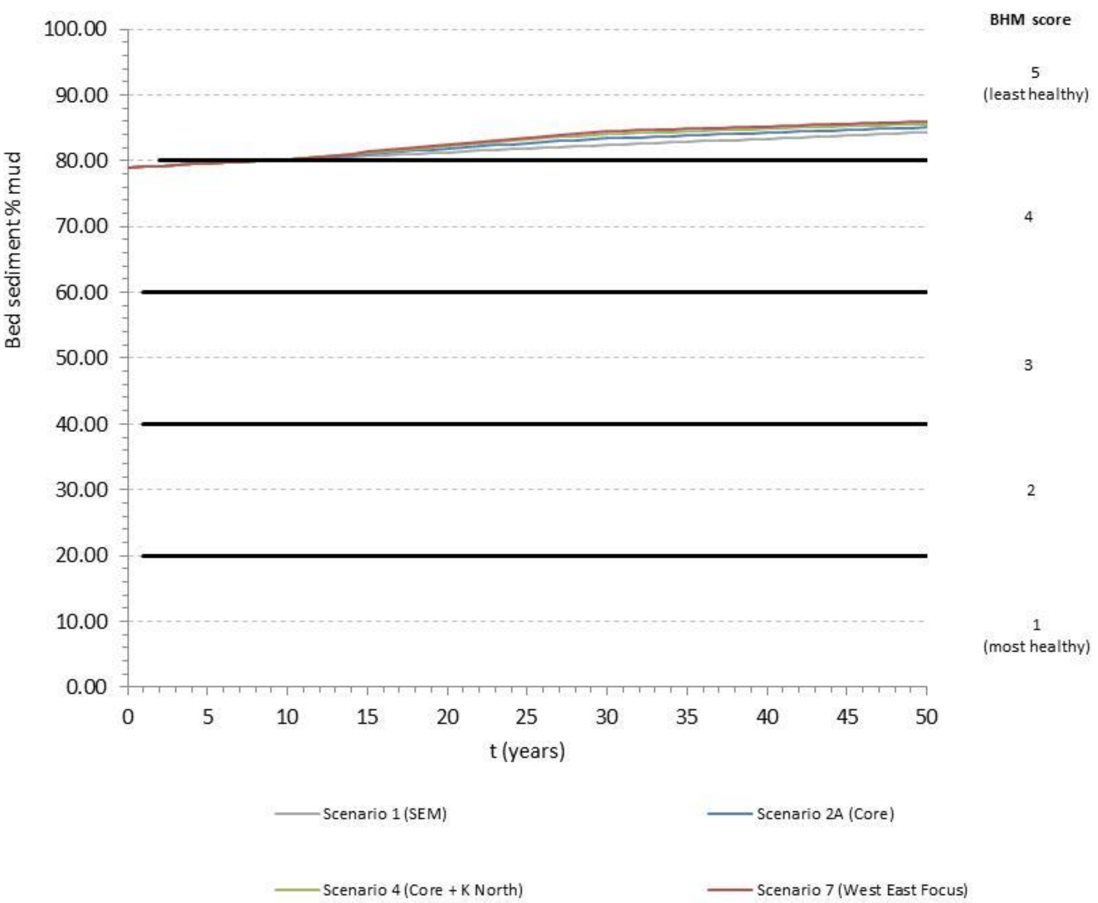


B.19 Predicted benthic health (mud) scores, Scenarios 2A, 4 and 7 (Core with northern additions) compared to Scenario 1 (SEM study)

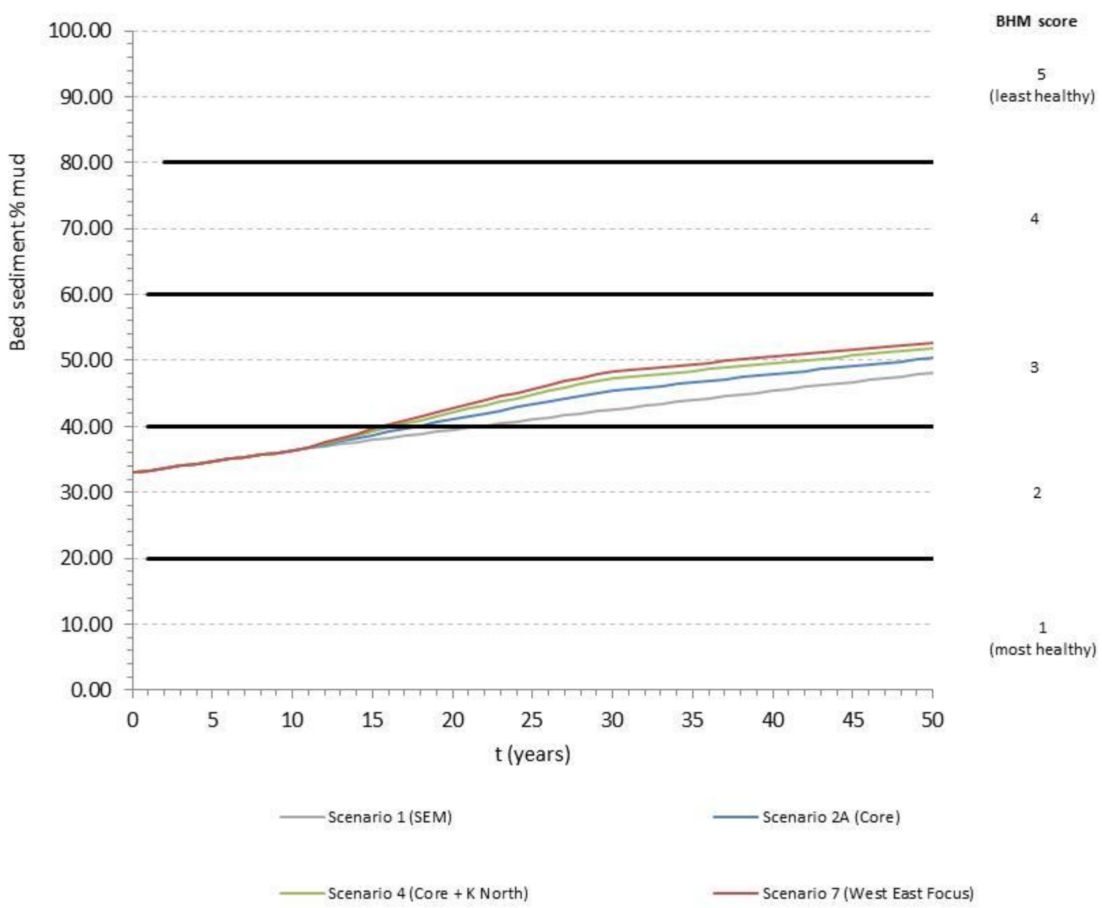
ERU 1 – Glassons Mouth West (SEM subestuary 3-GMW)



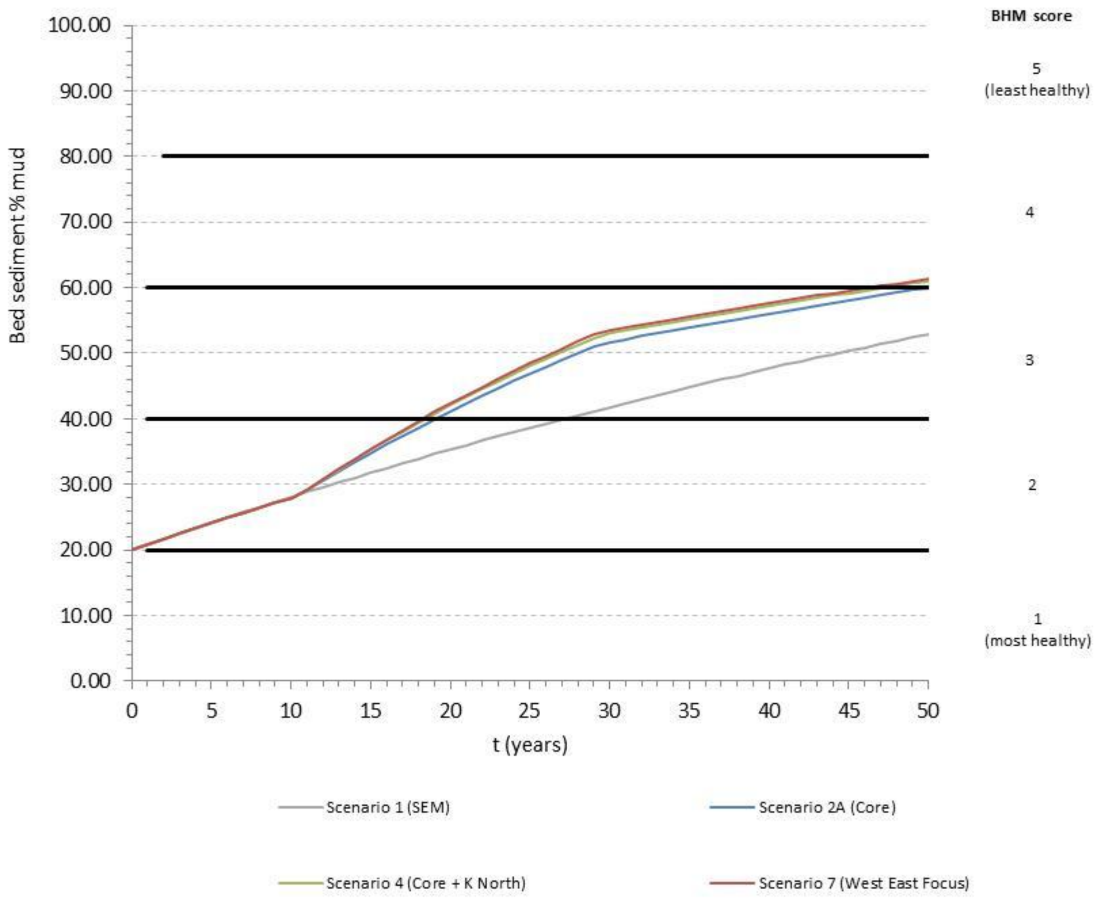
ERU 2 – Glassons Mouth East (SEM subestuary 4-GME)



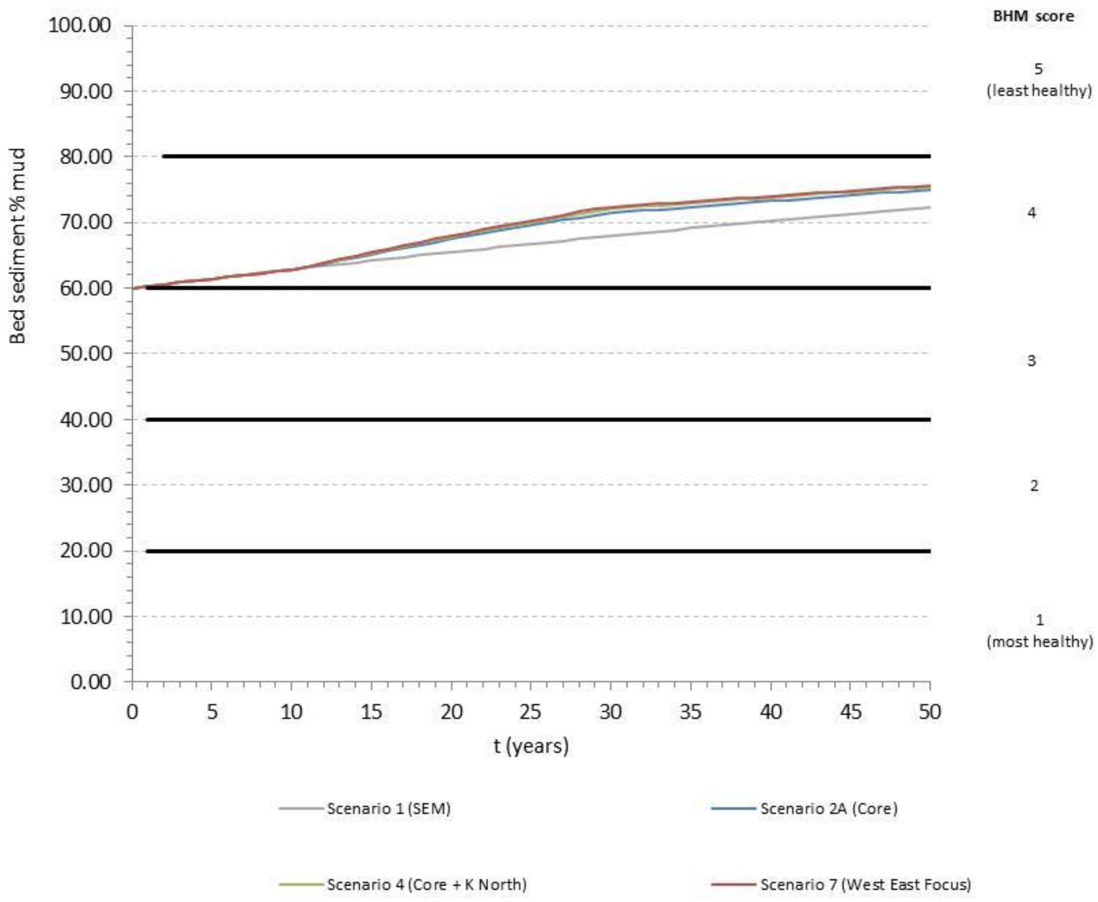
ERU 3 – Cape Horn (SEM subestuary 5-CHN)



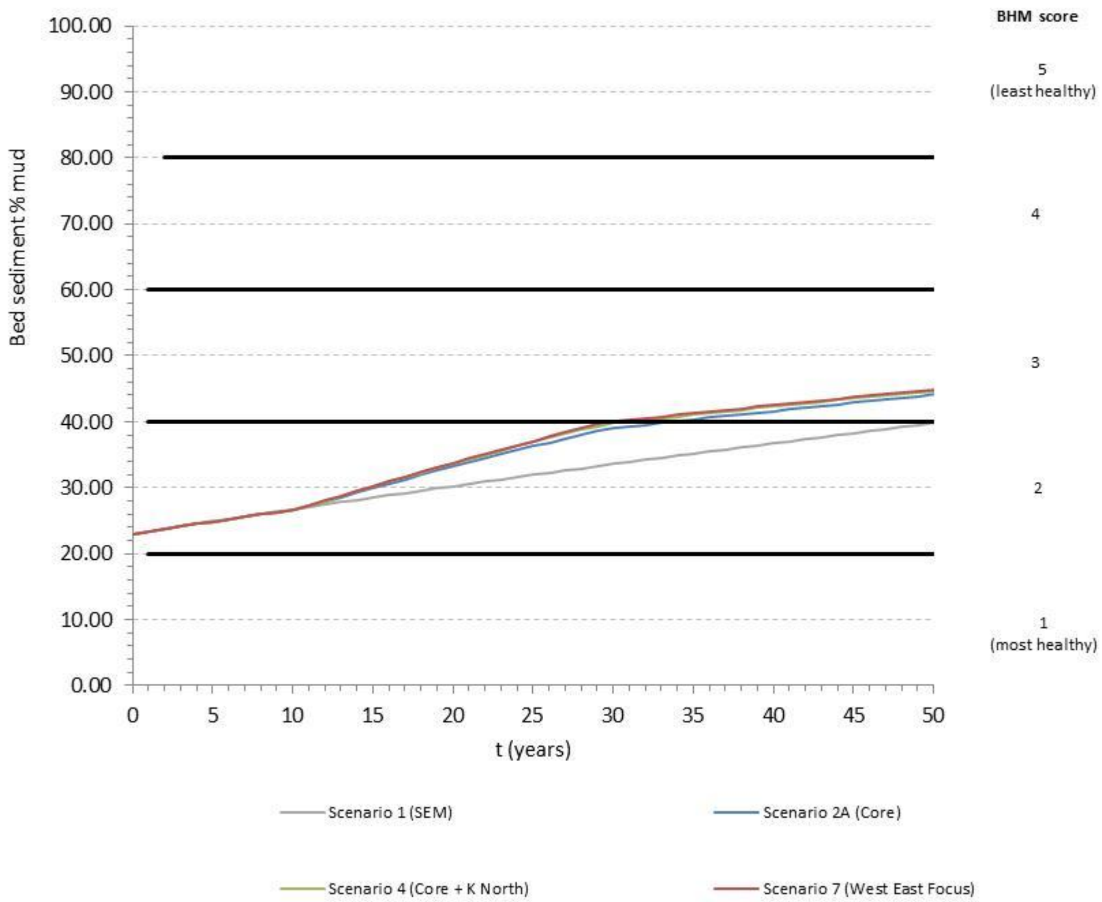
ERU 4 – Drury Creek Outer (SEM subestuary 6-DCO)



ERU 5 – Pahurehure Inner (SEM subestuary 7-PHI)



ERU 6 – Drury Creek Inner (SEM subestuary 16-DCI)



ERU 7 – Glasson Creek Inner (SEM subestuary 17-GCK)