SUSTAINABLE SEAS

Ko ngā moana whakauka

National SCIENCE Challenges

A. TITLE OF PROJECT

4.2.2 Stressor footprints and dynamics

B. IDENTIFICATION

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C. ABSTRACT

Effective Ecosystem-based Management (EBM) hinges on knowing how contaminants, such as land-derived sediments and those generated by marine activities such as dredging and aquaculture mix and spread through coastal waters. Understanding how contaminants disperse from their source is crucial to predicting how they interact with activities further afield and the resulting cumulative impact on coastal habitats. The aim of this project is to define 'footprints' of stressors in the Focal Area to resolve near and far-field effects of marine activities. The project examines three connected scales: the source or near-field mechanics of contaminant dispersal, the subsequent transport to other areas (the 'far-field context), and regional effects of large-scale biophysical stressors (e.g. climate change). New technologies (e.g., ocean gliders) will provide novel observation platforms of stressor dispersal and the hydrodynamics that drive it. Integrated with new biophysical models of the Focal Area, this project will deliver the fundamental physical framework that connects the footprints of marine activities across space and time in a changing world. The project is tightly integrated with other projects in *Dynamic Seas* and outputs such as visualisation models will help stakeholders understand how contaminants spread and interact across marine habitats. This project will feed directly into *Managed Seas*, fostering a greater understanding of physical transport and connectivity to determine the viable extent of marine economic activity in the Challenge Focal Area.

D. INTRODUCTION

Figure 1 Spatial variability extends beyond simply-defined geographic zones as this NASA image (MODIS, April 29, 2011) of sediment-laden surface waters in the case study region demonstrates.

Expansion of marine activities and realising their economic potential while sustaining the natural environment is predicated on understanding how near-field impacts of activities propagate into far-field effects [24]. This project is aimed at developing that understanding. In essence it looks at how stressors generated at one location dilute and evolve in space and time in response to biophysical transformations. This is complicated because of the range of spatial and temporal scales involved in regulating mixing and transport in coastal, shelf and deep sea systems [1]. This project will develop understanding of the relevant processes and scales affecting stressor dispersal, which will enable footprints of activities to be identified and quantified. This is necessary if reliable descriptions of cumulative and displaced footprints are to be predicted. It will seek to answer the question "*what is the spatial footprint of a particular activity in relation to responses over specified time scales*? There are three interconnected elements to the Project spanning small to large scales: (i) near-field footprints (i.e., the activity scale or initial dispersal of stressor), (ii) physical transport connectivity (how a stressor is transported to other places) and (iii) finally the far-field biophysical context (i.e., movement of stressors within and across the wider Focal Area).

One of the challenges of the work is the varied nature of marine activities and resulting disturbances in the focal region. The framework will need to provide, for example, understanding around river plumes and their sediment/contaminant loads and fate, aquaculture impacts from flow disturbance through to the dispersal of nutrients and waste, and plume dispersal resulting from seabed mining [18], the concomitant in-water light attenuation and associated effects on primary production. Crucially, this framework must provide understanding at an overarching Exclusive Economic Zone scale that will inform stakeholders and managers how a wide variety of activities would integrate into the NZ's oceanographic setting.

The project will conduct near-field footprint ground-truth and modelling, physical connectivity ground-truth and modelling and regional setting modelling. Footprint determination requires a multi-scale approach. Disturbance-generating activities (e.g., mining plume dispersion) need to be placed into a mid-field (e.g., embayment scale) and regional (Focal Area) transport and dilution context (Fig. 1). This requires understanding the initial (i.e. at source) characteristics of dispersal and transformations that will govern larger-scale transport. Physical connectivity is readily understood and modelled but challenges remain around sub-model grid scale processes (i.e., the models do not actually capture key elements of the dispersive nature of the focal region). Regional setting modelling is required to support a larger-scale understanding of transport and connectivity, as boundary conditions in any area are dominant controls of predictive modelling tools. This regional scale modelling is a vector for connecting immediate-scale stressors with longer-term controls like climate variability. This helps determine the answers to large-scale questions like "when is coastal primary production driven by oceanic or riverine inputs?"; "is coastal production upwelling or light-controlled?; and how will this be altered under climate change scenarios?"

The project will have direct linkages with Projects 4.1.1 (Tracking *Biochemical Fluxes*) through providing the physical framework to interpret biogeochemical alterations of material and contaminants as they course through food webs; with 4.2.1 (*Tipping Points*) through experimental ground-truthing of effects (see below); with Programmes 2 (*Valuable Seas*) through contextual understanding of stressor impacts on ecosystem services; with 5 (*Managed Seas*) through input into ecosystem models; with Programmes 1 and 3 (*Our Seas* and *Tangaroa*) through integration into Stakeholder workshops and contributing to building capacity and capability. This Project enables an integrative understanding of key transport processes underpinning EBM and the evolution of social licence. It will also have detailed and significant interactions with aligned funding projects, thereby maximising the production of significant *Challenge* outputs.

E. AIM OF THE RESEARCH AND RELEVANCE TO OBJECTIVE

Quantifying how the intensity of multiple stressors varies across space and time, and how these scales and quantities are connected, is crucial to predicting the impacts of new and on-going activities on marine ecosystems. This project will develop (i) tools to quantify the crucial initial dilution (in a general sense the near-field disturbance) of activities, (ii) understanding how this effect is redistributed (transport connectivity) and (iii) how this may generate into far-field effects through large scale drivers of change. In the initial period of 3.5 years the work has a cohesive set of four activities that combine historical data and new observations with the development of enhanced modelling tools supported by aligned funding programmes (especially around the far-field). The project will develop a deeper understanding of the multi-scale nature of physical connectivity underpinning EBM through generating modelling tools that directly address footprints of resource uses including economic activities, flows of land-sourced contaminants, and the relevant domains of effects.

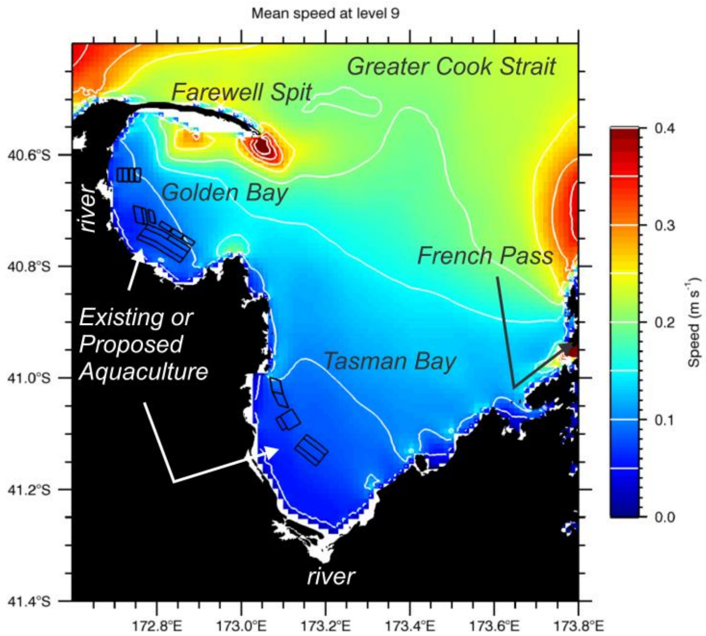

Figure 2 Initial (case) study area within the Focal Region overlaid on tidal speeds[29].

F. PROPOSED RESEARCH

This project will develop tools to enable activity footprints to be identified and quantified. Through oceanographic biophysical process understanding, it will determine the biophysical processes that lead to cumulative and displaced footprints in the focal region. There are four components to this project:

(1) Present Understanding – a salient point around the science of the *Challenge* is bringing together a wide range of activities relevant to marine resource usage. The first step will be to gather and make accessible the various relevant threads that includes a summary of existing oceanographic data (e.g., from buoys deployed in other programmes such as those of the Cawthron Institute) as well as concurrent programmes in aligned funding. There is substantial previous and on-going work on impacts in NZ's shelf seas. The Firth of Thames -Hauraki Gulf region [28] as well as the Marlborough Sounds, Kaikoura[4] and the Chatham Rise have all been the focus of multi-faceted research[28] that addresses various aspects relevant to Challenge goals. Further to this, Tasman and Golden Bays in particular have been examined from several distinct viewpoints relating to resource utilisation[6,7,13,16,18,25]. It is crucial, therefore, that this project leverages these studies to enable the highest launch-point for progress.

(2) Footprint determination – This requires a multi-scale approach. We will focus on localised disturbances (e.g., river/mining/trawl/aquaculture plume dispersion and sedimentation, Figure 2) but local disturbances need to be placed into mid-field (e.g., embayment scale) and regional (Challenge focal region) contexts [6]. Each of these spatial scales has accompanying time scales [7,17,23,27,9] This component will involve understanding the **activity-scale transformations** in terms of dilution and energy and then **develop models** around how these spread. This study will integrate with other projects in *Dynamic Seas* as it seeks to cover as many stressors as possible from the fate of riverine sediment plumes [13,7] through to deep sea disturbances of the sea bed. Sediments, nutrients and contaminants are the focus of Projects 4.2.1 and 4.1.1 in terms of ecological impacts and the capacity to drive change; this project focusses on their physical transformations and dispersal. We will develop a generic approach to measuring plumes and disturbances based on quantifying vertical diffusivities as a function of flow and stratification. Instrumentation for turbulence profiling in conjunction with those that measure suspended sediment concentrations and background flows will be deployed in field experiments ("PlumeEx" Fig. 3). Data from these experiments and associated numerical modelling (at a workable minimum spatial resolution) will produce outputs O1.1 and O1.2 (see below).

Geographic locations will be within the focal area and will be selected in conjunction with other projects in *Dynamic Seas*. Examples to be considered over the initial 3.5 years and beyond include but are not limited to river plumes in Golden Bay[13,7], mining plumes in the Taranaki Bight, mussel farm feeding plumes in Golden Bay[16], fish aquaculture plumes in the Marlborough Sounds, canyon fluxes in Kaikoura or deep sea boundary-layer processes on the Chatham Rise developed in association with other projects in Dynamic Seas (Figure 2).

(3) Physical transport connectivity – Connectivity is a complex concept with many facets relevant to ecosystem development [1]. At the scale of many processes relevant to EBM and economic activities, **transport connectivity** is the prime consideration. As such, it is readily visualised and modelled but substantial challenges remain around sub-grid scale processes (i.e., current models do not capture key elements of the dispersive nature of the focal region [26]) which generate considerable uncertainly in estimating dispersal/connectivity [1,22]. This work will conduct a single focal region scale dispersion study with satellite-tracked drifters ("ConEx" in Fig. 3b). We will drop several lines of tracked buoys throughout the focal area which will then be observed over a period of several weeks as they mix and eventually clear the region of interest. These drifters will be acquired through NIWA capital expenditure. This will provide a landmark data set that will help refine transport models highly relevant to the *Challenge*, particularly the smaller sub-grid processes that currently lack resolution but greatly affect transport processes (Output 2.1). Specifically we will build upon the MetOcean-developed MetOceanTrack model[15] (a MPI –supported tool that provides

a framework to understand material provenance and fate) by providing the ground-truthing required to evaluate its effectiveness for stakeholder needs. A particular challenge of applying this tool is in understanding how well it functions at the longer (~months) time-scales relevant to biological competency/viability (i.e., EBM).

Metrics for a Lagrangian perspective on transport have been developed and make a **comparison of model results and observations** possible[5]. This provides some certainty around modelled connectivity/footprint analyses. We therefore aim to deliver an **evaluated connectivity tool** (Output 2.2) that will provide information at a scale relevant to a range of stakeholders as well as the EBM toolbox. Geographically, this will extend over the whole focal area and contribute directly to understanding flows of stressors within the Case Study Area (initially, Tasman Bay and Golden Bay). Furthermore, Projects 4.1.1 and 4.2.1 within Dynamic Seas will provide relevant ecological connections through participation in field experiments, in conjunction with ship time from aligned funding.

(4) The Far-Field Context- A bio-geo-physico-chemical context is required to support footprint and larger-scale understanding of ecosystem dynamics and ability to recover from stressors. Without an adequately understood overarching framework for the oceanography [3,12,19,10,15], work within the focal region will be compromised. This work is separated because it will be resource-intensive, heavily supported from aligned research at NIWA and yet is critical to multiple parts of the Challenge. There will be significant innovation as we incorporate new data acquisition technologies (e.g., gliders [24]) and recent modelling advances (both primarily supported elsewhere). Geographically, this will serve to define how large the case study area really is – the ocean is not constrained by lines on a map and this component will provide evidence, in conjunction with knowledge around biophysical time scales, of the true scale of the case study area. Critically it will also provide a much needed mechanism to incorporate changes in larger scale drivers of oceanography (i.e., climate) into the local scale (case study area and focal region). This is likely to prove to be important as it will allow scenario discussion of how (for example) changes in upwelling intensity may influence aquaculture production.

Initially two glider transects a year will be conducted and a precision mooring capturing water column biophysical structure will be deployed. The glider technology is unable to reliably penetrate into the Tasman/Golden Bays System but it is well-suited to defining the boundary-conditions for the bays, which is a critical part of the modelling (Figure 3). The gliders, in their base form, measure temperature and salinity as well as phytoplankton biomass proxies. The precision mooring is a wire-walking profiling mooring that as well as temperature and salinity will capture dissolved oxygen concentration, phytoplankton biomass proxies and suspended sediment concentrations. We will also trail a dissolved nutrient sensor and real-time delivery of these data.

The specific locations for these efforts will be determined as other components of the *Challenge* evolve. These data will inform regional modelling using the Regional Ocean Modelling System (ROMS[14]) a state-of-the art open source modelling system which is used by researchers across the globe. This is a different model to the Connectivity Tool described above because the requirements and boundary conditions for the two applications are not the same. Using a ROMS readily permits international collaboration, allowing development of advanced particle tracking, sediment transport and biogeochemical models for a range of research applications. The viability and skill of this modelling will be evaluated through comparison with observation. A synthesised results package will be delivered through Output O3.1.

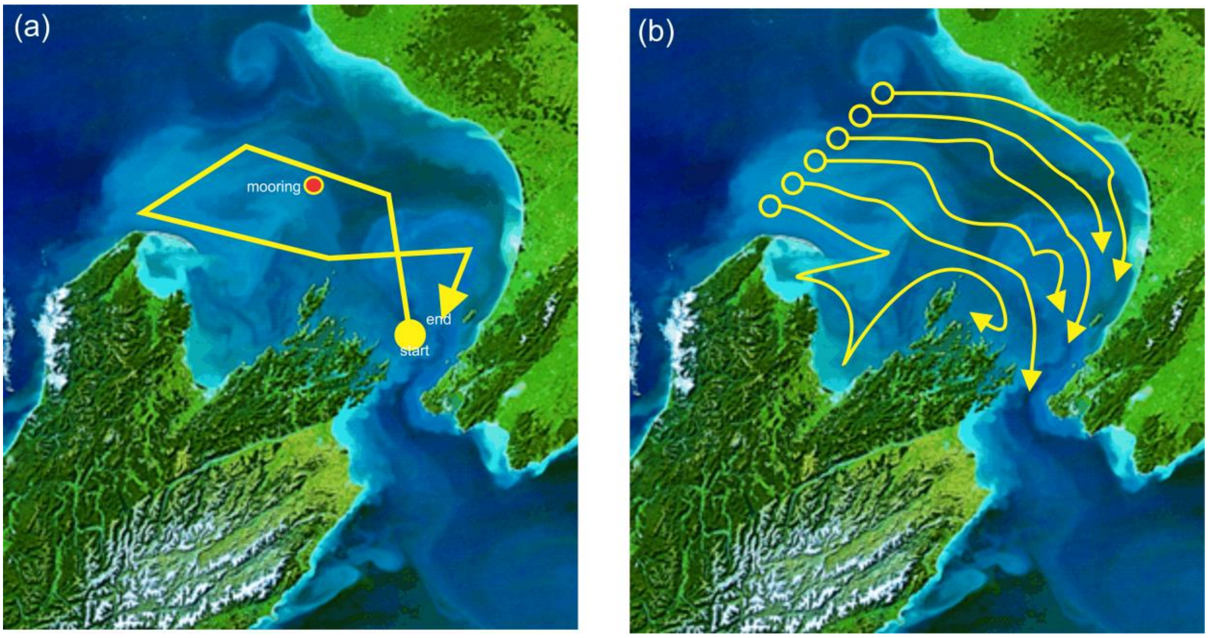

Figure 3 Potential (a) glider track and mooring location and (b) release points for ConEx drifter study.

Cross-Component Linkages – The work elements in this project are not separable. The large-scale processes provide the boundary conditions that drive smaller-scale (within region and near-field) dynamics. Climate provides an over-arching stressor that has drivers and scales outside the project scales and so is particularly difficult to connect to. It is possible that the ground-truthing of far-field contextual work will give scales of variability within which potential impacts can be evaluated. The plume development work for example can be evolved through scenario testing whereby disturbance can be examined against a background of enhanced wind or rain-induced stratification.

Geographic location – Location-specific mechanics at ecosystem-relevant time scales are strongly influenced by wind, ocean circulation and tidal mechanics, especially in shallow regions like Tasman-Golden Bay. These can have a strong influence on transport. For example, Te Aumiti - French Pass[21] and the tip of Farewell Spit[20] play crucial roles in the circulation of the Tasman and Golden Bays embayment. It is these areas that will provide part of the contextual studies to understand connectivity within the case study area of these bays. This will enable an understanding of the connectivity of near- and far-field effects, such as flow of contaminants from river plumes and source-specific sediments from activities such as dredging, in relation to mussel farms and other marine activities

Direct line of sight – a connection between manageable activity, impact and ecosystem outcome is central to the Challenge. There are several direct pathways to economic benefit within this project and Tasman and Golden Bays provide focus for highly relevant field and modelling studies to understand effects of activities of economic importance. For example, mussel farm harvesting is restricted during times of high freshwater input, but triggers for farm closures are very conservative because predictive models of river plume dispersal are not refined enough. Dredging for fish and scallops, and harvesting of mussel farms generate specific points of added sediments that potentially interact with river plumes in transport processes. Together, these have current economic costs, which can be modified with better predictive modelling. This project, therefore, provides the lens upon which a successful EBM approach relies. Without a physical understanding of the system we cannot begin to manage spatial and temporal scale of activities, or how stressors overlap in time and space; we also cannot scenario-test future impacts. This work will underpin EBM decision tools in *Managed Seas* by allowing stakeholders to visualise and discuss more clearly how impacts in one place may affect somewhere else, or as the climate changes how that might influence the marine economy? This work therefore underpins key knowledge on which successful EBM depends[23].

The Following Five Years – the first 3.5 years of the project will set the scene for several key developments for subsequent work that will directly inform stakeholders around marine space utilisation. The usage of marine space is expected to have evolved in that time and new activities/disturbance are likely. The approach developed here will be efficiently focused on these new stressor fields (see Fig. 2 for examples). Near- and far-field biogeochemical modelling will be connected so that we can identify displaced impacts. Beyond 2019, further ground-truth data acquisition is highly likely to be needed. While expensive, this provides real data to validate models and, in conjunction with our other *Sustainable Seas* programmes, increases the likelihood of substantial new tools that can be used by stakeholders. The model and observation trajectory in present aligned funding plans indicates development in real-time observation and forecast model result delivery that will complement Phase II of this project

G. LINKAGES AND DEPENDENCIES

This project is not dependent on other projects or programs within the *Challenge* but it is aligned and supported by research at NIWA, especially in the far-field context. Within the *Challenge* tight linkages with other projects is guaranteed through provision of physical connectivity metrics and future climate change scenario modelling. Specifically:

- 4.1.1: Provision of flux metrics, stratification metrics, timescale structure. We will provide descriptions of transport-related context with which project 4.1.1 can assess the impact of biogeochemical fluxes. For example, a key factor missing from physical descriptions is a good understanding of the stratified mechanics of the water column. As 4.2.2 seeks to understand this facet of transport it will collaborate with 4.1.1, given suitable combinations of location, to provide enhanced descriptions of these processes. Collectively the two projects provide the physical setting under which the biological transformations are taking place.
- 4.2.1: Provision of a context of physical stressor mechanics, nutrient and sediment supply and physical connectivity metrics. Also assist in study design/context – selecting sites across predicted stress (nutrient/sediment) gradients. Linkage to predicted stressor levels to feedback into CSMs developed in component 2.
- 5.1.1: Provision to ecosystem models of a quantitative description of physical controls and fluxes especially around the provenance and fate of sediment. While the 4.2.2 results might be at a mechanistic level they will provide a guide for 5.1.1 to assess its results.
- 5.1.2: Spatially explicit decision support tools require an understanding of the moving and mixing ocean in order to quantify the degree of spatial discretisation. While the 4.2.2 results might be at a mechanistic level they will provide a guide for 5.1.2 to assess its results.
- 5.1.4: Participatory tools will benefit from being able to demonstrate to stakeholders the degree of variability and complexity in the focal region ocean processes. 4.2.2 will provide a readily-understood set of observations that the public can relate to.

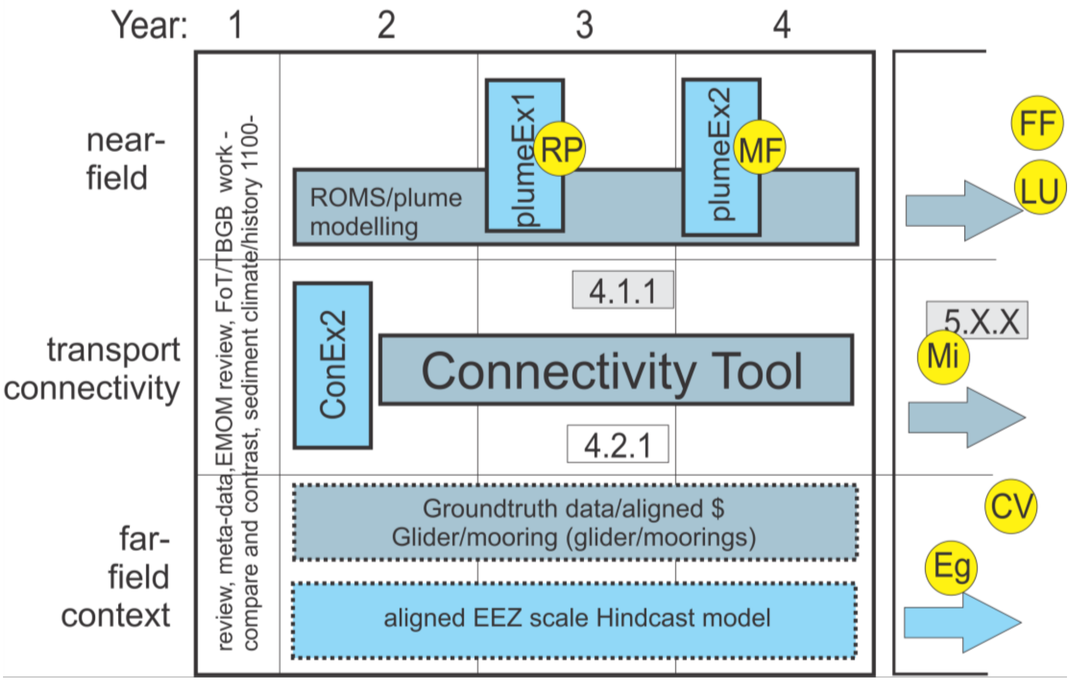

Figure 4 Project timeline for the initial four year period and beyond. The left hand side indicates the three interrelated scales of study and the different colours denote model tools vs ground truth/evaluation. Yellow circles denote stressor activities (RP river plume, MF mussel farm, FF fish farm, CV climate variability, E.g., energy extraction, LU land usage, Mi seabed mining) and the direct linkages to other programs/projects are shown in the numbered box (detailed in section G). Other abbreviations include EMOM environmental monitoring of offshore mining, FoT Firth of Thames, TBGB Tasman Bay and Golden Bay.

H. COLLABORATIONS

Numerous scientists are involved in this project (see below) and together they constitute a national best team. Value will be added through established international linkages, specified below. Beyond the in-project partnerships, however, including considerable interactions through aligned funding (involving key researchers in this project), this work does not depend on other collaborations.

I. INTERNATIONAL LINKAGES

- Dr Claire Spillman, Australian Bureau of Meteorology, will assist with seasonal predictive tools for ocean temperature. This collaboration will be supported by NIWA programmes.
- Dr John Middleton (SARDI) and his team have a strong track record around interactive model visualisation tools that connect activity scale mechanics with the regional outcomes. This project will seek to strengthen collaborative ties to look at mutual enhancement of model tools and associated approaches to ground-truthing.
- Dr Chari Pattiarachi (UWA) leads several components of Australia's shelf seas ocean observing systems work and we would seek to strengthen these ties both in terms of application as well as instrumentation implementation.

J. ALIGNED FUNDING AND CO-FUNDING

This project uses aligned funding in NIWA's Coasts and Oceans Flows and Productivity Programme. In particular it uses significant support around (i) ground-truthing, (ii) vessel operations and (iii) large scale model tools. These large scale information provisions are fundamental to the footprint-transport-connectivity scale work. It does however generate constraints for work predicated on components of this aligned funding going ahead with timing that suits the Challenge work.

K. VISION MĀTAURANGA

Vision Mātauranga is seeking to develop innovative and/or distinctive products, processes, systems, and services, through the use and application of Māori knowledge, resources and people. One of the four themes in the Vision Mātauranga (VM) policy framework is indigenous innovation.

This project will connect to the VM programme through the participation of a VM programme team member. The intent of VM is to work with the project leader and team to identify opportunities for Māori knowledge, resource and people, to be applied in the project, as well as identify whether further investigation is necessary and how the VM and Dynamic Seas programmes will work together to address that need. This may be identified during the first step of the project when previous and on-going science activities are pulled together regarding the impacts in New Zealand's shelf seas.

Additionally, VM will seek to either work with the Dynamic Seas programme and project team, or work independently within the Challenge, to potentially develop a predictive and connectivity model that acknowledges, and is reflective of, Maori knowledge, resources and people. Such a model would ideally identify the footprints of activities but measured or quantified by mātauranga Māori (indigenous knowledge) and western science. Currently, there is a model being used in resource management decision-making which measures the mauri in four dimensions (environment, cultural, social and economic) in the assessment of impacts from activities on the environment[1]. There is potential to develop a similar yet distinct predicative model as a result of this project. Also, the VM programme will look to develop relationships within the research and science community with the aim to share knowledge and identify opportunities and synergies that will advance the VM policy framework.

L. ENGAGEMENT AND CAPACITY BUILDING

The public, through the Social License to Operate, are the ultimate stakeholder. The work supports high value levels of engagement whereby it generates science elements that non-experts can readily connect with. Furthermore, with the aspirational goal of real-time data as an endpoint for the present tranche of work, this will drive a paradigm shift in engagement. Modelling tools, for example, will enable people to interact and visualise movement of contaminants, aiding in understanding the processes and influences of activities. Other stakeholder activity will be through pathways defined by the connections with *Managed Seas* as identified in Section G.

Co-creation is hardwired into the work through specific linkages to key elements within *Dynamic Seas*, participation in stakeholder workshops in *Our Seas* and a commitment to Vision Mātauranga. We will seek opportunities to engage with stakeholders and Maori in increasing understanding, capability and capacity.

Resources are included to support a graduate student which future-proofs the research by connecting it to a new career. The expectation is that the student will be enrolled at the University of Auckland, however depending on the combination of student, project and supervision expertise enrolment maybe at the University of Otago. This is conditional upon a suitably-skilled student being found. Opportunities to increase student involvement will be sought from scholarships external to the project.

Dr Mark Hadfield has been a mainstay of ocean modelling in New Zealand for the past two decades and Dr Helen MacDonald has recently been employed to provide a succession capability. Hadfield's time relating to the theme of ocean modelling will be supported from aligned funding, as will some of MacDonald's time.

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[1] http://www.mauriometer.com/

We will contribute to effective communication, aid in the development of visualisation tools for the web, and engage with the scientific community at the national and international levels to bring a higher profile to the Challenge and its innovations.

M. ROLES, RESOURCES

Craig Stevens (NIWA), Leadership of project, ocean and tracer mixing;
Stephen Chiswell (NIWA), Physical connectivity and biogeochemical fluxes;
Mark Hadfield (NIWA), ocean modelling;
Helen MacDonald (NIWA), Biogeochemical modelling;
Iain MacDonald (NIWA), Sediments and near-field mixing;
Joanne O'Callaghan (NIWA), Real-time data delivery and glider operations;
Ben Knight (Cawthron), Coastal modelling;
David Johnson (MetOcean), Model delivery and connectivity tools;
Ross Vennell (Otago Uni), Physical oceanography;
Andrew Swales (NIWA), Sedimentation processes;
John Zeldis (NIWA), Biophysical fluxes;
David Plew (NIWA), Flow-structure interaction;
**Not all of these investigators will be active in each year and a number are in essentially consultative roles within the Challenge and supported elsewhere (see budget).*

N. RISKS AND MITIGATION.

Primary risks are around observational operations. As is always the case in environmental work, and all the more so for ocean work, weather has a significant influence. It can either push the project beyond its resources or it can damage equipment or generate unacceptable health and safety risks. NIWA and the associated organisations have, and continue develop, world class safety protocols. Mitigation is achieved through having multi-staged work that can access a variety of secondary information to synthesize mitigating datasets.

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